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PREPARED FOR
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Air Quality Management In Otago

An evaluation of management options to achieve air quality targets for PM_{10} and $PM_{2.5}$ in Arrowtown, Clyde, Clyde, Cromwell, Milton and Mosgiel.

EXECUTIVE SUMMARY

Air quality is a concern in many urban towns in the Otago Region. The main contaminant of interest is particles in the air and in particular concentrations of PM_{10} (particles less than 10 microns in diameter) and $PM_{2.5}$ (particles in the air less than 2.5 microns in diameter). Air quality monitoring data shows concentrations of these contaminants in excess of health guidelines and standards. This report evaluates the reduction required in PM_{10} and $PM_{2.5}$ concentrations to meet air quality targets in Arrowtown, Alexandra, Cromwell, Clyde, Milton, Mosgiel and Dunedin.

The main source of PM_{10} and $PM_{2.5}$ concentrations in Otago towns is solid fuel burning for domestic heating. Characteristics of dwellings and households that might influence household warmth are considered and information that may assist decision makers is presented. This data shows a relatively small proportion of dwellings in these towns are rented (11-18%) and that whilst a large proportion of households (>90%) have ceiling insulation only 40% of dwellings in these areas (excluding Mosgiel at 48%) have underfloor insulation in these towns. Around 60-70% of firewood in most towns is purchased with the remainder being obtained free of charge. The exception is Milton where 57% of firewood is obtained free of charge.

A 2016 evaluation of the operating costs of domestic heating options was updated for more current wood burning and electricity costs. One implication relevant to assessing the impacts of solid fuel burner interventions is that as a result of a significant increase in electricity costs since 2016, heat pumps are no longer equivalent in operating costs to a solid fuel burner. Solid fuel burning for domestic home heating has the lowest operating expenditure per kilowatt hour of heat in Otago.

The annual average $PM_{2.5}$ guideline is the most significant health target in terms of health benefits. The air quality targets examined for this indicator were the Ministry for the Environment's proposed NES of 10 $\mu g/m^3$ (Ministry for Environment, 2020) and the WHO (2021) guideline of 5 $\mu g/m^3$ (chapter two and appendix B). Management measures were considered relative to progress towards the WHO (2021) annual average guideline as the proposed NESAQ was found to be obsolete.

Alexandra and Cromwell require the most improvement in annual average $PM_{2.5}$ concentrations to meet the WHO (2021) guideline of 5 $\mu g/m^3$. In these areas a 57% reduction in annual average $PM_{2.5}$ is required to meet that target. The locations with the least improvement required in annual average $PM_{2.5}$ are Mosgiel (23%) and Dunedin (32%).

An evaluation of the effectiveness of management options for this and the other air quality targets was carried out for Arrowtown, Alexandra, Cromwell, Clyde, Milton and Mosgiel. No assessment was made for Dunedin owing to uncertainties around the nature of the sources contributing at the monitoring site and the lower concentrations generally. A range of management options were considered primarily targeting domestic heating but with additional recommendations for other sources that may also be contributing to PM_{10} and $PM_{2.5}$ concentrations. Key management options evaluated for domestic heating include a phase out of burners not meeting the emission criteria required for Ultra Low Emission Burners (ULEB), a behaviour change programme targeting household operation of wood burners and a prohibition on the installation of wood burners in new dwellings and existing dwellings currently using other heating methods.

An objective of compliance with the WHO (2021) $PM_{2.5}$ annual average target gave rise to the follow groupings and management measures:

- ❖ Group A – Alexandra – total solid fuel ban
- ❖ Group B – Cromwell and Clyde – phase out non ULEB, no burners in new dwellings and behaviour change plus ensure outdoor burning is not contributing to airshed $PM_{2.5}$
- ❖ Group C – Arrowtown and Milton – phase out non ULEB
- ❖ Group D – Mosgiel – ULEB emission criteria for new installations and behaviour change

Alternative approaches to management including different groupings and severity of options have been defined as management options 2, 3 and 4 in Table E1, which also details the likely impacts on annual average $PM_{2.5}$. It is noted that this summary is based on the towns examined in this report with all other areas falling into the categories of "other Air Zone 2 towns" or "Regionwide on properties < 2 ha".

Table E1: Potential area groupings for air quality management (based on annual average PM2.5 concentrations)

	Areas	Management option – 2	Impact on annual average $PM_{2.5}$ concentrations	Management option – 3	Impact on annual average $PM_{2.5}$ concentrations
Group A	Alexandra, Cromwell and Clyde.	Phase out non ULEB, no burners in new dwellings and behaviour change*.	Likely compliance with WHO (2021) in Cromwell and Clyde and improvements to potentially around 6 µg/m^3 in Alexandra.	Phase out non ULEB and behaviour change*.	Potential compliance with WHO (2021) in Clyde and improvements to potentially around 6 µg/m^3 in Cromwell and 6.5 µg/m^3 in Alexandra.
Group B	Arrowtown and Milton.	Phase out non ULEB.	Likely compliance with WHO (2021).	Phase out non ULEB.	Likely compliance with WHO (2021).
Group C	Mosgiel, plus other Air Zone 2 towns.	All new installations meet ULEB criteria and behaviour change programme.	Likely compliance with WHO (2021) in Mosgiel and unquantified improvements in other towns.	All new installations meet ULEB criteria and behaviour change programme.	Likely compliance with WHO (2021) in Mosgiel and unquantified improvements in other towns.
Group D	Regionwide on properties < 2 ha.	All new installations meet ULEB criteria.	Improvements in air quality and/or prevention of degradation (high growth areas).	All new installations meet ULEB criteria.	Improvements in air quality and/or prevention of degradation (high growth areas.

	Areas	Management option – 4	Impact on annual average $PM_{2.5}$ concentrations
Group A	Alexandra, Cromwell, Clyde, Arrowtown and Milton	Phase out non ULEB*	Likely compliance with WHO (2021) in Arrowtown and Milton and improvements to potentially around 6 µg/m^3 in Clyde, 6.5 µg/m^3 in Cromwell and 7 µg/m^3 in Alexandra.
Group B	Mosgiel, plus other Air Zone 2 towns	All new installations meet ULEB criteria and behaviour change programme	Likely compliance with WHO (2021) in Mosgiel and unquantified improvements in other towns
Group C	Regionwide on properties < 2 ha.	All new installations meet ULEB criteria	Improvements in air quality and/or prevention of degradation (high growth areas

*plus ensure outdoor burning is not contributing to airshed $PM_{2.5}$

The most difficult standard to meet in most urban areas in Otago is the WHO (2021) daily guideline for $PM_{2.5}$ of 15 µg/m^3 with required reductions ranging from 62% to 84% excluding Dunedin (18%). An evaluation of the basis for this WHO guideline found the level to have been set based on the desired annual average $PM_{2.5}$ guideline (5 µg/m^3) and an extrapolation to a daily concentration based on an average data distribution. The average distribution used by WHO was found to differ significantly to the Otago towns with the exception of Dunedin, which is predicted to meet the daily $PM_{2.5}$ target under the status quo. Achievement of the daily WHO (2021) guideline would require a ban on solid fuel burning for domestic home heating in all other areas examined.

A total ban on the use of solid fuel burning has the potential for unintended consequences for the Otago Region because of very cold wintertime temperatures, the quality of the existing housing stock and thus the high potential for reduced household warmth. As the benefits of improved air quality are unlikely to be realised if at the expense of warm homes, further analysis of the impact on household warmth and consequently health is recommended if this option is to be pursued.

Uncertainties in the analysis including a lower level of certainty around existing $PM_{2.5}$ concentrations and potential future variabilities in emission rates from ULEB appliances are identified. These uncertainties support a staged approach to airshed management whereby initial measures to improve concentrations are implemented with the effectiveness tracked over time with subsequent management options to follow these if further improvements are required.

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1 INTRODUCTION

Air quality is a concern in many urban towns in the Otago Region. The main contaminant of interest is particles in the air and in particulate concentrations of PM_{10} (particles less than 10 microns in diameter) and $PM_{2.5}$ (particles in the air less than 2.5 microns in diameter). A further contaminant of emerging concern is nitrogen dioxide (NO_2). The main source of NO_2 in urban towns in New Zealand is motor vehicles, a source not directly managed by Regional Councils. The focus of this report is concentrations of PM_{10} and $PM_{2.5}$ in Otago towns.

The current National Environmental Standard for particulate is a 24-hour average standard for PM_{10} of 50 $\mu g/m^3$ (one allowable exceedance per year). In February 2020, the Ministry for the Environment proposed revisions to the NESAQ including the introduction of air quality standards for $PM_{2.5}$. Two standards were proposed including a daily limit of 25 $\mu g/m^3$ and an annual standard of 10 $\mu g/m^3$. Subsequently the World Health Organization has released updated guidelines for both PM_{10} and $PM_{2.5}$ which include values of 45 $\mu g/m^3$ and 15 $\mu g/m^3$ for PM_{10} and 15 $\mu g/m^3$ and 5 $\mu g/m^3$ for $PM_{2.5}$ for daily and annual averages respectively.

In many urban areas of the Otago Region concentrations of particles exceed National Environmental Standards (PM_{10}) or proposed standards ($PM_{2.5}$) as well as the 2021 WHO guidelines. The areas of Clyde, Arrowtown, Milton, Mosgiel, Clyde, Cromwell, Laurence, Oamaru and Balclutha have all recorded exceedances of the NES for PM_{10}.

The main source of anthropogenic PM_{10} and $PM_{2.5}$ emissions in these areas is solid fuel burning for domestic heating. In winter meteorological conditions conducive to elevated concentrations coincide with increased emissions and give rise to PM_{10} concentrations in excess of the current NESAQ in many areas of New Zealand.

The Otago Regional Council has gazetted three Air Zones for the management of air quality and in particular concentrations of PM_{10} in the Region. These are:

- Air Zone 1: Clyde, Arrowtown, Alexandra, Clyde and Cromwell.
- Air Zone 2: Balclutha, Dunedin, Hawea, Kingston, Milton, Mosgiel, Naseby, Oamaru, Palmerston, Port Chalmers, Queenstown, Ranfurly, Roxburgh, Waikouaiti and Wanaka.
- Air Zone 3: The rest of Otago.

Measures have been adopted in the Otago Regional Air Plan to manage air quality within the Airsheds with Air Zone 1 implementing the most stringent measures because of the extent of air quality degradation historically. These have included emission requirements for new burner installations in all three air zones with zone 1 requiring more stringent emission limits. Additionally in zone 1 burners not meeting specified emission limits were required to be phased out by 2013.

The Air Plan also includes rules relating to outdoor burning which mean it is effectively prohibited all year in most urban areas in the Region except on larger land holdings. Emissions from industrial activities are largely controlled through the resource consent process although some activity types that are classified as permitted activities may contribute in areas.

Despite these measures being adopted air quality in many urban areas remains in breach of the NES for PM_{10}. Because the proposed NES standard and the WHO $PM_{2.5}$ guidelines are more stringent relatively than the PM_{10} standard additional management measures will likely be required for any targets for this contaminant to be met.

The purpose of this evaluation is to determine the extent of improvements in particulate concentrations necessary in urban towns in the Otago Region and the effectiveness of different measures in achieving the required improvements. A scientific evaluation will be carried out to identify the likely reductions in both PM_{10} and $PM_{2.5}$ concentrations necessary to meet the current and proposed NES for PM_{10} and $PM_{2.5}$ as well as the WHO (2021) guideline values in Arrowtown, Clyde, Clyde, Cromwell, Milton, Mosgiel and Dunedin.

Other variables which impact the cost effectiveness of management options targeting domestic home heating will also be examined to enable informed decision making. These variables include the extent of insulation in homes, reported warmth and mould in dwellings and linkages between home ownership and heating methods. Where possible these variables will also be assessed relative to income as fuel poverty is a potential outcome of some regulatory measures. These considerations are relevant to decision making as the health benefits of improving air quality are unlikely to be achieved if at the expense of warm homes.

2 AIR QUALITY TARGETS

In areas where air quality targets are breached, the reductions required to meet the targets can be estimated using air quality monitoring data. An evaluation of monitoring data for each area has been carried out to assist with quantification of the reductions required in PM_{10} and $PM_{2.5}$ concentrations to meet the different targets. Appendix A provides an overview of air quality monitoring data for each area and details matters relevant to the assessment of reduction targets. This section outlines the assessment of the reductions required in concentrations to meet each of the following targets:

PM_{10} daily	$PM_{2.5}$ daily
○ Current NES (50 µg/m3)	○ Proposed NES (2020) (25 µg/m3)
○ WHO 2021 guideline (45 µg/m3)	○ WHO 2021 guideline (15 µg/m3)
PM_{10} annual	**$PM_{2.5}$ annual**
○ Current Ambient Air Quality Guidelines (AAQG) (20 µg/m3)	○ Proposed National Environmental Standard (NES) (2020) (10 µg/m^3)
○ World Health Organisation (WHO) 2021 guideline (15 µg/m3)	○ WHO 2021 guideline (5µg/m^3)

The costs and benefits of achieving the different targets is a key consideration for air quality management in New Zealand. As no National Environmental Standards currently exist for the main contaminant and duration of impact (annual average $PM_{2.5}$) the emphasis put on achievement of this target and other targets for which there are no standards requires consideration in the context of costs, effectiveness and efficiency. In New Zealand the additional cost consideration is that the health benefits of improvements in air quality may not be realised if they come at the expense of cold houses.

A review of the basis for the different targets is given in Appendix B to assist with prioritisation of air quality targets and evaluation of effective and efficient air quality management. That review recommends prioritisation of the annual average $PM_{2.5}$ target and notes a much weaker basis for the daily guideline values for both PM_{10} and $PM_{2.5}$. It identifies the basis of the proposed NES for annual $PM_{2.5}$ (10 µg/m^3) as the outdated WHO (2005) guidelines and as such the only current target for this indicator, of those considered above, is the WHO (2021) guideline of 5 µg/m^3. The review (Appendix B) notes that this target is set based on the lowest concentration for which effects have been observed providing a higher level of protection and different philosophy of guideline settling to previous versions of WHO guidelines.

It is recommended that the approach to air quality management in the Otago towns be based on annual average $PM_{2.5}$ concentrations and that management measures be considered in the context of progress towards the achievement of the WHO (2021) guideline of 5 µg/m^3. Management measures targeting annual concentrations will result in significant reductions in daily PM_{10} and $PM_{2.5}$ concentrations but are unlikely to result in compliance with the WHO (2021) daily $PM_{2.5}$ target for the reasons detailed in Appendix B.

2.1 Methodology

The reduction required in concentrations is calculated for each target using Equation 2.1. The reduction required is expressed as a percentage of concentrations at a point in time. For example, if the base year used to calculate the reduction was 2022 then the reduction would be expressed as an x% reduction in 2022 PM_{10} concentrations.

$$R = 100(1 - \frac{t}{c})$$ Equation 2.1

where

R = the percentage reduction

t = the air quality target (e.g., 50 µg m^{-3})

c = the concentration identified as representing the reduction required

Determining the concentration (c) representing the reduction required involves identifying:

I. The concentration that represents the extent of non-permissible exceedances as detailed by the air quality target. For example, if the standard specifies one allowable exceedance per year of a daily average then the second highest daily average represents the concentration of interest.

II. The impact of the worst case meteorological conditions on concentrations for the day identified in bullet point one. An assessment based on worst case meteorology is required to ensures consistency of compliance.

Assessing worst case years for meteorology can be problematic where downward trends in concentrations occur as the magnitude of the concentrations alone no longer provide an indication of the impact of the meteorological conditions. The methodology used for this assessment to identify worse case meteorology was to establish a peak (second highest daily PM_{10}) to winter average PM_{10} ratio (i.e., dividing the second highest PM_{10} concentrations by the annual average PM_{10}).

Where worst case meteorology occurred prior to 2021, the impact of those meteorological conditions on current day emissions was estimated by applying the peak to mean ratio to the 2022 winter mean to estimate the 2022 peak concentration under worst case meteorology. This approach takes into account reductions in emissions that may have occurred between the two periods. Further methodological detail relating to meteorology is outlined in Appendix B.

2.1.1 Daily PM_{10} and $PM_{2.5}$ targets

The NESAQ specifies a limit for PM_{10} of 50 µg/m^3 with one allowable exceedance per year. Thus, the second highest 24-hour PM_{10} concentration, and associated worst case meteorology, is the most relevant in terms of determining the reduction in daily PM_{10} concentrations required to meet the standard.

The WHO (2021) daily PM_{10} and $PM_{2.5}$ guideline values of 45 µg/m^3 and 15 µg/m^3 are based on the 99^{th} percentile concentration which equates to approximately three exceedances per year. Thus, the fourth highest PM_{10} and $PM_{2.5}$ concentration, and associated worst case meteorology, are the most relevant in terms of determining the reduction in daily PM_{10} concentrations required to meet the guidelines.

The proposed NESAQ for $PM_{2.5}$ (Ministry for the Environment, 2020) is 25 µg/m^3 with three allowable exceedances per year and was based on the previous WHO (2005) guidelines. As per the WHO (2021) targets the fourth highest $PM_{2.5}$ concentration is the most relevant for determining the reductions in daily $PM_{2.5}$ concentrations to meet this proposed standard.

The reduction in PM_{10} concentrations required to meet the NESAQ (target 50 µg/m^3) could be greater than the reduction required to meet the WHO (2021) PM_{10} guideline (target 45 µg/m^3) because of the difference in allowable exceedance days.

2.1.1 Annual PM_{10} and $PM_{2.5}$ targets

Annual data are less influenced by year-to-year variability in meteorological conditions than the daily concentrations. The annual PM_{10} and $PM_{2.5}$ reductions have therefore been calculated based on annual average concentrations for the years 2020 to 2022. The approach taken varies by area depending on the data available but typically will involve an average of these three years unless the most recent year of data are the highest (in which case that will be used) or if there is a clear downward trend in data, in which case data preference will be given to more recent information.

2.2 Reductions required to meet air quality targets

Table 2.1 summarises the reduction required in PM_{10} and $PM_{2.5}$ concentrations in each area relative to each air quality target based on the evaluation of air quality monitoring data detailed in Appendix A. With the exception of in Dunedin, the target requiring the greatest reductions in concentrations is the daily WHO (2021) guideline for $PM_{2.5}$ (15 µg/m^3). Alexandra is the town where the largest improvements are required for this indicator.

The guideline or standard with the most significance from a health viewpoint is the annual average $PM_{2.5}$ concentration. Alexandra and Cromwell are the areas that require the most improvement (both 57%) in annual average $PM_{2.5}$ concentrations. It is noted that the reductions required in Alexandra are based on the current monitoring site which may underestimate annual average concentrations by around 20%. The locations with the least improvement required in annual average $PM_{2.5}$ to meet the WHO (2021) guideline of 5 µg/m^3 are Mosgiel (23%) and Dunedin (32%).

For PM_{10} the location with the greatest reduction required is Milton.

Table 2.1: Reductions required to meet air quality targets in Arrowtown, Clyde, Clyde, Cromwell, Mosgiel, Milton and Dunedin

	NES for PM_{10} (24-hour average of 50 µg/m^3)	WHO (2021) PM_{10} (24-hour average of 45 µg/m^3)	AAQG annual average PM_{10} guideline of 20 µg/m^3	WHO (2021) annual average PM_{10} guideline of 15 µg/m^3	Proposed NES for $PM_{2.5}$ (24-hour average of 25 µg/m^3)	WHO (2021) $PM_{2.5}$ (24-hour average of 15 µg/m^3)	Proposed NES annual average $PM_{2.5}$ of 10 µg/m^3	WHO (2021) annual average $PM_{2.5}$ of 5 µg/m^3
Arrowtown	**Not compliant**	**Not compliant**	**Compliant**	**Likely compliant**	**Not compliant**	**Not compliant**	**Likely compliant**	**Not compliant**
Reduction	**44%**	**41%**	**n/a**	**n/a**	**60%**	**76%**	**n/a**	**48%**
Alexandra	**Not compliant**	**Not compliant**	**Compliant**	**Not compliant**	**Not compliant**	**Not compliant**	**Not compliant**	**Not compliant**
Reduction	**45%**	**23%**	**n/a**	**8%**	**73%**	**84%**	**15%**	**57%**
Clyde	**Not compliant**	**Not compliant**	**Compliant**	**Compliant**	**Not compliant**	**Not compliant**	**Likely compliant**	**Not compliant**
Reduction	**33%**	**18%**	**n/a**	**n/a**	**42%**	**65%**	**n/a**	**38%**
Cromwell	**Not compliant**	**Not compliant**	**Compliant**	**Not compliant**	**Not compliant**	**Not compliant**	**Not compliant**	**Not compliant**
Reduction	**37%**	**41%**	**n/a**	**7%**	**63%**	**78%**	**14%**	**57%**
Milton	**Not compliant**	**Not compliant**	**Likely compliant**	**Not compliant**	**Not compliant**	**Not compliant**	**Compliant**	**Not compliant**
Reduction	**50%**	**45%**	**n/a**	**30%**	**57%**	**74%**	**n/a**	**43%**
Mosgiel	**Not compliant**	**Not compliant**	**Compliant**	**Not compliant**	**Not compliant**	**Not compliant**	**Compliant**	**Not compliant**
Reduction	**37%**	**31%**	**n/a**	**17%**	**36%**	**62%**	**n/a**	**23%**
Dunedin	**Compliant**	**Compliant**	**Compliant**	**Likely compliant**	**Compliant**	**Not compliant**	**Compliant**	**Not compliant**
Reduction	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**18%**	**n/a**	**32%**

3 DWELLING CHARACTERISTICS AND INCOME

The extent of dwelling insulation was included as a survey question in the 2016 and 2019 air emission inventories (Wilton, 2017, 2019). Table 3.1 summarises the survey responses for insulation questions. Insulation levels were lowest in Mosgiel, Milton and Alexandra. The 2016 inventory survey also queried adequacy of household warmth. Figure 3.1 shows that the greatest reported levels of warmth occur in Arrowtown with 69% of houses being referred to as warm. In Milton 9% of households reported the dwelling was too cold.

Figure 3.2 shows the 2018 census reported variable for dampness by area. The highest levels of dampness are reported in Milton and Dunedin (over 20% of households) followed by Mosgiel and Arrowtown. The census also collected data on mould prevalence which is summarised by area in Figure 3.3. Milton and Dunedin also have the highest reported mould prevalence.

Table 3.1: Insulation prevalence in Otago towns in 2016 (Alexandra, Arrowtown, Mosgiel and Milton) and 2019 (Cromwell/ Clyde)

	Arrowtown	Alexandra	Cromwell	Clyde	Milton	Mosgiel
Ceiling	89%	91%	96%	96%	89%	92%
Underfloor	41%	37%	42%	42%	39%	48%
Wall	70%	61%	82%	82%	52%	56%
Cylinder wrap	25%	28%	27%	27%	19%	32%
Double glazing	55%	47%	65%	65%	35%	46%
None	1%	0%	0%	0%	5%	1%
Don't know	4%	5%	2%	2%	4%	5%
Other	1%	2%	9%	9%	2%	2%

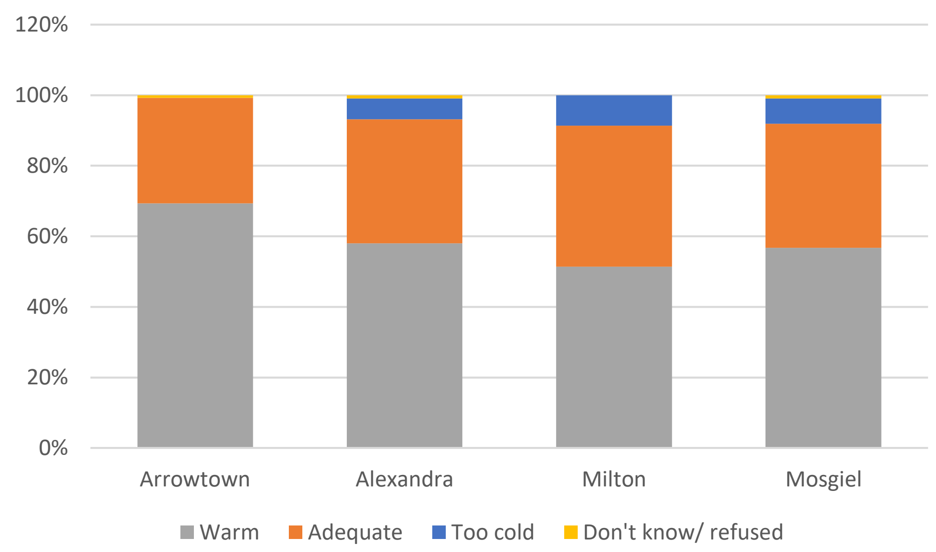


Figure 3-1: Perception of household warmth (additional analysis of data from Wilton, 2017)

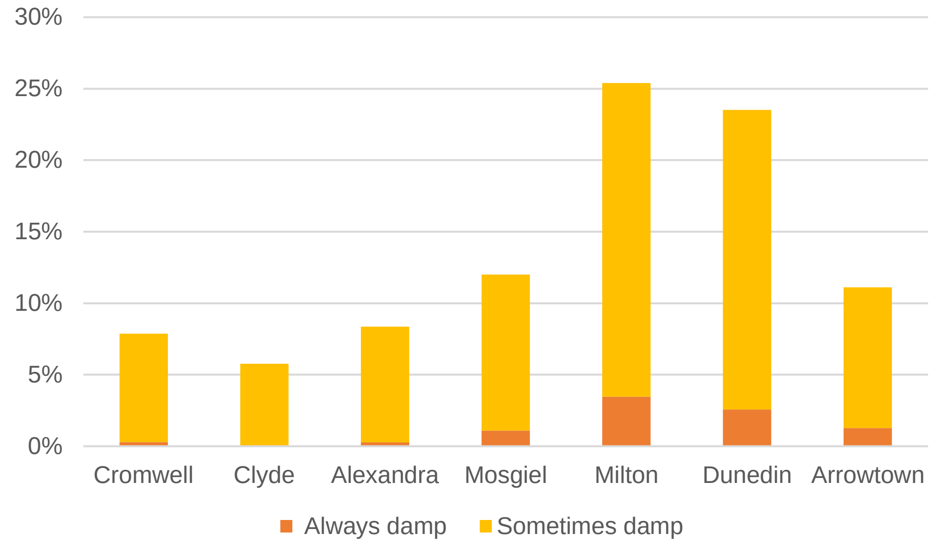


Figure 3-2: Proportion of households that report dampness by area (from 2018 census, StatsNZ)

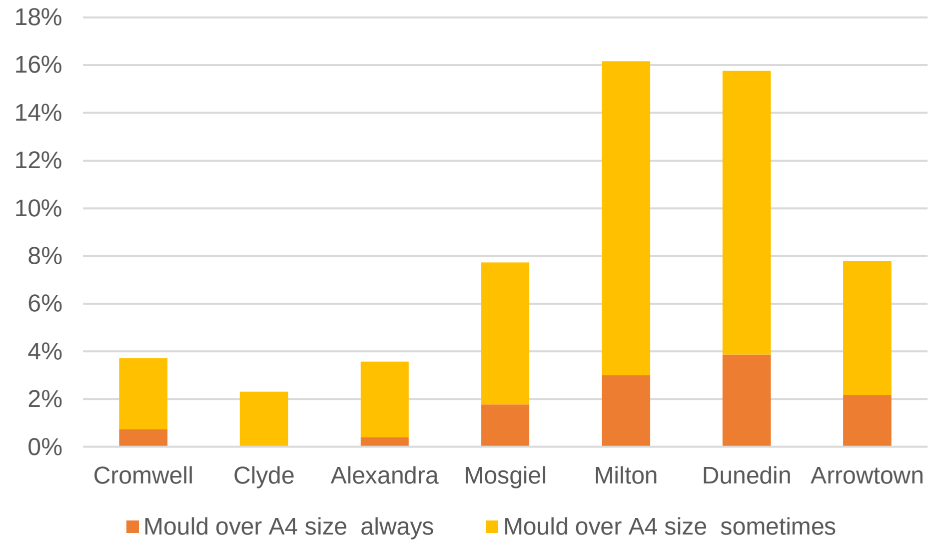


Figure 3-3: Proportion of households that report mould by area (from 2018 census, StatsNZ)

Tables 3.2 and 3.3 shows differences in rental versus home ownership in Otago towns and the age of dwellings. In all areas property ownership is relatively high. Milton and Mosgiel have the greatest proportion of older dwellings followed by Alexandra. Around half of the dwellings in Cromwell/Clyde and Arrowtown were less than 20 years old in 2019 (Cromwell/Clyde) and 2016 (Arrowtown) when the surveys were conducted.

Table 3.2: Property ownership versus renting in Otago towns in 2016 (Alexandra, Arrowtown, Mosgiel and Milton) and 2019 (Cromwell/ Clyde)

	Arrowtown	Alexandra	Cromwell	Clyde	Milton	Mosgiel
Own	82%	85%	89%	89%	82%	83%
Rent	18%	15%	11%	11%	18%	17%

Table 3.3: Dwelling age in Otago towns in 2016 (Alexandra, Arrowtown, Mosgiel and Milton) and 2019 (Cromwell/ Clyde)

	Arrowtown	Alexandra	Cromwell	Clyde	Milton	Mosgiel
10 years or less	24%	18%	25%	25%	13%	16%
11 - 20 years	27%	12%	28%	28%	8%	14%
21 - 40 years	30%	33%	25%	25%	21%	21%
41 + years	16%	34%	20%	20%	55%	42%
Refused/not sure	3%	3%	3%	3%	3%	7%

Figure 3.4 shows that the area with the highest household incomes is Arrowtown where at least 17% of households earned more than $150,000 per year in 2016 and over 40% of households earned more than $80,000 per year. In Arrowtown no households reported incomes of less than $21,000 per year. This area also has the highest proportion of households not responding to the income question (27%). Milton and Mosgiel have the lowest annual income levels followed by Alexandra.

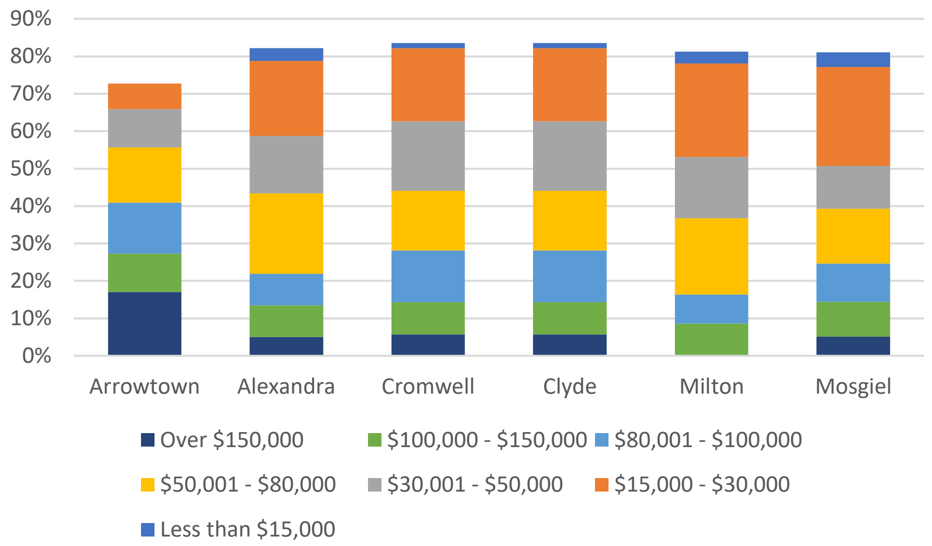


Figure 3-4: Total household income in 2016 (Arrowtown, Alexandra, Mosgiel and Milton) and 2019 (Cromwell/Clyde)

Figure 3.5 shows the total household income as per Figure 3.4 but for households just using wood burners for home heating. The distribution is similar to that in Figure 3.5 although the proportions of households with wood burners earning less than $50,000 is less than the general population. This indicates wood burners are slightly less common in lower income households.

Table 3.4 shows that with the exception of Mosgiel wood burners are used in at least half of the towns' rental accommodations. Wood burner use in Mosgiel is lower than other areas at less than 40% of households. Alexandra had the highest proportion of households using wood burners for home heating in 2016 at 58%. Table 3.5 shows wood burner use by households earning less than $50,000 in 2018 compared with their prevalence across all income categories. This shows a lower level of access to wood burner use in low income households relative to the total households.

Table 3.4: Wood burner use by dwelling tenure in 2016 (Alexandra, Arrowtown, Mosgiel and Milton) and 2019 (Cromwell/ Clyde)

		Mosgiel	Milton	Arrowtown	Alexandra	Cromwell
Own home	Wood burner	34%	44%	44%	50%	49%
Rental	Wood burner	5%	9%	10%	8%	8%
Own home	No wood burner	49%	38%	38%	35%	39%
Rental	No wood burner	12%	9%	8%	7%	5%

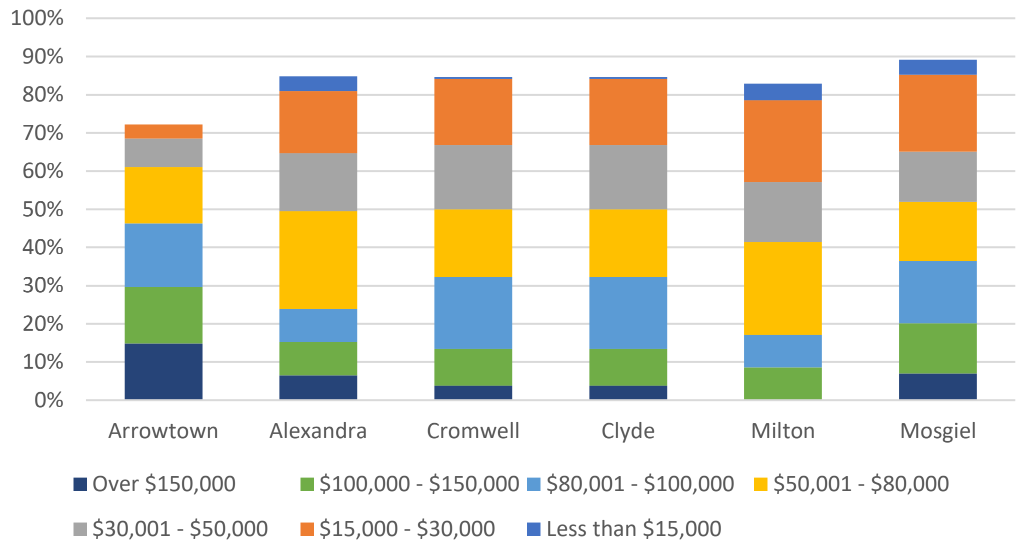


Figure 3-5: Proportion of households using wood burners by total household income

Table 3.5: Wood burner prevalence in low income households

	Arrowtown	Alexandra	Cromwell	Clyde	Milton	Mosgiel
Households earning less than $50,000 with wood burners	11%	35%	35%	35%	41%	37%
Households earning less than $50,000 proportion of population	17%	39%	39%	39%	45%	42%

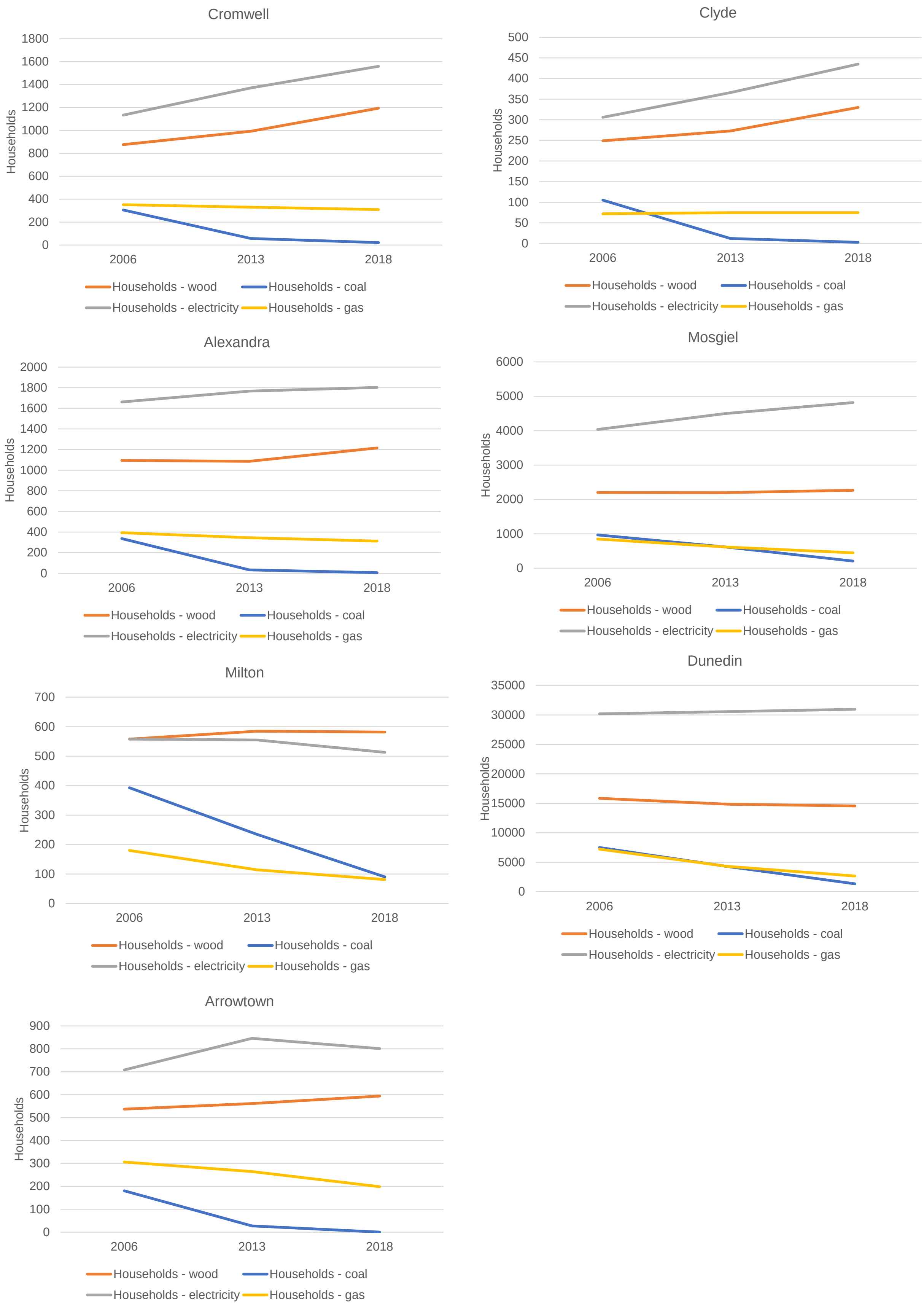


Figure 3-6: Trends in fuels used to heat dwellings from 2006 to 2018 (Stats NZ, 2018)

Figure 3.6 shows the changes in households using different fuel for heating from 2006 to 2018. In all areas electricity and wood are the most prevalent methods in that order. In Milton wood use is more common than electricity. Table 3.4 shows the proportion of wood that is purchased versus obtained free of charge in each area excluding Dunedin. In Milton around 57% of wood is obtained free of charge. Management measures which restrict the use of wood domestic home heating are likely to have the greatest impact in areas where wood is largely obtained free of charge as households that can not afford the capital costs of replacing a wood burner for example, lose out on the ability to legally operate their heating method at low or no cost.

Table 3.7 shows the costs c/kWh of space heating using different fuels and methods in Otago in 2016.

Table 3.6: Source of firewood in Otago towns in 2016 (Alexandra, Arrowtown, Mosgiel and Milton) and 2019 (Cromwell/ Clyde)

	Source of firewood	
	Bought	Free
Arrowtown	66%	34%
Alexandra	59%	41%
Cromwell	68%	32%
Clyde	68%	32%
Milton	43%	57%
Mosgiel	62%	38%

Operational costs associated with different heating options for the Otago Region for 206 are shown in Figure 3.7. This indicates that the most cost-effective energy sources for residential space heating for the Region in 2016 were heat pumps (electricity) followed by wood. Since 2016 electricity prices have increased significantly with the lower end cost for central Otago increasing to around 45 c/kwh, an 80% increase. Wood prices have increased by around 31% in Central Otago over the same period. This means that the c/kWh costs for wood (lower end 13 c/kWh) is now lower than for a heat pump (lower end 15 c/kWh).

Table 3.7: Relative costs of heating methods in Otago in 2016

	Otago Lower end c/kWh	Otago Upper end c/kWh	Consumer – national 2015 Lower end c/kWh	Consumer – national 2015 Upper end c/kWh
Wood	10	17	8	28
Coal	12	14		
Pellet burner	17	26		
Unflued gas (LPG)	21	40	31	41
Flued gas (LPG)	19	19	19	23
Electricity – heat pump Dunedin	8	10	6*	12*
Electricity – heat pump Otago	8	13		
Electricity Dunedin	23	29	16*	35*
Electricity Otago	25	40		

* national rather than area specific

4 AIR QUALITY MANAGEMENT IN OTAGO

Solid fuel burning for domestic home heating is used extensively throughout Otago (Wilton, 2017, 2019). The attractiveness of this option is likely a combination of the relatively low operating cost, the ability to heat larger spaces or less insulated properties (high heat output options) and a general preference for the type of heat or the aesthetic of a fire. Solid fuel heating appliances in Otago include wood burners, pellet burners, open fires, multi fuel burners (wood and coal) and central heating systems (various fuels but can include coal). Central heating systems provide whole house heating and have typically come at a high cost for households that have installed them.

Open fires, multifuel burners, pellet burners and central heating systems are less common than wood burners with typically less than 3% of households using these. Open fires have been phased out in many areas of New Zealand owing to their relative ineffectiveness and low efficiency. Similarly, multifuel burners burning coal emit disproportionate amounts of particulate and have also been phased out in many areas of New Zealand. The 2016 and 2019 air emission inventories for Otago towns showed only a very small number of households using open fires or multifuel burners. As these appliances are non-compliant in most of the areas surveyed the response likely represents a small degree of non-compliance with rules that may have been subsequently rectified.

The predominant solid fuel heating method used in the Region is wood burners. In Air Zone 1 only domestic heating appliances meeting an emission limit of 0.7 grams of particulate per kilogram of wood burnt have been able to be installed since 2007 (2009 in Clyde). Additionally, domestic heating appliances not meeting an emission limit of 1.5 g/kg were required to be replaced prior to 2012 in Air Zone 1 areas. The definition of a domestic heating appliance in the plan is "*A combustion appliance, with a heat generation capacity of up to 50 kW in which solid fuel is burnt for heating or cooking, and is primarily used in residential dwellings. It includes, but is not limited to, any open fire, woodburner, multifuel, pellet or coal burning heater, or cooker including coal range*".

The burner emission limits for domestic heating appliances for the Otago towns, whilst lower than the NESAQ design criteria for wood burners (1.5 g/kg and 65% efficiency), are based on the same AS/NZS 4012 and 4013 test regime.

Since the adoption of the emission limit in Air Zone 1 towns in Otago, a new "real life" test method has been developed to simulate the burn cycle and fuels more closely and to drive technology improvements to lower emissions and ideally minimise the impact of the burner operator on emissions. The Ultra Low Emission Burner (ULEB) was originally classified as a burner that meets a particulate emission limit of 0.5 grams of particulate per kilogram of fuel burnt when tested to the Canterbury Method (CM1). In the Canterbury Air Regional Plan the limit is specified as 38 mg/MJ. The 38 mg/MJ emission limit is equivalent of 0.5 g/kg at 65% efficiency but allows for a slightly higher emission level if the space heating efficiency is greater or requires a lower emission level if the efficiency does not meet 65%.

In Air Zones 2 and 3 any domestic heating appliance installed prior to 2007 is able to continue to be used including open fires, multifuel burners, wood burners and cookers. All new installations of solid fuel burners in Air Zone 2 must comply with an emission limit of 1.5 g/kg. This is more stringent than the NESAQ design criteria for wood burners because it applies to any appliance meeting the definition of a domestic heating appliance. In Air Zone 3 new solid fuel cooking appliances that do not meet the 1.5 g/kg criteria can be installed and properties greater than 2 hectares in size are exempt from the installation rules. The 2016 and 2019 air emission inventories indicate around 1% of households report the use of wood fired cooking devices in the Air Zone 1 and 2 areas surveyed.

Other sources that may require management to improve particulate concentrations in urban areas of Otago include outdoor burning and industrial and commercial activities. In the urban areas evaluated in this report industrial and commercial activities are not significant contributors to $PM_{2.5}$ but some management of the coarse mode (PM_{10}-$PM_{2.5}$) size fraction, which is PM_{10}, may be required. This might include sources of fugitive dusts such as construction sites and vehicle movements on unpaved yards. Outdoor burning is currently regulated for some properties but may still be a contributing source in some areas.

4.1 Assessing effectiveness of management measures

4.1.1 Tailoring management to air quality targets

In most areas a combination of management options is likely required to meet air quality targets. There are a number of area specific factors that influence the effectiveness of different management measures or combinations of measures in achieving air quality targets. These include the relative contributions of sources to the different air quality targets, variables relating to emissions including population projections and existing regulatory measures and area specific meteorology. For example, an option of prohibiting the installation of solid fuel burners in new dwellings relative to the status quo projection will vary by area depending on projected growth in housing/ population.

In addition to area dependent factors the suite of management options selected will also be dependent on which air quality target is prioritised.

The effectiveness of options also differs between the annual and daily targets because the relative contributions of sources to these also differ.

The air quality target with the greatest health significance is the annual average $PM_{2.5}$ concentration. It is unclear when or whether New Zealand will adopt the WHO (2021) guideline for annual $PM_{2.5}$ as a NES. However, it should be noted that whilst this target has the most significant health benefits, Table 2.1 illustrates that it is not the most stringent of the guidelines in a New Zealand context. The daily $PM_{2.5}$ targets of 25 µg/m^3 (proposed NES) and 15 µg/m^3 (WHO 2021) require much more stringent air quality management measures. This is because the method used by WHO to derive these guidelines is based on an average distribution of annual air quality data which urban areas in New Zealand typically fall well outside of. Appendix B provides an overview of the WHO guidelines and their derivation and relative significance.

4.1.2 Selecting management measures to evaluate

Management measures for evaluation were selected using a combination of reviewing the key contributors to PM_{10} and $PM_{2.5}$ (daily and annual), understanding existing regulatory measures and their impact, and combining this with cost, benefit and equity considerations. There are other management options that have been evaluated and discounted in other Regions for reasons that would also be applicable to Otago towns. For example, the use of high pollution forecasts and the requirement of using non solid fuel heating methods on high pollution nights has been discounted elsewhere because of the extent of days likely to be forecast as high pollution potential and because the costs of the option are very high owing to households needing to fund alternative heating methods. These have not been re-evaluated here.

Further options such as the impact of meteorological interventions, house design and the potential for community heating (district heating) have been considered in reports commissioned by the Otago Regional Council (Conway et al., 2016; Wilton, 2016).

Table 4.1 summarises the different options considered for inclusion in the evaluation.

Table 4.1: Management options to improve particulate concentrations in urban areas of Otago

Source and option	Background	Quantification	Areas of greatest impact
Domestic heating Phase out indoor open fires and multifuel burning appliances	These options are the status quo in Air Zone 1 but could be considered in other urban towns in the Region where air quality may be of concern. In the Otago Air Strategy an option to regulate specifies that the plan review will consider a ban on the use of coal. Whilst coal burning appliances (multi fuel burners and open fires) are unable to be installed in Otago under the existing air plan, those installed prior to 2007 (2009 in Clyde) in Air Zones 2 and 3 can be legally used.	Improvements in both home warmth and emissions through an open fire replacement with ULEB. Replacement of multi fuel burner with ULEB results in an improvement in particulate emissions.	Milton and Mosgiel.
Domestic heating Require all new installations of solid fuel burners meet the ULEB criteria.	This option is relatively simple in that it would replace the current installation criteria with a ULEB installation criteria. In the absence of additional regulation, the impact is slow as it requires the replacement of burners through natural attrition. This measure is most effective when used in combination with a phase out of higher emitting burners. This regulation has been applied in Christchurch for all households and in Nelson in selected airsheds for new dwellings and existing dwellings using other heating methods.	Improvement relates to difference in real life particulate between ULEB and existing solid fuel burner fleet.	All areas where domestic heating is a significant contributor.
Domestic heating Phase out burners not meeting the ULEB criteria.	This includes solid fuel burners meeting the 1.5 g/kg or 0.7 g/kg limits that do not also meet the ULEB emission criteria, as well as open fires and multi fuel burners where these are currently permitted. Enclosed solid fuel burners typically have a limited useful life which has been described previously as 15 years on average by the home heating association. Anecdotally, some burners are known to have been operating for well over 25 years. Burner phase outs were part of the Otago Air Plan for Air Zone 1 so in those areas there may be increased resistance as a result of a change in approach. The option has been evaluated based on a phase out period of 20 years starting from 2025.	Improvement depends on the baseline regulations. In areas where all but LEB plus 1.5 g/kg burners installed before 2007/2009 have been phased out (Air Zone 1) the improvements will be less than in other areas.	All areas where domestic heating is a significant contributor.

	This regulation has been applied in Christchurch. Burner phase outs more generally (those not meeting the NES design criteria for example) have been applied more broadly (e.g., Blenheim, Hastings, Napier, Rotorua, Invercargill and Gore)		
Domestic heating Prohibit the installation of solid fuel burners in new dwellings or existing dwellings using other heating methods.	This rule means that new dwellings are unable to install a solid fuel burner regardless of the emission standard that it can meet. Existing dwellings that previously used other heating methods are also unable to install solid fuel burners if included in the regulation. When considered in conjunction with a burner phase out a key consideration is whether you allow households that do not replace phased out burners by the required dates the ability to install a replacement burner. This regulation has been applied in Nelson (ongoing in Airshed A and B) and Christchurch (prior to the introduction of ULEB only)	Improvement depends on the projected increase in dwellings.	Most effective in areas where population increases are projected and where domestic heating is a key contributor. Of the towns evaluated in this report, this will have greatest impact in Mosgiel, Cromwell and Clyde. Other high growth areas where air quality is yet to be quantified may also benefit.
Domestic heating Behaviour change programme targeting the operation of solid fuel burners potentially supported by a no visible smoke rule.	Analysis of real life emission test data from solid fuel burners indicates a high variability in emissions depending on burner operation for NES compliant wood burners. Wilton, (2014a) shows targeting the operation of the worst 10% of NES compliant burners could result in a reduction in particulate of around 27%. Improvements in emissions can occur through improved burner operation and are therefore low cost. It is noted that a behaviour change programme is not just the provision of education and information material. It requires identifying gross emitters and working with them to resolve operational issues. A behaviour change tool kit was developed by Environment Canterbury and a very effective programme was implemented in Nelson. An additional tool that may assist with the programme is a no visible smoke rule. Having a regulatory basis for a programme may not	The impact of a behaviour change programme will depend on resourcing, the programme, implementation and potentially the wood burner fleet. The effectiveness for modelling purposes has been assumed at 10% of overall burner emissions but a well implemented programme could achieve more.	All areas where domestic heating is a significant contributor.

	be an advantage however, as the perception that the programme is enforcement based may compromise its effectiveness. One uncertainty with the behaviour change programme is the impact on ULEB burners relative to other authorised burners. For the ULEB with technology designed to minimise emissions regardless of operation (e.g., catalytic converters) there may be less impact. However, with an increasing proportion of ULEB that are traditional design burners the effectiveness of a programme is likely the same. Nelson City Council implemented a behaviour change programme as part of their Plan Change 3 with an aim of reducing the daily winter PM_{10} emissions by 10%. It is likely that greater reductions could be achieved with a high level of resourcing and implementation.		
Domestic heating Phase out all solid fuel burners	The impact of phasing out of solid fuel burners has been modelled based on two stages. Firstly, prohibiting the installation of new solid fuel burners in any dwellings and secondly phasing out of existing dwellings based on a 20 year useful life. If the first stage is implemented as modelled in 2025 then some solid fuel burners installed between 2020 and 2025 are still operating at the model end point in 2040. Thus, additional reductions beyond 2040 would occur with this option. No Councils have fully prohibited the use of solid fuel burners in any areas of New Zealand to date.	The impact is easily quantified and likely reliable.	All areas where domestic heating is a significant contributor.
Outdoor burning Prohibit outdoor burning	Current outdoor burning regulation effectively prohibit outdoor burning on small lot sizes by requiring a buffer or separation distance from a burn location to the property boundary. Notwithstanding this, households in some urban areas report outdoor burning (in inventory surveys and it is unclear if they are compliant or non-compliant with the rules). Contributions from larger lot sizes may require reconsideration. It is unclear if increased regulation, education and awareness, compliance monitoring or a combination of these is required A prohibition on outdoor burning year round or during the winter months exists in many urban areas where PM_{10} concentrations exceed the NES (e.g., Nelson, Blenheim, Richmond, Invercargill, Gore, Christchurch and other Canterbury	Uses emission inventory estimates as baseline and assumption of no outdoor burning contribution. Outdoor burning not quantified for 2016 emission inventory areas.	Cromwell (but potentially other areas as well)

	Airsheds, Napier, Hastings). Some exceptions exist for diseased material on production land.		
Outdoor burning Solid fuel fired barbeque, braziers, fireplaces, hangi, domestic pizza ovens	These sources are not typically significant contributors to ambient particulate concentrations as domestic use of outdoor cooking and heating/ aesthetic options are infrequent particularly during the winter months when meteorological conditions are most conducive to elevated concentrations. They may cause nuisance impacts on neighbours, however. Some restrictions may need to be considered in areas where achievement of air quality targets is more challenging. This could include prohibitions on use during winter months, prohibitions on new installations or prohibition on the use all year. Recommend inclusion of this source in future inventories.	Not quantifiable with current information base.	
Industry Paving of unpaved yards	In areas where there is a substantive coarse mode (PM_{10}-$PM_{2.5}$) contribution to PM_{10} fugitive dusts can be a contributing source. Vehicle movements on unpaved yards crush dusts to form coarse mode particles. These can be resuspended with vehicle movement or winds. Quantification of contribution typically requires source apportionment studies. Consideration could be given to making unpaved yards over a certain size a discretionary activity to encourage paving of yards in areas where data indicate coarse mode contributions to particulate. As paving of yards can contribute to other impacts such as flooding locations specific evaluation of the need and potential impacts of this rule may be required.	Not quantifiable with current information base.	Milton, Dunedin
Industry Discretionary activities for bulk solid materials handling and storage of logs	In areas where there is a substantive coarse mode (PM_{10}-$PM_{2.5}$) contribution to PM_{10} and there are port activities or industrial and trade activities involving the handling of bulk solid materials these sources can be significant contributors. Mitigation whilst assessed through a resource consent process is likely to include measures such as dust management plans, covering of storage areas and changes to operational practices (e.g., increased trailer loading of logs at Port).	Insufficient information at present to quantify contributions.	Dunedin, Milton

4.1.3 Key variables

A key factor influencing the effectiveness assessment is the relationship between real life emissions from low emission burners (meeting the 0.7 g/kg or 1.5 g/kg emission limits when tested to NZS 4013) and those from ULEB (38 mg/MJ when tested to CM1).

Testing of real-life emissions from a range of ULEB design types was carried out in Arrowtown in 2022. The study indicates average real-life emissions of around 2.05 g/kg (dry weight) and compares with test data from previous ULEB testing (down draught burners only) of 1.58 g/kg in Waimate (down draught burners) and 2.03 g/kg in Nelson (single chamber traditional burners). The emission factor used in the evaluation was 2.0 g/kg (wet weight) which is conservative relative to the current real life test data[1]. There is justification for conservatism however, as initial ULEB authorised had design features such as down draught dual combustion chambers, catalytic converters or automated air supply. More recently traditional burner designs have been authorised as ULEB which increases the potential for impact of household operation on emissions. As a result, the emission rate may change over time with increasing market share of traditional design ULEB burners.

The emission factor used for NESAQ compliant burners and 0.7 g/kg burners is 4.5 g/kg and is based on analysis of real life test data (Wilton et al., 2015). No differentiation is made between the 1.5 g/kg and the 0.7 g/kg burners because the data available for these burners does not support use of a lower emission factor.

The extent of ULEB prevalence in the existing burner stock is another variable which influences the assessment of effectiveness of in particular burner phase out options. As the authorised burner list for Air Zone 1 was revised to refer to the ULEB authorised burners in 2020 it has been assumed that all burner installations in Air Zone 1 areas since 2020 will be ULEB.

Another variable influencing projected improvements is the transition of households from older burners in accordance with Air Plan rules and the timeframe over which this has or will occur. Emission inventories carried out for these areas in 2016 and 2019 suggested some households had retained non-complying methods following phase out dates. It is likely that many of these households have subsequently replaced noncomplying heating methods as improvements in PM_{10} concentrations are observed in monitoring data over this period in a number of urban areas.

4.1.4 Projections methodology and assumptions

The base data for emissions for anthropogenic sources is the most recent air emission inventory. This is 2016 for Clyde, Arrowtown, Milton and Mosgiel and 2019 for Cromwell and Clyde. The Dunedin inventory had not been updated since 2005 and has not been included in the management options assessment.

Outdoor burning emissions were not included in the 2016 emission inventory because regulation was assumed equivalent to a prohibition. However, in 2019 a question was included in the inventory to ascertain if legitimate or illegitimate burning was being carried out in Cromwell, Clyde and Wanaka. A small amount of outdoor burning was found to occur within the study areas. This has been included in the projections analysis for Cromwell and Clyde. In other areas it is assumed that the burning impact was negligible. However, it is recommended that if additional measures targeting outdoor burning are adopted that they apply to all the areas evaluated in this study to ensure the contribution from this source is negligible.

The contribution of outdoor burning from areas outside of the airshed to concentrations within the airsheds has not been accounted for in the analysis because of difficulties in quantifying this source. Management of outdoor burning in areas surrounding airsheds could also be considered to minimise potential impacts.

The contribution of natural sources (primarily marine aerosol and soil) to concentrations of PM_{10} in the more inland locations of Arrowtown, Clyde, Cromwell and Clyde was estimated based on seasonal natural background concentrations for Blenheim (average PM_{10} of 3.6 µg/m^3) as source apportionment studies in this location gave relatively low marine aerosol contributions. For Milton, Mosgiel and Dunedin seasonal natural source contributions from Nelson (average PM_{10} of 6.9 µg/m^3) have been used. Data from these three locations suggest a greater coarse mode contribution to PM_{10} (lower proportion of PM_{10} that is $PM_{2.5}$). The

[1] The average wet weight emission rate from the Arrowtown data is 1.6 g/kg based on a 20% wood moisture content

natural source contribution to $PM_{2.5}$ is assumed to be 34% of the PM_{10}. There are no changes assumed to this baseline information.

The daily projections graphs will show all data expressed as a percentage of the base year concentrations. Reductions targets will be adjusted to the base year. For the annual assessment the base year will be 2022 and projections will be expressed as concentrations by source and compared directly with the concentration targets.

The change in PM_{10} and $PM_{2.5}$ motor vehicle emissions from 2022 to 2040 was estimated using the VFEM (version 6.0). The VFEM model outputs suggest a decrease in total motor vehicle $PM_{2.5}$ emission rates by around 63% between 2022 and 2040. The change in PM_{10} emissions was lower at 57% owing to the larger proportion of non tailpipe emissions contributing to this indicator. A 20% increase in VKT over the emission inventory levels was assumed. No assessment of other contaminants from motor vehicles (e.g., nitrogen oxides) has been made as this is outside of the scope of this work.

No increase in industrial emissions was assumed for the period from inventory until 2040 owing to the limited existing sources and low probability of industry in most of the areas.

No other contributing sources have been identified.

The assessment is based on the following additional assumptions which are integrated into all airsheds unless stated otherwise:

- 100% of wood burners installed in Arrowtown, Alexandra, Cromwell and Clyde since 2020 are ULEB
- 20% of wood burners installed in Milton, Dunedin and Mosgiel to replace existing solid fuel burners will be ULEB. This is the status quo assumption but given most management options include a ULEB installation requirement it only applies to that scenario.
- All of the pre 2005 wood burners will be replaced between 2025 and 2030 through natural attrition.
- Real life emissions from ULEB will be 2.0 g/kg[2] for both PM_{10} and $PM_{2.5}$
- Other emission factors and fuel use variables as per the most recent air emission inventory for each area.
- Projected motor vehicle emissions based on a 20% increase in VKT from 2017 to 2040 and a 63% reduction in motor vehicle $PM_{2.5}$ emission factors (VEPM 6.0) from 2022 to 2040 (based on 69% from 2017 to 2040) and a 51% reduction in motor vehicle PM_{10} emission factors from 2022 to 2040 (based on 57% from 2017 to 2040).
- A behaviour change programme (when implemented) reduces average emission factors from wood burners and ULEB by around 10%.

There are a range of assumptions in the analysis. However, the majority have minimal impact on the evaluation of the effectiveness of management options. The key assumptions impacting the evaluation for which there is uncertainty are:

- the contribution of natural sources
- the emission factors for ULEB and the difference between LEB and ULEB
- the impact of a behaviour change programme.

The latter will depend on the extent to which any programme is resourced. The issue around ULEB relates to limited testing to specific burner models and the recent approval of existing technology burners as ULEB.

[2] Wet weight emission factors established based on an evaluation of emission rates from testing of ULEB in Waimate, Nelson and Arrowtown, noting the increase in proportion of ULEB that are traditional burners and the seemingly higher real life emissions for these from the limited testing done and a wood moisture content of 20%.

4.2 Costs and benefits of management measures

A number of Councils have commissioned an economic analysis of the costs and benefits of management measures to reduce particulate concentrations whilst others have taken a more qualitative approach to the cost benefit evaluation.

The following provides costs and benefit considerations for a range of management options based on experience with air quality management and cost and benefit evaluations for other areas.

	Cost, benefit, practicality, equity, effectiveness considerations	Notes	Additional reference resources
Domestic heating Compliance check of air zone 1 airsheds for use of prohibited burners.	Some improvements may be able to be obtained through a publicised "smoke police" type campaign whereby neighbourhood audits of smoky chimneys and checks on consents databases for the prevalence of appropriate burners is carried out. Measures that assist with compliance aid in the achievement of the modelled results rather than having their own quantified benefit. The health benefits of this option will vary depending on the extent of non-compliance and the impact it has on households transitioning to authorised solid fuel burner devices. The cost, borne by Council, could vary depending on the resource allocated. Some benefit may be obtained by sourcing smoky chimneys and some by the public being exposed to media advertising of the campaign.	Council will need to consider the community impacts of enforcement prior to the potential resetting of targets (and seen negatively by some as changing the goal posts).	Bay of Plenty Regional Council
Domestic heating Require all new installations of solid fuel burners meet the ULEB criteria.	This is a low to no cost option for improving PM_{10} and $PM_{2.5}$ from domestic heating. Unlike when ULEB were first introduced, the price point between ULEB, NES compliant burners and ULEB is now negligible. The range of appliance types available may include some limitations that could result in increased costs to some households. However, the ULEB authorisation list now includes wetback and insert options as well as wood fired boilers. There is a cost to solid fuel appliance manufacturers that do not have ULEB burners through loss of potential income. The benefits of this option are gradual replacement of the solid fuel burners with ULEB through natural attrition. It is noted that total replacement without management intervention (phase outs) would be a very lengthy process and unlikely to be achieved in a 30 year timeframe if at all.	Does the ULEB criteria need to be revised to ensure the operational variables are being mitigated as was originally intended with this standard.	Environment Canterbury
Domestic heating Phase out burners not meeting the ULEB criteria.	This option is really required if you want the benefits of the installation standard upgrade to ULEB to occur within a reasonable timeframe. The costs associated with this option are the difference in the regulated useful life versus the actual useful life of the appliance (for example if the allowed useful life is 15 years and the actual useful life is 20 years then a householder loses five years of use). In	Access to consent databases with mechanisms set up to enable detection of wood burner types	Many Councils including ORC have implemented burner phase outs. For example, Nelson City Council, Hawkes Bay Regional Council, Bay of Plenty Regional Council, Marlborough District Council, Southland Regional Council. Nelson City

	households where appliances are used less regularly (e.g., holiday homes) the householders may get a lot less use from their burner than anticipated. There is the potential for an additional cost whereby a household is unable to replace their burner at the regulated time and either uses it illegally (cost to the environment) or the level of warmth in the home decreases if the household is unable to afford higher operating costs of other heating method. The cost compounds if the household is able to source firewood for free or low cost but can not manage large capital outlay associated with burner replacement. Provision of financial incentives for low income households can be used to mitigate some of the financial burden of capital costs of replacement methods. It is noted that appliances that are nearer or in reality past the end of the useful life are more likely to be operating with higher emissions than anticipated as firebox is less able to function in the manner it did was tested owing to wear and tear. The benefits of this option are certainty of emission reductions associated with the replacement of older burners with newer technology and the associated health impacts.	installed is an additional tool for enforcement. Consider assistance for low income households to manage the cost issues of replacing burners.	Council had a communication strategy around implementing their air plan rules which was an effective approach in my view.
Domestic heating Prohibit the installation of solid fuel burners in new dwellings or existing dwellings using other heating methods.	The benefit of this regulation is that there is no growth in solid fuel burner emissions with increasing population. Existing households that might otherwise have wanted to have installed solid fuel burner experience a loss of choice in future heating options. These households may or may not have been adequately heated historically using other methods and existing insulation. New dwellings are subject to improved insulation standards and should have less need for space heat. However, with winter temperatures in some locations in Central Otago averaging less than four degrees there will still be a high heat requirement for many dwellings. These will likely come at increased cost if solid fuel is not an option as the wood burner provides the lowest operating cost (see section .		Nelson City Council

	For households that have access to free firewood purchasing a new dwelling or an existing dwelling using other heating methods would result in additional operational cost. Historically the purchase of a new dwelling would have been more expensive than an existing dwelling and it may have been argued that if a person could afford a new dwelling then they can afford more expensive heating options. However, in some instances new dwellings may be more affordable than existing houses because they are on smaller lot sizes or are smaller dwellings or semi attached. A key equity issue relating to this type of policy is whether households should be able to operate burners that are high emissions whilst low emission (ULEB) burners are being prohibited to others. This issue is removed in an environment where all households are required to be low emissions (e.g., ULEB) and at that point the regulation becomes less inequitable albeit that new dwelling owners have reduced heating options and higher ongoing operating costs (see chapter three for operating costs). The cost in this instance is a choice cost for households who may end up with higher heating operating costs or who may not be able to get adequate heat to an existing dwelling using other cost-effective methods.		
Domestic heating Behaviour change programme targeting the operation of solid fuel burners potentially supported by no visible smoke rule	The behaviour change programme approach is well rated from a cost benefit viewpoint. The disproportionate emissions occurring as a result of poor operation of burners mean benefits can be significant if a programme is properly implemented. The cost to the householder is low, although it may require some investment in either time (spending more time being attentive of the fire) or resource (investing in better storage for fuel or purchasing/ gathering wood a year early). The main cost of this option is to Council in designing and implementing the programme.		Nelson City Council and Environment Canterbury.
Domestic heating	The costs of this option for energy switching are the capital cost of an alternative appliance and the operating cost difference between solid fuel and the other heating source (if there were heating sources lower cost than solid fuel this would be a cost saving). The capital cost is assessed similar to the burner phase out in that the cost relates only to the lost years of useful life of the burner	The electricity network may be unable to cope with the increased peak	N/a

Prohibit solid fuel burning for domestic home heating	as this would require replacement either way. There may be an increased cost to replace the kWh rating of the wood burner with another heating method and in some situations achieving the same heat output with an alternative method may be problematic. The operational costs may also be significant, especially for households that could previously obtain wood free of charge. Electricity prices in Central Otago are higher than most areas of the country. Higher heat output heat pumps are less efficient so replacing high heat output burners heating larger spaces with a heat pump will cost more than the average kWh heat pump operation rates. The capital costs may be significant relative to replacement with a burner if multiple options are required to achieve the same heat output. A further consideration of this option is the high potential for households to have reduced levels of comfort. Older and larger dwellings in particular can be hard to heat effectively and solid fuel burners offer higher heat outputs at relatively lower operational cost. Retrospective insulation can result in improved levels of comfort and may achieve adequate comfort levels when coupled with lower heat output devices in some dwellings. It is likely that this option would result in cold homes. It is likely that the benefits of improved air quality associated with this option would not be achieved if they are at the expense of warm homes. Further evaluation of the likely health impacts of cold homes that might occur with this option is recommended. There would be an additional cost to solid fuel burner manufacturers, and retailers, in the Region through loss of income. There would be a benefit to suppliers of other heating types in the region through increased market share.	load associated with this option.	
Outdoor burning Prohibit outdoor burning	Revision to the existing outdoor burning rule in some areas at least is warranted. This is because survey data shows prevalence of outdoor burning to the extent that it is detrimental to achievement of air quality targets in Cromwell at least. Additionally outdoor burning plumes carry significant distances and contributions from areas outside of the urban area is also a concern in many locations.	Allowing an exemption for the burning of diseased material from orchards should be considered. The reason for this is to reduce the spread of	See air plans for Tasman and Hawkes Bay for examples of prohibitions and exclusions for diseased material. Note both Councils have ongoing issues with outdoor burning contributions to air quality including from areas outside of air zones and urban areas contributing on calm still days.

	The prohibition on outdoor burning is practically possible and has been implemented in many areas of New Zealand. Larger lot sizes can produce more green waste material and whilst disposal by burning is convenient and cheap it provides a cost to the community by way of degraded air quality. The main impacts are adverse health effects of $PM_{2.5}$ exposure but it can also cause degraded visibility and smoke nuisance. Alternatives include removal to green waste facilities/ compost operations or mulching. Requiring landowners to dispose of vegetation waste increases the cost to households managing vegetation on rural and urban blocks. Costs include time or labour costs to remove or mulch as well as disposal costs and/or hiring of a mulcher and potentially a trailer. The benefits are improved health through reduced particulate concentrations. The benefits would lie with the community.	disease. In previous hearings horticulture representatives have given evidence of no viable alternatives for diseased material. Tasman have evaluated conditions to limit the ability to burn on the guise of disease.	
Industry Discretionary activities for bulk solid materials handling and storage of logs and unpaved yards	Bulk solid materials handling has the potential to result in significant PM_{10} discharges when large quantities of materials are handled in the absence of adequate mitigation. Log storage and handling also has the potential for discharges of PM_{10} emissions as material from logs is dislodged and crushed as logs are dropped and subsequent ground based material is resuspended as a result of vehicle abrasion and wind. Unpaved yards is another source of fugitive dust emissions with particle sizes that also occur in the coarse (PM_{10}-$PM_{2.5}$) size fraction. Commercial yards with exposed gravel or soil that are subject to vehicle movements can result in both dust nuisance and increase PM_{10} emissions.		Bay of Plenty Regional Council
Other Prohibit the installation of new wood fired hot tubs in Air Zones	Wood fired hot tubs appear to be increasing in popularity in the Otago Region. The combustion technology in the hot tub is not advanced and high emissions are likely. The heat does not serve a basic need for warmth and hot tubs can be adequately heated using other less polluting fuels. Allowing this type of combustion of wood in airsheds where there is limited capacity for particulate pollution uses up a disproportionate amount of airshed capacity (per combustion process) for a benefit that is a luxury rather than basic need.	Impact not quantifiable because of limited knowledge of installation rates.	

	Inclusion of this source in future inventories is recommended to enable adequate assessment of the potential contributions.		
Other Prohibit the use of pizza ovens, outdoor fires, braziers and solid fuel burning barbeque during the winter months	The combustion technology in pizza ovens which operate with a restricted air supply is not advanced and high emissions are likely. Outdoor fires also have the potential for emissions owing to the fast burn rate. The impact of these devices on particulate concentrations will be greater during the winter months when meteorological conditions are conducive to elevated concentrations. However, use rates are likely low during the winter months. Inclusion of this source in future inventories is recommended to enable adequate assessment of the potential contributions.	Impact not quantifiable because of limited knowledge of prevalence and use rates in Otago towns.	

5 ARROWTOWN MANAGEMENT OPTIONS

5.1 Annual $PM_{2.5}$

Projections in annual $PM_{2.5}$ concentrations in Arrowtown are based on the methodology outlined in section three with the following additions:

- Population projections of 0.1% per year based on the Queenstown Lakes District Council projections for Arrowtown from 2018 to 2028[3].
- Household appliance distributions at 2017 and average fuel quantities for Arrowtown from the air emission inventory (Wilton, 2017).
- The proportion of new dwellings installing wood burners was assumed at 69% based on the relationship between wood use and dwelling increases from 2013 to 2018 census data.

Improvements in annual average $PM_{2.5}$ concentrations are predicted for the status quo projections in Arrowtown (Figure 5.1). The impact of phasing out all burners not meeting the ULEB criteria in Arrowtown and in conjunction with a behaviour change programme and collectively with no burner installations in new dwellings are shown in Figures 5.2 to 5.4. Analysis suggests the potential for compliance with the WHO guideline to be achieved in Arrowtown with a phase out of burners not meeting the ULEB criteria with the latter two combinations of options providing additional reductions that increase the certainty of achievement of the WHO (2021) guideline.

These evaluations include allowing new installations of ULEB in new dwellings and existing dwellings using other heating methods in Arrowtown.

A key factor in the success of the implementation of this suite of management options is the effectiveness of ULEB technology, in conjunction with behaviour change programmes in minimising the impact of householder operation on burner emissions.

In theory ULEB were intended to have technology to ensure low emissions despite operational factors. Whilst the early authorised ULEB included technologies such as down draught burners and catalytic converters, the technology of most recently authorised ULEB is similar to the NES design criteria burners. Real life testing of the NES design criteria burners shows significant variability in real life emissions as a result of householder operation. This has the potential to result in emissions higher than those assumed for ULEB. Potential mechanisms for limiting this potential impact is requiring demonstration of technology to minimise operational components (e.g., through catalytic converters) as a criterial for ULEB eligibility or increased efforts at manging operation through behaviour change programmes and including targeting of households with smoky chimneys. Inclusion of a rule relating to smoky chimneys may assist with this.

[3] https://www.qldc.govt.nz/media/gy0dwriy/qldc-growth-projections-2018-to-2048-summary-table.pdf

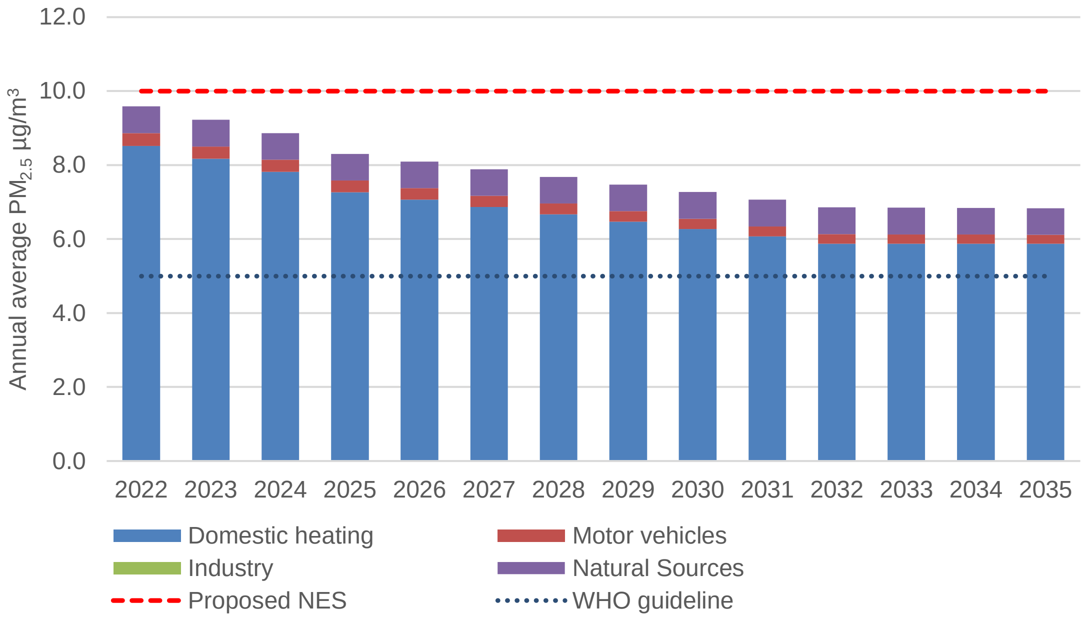


Figure 5-1: Status quo – only ULEB can be installed in Arrowtown

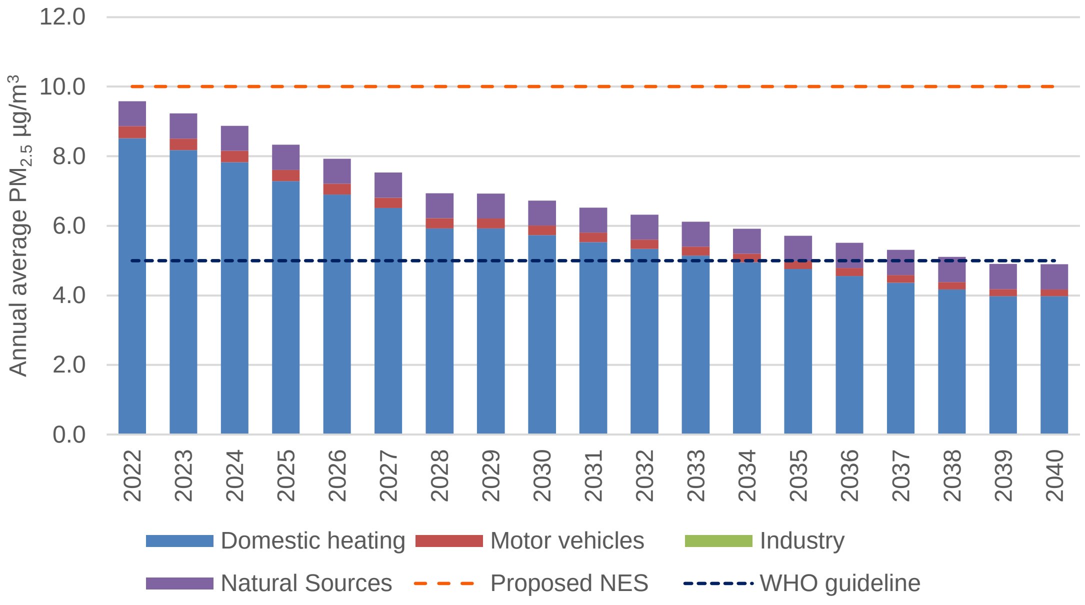


Figure 5-2: Phase out all burners not meeting the ULEB criteria in Arrowtown, allow new installations of ULEB.

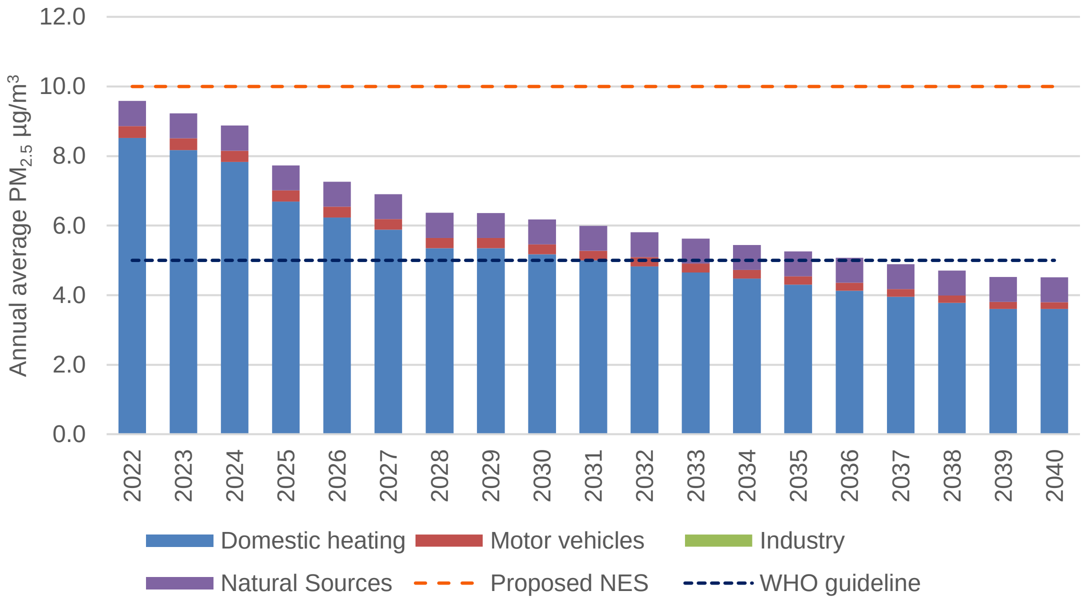


Figure 5-3: Phase out all burners not meeting the ULEB criteria in Arrowtown, allow new installations of ULEB and behaviour change.

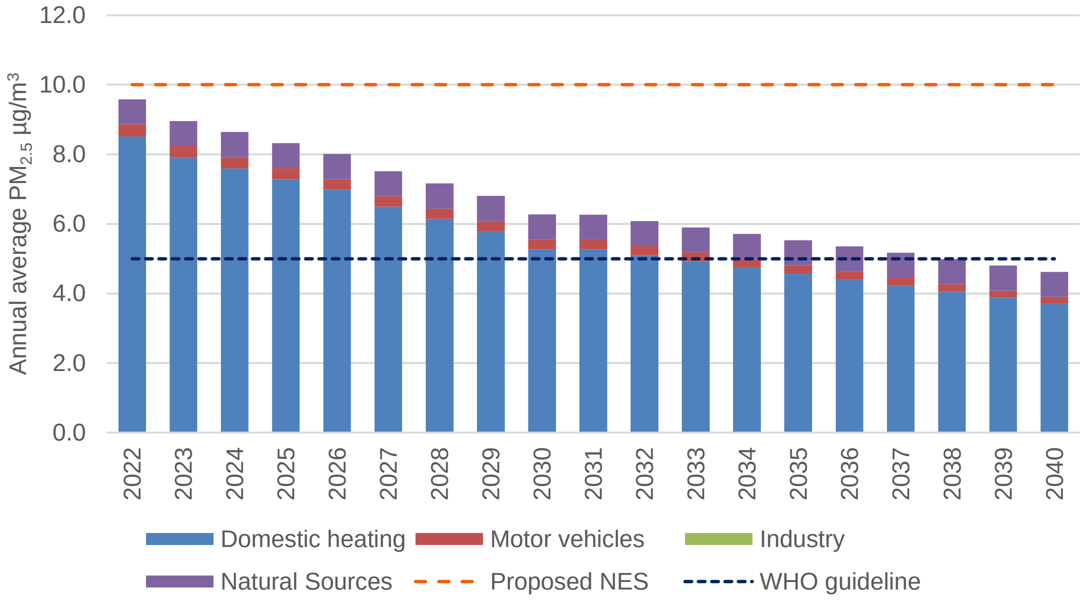


Figure 5-4: Phase out all burners not meeting the ULEB criteria in Arrowtown, no new installations of ULEB and behaviour change.

5.2 Daily $PM_{2.5}$

Figure 5.5 shows the projected daily winter $PM_{2.5}$ concentrations in Arrowtown relative to the two air quality targets for daily $PM_{2.5}$ (25 µg/m^3 and 15 µg/m^3) for the status quo and a phase out of burners not meeting the ULEB criteria.

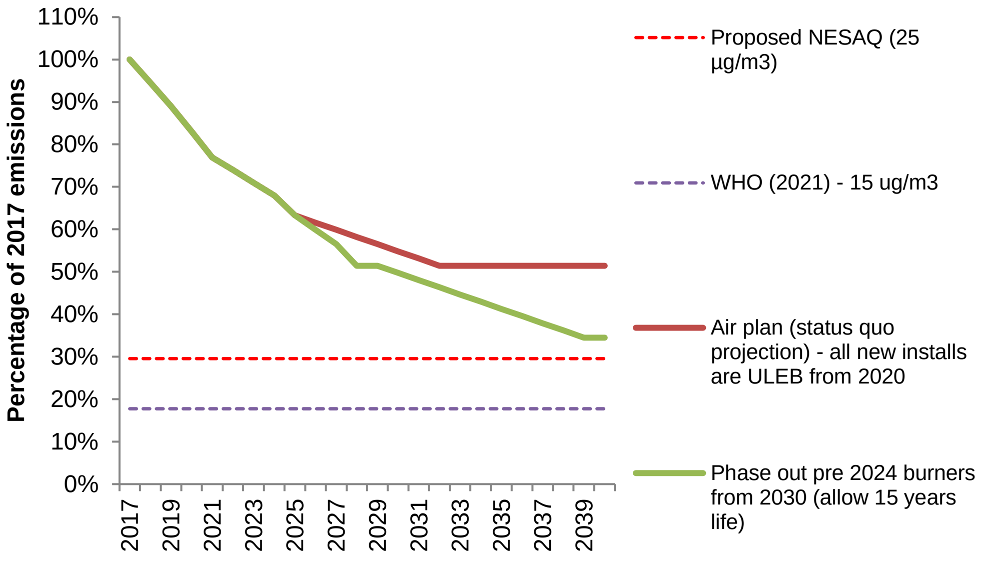


Figure 5-5: Status quo projections and impact of options on $PM_{2.5}$ daily winter concentrations in Arrowtown

Figure 5.6 shows that the additional impact of a behaviour change programme and prohibiting the installation of burners in new dwellings are unlikely meet the daily targets in Arrowtown. Collectively measures may achieve the proposed NES daily target but will not be sufficient to meet the WHO (2021) guideline.

A total burner phase out would likely be required to meet the WHO (2021) guideline in Arrowtown. The effectiveness of this option based on no new burner installations from 2025 and the phase out of burners after15 years useful life is shown in Figure 5.6.

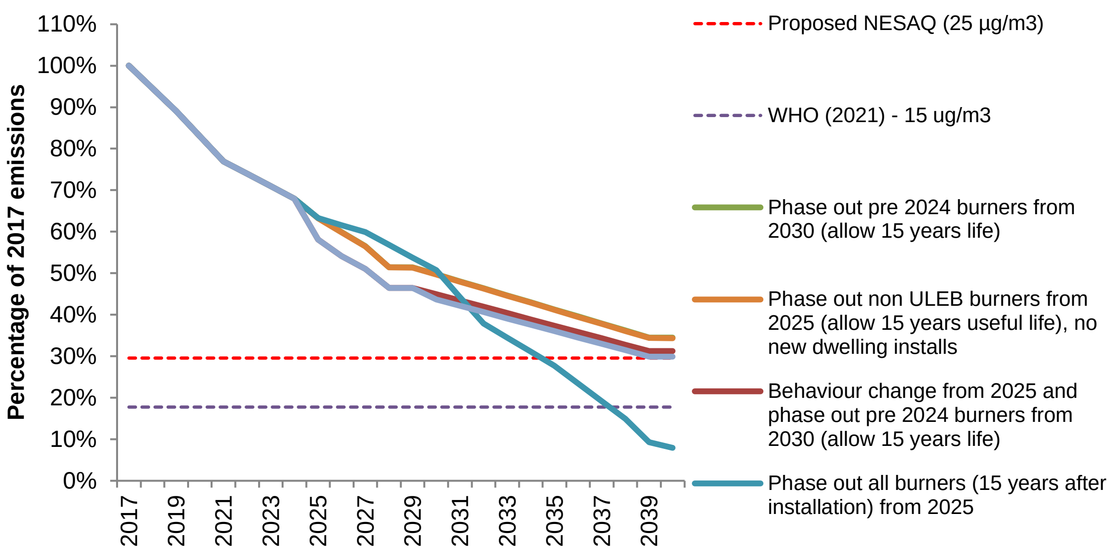


Figure 5-6: Impact of further options on $PM_{2.5}$ daily winter concentrations in Arrowtown

5.3 Daily PM_{10}

Figure 5.7 shows an estimated reduction in PM_{10} emissions from 2017 to 2022 which is consistent with air quality monitoring data (see Appendix A). In the projections model this is primarily occurring as a result of the delayed replacement of older burners, multi fuel burners and open fires with LEB and ULEB. The 2017 emission inventory suggested there might be around 250 of these burner types still to be replaced in Arrowtown. The projections analysis suggests that at the conclusion of the replacement of these burners that PM_{10} concentrations in Arrowtown are likely to taper and further reductions are unlikely in the absence of additional management measures. Under this scenario, the airshed is unlikely to become compliant with the NESAQ for PM_{10}.

Figure 5.7 also shows that phasing out of non ULEB wood burners is likely to achieve the NES target.

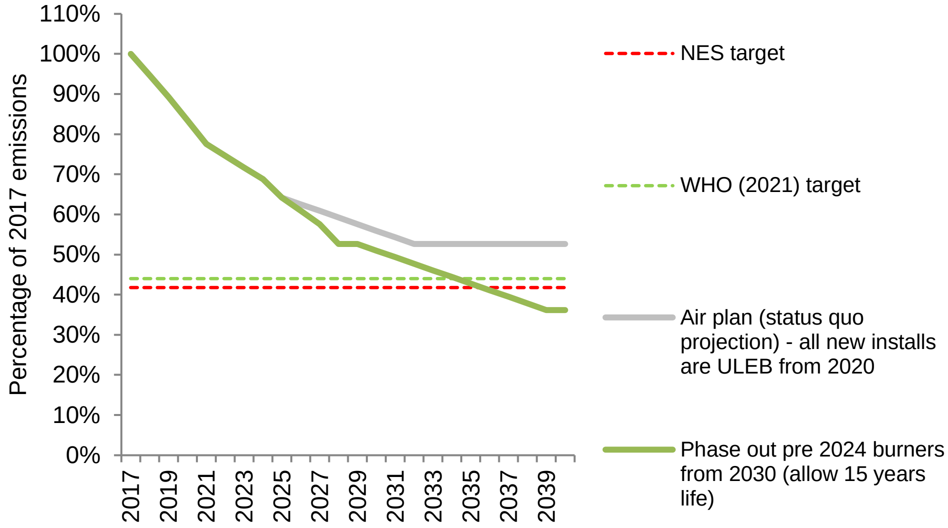


Figure 5-7: Status quo projections for 24-hour average winter PM_{10} in Arrowtown

6 ALEXANDRA MANAGEMENT OPTIONS

6.1 Annual $PM_{2.5}$

Projections in annual $PM_{2.5}$ concentrations in Alexandra are based on the methodology outlined in section three with the following additions:

- Population projections of 1.3% per year based on the medium annual growth rate for Alexandra from 2021 to 2034 (Rationale Limited, 2022).
- Household appliance distributions at 2017 and average fuel quantities for Alexandra from the air emission inventory (Wilton, 2017).
- The proportion of new dwellings installing wood burners was assumed at 50% based on the relationship between wood use and dwelling increases from 2013 to 2018 census data.

Figure 6.1 shows some improvements in annual average $PM_{2.5}$ concentrations for the status quo projections in Alexandra.

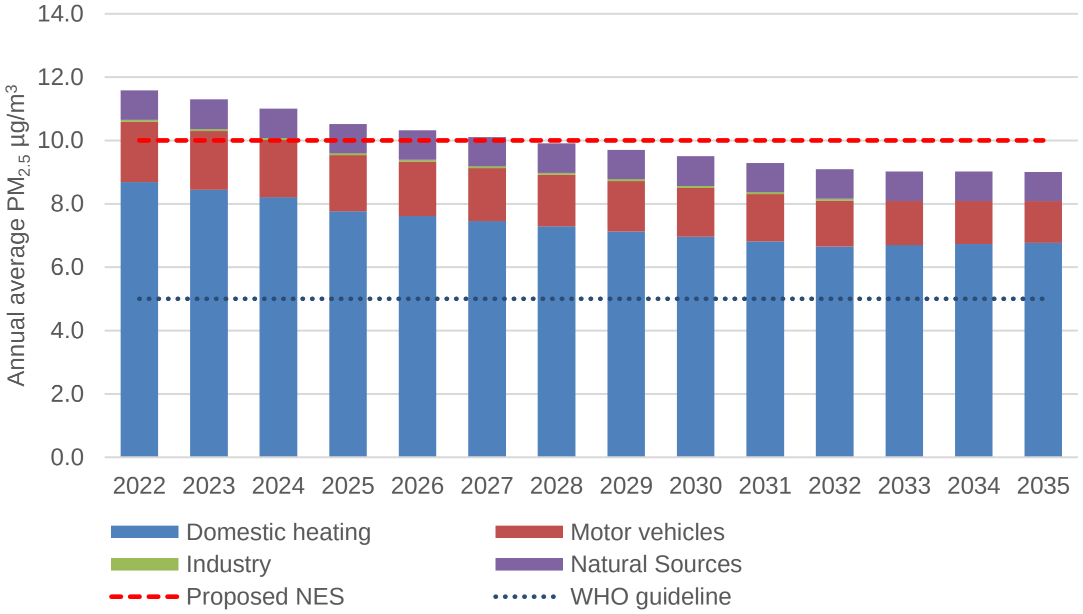


Figure 6-1: Status quo – only ULEB can be installed in Alexandra

The estimated impact of phasing out all burners not meeting the ULEB criteria in Alexandra and in conjunction with a behaviour change programme are shown in Figures 6.2 and 6.3 respectively. Figure 6.4 shows the additional impact of not allowing new dwellings to install solid fuel burners. An annual average $PM_{2.5}$ concentration of around 5.8 µg/m^3 is estimated by 2040 using this combination of measures.

Further improvements, if deemed necessary, are likely to require the phasing out of solid fuel burners in Alexandra (Figure 6.5) although there is the potential that a behaviour change programme could achieve greater reductions than predicted if well resource and implemented. Fully phasing out of solid fuel burners in Alexandra is likely to result in an increase in cold homes which is likely to be difficult to fully mitigate owing to the cold temperatures, existing housing stock and the high costs of other heating methods. The anticipated additional health benefits of the air quality improvements may not be realised if they come at the expense of household warmth. Quantification of the relative impacts is recommended if a full phase out of solid fuel burners is to be considered.

As with Arrowtown, a key factor in the success of the implementation of this suite of management options is the effectiveness of ULEB technology, in conjunction with behaviour change programmes in minimising the impact of householder operation on burner emissions.

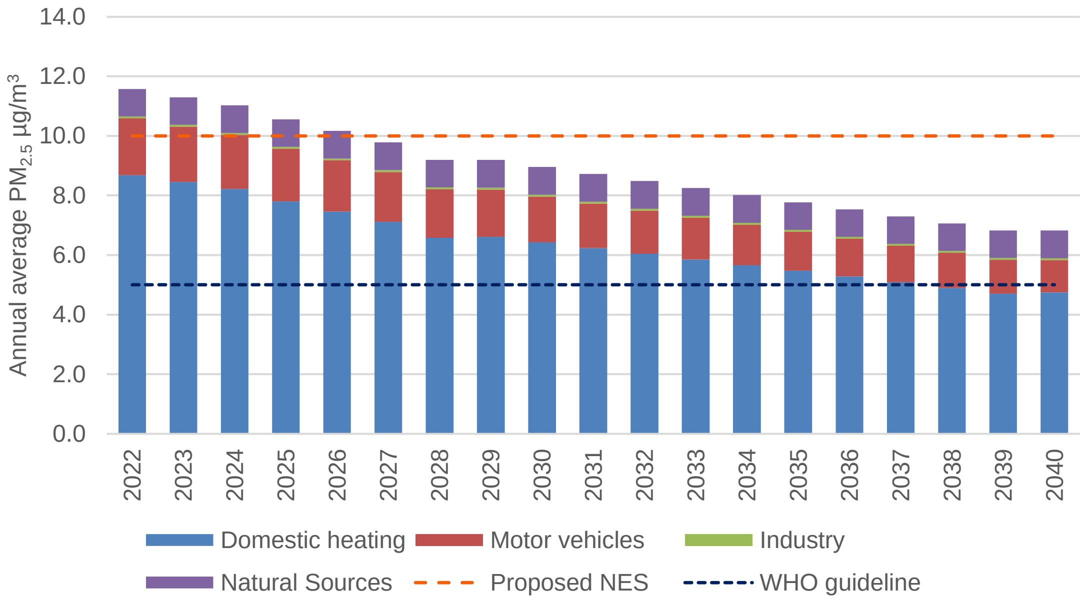


Figure 6-2: Phase out all burners not meeting the ULEB criteria in Alexandra, allow new installations of ULEB.

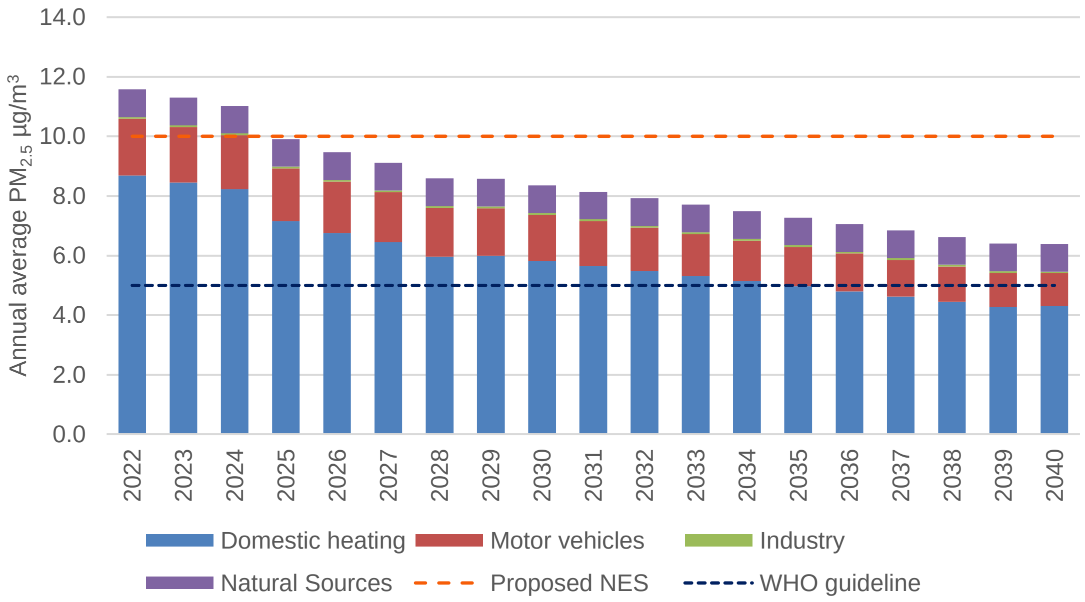


Figure 6-3: Phase out all burners not meeting the ULEB criteria in Alexandra, allow new installations of ULEB and behaviour change.

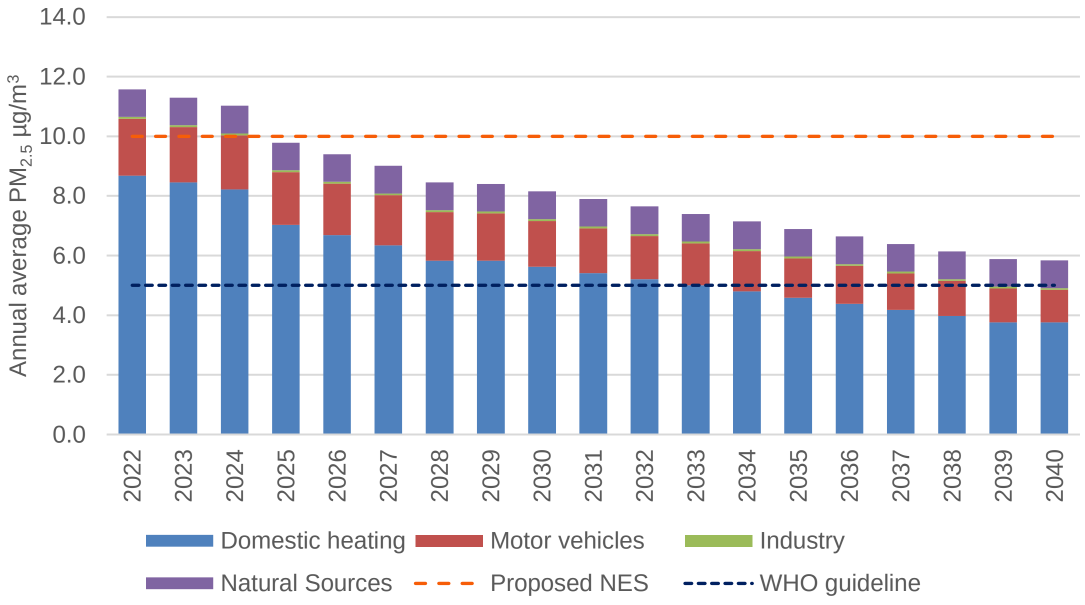


Figure 6-4: Phase out all burners not meeting the ULEB criteria in Alexandra, no new installations of ULEB and behaviour change.

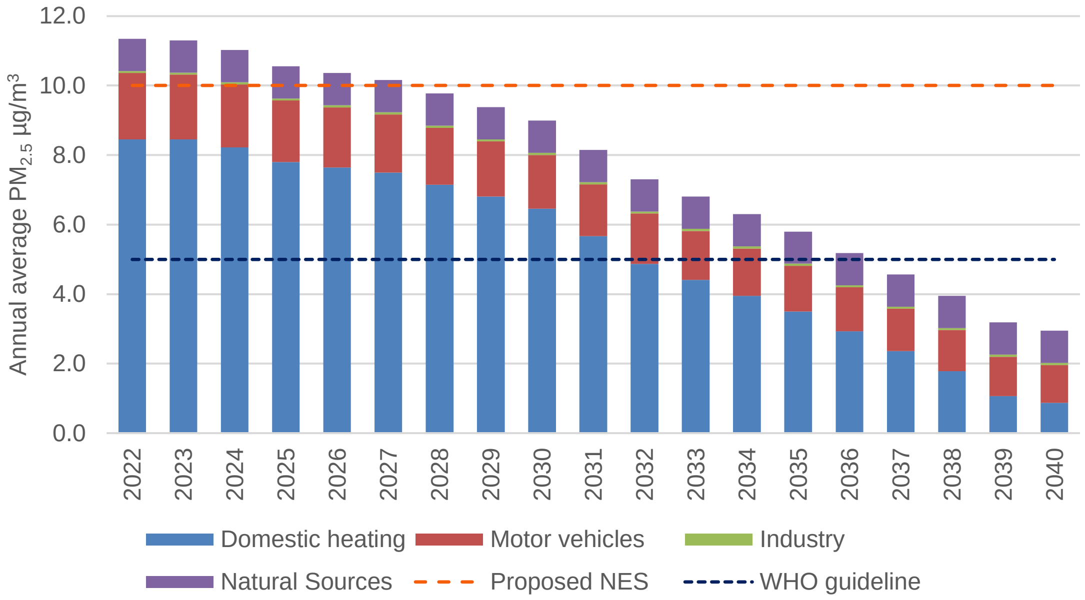


Figure 6-5: Phase out all burners in Alexandra from 2025 (allow 15 years useful life).

6.2 Daily $PM_{2.5}$

Figure 6.6 shows the projected daily winter $PM_{2.5}$ concentrations in Alexandra relative to the two air quality targets for daily $PM_{2.5}$ (25 µg/m^3 and 15 µg/m^3) for a range of management scenarios.

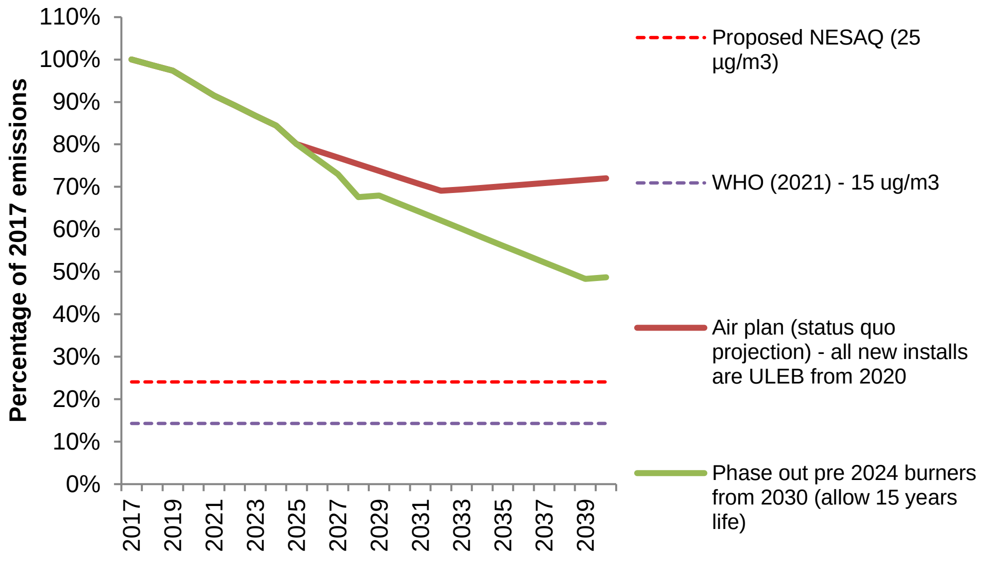


Figure 6-6: Status quo projections and impact of options on $PM_{2.5}$ daily winter concentrations in Alexandra

Figure 6.7 shows the impacts of phasing out all but ULEB burners in conjunction with:

- Not allowing the installation of burners in new dwellings or existing dwellings using other heating methods
- A behaviour change programme targeting householder operation of wood burners
- No burners in new dwellings and a behaviour change programme
- Phase out all burners from 2025 after a 15 year useful life

The evaluation indicates that a total burner phase out would likely be required to meet the daily $PM_{2.5}$ targets in Alexandra.

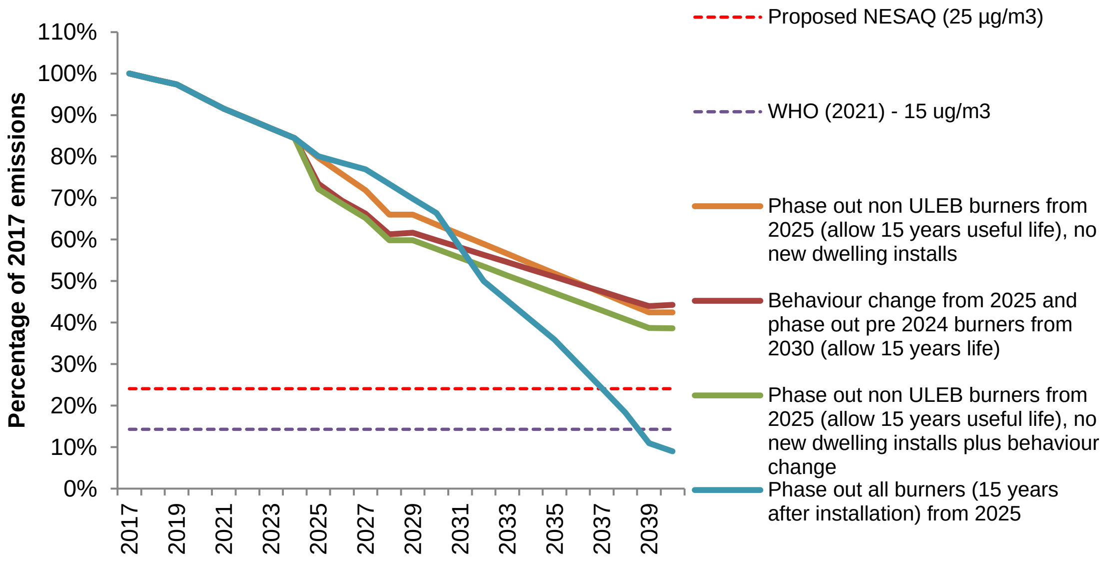


Figure 6-7: Impact of further options on $PM_{2.5}$ daily winter concentrations in Alexandra

6.3 Daily PM_{10}

Figure 6.8 shows an estimated reduction in PM_{10} emissions until around 2032 under the status quo projection. From 2033 daily PM_{10} concentrations are estimated to increase in the absence of further mitigation as a result of the increased dwellings and associated wood burners.

Improvement in PM_{10} are predicted with the phasing out of non ULEB wood burners and this option is likely to achieve the WHO (2021) guideline but may fall short of the NES target in Alexandra.

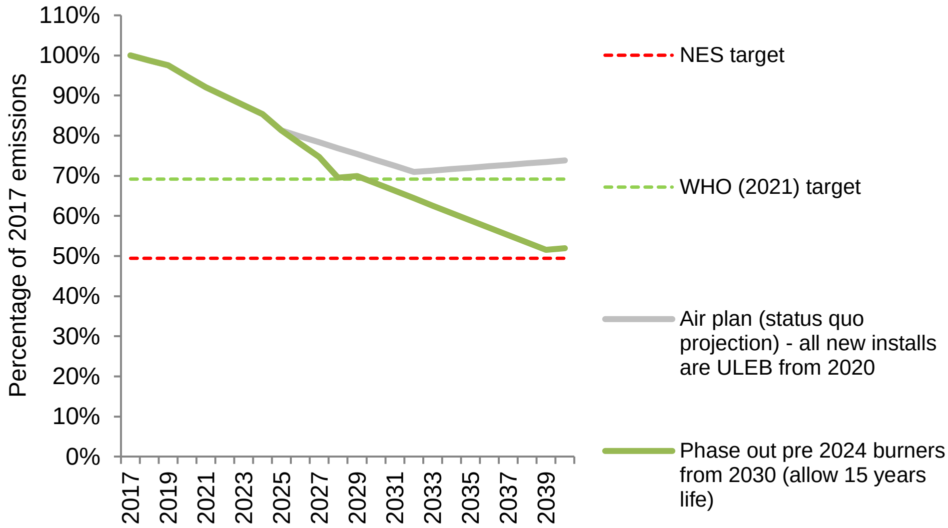


Figure 6-8: Status quo projections and phase of non ULEB burners on 24-hour average winter PM_{10} in Alexandra

Figure 6.9 shows the impact of a behaviour change programme and prohibiting the installation of wood burners in new dwellings and existing dwellings using other heating options in addition to the phase out of non ULEB burners in Alexandra. Analysis suggests that the NES for PM_{10} may be met with any of these air quality management measures.

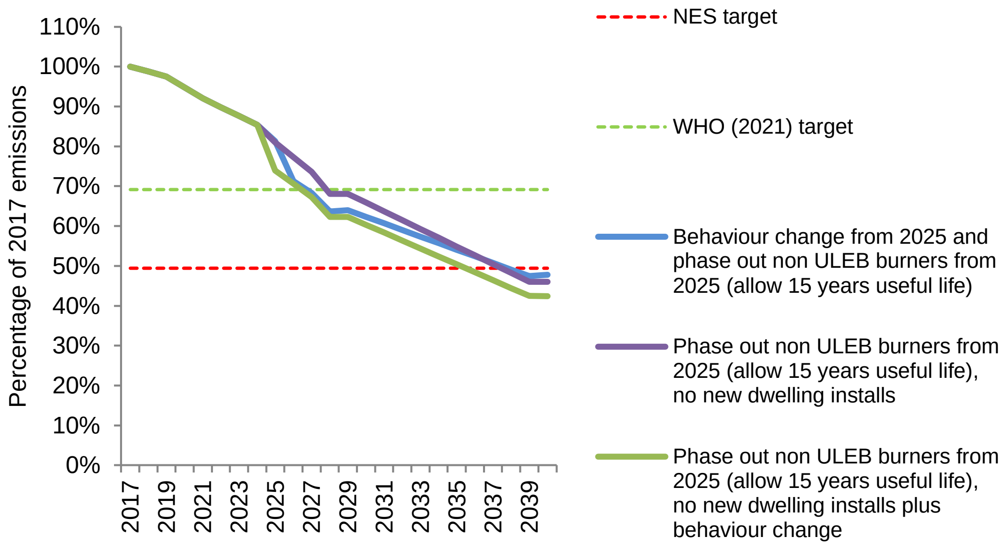


Figure 6-9: Air quality management projections for 24-hour average winter PM_{10} in Alexandra

6.4 Annual PM_{10}

Annual average PM_{10} concentrations in Alexandra currently comply with the ambient air quality guideline of 20 µg/m^3 and are likely to be compliant with the WHO (2021) guideline in the absence of additional management measures by around 2024 (Figure 6.10).

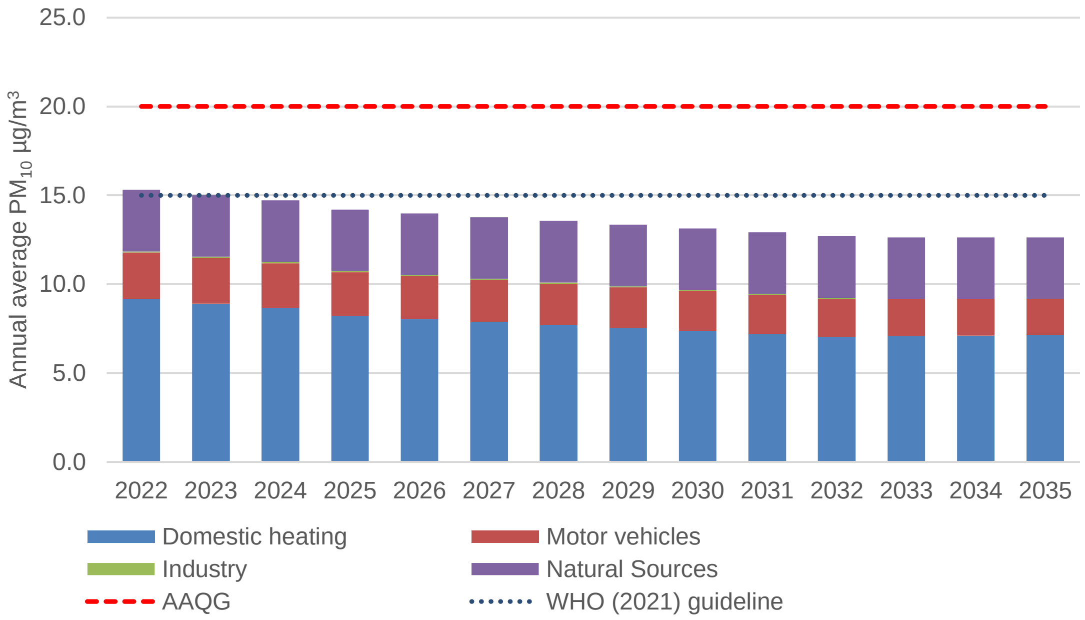


Figure 6-10: Air quality management projections for 24-hour average winter PM_{10} in Alexandra

7 CLYDE MANAGEMENT OPTIONS

7.1 Annual $PM_{2.5}$

Projections in annual $PM_{2.5}$ concentrations in Clyde are based on the methodology outlined in section three with the following additions:

- Population projections of 1.0% per year based on the medium annual growth rate for Clyde from 2021 to 2034 (Rationale Limited, 2022).
- Household appliance distributions at 2019 and average fuel quantities for Cromwell/ Clyde from the air emission inventory (Wilton, 2019).
- The proportion of new dwellings installing wood burners was assumed at 50% based on the relationship between wood use and dwelling increases from 2013 to 2018 census data.

Figure 7.1 shows an improvement in annual average $PM_{2.5}$ concentrations for the status quo projections in Clyde.

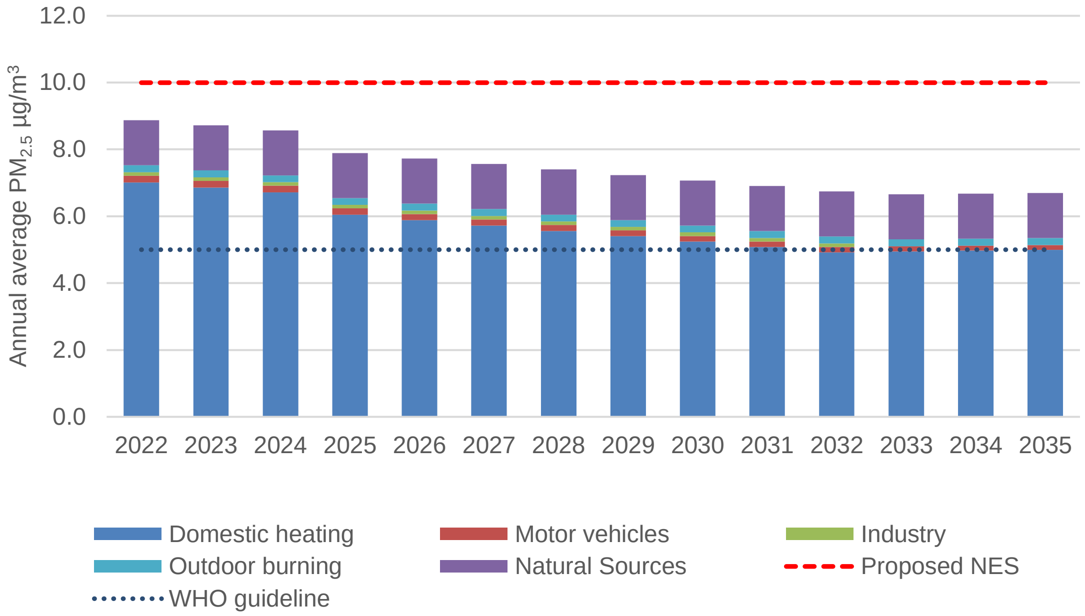


Figure 7-1: Status quo – only ULEB can be installed in Clyde

The estimated impact of phasing out all burners not meeting the ULEB criteria in Clyde and in conjunction with a behaviour change programme on annual average $PM_{2.5}$ concentrations are shown in Figures 7.2 to 7.4. This suggests that achievement of the WHO (2021) annual average $PM_{2.5}$ guideline may occur by 2040 using a combination of phasing on burners that do not meet the ULEB criteria, not allowing new installations of burners in new dwellings and existing dwellings using other heating methods and a behaviour change programme aimed at improving burner operation.

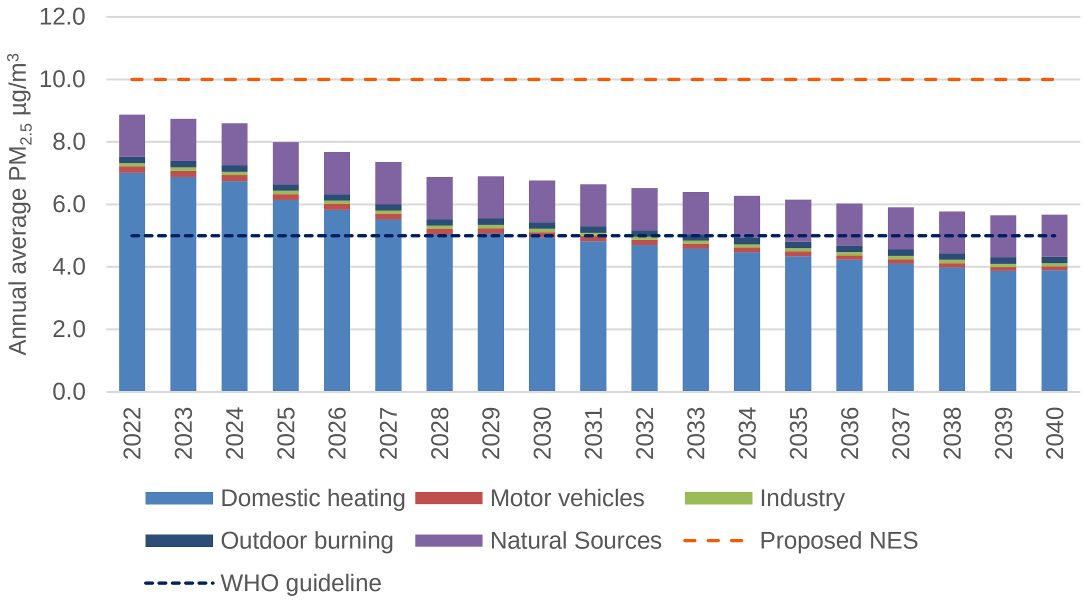


Figure 7-2: Phase out all burners not meeting the ULEB criteria in Clyde, allow new installations of ULEB.

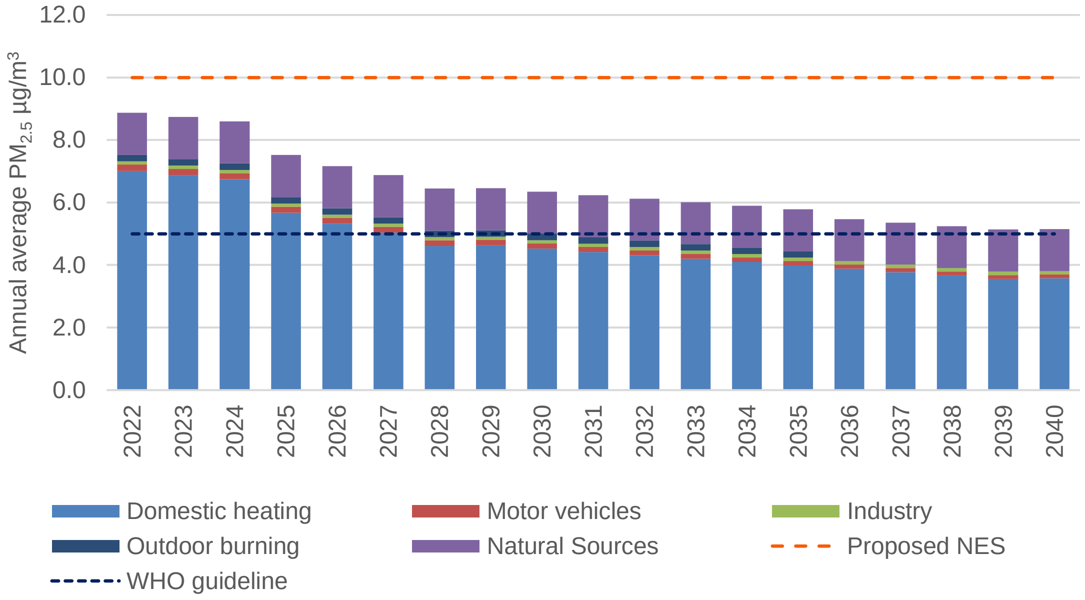


Figure 7-3: Phase out all burners not meeting the ULEB criteria in Clyde, allow new installations of ULEB and behaviour change.

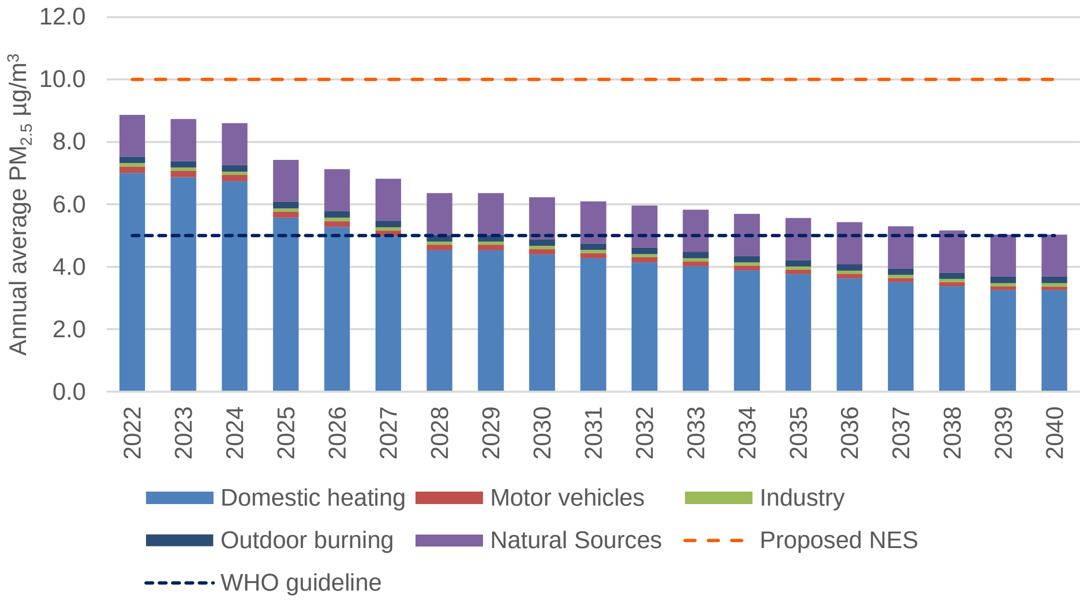


Figure 7-4: Phase out all burners not meeting the ULEB criteria in Clyde, no new installations of ULEB and behaviour change.

7.2 Daily $PM_{2.5}$

Figures 7.5 and 7.6 show the projected daily winter $PM_{2.5}$ concentrations in Clyde relative to the two air quality targets for daily $PM_{2.5}$ (25 µg/m^3 and 15 µg/m^3) for a range of management scenarios.

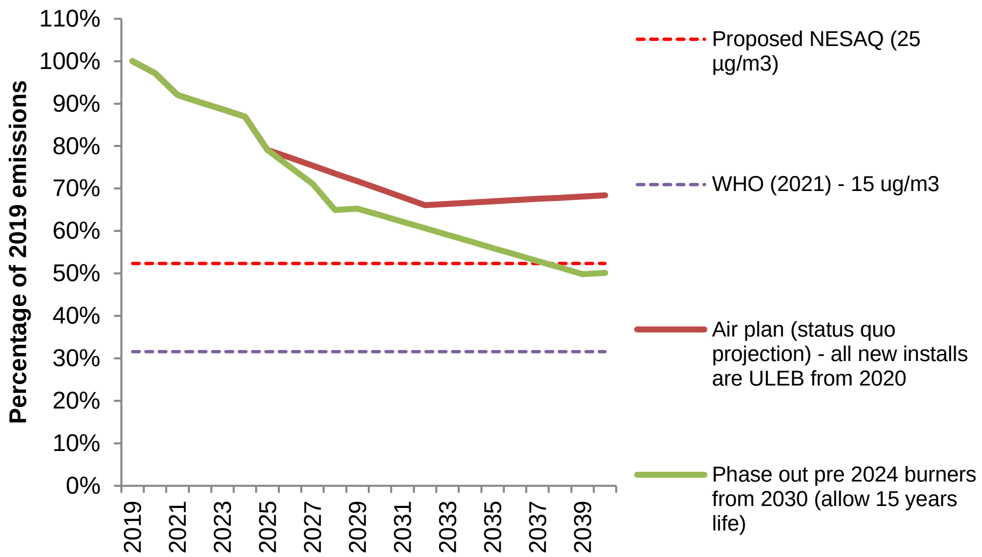


Figure 7-5: Status quo projections and impact of options on $PM_{2.5}$ daily winter concentrations in Clyde

The evaluation indicates that phasing out burners not meeting the ULEB emission criteria is likely to be adequate to achieve the proposed NESAQ of 25 µg/m^3. A total burner phase out would likely be required to meet the daily WHO (2021) $PM_{2.5}$ target of 15 µg/m^3 in Clyde.

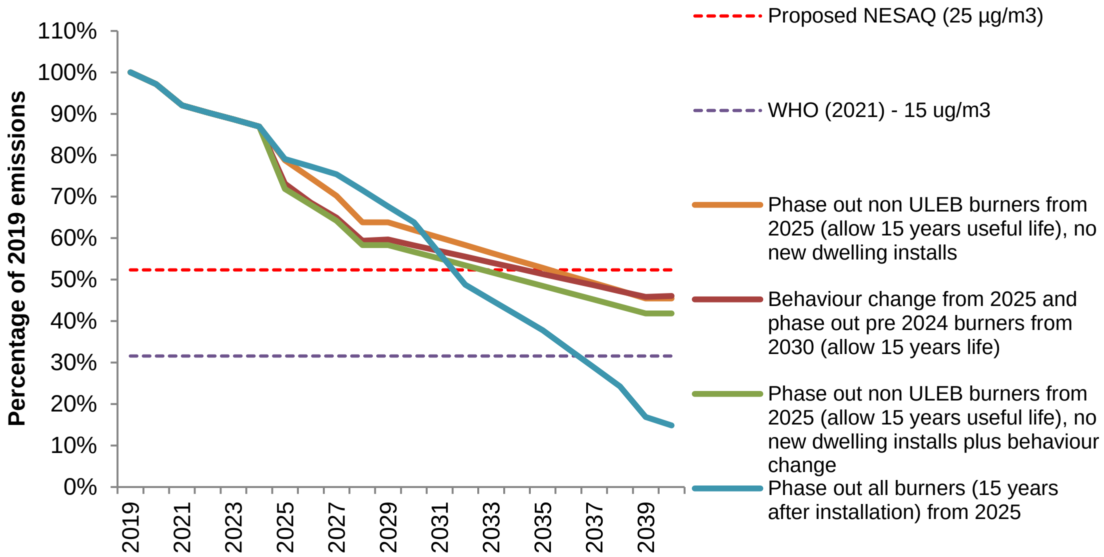


Figure 7-6: Impact of further options on $PM_{2.5}$ daily winter concentrations in Clyde

7.3 Daily PM_{10}

The estimated trend in PM_{10} concentrations for the status quo is shown in Figure 7.7 along with the option of phasing out of burners that do not meet the ULEB criteria. The latter is estimated to be sufficient to achieve both the NES for PM_{10} and the WHO (2021) air quality guideline for 24-hour average PM_{10}.

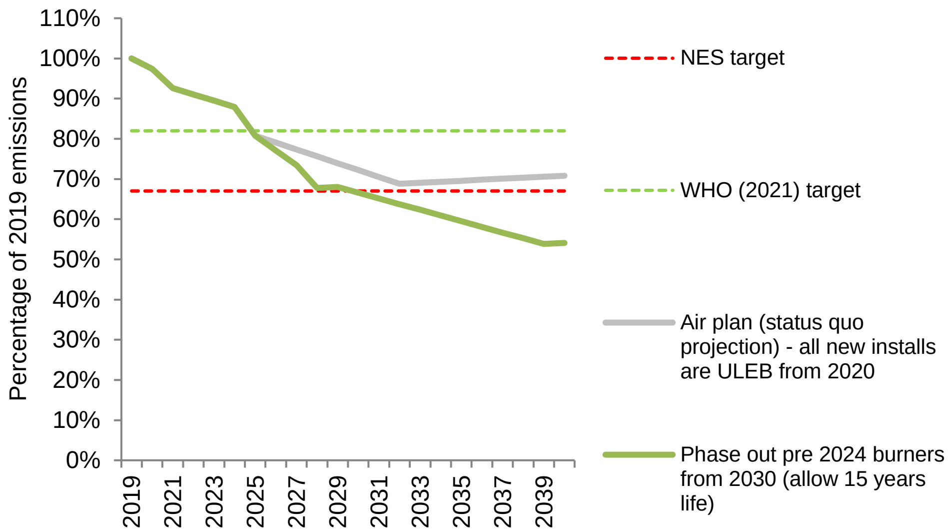


Figure 7-7: Status quo projections and management measures for 24-hour average winter PM_{10} in Clyde

8 CROMWELL MANAGEMENT OPTIONS

8.1 Annual $PM_{2.5}$

Projections in annual $PM_{2.5}$ concentrations in Cromwell are based on the methodology outlined in section three with the following additions:

- Population projections of 2.4% per year based on the medium annual growth rate for Clyde from 2021 to 2034 (Rationale Limited, 2022).
- Household appliance distributions at 2019 and average fuel quantities for Cromwell/ Clyde from the air emission inventory (Wilton, 2019).
- The proportion of new dwellings installing wood burners was assumed at 50% based on the relationship between wood use and dwelling increases from 2013 to 2018 census data.

Figure 8.1 shows improvements in annual average $PM_{2.5}$ concentrations for the status quo projections in Cromwell.

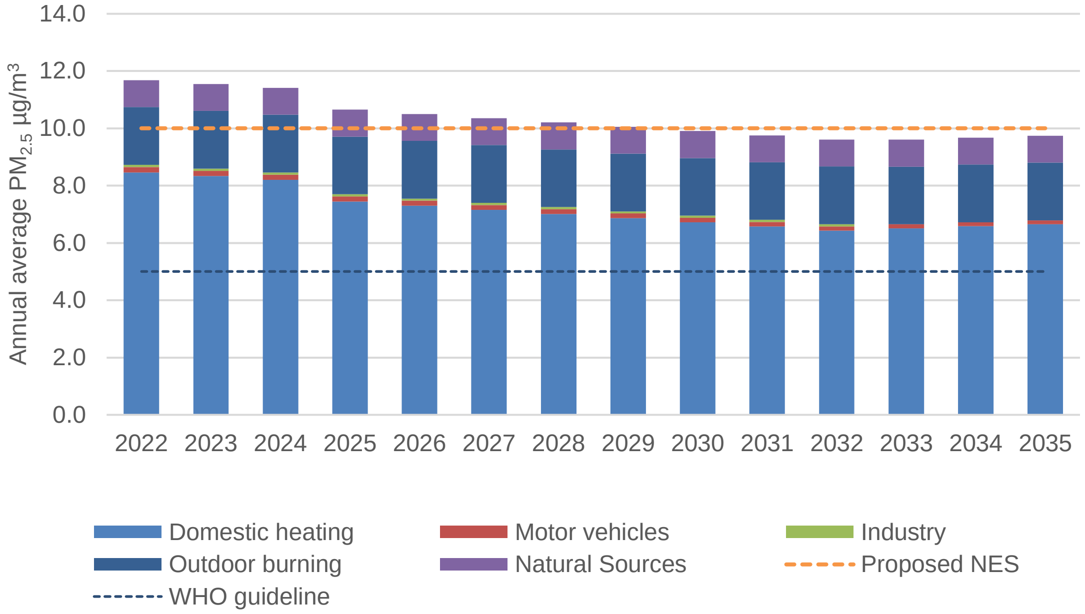


Figure 8-1: Status quo – only ULEB can be installed in Cromwell

The estimated impact on annual average $PM_{2.5}$ concentrations as a result of phasing out all burners not meeting the ULEB criteria in Cromwell and in conjunction with prohibiting outdoor burning, not allowing new installations of burners in new dwellings and existing dwellings using alternative heating methods and a behaviour change programme are shown in Figures 8.2 to 8.5.

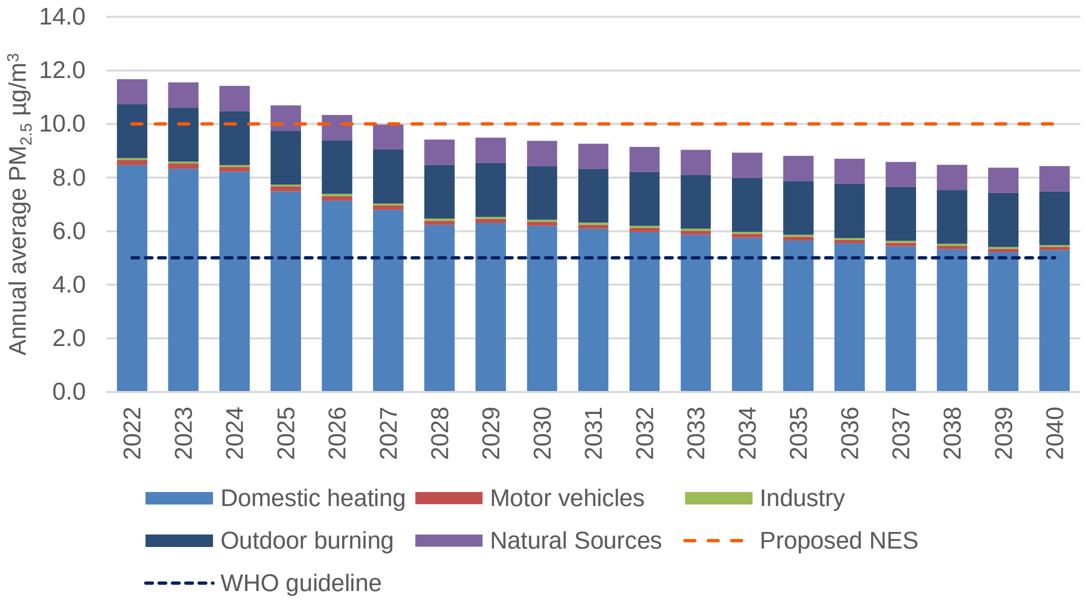


Figure 8-2: Phase out all burners not meeting the ULEB criteria in Cromwell, allow new installations of ULEB.

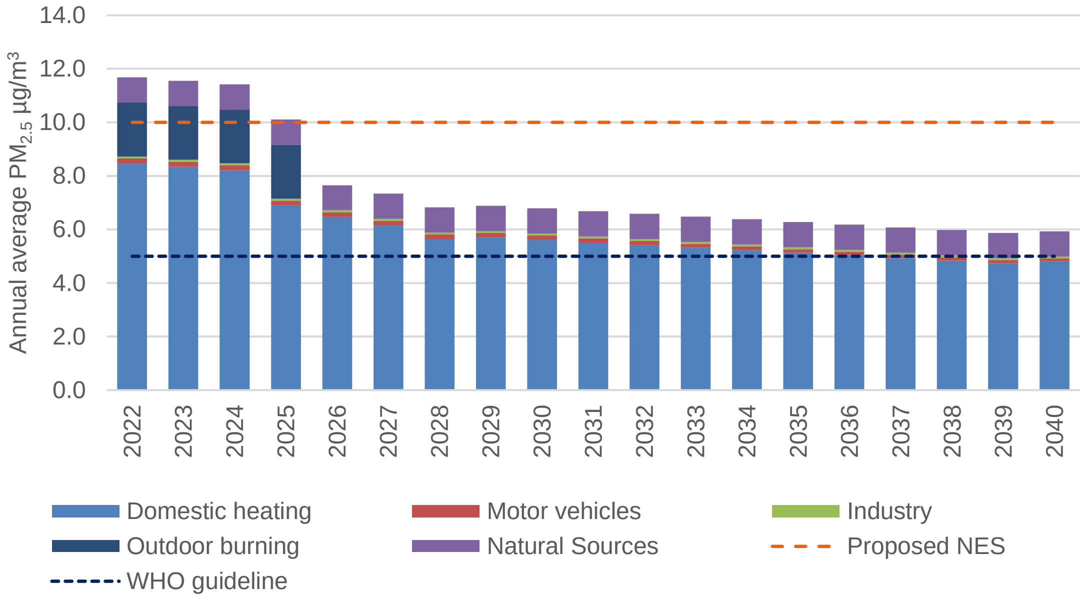


Figure 8-3: Phase out all burners not meeting the ULEB criteria in Cromwell, allow new installations of ULEB, prohibit outdoor burning.

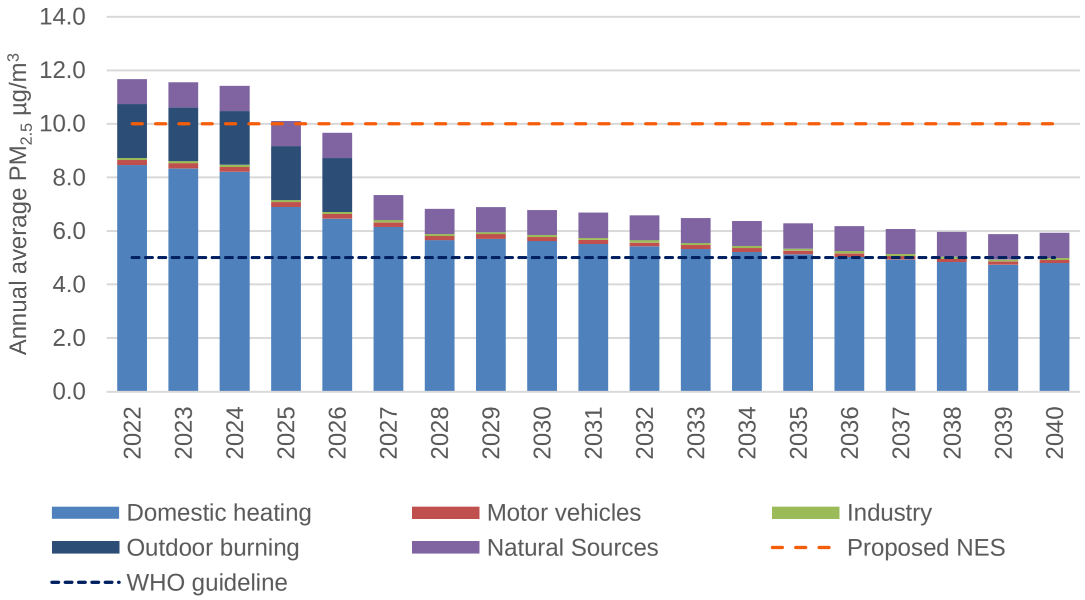


Figure 8-4: Phase out all burners not meeting the ULEB criteria in Cromwell, allow new burner installations, prohibit outdoor burning and behaviour change.

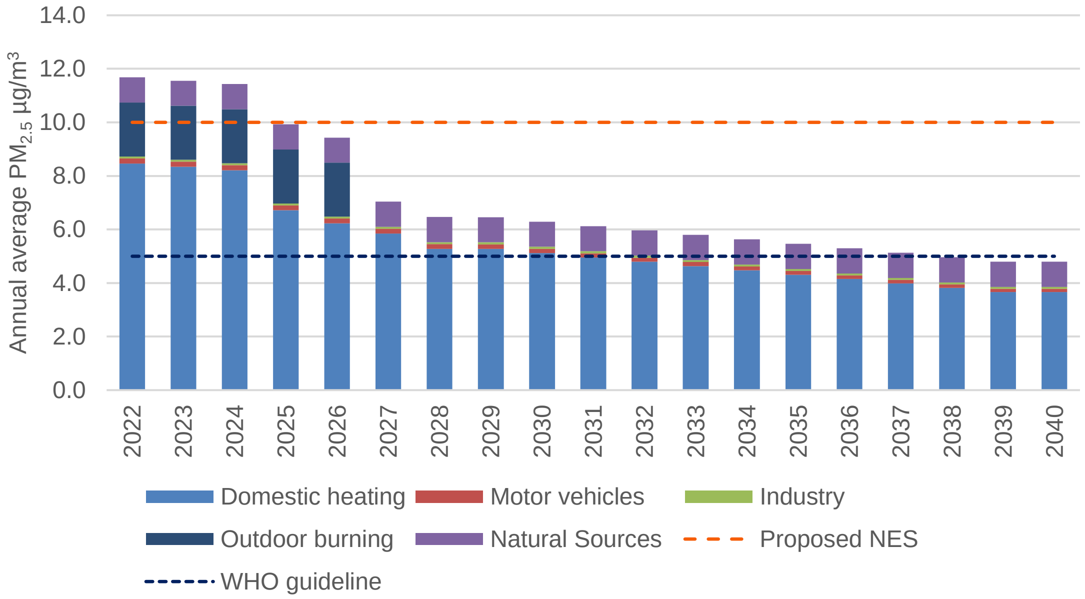


Figure 8-5: Phase out all burners not meeting the ULEB criteria in Cromwell, no new burner installations, prohibit outdoor burning and behaviour change.

8.2 Daily $PM_{2.5}$

Figures 8.6 and 8.7 show the projected daily winter $PM_{2.5}$ concentrations in Cromwell relative to the two air quality targets for daily $PM_{2.5}$ (25 µg/m^3 and 15 µg/m^3) for a range of management scenarios.

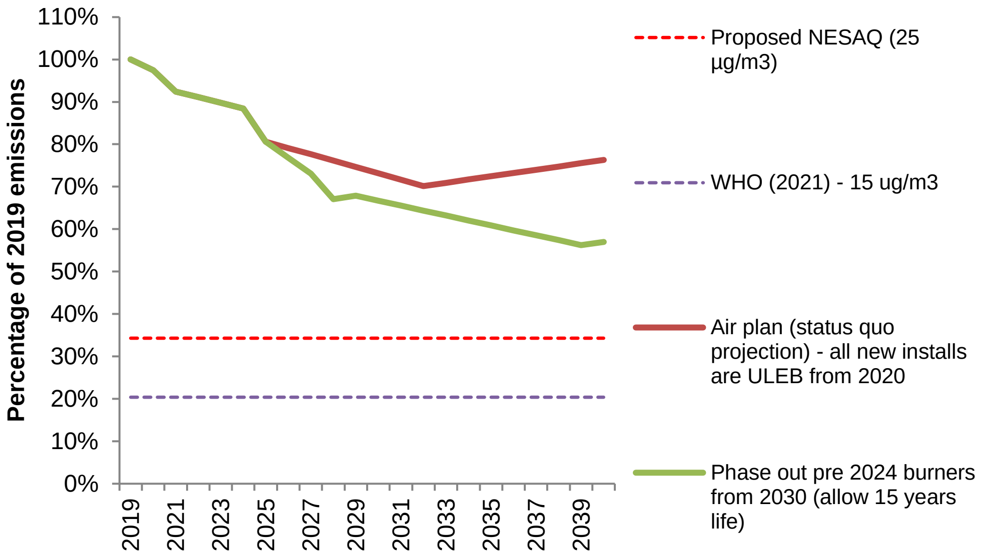


Figure 8-6: Status quo projections and impact of options on PM2.5 daily winter concentrations in Cromwell

The evaluation indicates that phasing out burners that do not meet the ULEB criteria in conjunction with a behaviour change programme or prohibiting the installation of burners in new dwellings or existing dwellings using other heating methods plus a prohibition on outdoor burning is unlikely to be adequate to achieve the proposed NESAQ of 25 µg/m^3. A total burner phase out would likely be required to meet both of the daily $PM_{2.5}$ targets in Cromwell.

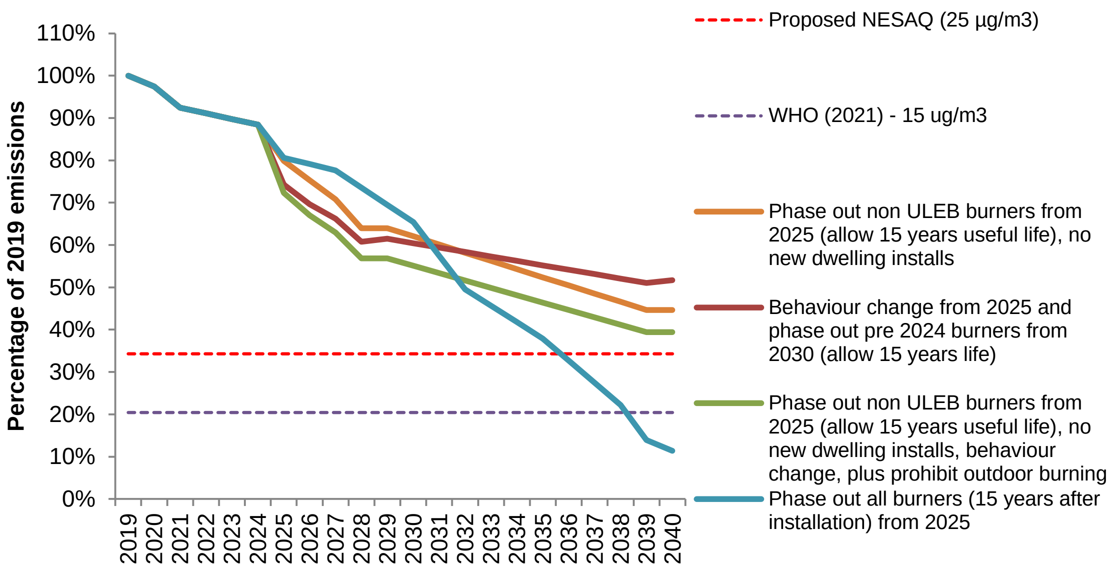


Figure 8-7: Impact of further options on PM2.5 daily winter concentrations in Cromwell

8.3 Daily PM10

The estimated trend in PM_{10} concentrations for the status quo is shown in Figure 8.8 along with the option of phasing out of burners that do not meet the ULEB criteria. The latter is estimated to be sufficient to achieve the current NES and WHO targets for 24-hour average PM_{10}.

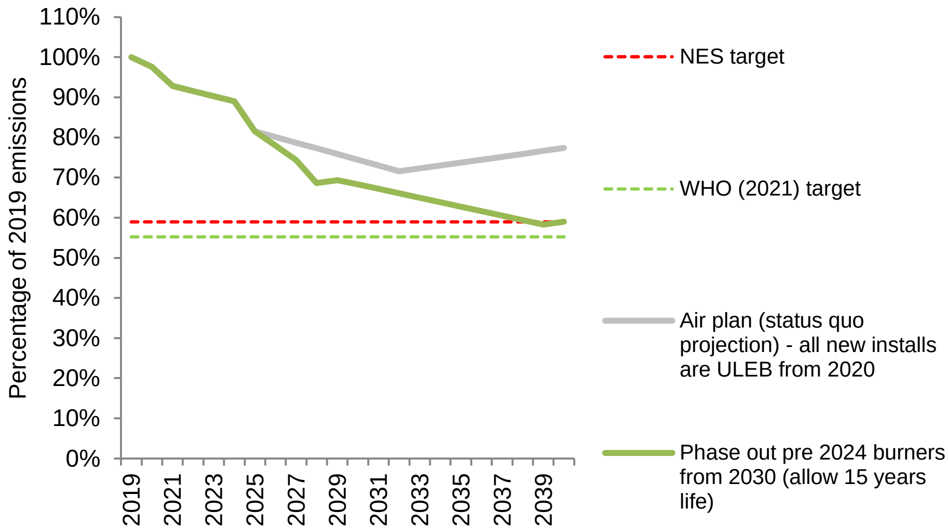


Figure 8-8: Status quo projections and management measures for 24-hour average winter PM_{10} in Cromwell

8.1 Annual PM_{10}

Annual average PM_{10} concentrations in Cromwell currently comply with the ambient air quality guideline of 20 µg/m^3 and may be compliant with the WHO (2021) guideline in the absence of additional management measures by around 2030 (Figure 8.9).

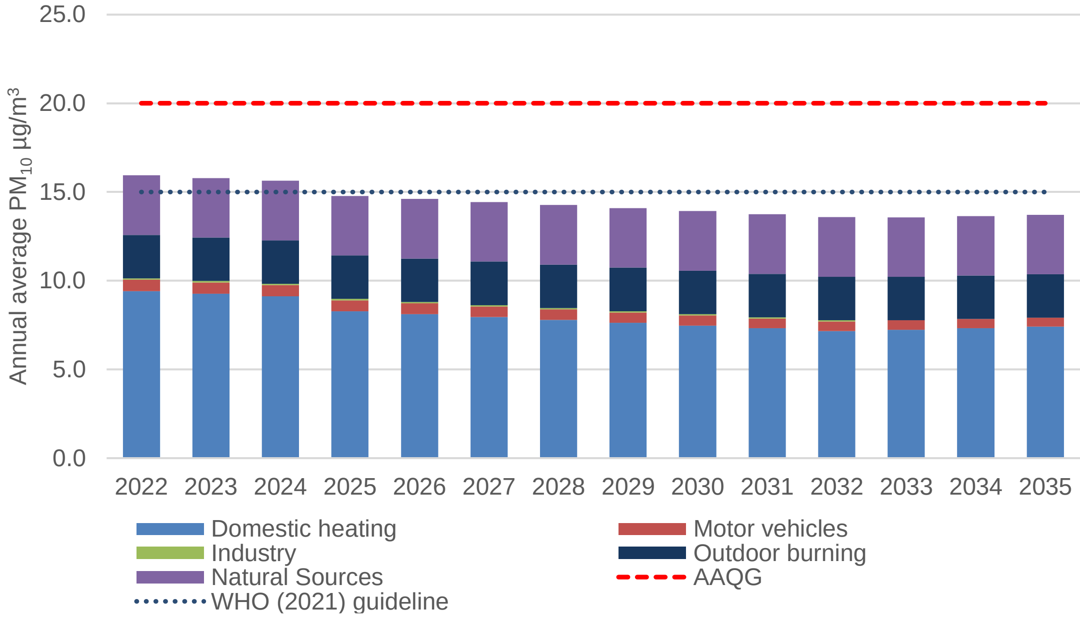


Figure 8-9: Air quality management projections for 24-hour average winter PM_{10} in Cromwell

9 MILTON MANAGEMENT OPTIONS

9.1 Annual $PM_{2.5}$

Projections in annual $PM_{2.5}$ concentrations in Milton are based on the methodology outlined in section three with the following additions:

- Population projections are 0.8% per year based on the medium growth rate for the Clutha District (Statistics NZ, 2022) but no new dwelling installations of wood burners are assumed for Milton because of a decrease in households using wood for home heating from 2013 to 2018.
- Household appliance distributions at 2016 and average fuel quantities for Milton from the air emission inventory (Wilton, 2017).
- No reduction in households using open fires for the status quo and multi fuel burner used phased out through natural attrition by 2030.

Figure 9.1 shows improvements in annual average $PM_{2.5}$ concentrations for the status quo projections in Milton.

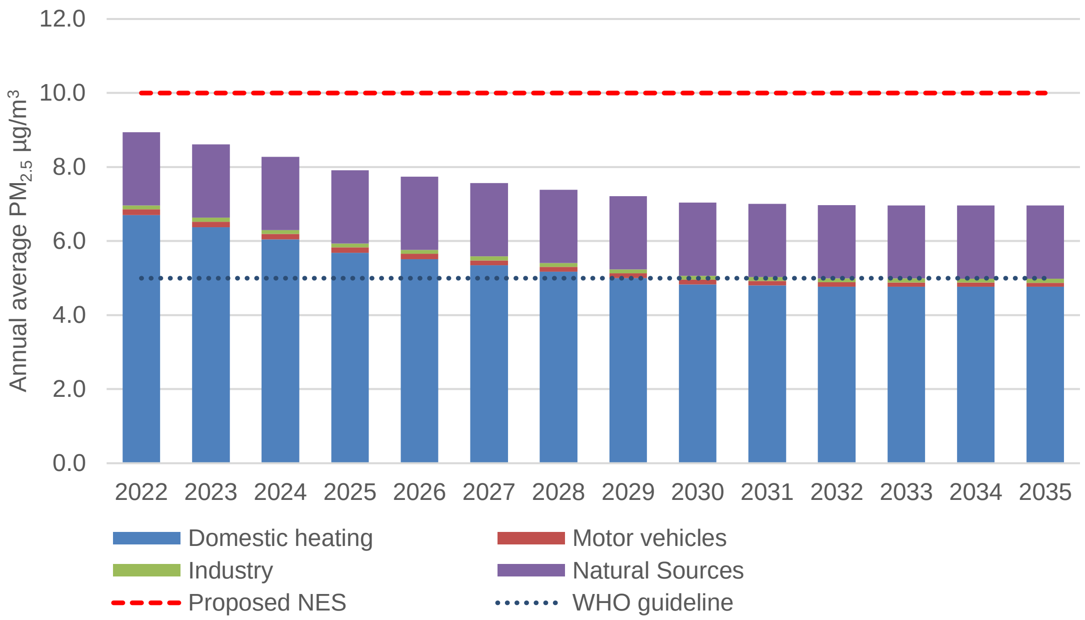


Figure 9-1: Status quo – only LEB and ULEB can be installed in Milton

The estimated impact on annual average $PM_{2.5}$ concentrations as a result of allowing only ULEB installations, phasing out all burners not meeting the ULEB criteria in Milton and these two measures in conjunction with a behaviour change programme are shown in Figures 9.2 and 9.3. This combination of options appears likely to achieve the annual average $PM_{2.5}$ WHO (2021) guideline in Milton.

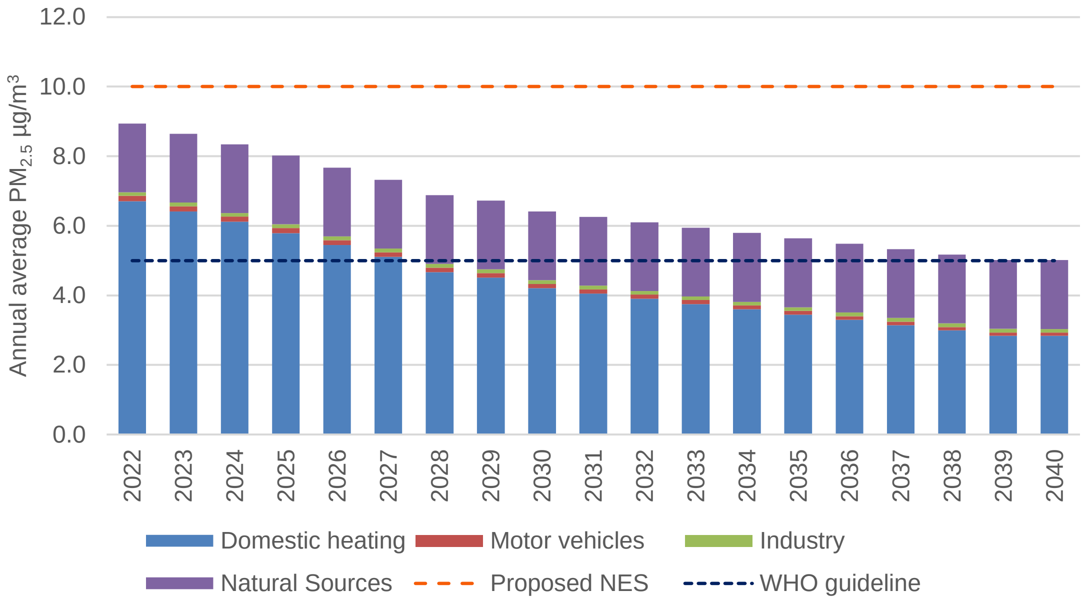


Figure 9-2: Phase out all burners not meeting the ULEB criteria in Milton, allow new installations of ULEB.

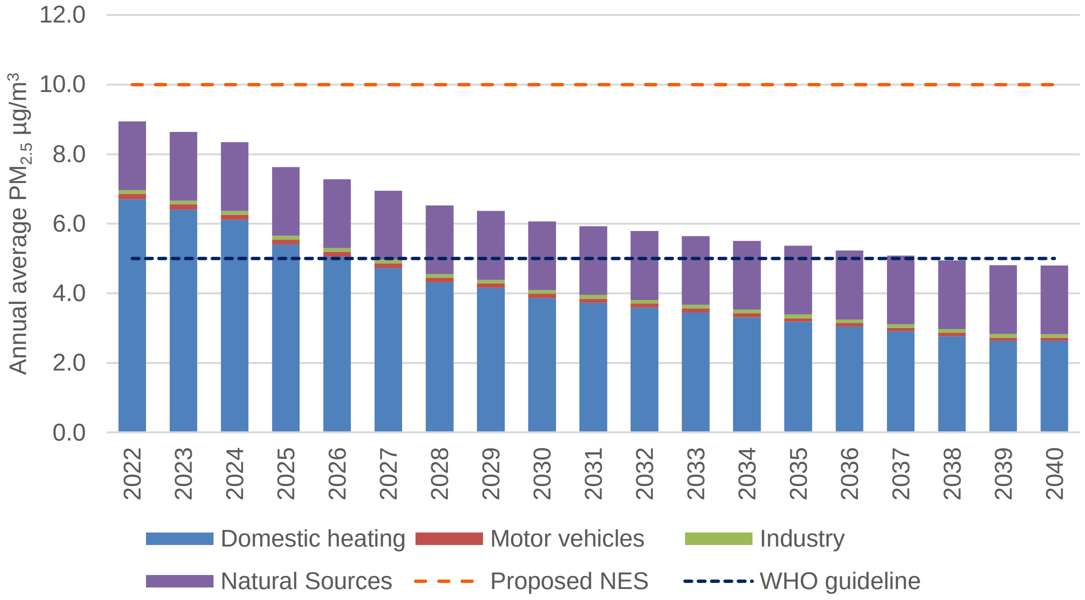


Figure 9-3: Phase out all burners not meeting the ULEB criteria in Milton, allow new burner installations and behaviour change.

9.2 Daily $PM_{2.5}$

Figures 9.5 and 9.6 show the projected daily winter $PM_{2.5}$ concentrations in Milton relative to the two air quality targets for daily $PM_{2.5}$ (25 µg/m^3 and 15 µg/m^3) for a range of management scenarios.

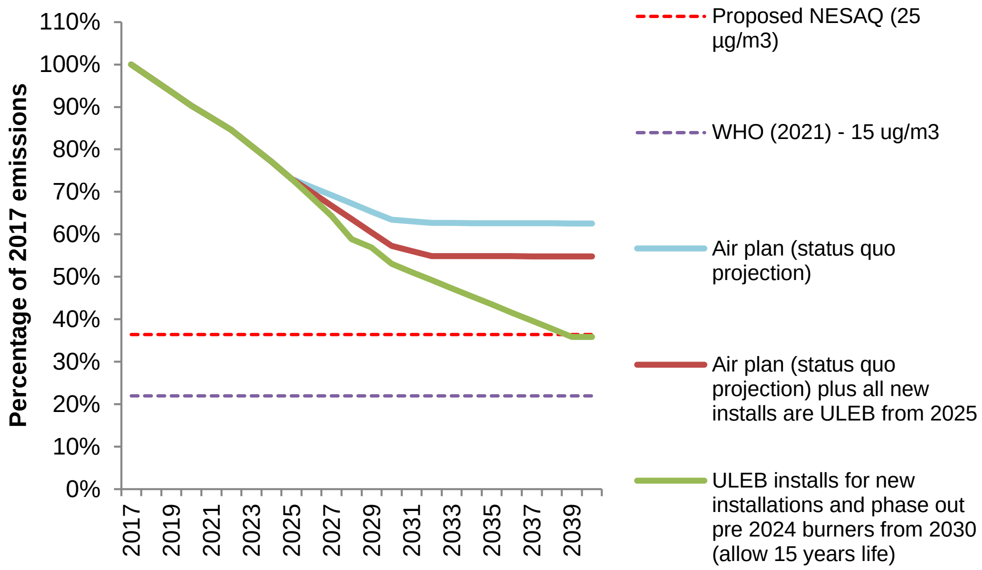


Figure 9-4: Status quo projections and impact of options on $PM_{2.5}$ daily winter concentrations in Milton

The evaluation indicates that phasing out burners that do not meet the ULEB criteria in conjunction with a behaviour change programme may be adequate to achieve the proposed NESAQ of 25 µg/m^3. The impact of a prohibition on installations of burners in new dwellings is unlikely to be effective in Milton because of the low population projections. A total burner phase out would likely be required to meet the WHO (2021) $PM_{2.5}$ target in Milton.

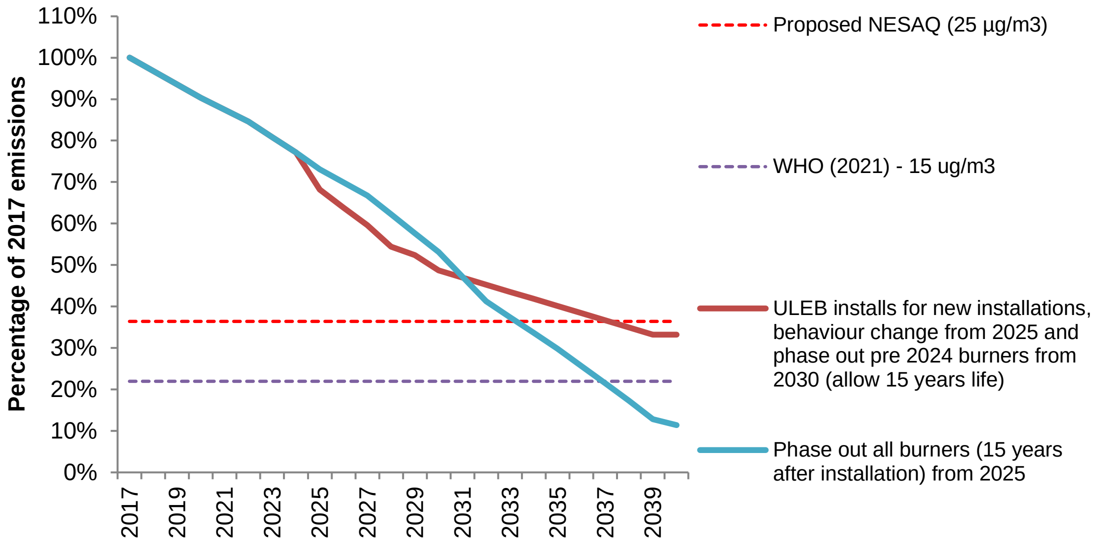


Figure 9-5: Impact of further options on $PM_{2.5}$ daily winter concentrations in Milton

9.3 Daily PM_{10}

The estimated trend in PM_{10} concentrations for the status quo is shown in Figure 9.7 along with the option of requiring all new installations meet the ULEB criteria and the additional phasing out of burners that do not meet the ULEB criteria. Figure 9.8 shows the estimated impact of a range of other management options. The phase out of solid fuel burners appears to be the only option targeting domestic heating alone likely to meet the NES for PM_{10} in Milton.

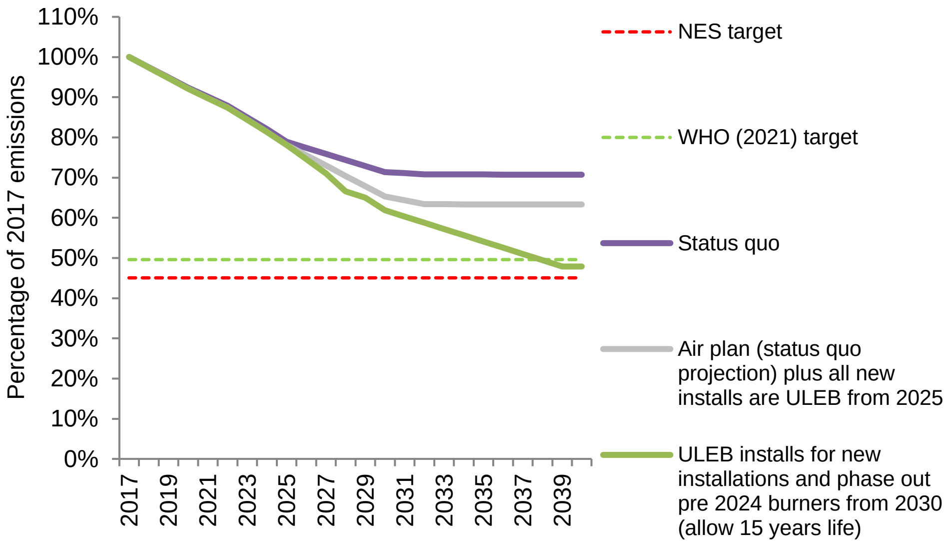


Figure 9-6: Status quo projections and management measures for 24-hour average winter PM_{10} in Milton

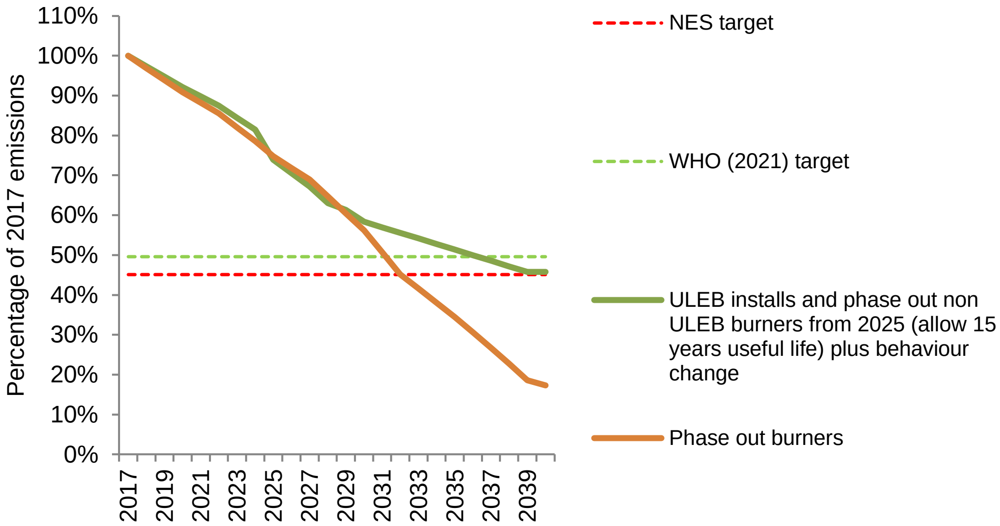


Figure 9-7: Status quo projections and management measures for 24-hour average winter PM_{10} in Milton

9.4 Annual PM_{10}

Annual average PM_{10} concentrations in Milton currently comply with the ambient air quality guideline of 20 µg/m^3 but are not compliant with the WHO (2021) guideline. Figure 9.9 shows this target may be met in the absence of additional management measures.

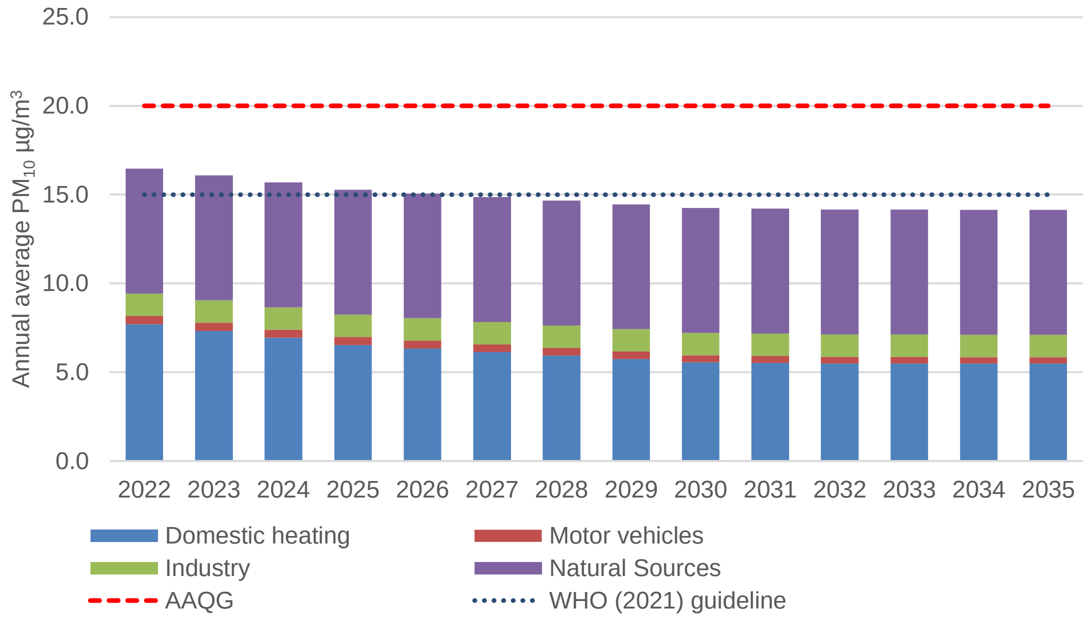


Figure 9-8: Air quality management projections for 24-hour average winter PM_{10} in Milton

10 MOSGIEL MANAGEMENT OPTIONS

10.1 Annual $PM_{2.5}$

Projections in annual $PM_{2.5}$ concentrations in Mosgiel are based on the methodology outlined in section three with the following additions:

- Population projections of 0.7% per year based on the medium growth rate for the Dunedin City (Statistics NZ, 2022).
- Household appliance distributions at 2017 and average fuel quantities for Mosgiel from the air emission inventory (Wilton, 2017).
- No reduction in households using open fires for the status quo and multi fuel burner used phased out through natural attrition by 2030.
- The proportion of new dwellings installing wood burners was assumed at 12% based on the relationship between wood use and dwelling increases from 2013 to 2018 census data.

Figure 10.1 shows annual average $PM_{2.5}$ concentrations for the status quo projections in Mosgiel for the period 2022 to 2035.

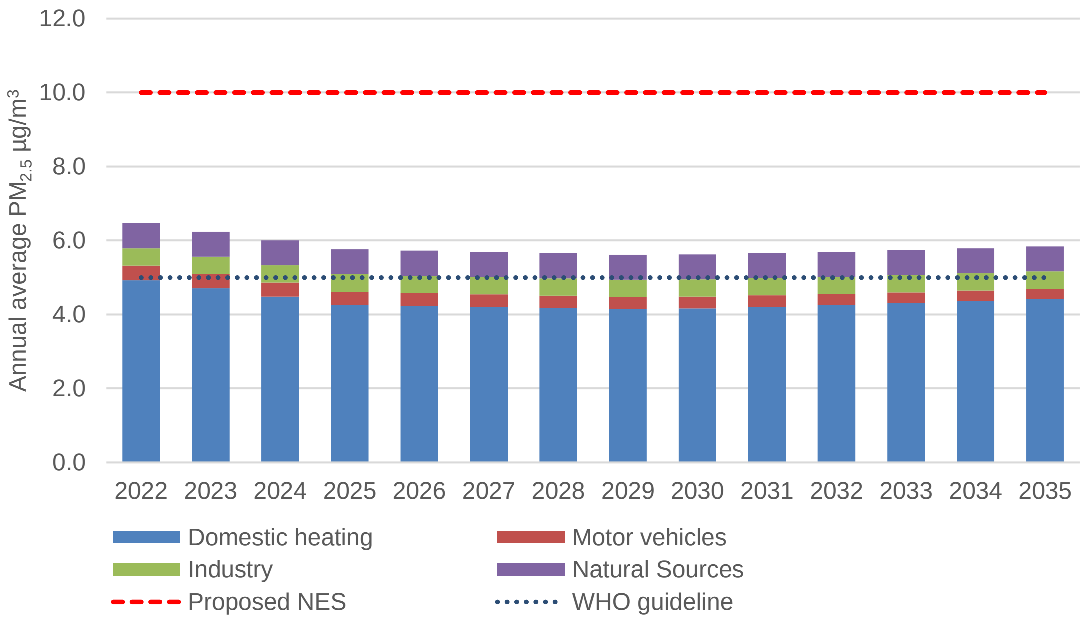


Figure 10-1: Status quo – only LEB and ULEB can be installed in Mosgiel

The estimated impact on annual average $PM_{2.5}$ concentrations as a result of allowing only ULEB installations, in Mosgiel is shown in Figure 10.2. This suggests that the WHO (2021) target may met with this option.

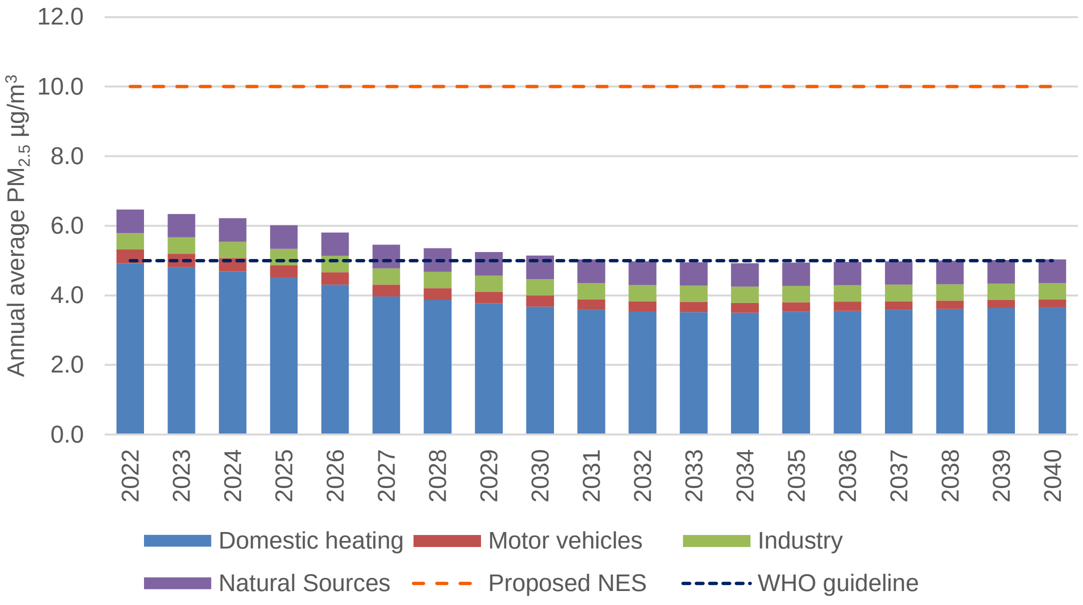


Figure 10-2: All new burners meet the ULEB criteria in Mosgiel.

10.2 Daily $PM_{2.5}$

Figures 10.3 and 10.4 show the projected daily winter $PM_{2.5}$ concentrations in Mosgiel relative to the two air quality targets for daily $PM_{2.5}$ (25 µg/m^3 and 15 µg/m^3) for a range of management scenarios.

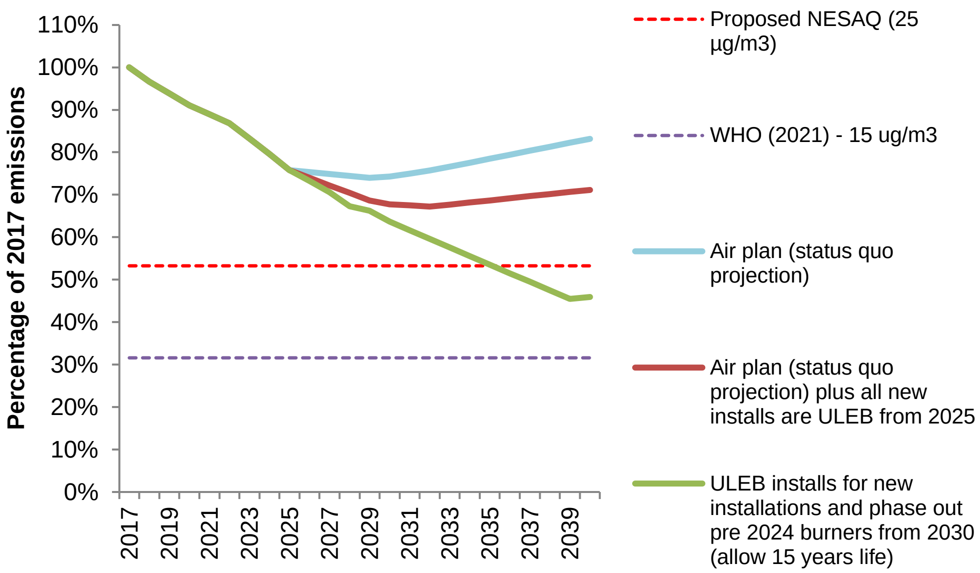


Figure 10-3: Status quo projections and impact of options on $PM_{2.5}$ daily winter concentrations in Mosgiel

The evaluation indicates that phasing out appliances that do not meet the ULEB criteria is likely to be adequate to achieve the proposed NESAQ of 25 µg/m^3 but unlikely to meet the WHO (2021) guideline. A total burner phase out would likely be required to meet the WHO (2021) daily $PM_{2.5}$ guideline in Mosgiel (Figure 9.4).

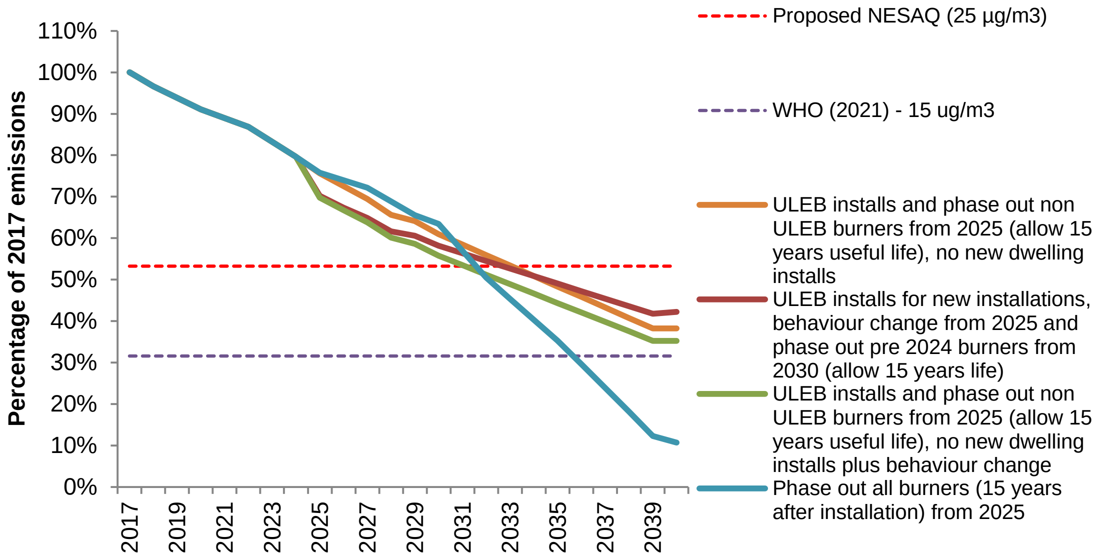


Figure 10-4: Impact of further options on $PM_{2.5}$ daily winter concentrations in Mosgiel

10.3 Daily PM_{10}

The estimated trend in PM_{10} concentrations for the status quo is shown in Figure 10.5 along with the option of requiring all new installations meet the ULEB criteria and the additional phasing out of burners that do not meet the ULEB criteria. The latter option appears sufficient to meet the daily PM_{10} air quality targets.

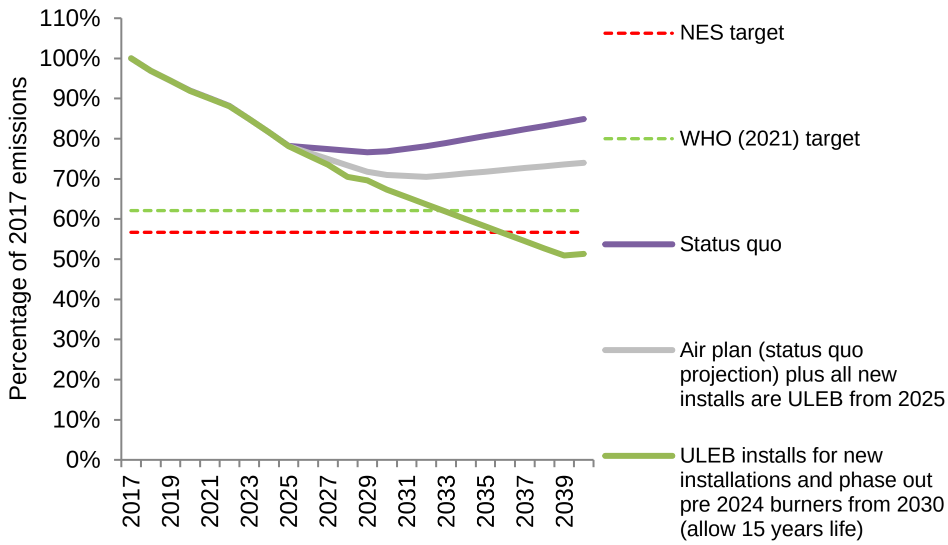


Figure 10-5: Status quo projections and management measures for 24-hour average winter PM_{10} in Mosgiel

10.4 Annual PM_{10}

Annual average PM_{10} concentrations in Mosgiel currently comply with the ambient air quality guideline of 20 µg/m^3 but are not compliant with the WHO (2021) guideline. Figure 10.6 shows this target is unlikely to be met in the absence of additional management measures. Figure 10.7 shows that the requirement that all newly installed burners meet the ULEB criteria and the phase out of burners not meeting this criteria is likely to result in achievement of the WHO (2021) annual PM_{10} guideline in Mosgiel.

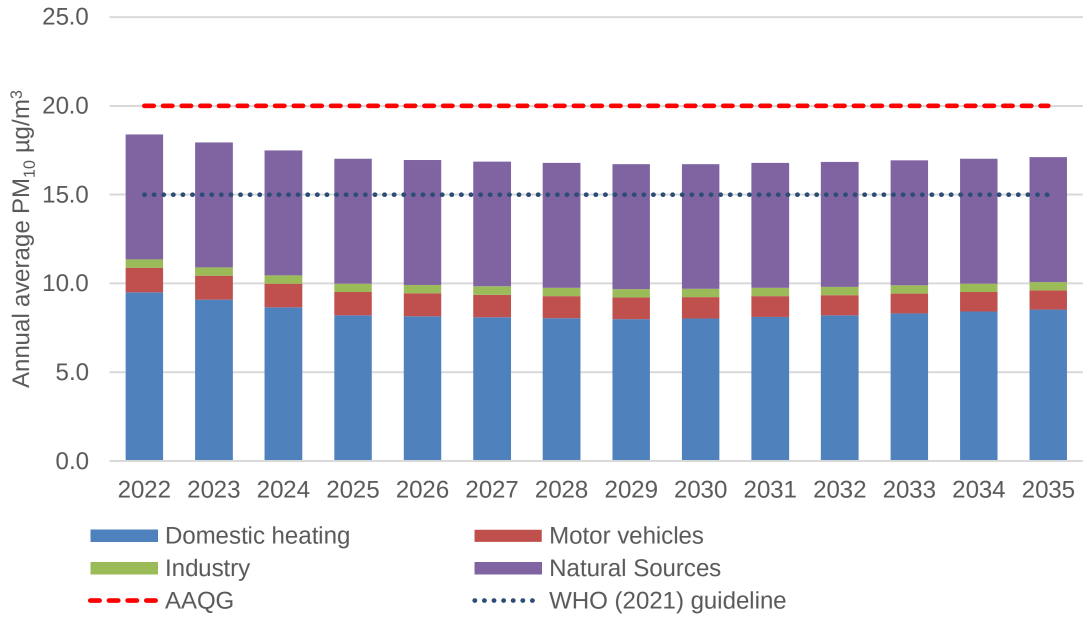


Figure 10-6: Air quality management projections for 24-hour average winter PM_{10} in Mosgiel

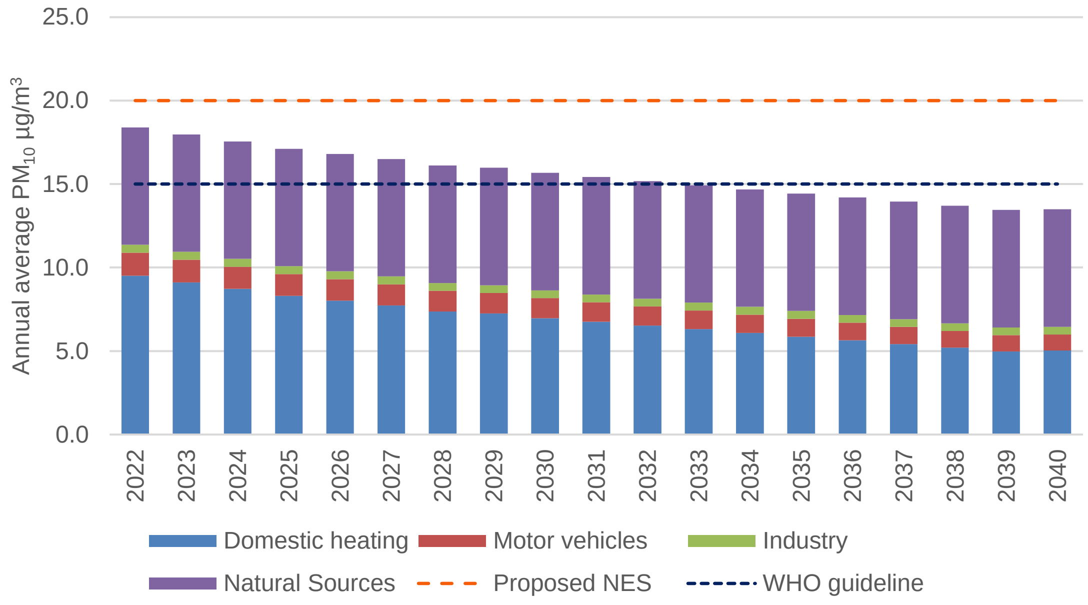


Figure 10-7: Air quality management projections for phasing out burners not meeting the ULEB criteria on annual average PM_{10} in Mosgiel

11 EVALUATION OF MANAGEMENT MEASURES

The most stringent air quality target for all towns is the WHO (2021) $PM_{2.5}$ daily guideline of 15 µg/m^3. In all areas a ban on solid fuel burning is likely required to meet this target. The proposed daily $PM_{2.5}$ NES of 25 µg/m^3 is also a very stringent target and would likely require a ban on solid fuel burning in Arrowtown, Alexandra and Cromwell. As air quality targets for daily $PM_{2.5}$ have been derived based primarily on their support of achievement of the annual target it is recommended that air quality management instead be based on effectiveness relative to the annual average $PM_{2.5}$ concentrations.

Annual average $PM_{2.5}$ concentrations are the most significant from a health viewpoint. Table 11.1 shows the likely effectiveness of management options in achieving the WHO (2021) annual average $PM_{2.5}$ guideline of 5 µg/m^3. This indicates that compliance with this guideline in Alexandra is likely to require a total ban on the use of solid fuel for domestic heating. In Cromwell and Clyde, the phase out of non ULEB burners, prohibiting the installation of solid fuel burners in new dwellings and existing dwellings using other heating methods and a behaviour change programme are likely required to meet the target. In Arrowtown and Milton the phase out of non ULEB burners likely achieve this target and in Mosgiel the introduction of a ULEB installation criteria and a behaviour change programme is likely to achieve the target without the need for burner phase outs. The analysis is subject to assumptions and uncertainties as detailed in the report.

Table 11.1: Likely effectiveness of options in achieving WHO (2021) annual average $PM_{2.5}$

	Arrowtown	Alexandra	Clyde	Cromwell	Milton	Mosgiel
Status quo	No	No	No	No	No	No
Behaviour change	No	No	No	No	No	No
ULEB installations only plus behaviour change	No	No	No	No	No	Yes
ULEB installations, phase out non ULEB burners	Yes	No	No	No	Yes	Yes
ULEB installations, phase out non ULEB burners, plus behaviour change	Yes	No	Maybe	No	Yes	Yes
ULEB installations, phase out non ULEB burners, behaviour change and no new installations in new dwellings etc	Yes	No	Yes	Yes	Yes	Yes
Phase out solid fuel burners	Yes	Yes	Yes	Yes	Yes	Yes

The groupings of towns based on achievement of the WHO (2021) $PM_{2.5}$ annual average guideline is given as follows as management option – 1:

- Group A (most stringent measures) – Alexandra – total solid fuel ban.
- Group B – Cromwell and Clyde – phase out non ULEB, no burners in new dwellings and behaviour change (plus ensure outdoor burning is not contributing to airshed $PM_{2.5}$).
- Group C – Arrowtown and Milton – phase out non ULEB.
- Group D – Mosgiel – ULEB emission criteria for new installations plus behaviour change.

An alternative approach to management in the six towns evaluated might be to further collate towns into fewer groups. Table 11.2 gives some potential grouping options and the likely impact on air quality targets for three alternative grouping suggestions referred to as management options 2 – 4.

The analysis cannot be extrapolated for other towns in the Region. Even if emission sources and quantities were the same, the impact of meteorology is unique to each location and thus the PM_{10} and $PM_{2.5}$ concentrations differ. As a result, the effectiveness of management options in achieving air quality targets cannot be inferred although some basic principles can be applied. For example, in areas where domestic heating is a key contributor to daily and annual concentrations the introduction of a ULEB emission criteria will result in a gradual improvement in concentrations, noting that in the towns studied here this was not sufficient to meet air quality targets alone. Similarly, a phase out of burners not meeting the ULEB criteria is likely to achieve the greatest reduction in concentrations for a single intervention, other than a total solid fuel burner ban, but still may not be adequate to achieve air quality targets as is illustrated above for some areas.

Establishing an air quality management approach for other towns in the Region that might result in compliance with the air quality targets is difficult. Adopting low-cost measures such as the introduction of a ULEB criteria for new installations and a Council borne cost such as a behaviour change programme is likely a good approach in other areas, as small improvements can be achieved without significant household cost. In areas where air quality may be more degraded, a burner phase out would achieve greater improvements but may be hard to justify without adequate quantification of its necessity. It is therefore recommended that the low-cost measures be considered for other towns in the Region. An expanded monitoring programme to identify which of these areas may require further management is also recommended.

Table 11.2: Potential area groupings for air quality management (based on annual average $PM_{2.5}$ concentrations)

	Areas	Management option – 2	Impact on annual average $PM_{2.5}$ concentrations	Management option – 3	Impact on annual average $PM_{2.5}$ concentrations
Group A	Alexandra, Cromwell and Clyde.	Phase out non ULEB, no burners in new dwellings and behaviour change*.	Likely compliance with WHO (2021) in Cromwell and Clyde and improvements to potentially around 6 µg/m^3 in Alexandra.	Phase out non ULEB and behaviour change*.	Potential compliance with WHO (2021) in Clyde and improvements to potentially around 6 µg/m^3 in Cromwell and 6.5 µg/m^3 in Alexandra.
Group B	Arrowtown and Milton.	Phase out non ULEB.	Likely compliance with WHO (2021).	Phase out non ULEB.	Likely compliance with WHO (2021).
Group C	Mosgiel, plus other Air Zone 2 towns.	All new installations meet ULEB criteria and behaviour change programme.	Likely compliance with WHO (2021) in Mosgiel and unquantified improvements in other towns.	All new installations meet ULEB criteria and behaviour change programme.	Likely compliance with WHO (2021) in Mosgiel and unquantified improvements in other towns.
Group D	Regionwide on properties < 2 ha.	All new installations meet ULEB criteria.	Improvements in air quality and/or prevention of degradation (high growth areas).	All new installations meet ULEB criteria.	Improvements in air quality and/or prevention of degradation (high growth areas.

	Areas	Management option – 4	Impact on annual average $PM_{2.5}$ concentrations
Group A	Alexandra, Cromwell, Clyde, Arrowtown and Milton.	Phase out non ULEB*.	Likely compliance with WHO (2021) in Arrowtown and Milton and improvements to potentially around 6 µg/m^3 in Clyde, 6.5 µg/m^3 in Cromwell and 7 µg/m^3 in Alexandra.
Group B	Mosgiel, plus other Air Zone 2 towns.	All new installations meet ULEB criteria and behaviour change programme.	Likely compliance with WHO (2021) in Mosgiel and unquantified improvements in other towns.
Group C	Regionwide on properties < 2 ha.	All new installations meet ULEB criteria.	Improvements in air quality and/or prevention of degradation (high growth areas.

*plus ensure outdoor burning is not contributing to airshed $PM_{2.5}$

It is noted that the annual average $PM_{2.5}$ concentrations in many of the urban towns is based on estimates using PM_{10} data and relationships observed elsewhere. As such the annual average estimates in particulate have a higher degree of uncertainty than if $PM_{2.5}$ monitoring had been carried out using reference or equivalent sampling methods for both summer and winter period (as is the case for Arrowtown). As such there is a higher degree of uncertainty around the effectiveness estimates.

A staged or iterative approach to air quality management may be warranted for example adopting management option 4 initially, with implementation of subsequent components, for example behaviour change programmes in group A, dependent on the outcomes of $PM_{2.5}$ monitoring. If greater certainty of achieving reductions is required then Option 2 or 3 (from Table 11.2) might be more appropriate.

Table 11.3 shows the effectiveness of the different management measures in achieving the different PM_{10} targets.

Table 11.3: Management options effectiveness in achieving WHO (2021) and NESAQ PM_{10} targets

Management Option	WHO (2021) PM_{10} Annual	WHO (2021) PM_{10} Daily	NESAQ PM_{10} Daily
Status quo	Milton, Alexandra, Arrowtown, Clyde	Dunedin	Dunedin
ULEB installations, phase out non ULEB burners	Milton, Alexandra, Arrowtown, Clyde, Dunedin, Mosgiel, Cromwell	Dunedin, Clyde, Arrowtown, Alexandra, Milton, Mosgiel	Dunedin, Clyde, Arrowtown, Mosgiel, Cromwell
ULEB installations, phase out non ULEB burners, plus behaviour change	Milton, Alexandra, Arrowtown, Clyde, Dunedin, Mosgiel, Cromwell	Dunedin, Clyde, Arrowtown, Alexandra, Milton, Mosgiel, Cromwell	Dunedin, Clyde, Arrowtown, Mosgiel, Cromwell, Milton
ULEB installations, phase out non ULEB burners, behaviour change and no new installations in new dwellings etc	Milton, Alexandra, Arrowtown, Clyde, Dunedin, Mosgiel, Cromwell	Dunedin, Clyde, Arrowtown, Alexandra, Milton, Mosgiel, Cromwell	Dunedin, Clyde, Arrowtown, Mosgiel, Cromwell, Milton, Alexandra,

12 CONCLUSIONS AND RECOMMENDATIONS

The annual average $PM_{2.5}$ concentration should be the main indicator used to inform air quality management of particulate (PM_{10} and $PM_{2.5}$) in the Otago Region. Achievement of this standard is likely to require a total solid fuel burner prohibition in Alexandra, the phase out of non ULEB burners, a prohibition on the installation of burners in new dwellings and behaviour change programme in Cromwell, Clyde and the phase out of non ULEB burners in Arrowtown and Milton. In Mosgiel the introduction of a ULEB emission criteria for new burners in conjunction with a behaviour change programme are likely adequate for compliance.

Adoption of measures to achieve the annual WHO (2021) guideline for $PM_{2.5}$ will result in significant improvements in daily concentrations but will not result in compliance with the daily WHO (2021) guideline in towns in the Otago Region. The evaluation indicates that a prohibition on solid fuel burning for domestic heating is likely required to meet the WHO (2021) daily guideline of 15 $\mu g/m^3$ for $PM_{2.5}$.

The WHO (2021) daily $PM_{2.5}$ guideline level of 15 $\mu g/m^3$ was selected based on the health burden of annual average exposures (using an average relationship between peak and annual concentrations) rather than on the specific acute impacts of short-term exposures. Adopting more stringent measures than those required to achieve the guideline on which it was based is questionable.

If a total solid fuel burner ban is considered a preferred option, either to achieve the annual $PM_{2.5}$ WHO (2021) guideline in Alexandra or across all towns to achieve the WHO (2021) daily guideline of 15 $\mu g/m^3$, further analysis is recommended to ensure that the health benefits of the additional improvements associated with this management option are not negated by increased health impacts of cold homes.

As this report is the first nationally to demonstrate the impact of ambient air quality management of the annual versus daily $PM_{2.5}$ relative to the WHO (2021) guidelines it is recommended that Council share this information with the Ministry for the Environment. Establishing a NES for annual $PM_{2.5}$ and retaining the daily target as an ambient air quality guideline with appropriate guidance might be an approach worth advocating. The latter could then be used for example in the resource consent process for managing localised impacts with the potential for acute health effects rather than forming the basis for ambient air quality management.

Recommendations:

- The development of a strategy for progressing $PM_{2.5}$ monitoring in towns across the Region.
- Selection of management measures for particulate based on their effectiveness relative to the annual average $PM_{2.5}$ guideline.
- Adopt management measures for domestic heating based on an evaluation of effectiveness and costs.
- Review regulations for outdoor burning to ensure no unnecessary contributions to airsheds.
- Adoption of low-cost management measures in urban areas/ towns where monitoring data or source data preclude scientific evaluation.
- Any burner phase outs be implemented in such a way as to mitigate adverse effects (e.g., adequate notice to enable financial preparation for households able to save) and consideration be given to financial support for low income households.

REFERENCES

Ayers, G. P. (2001). Comment on regression analysis of air quality data. *Atmospheric Environment*, *35*(13), Article 13. https://doi.org/10.1016/S1352-2310(00)00527-6

Conway, J., Hansen, M., & Bodecker, G. (2016). *Investigating Meteorological Interventions for Improving Air Quality in Airshed 1 Towns*. Bodecker Environmental.

Ministry for the Environment. (2020). *Proposed amendments to the National Environmental Standards for Air Quality, particulate matter and mercury emissions*. Ministry for Environment.

Rationale Limited. (2022). *Growth Projections—2022*. Central Otago District Council.

Wilton, E. (2014). *Behavioural factors influencing emissions from wood burners – a literature review to identify key points for burner operation*.

Wilton, E. (2016). *Domestic home heating technologies – review of existing and emerging technologies promoting low emissions*. Otago Regional Council.

Wilton, E. (2017). *Alexandra, Arrowtown, Mosgiel and Milton Air Emission Inventory*. Otago Regional Council Report.

Wilton, E. (2019). *Wanaka, Cromwell and Clyde Air Emission Inventory—2019*. Otago Regional Council Report.

Wilton, E., Bluett, J., & Chilton, R. (2015). *Home heating emission inventory and other sources evaluation*.

World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. https://apps.who.int/iris/handle/10665/345329

APPENDIX A: AIR QUALITY MONITORING DATA

Arrowtown

Concentrations of PM_{10} in Arrowtown

The airshed is polluted under the National Environment Standards as the NES for PM_{10} (50 µg/m^3, 24-hour average, one allowable exceedance) is breached during the winter in Arrowtown. Figure 0-1 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Arrowtown since 2012. A new monitoring site was established in Arrowtown in 2015. The new Arrowtown monitoring site appears to have similar to higher exceedance frequencies and maximum PM_{10} concentrations to the old site for the years 2015 to 2018.

Figure 0-2 shows the daily PM_{10} concentrations by air quality indicator category. This shows that the despite having fewer exceedances of the NES, the older site experienced a greater proportion of days when PM_{10} concentrations were elevated and in the range of 17 – 50 µg/m^3. The NES requires that PM_{10} be monitored in a location that experiences the worst case PM_{10} concentrations or the greatest frequency of high PM_{10} concentrations. The new site appears to be a suitable monitoring site for NES purposes.

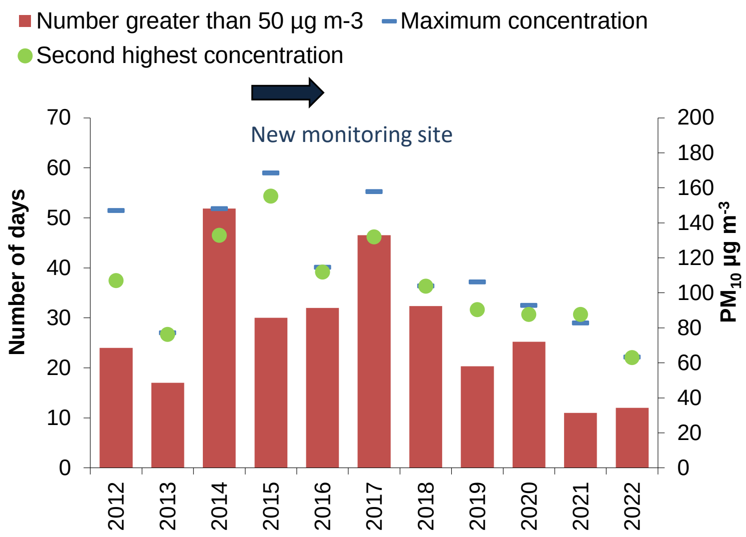


Figure 0-1: Annual exceedances of daily PM_{10} NES (50 µg/m^3), maximum and second highest 24-hour PM_{10} concentration.

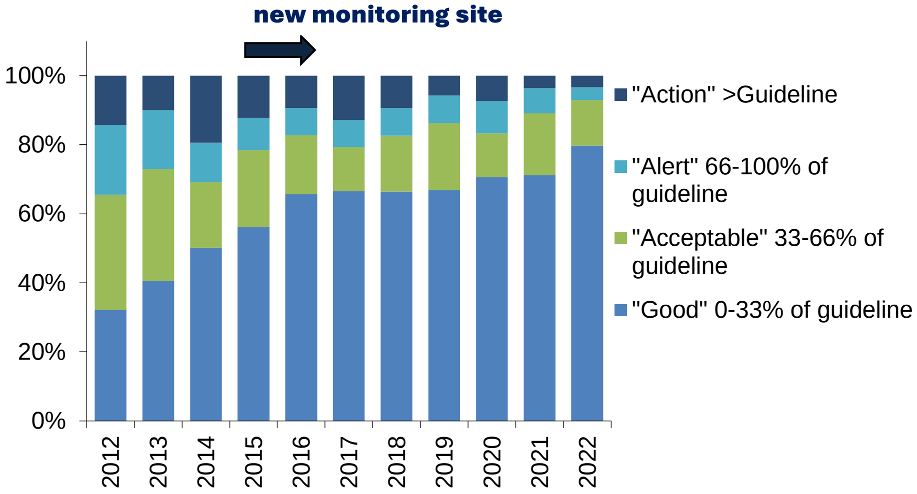


Figure 0-2: Distribution of daily PM_{10} concentrations in Arrowtown from 2012 to 2022

Summary PM_{10} data for the ten years from 2012 to 2022 is shown in Table 0-1. Figure 0-3 shows a downward trend in annual average PM_{10} concentrations at the new Arrowtown site over an eight year period from 2015 to 2022 (new Arrowtown monitoring site).

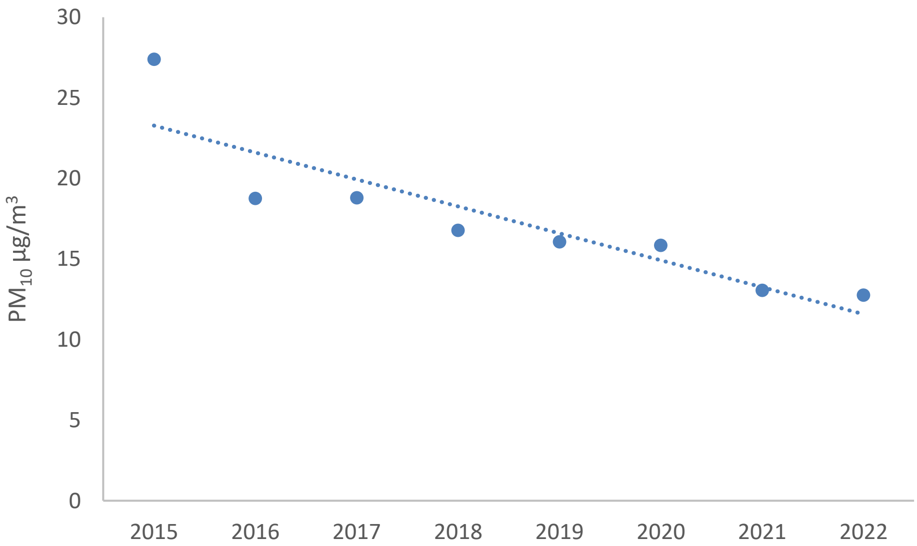


Figure 0-3: Annual average PM_{10} concentrations in Arrowtown from 2015 to 2022

Table 0.1: Summary of PM_{10} concentrations measured at Arrowtown from 2012-2022

	2012*	2013*	2014*	2015	2016	2017	2018	2019	2020	2021	2022
Monitoring method											
"Good" 0-33% of guideline	32%	41%	50%	56%	66%	66%	67%	67%	71%	71%	80%
"Acceptable" 33-66% of guideline	33%	33%	19%	22%	17%	13%	16%	19%	13%	18%	13%
"Alert" 66-100% of guideline	20%	17%	11%	9%	8%	8%	8%	8%	9%	7%	4%
"Action" >Guideline	14%	10%	19%	12%	9%	13%	9%	6%	7%	4%	3%
Percentage of valid data	46%	46%	68%	67%	93%	96%	88%	95%	93%	82%	98%
Annual average ($\mu g\ m^{-3}$)		17.7	24.7	27.4	18.8	18.8	16.8	16.1	15.8	13.0	12.8
Measured PM_{10} concentrations above 50 $\mu g\ m^{-3}$	24	17	48	30	32	45	30	20	25	11	12
Second highest PM_{10} concentration ($\mu g\ m^{-3}$)	107	76	133	155	112	132	104	90	88	88	63
Annual maximum ($\mu g\ m^{-3}$)	147	77	148.1	169	115	158	104	106	93	83	63.4
Number of records	168	168	247	246	340	349	321	346	339	301	356

* Old monitoring site

An analysis of the peak to mean ratio for PM_{10} was undertaken to characterise years in terms of likely worst case meteorology with respect to the peak (in this case second highest) concentrations. The worst case year for second highest daily PM_{10} based on the peak to mean ratio was 2017[4]. The estimated equivalent 2022 worst case concentration based on this ratio was 89 $\mu g/m^3$. The estimate was made for 2022 rather than using the 2017 value because data are indicative of emissions having reduced from 2017 to 2022 and this approach enables an estimate of the 2022 concentration based on the 2017 meteorology. A 44% reduction in 2022 daily winter PM_{10} concentrations is required to meet the NESAQ in Arrowtown.

The worst case fourth highest daily PM_{10} based on the peak to mean ratio was 2021 with a PM_{10} concentrations of 87 $\mu g/m^3$. It is noted that 2017 and 2021 were similar in both the second highest and fourth highest peak to mean PM_{10} ratios and using either year would have given similar results. A 41% reduction in 2022 daily winter PM_{10} concentrations is required to meet the WHO (2021) daily PM_{10} target of 45 $\mu g/m^3$ (three allowable exceedances).

The annual average PM_{10} concentrations in Arrowtown in 2020, 2021 and 2022 were 16 $\mu g/m^3$, 13 $\mu g/m^3$ and 13 $\mu g/m^3$ respectively. As the 2021 and 2022 concentrations are lower than the national AAQG and the WHO (2021) guideline it is unlikely that any reductions in annual average PM_{10} concentrations will be required for compliance with these targets.

Concentrations of $PM_{2.5}$ in Arrowtown

Concentrations of $PM_{2.5}$ have been measured in Arrowtown since May 2021. Figure 0-4 shows low daily $PM_{2.5}$ concentrations during the non winter months with elevated concentrations from late April to September and peak concentrations or around 60 - 80 $\mu g/m^3$ (24-hour average). Table 0.2 shows annual average $PM_{2.5}$ concentrations in Arrowtown around 9 $\mu g/m^3$ and exceedances of the proposed NES of 25 $\mu g/m^3$ on around 30-40 days per year. Data measured using the T640x has been adjusted based on a correction factor developed in an alternative New Zealand wood burning environment. It is unclear if there will be implications for Arrowtown concentrations.

[4] This was closely followed by 2021 for worst case second highest PM_{10} peak to average ratio.

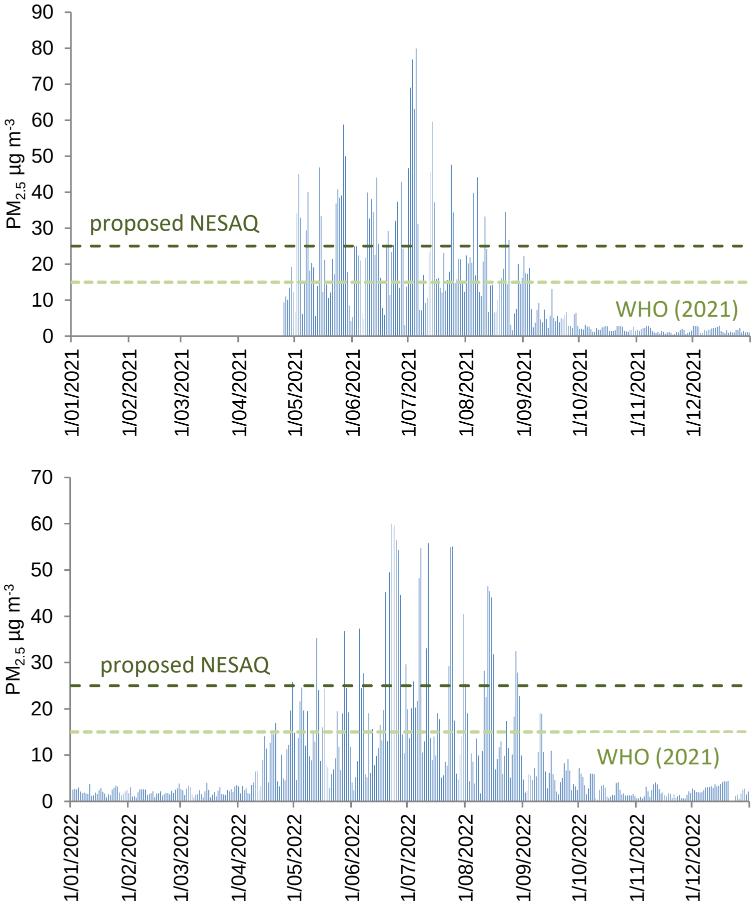


Figure 0-4: Daily $PM_{2.5}$ concentrations in Arrowtown during 2021 and 2022

Table 0.2: Summary of $PM_{2.5}$ concentrations measured at Arrowtown from 2021-2022

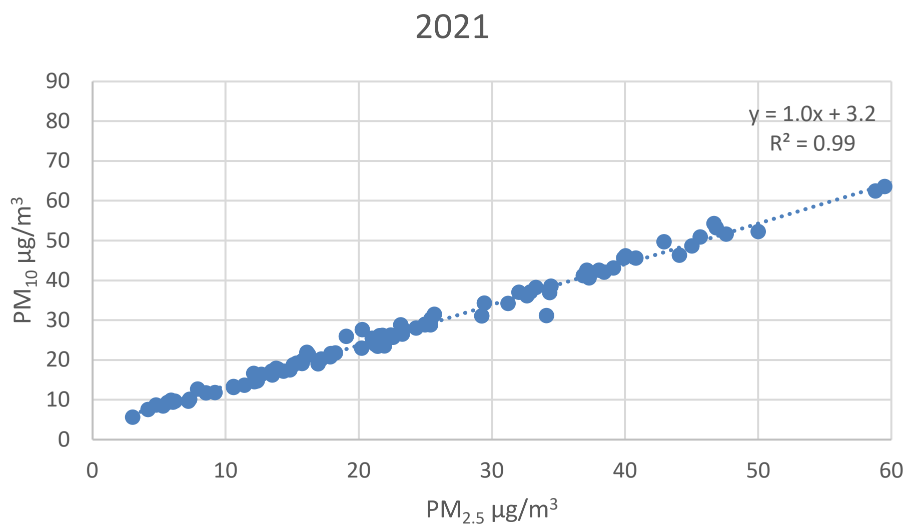
AAQG – 25 µg/m^3	2021	2022
Monitoring method		
"Good" 0-33% of guideline	54%	68%
"Acceptable" 33-66% of guideline	16%	15%
"Alert" 66-100% of guideline	14%	8%
"Action" >Guideline	15%	8%
Percentage of valid data	69%	99%
Annual average (µg m^{-3})	10.3	8.8
Measured $PM_{2.5}$ concentrations above 25 µg m^{-3}	39	30
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	63	56
Annual maximum (µg m^{-3})	80	60
Number of records	252	362

The worst case fourth highest $PM_{2.5}$ concentration in Arrowtown was for 2021 and was 63 µg/m^3 (2021). No extrapolation for $PM_{2.5}$ based on PM_{10} concentrations was required because the PM_{10} analysis found 2021 to be the worst case year for fourth highest concentrations. A 60% reduction in daily $PM_{2.5}$ concentrations would be required to meet the proposed NES for $PM_{2.5}$ (25 µg/m^3, three allowable exceedances). The reduction required to meet the WHO $PM_{2.5}$ guideline of 15 µg/m^3 (three allowable exceedances) based on the same value is 76%.

The annual average $PM_{2.5}$ concentrations in Arrowtown for 2021 and 2022 (monitoring commenced in 2021) were estimated at 10.3 and 8.8 µg/m^3 respectively. This suggests that Arrowtown is likely compliant with the proposed NESAQ for $PM_{2.5}$ but that a reduction of around 48% in annual average $PM_{2.5}$ is required to meet the WHO (2021) air quality guideline.

Relationship between $PM_{2.5}$ and PM_{10} in Arrowtown

Figure 0-4 shows the relationship between PM_{10} and $PM_{2.5}$ concentrations from May to August in Arrowtown during 2021 and 2022. A strong correlation is observed both years (r^2 >0.96) and the majority of the PM_{10} is in the $PM_{2.5}$ size fraction. The relationship between the $PM_{2.5}$ and the PM_{10} in Arrowtown is typically consistent and coherent and indicative of quality data.



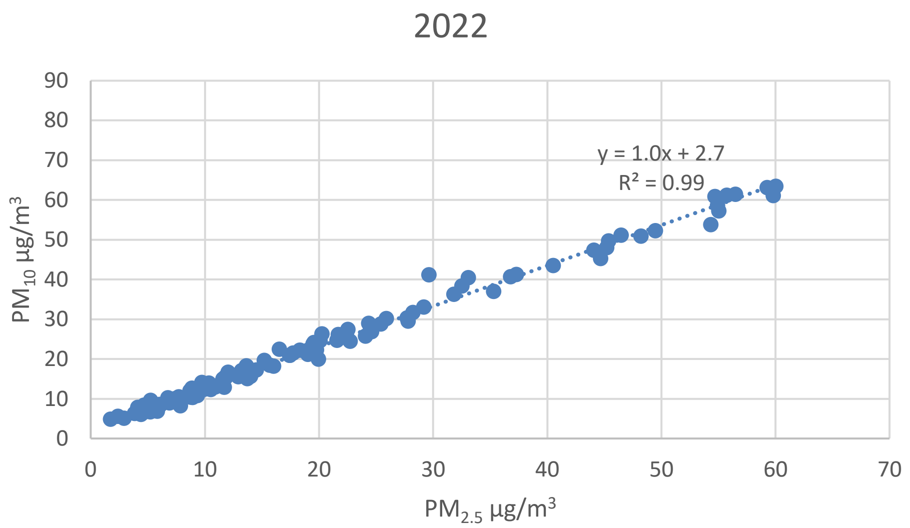


Figure 0-5: Annual average PM_{10} concentrations in Arrowtown from 2015 to 2022

Extrapolation of the Arrowtown $PM_{2.5}$ to PM_{10} relationship to other Otago towns

In areas where combustion sources and in particular biomass burning is the main source of PM_{10} the majority of the PM_{10} is in the $PM_{2.5}$ size fraction. The relationship between $PM_{2.5}$ and PM_{10} is typically highest during the winter months when domestic heating emissions is the main contributor to both size fractions.

The relationship between PM_{10} and $PM_{2.5}$ in Arrowtown is strongest in 2022 and can be described by the following equations derived using RMA regression, (Ayers, 2001):

Summer – $PM_{2.5}$ = 0.77 x PM_{10} – 2.4

Winter – $PM_{2.5}$ = .97 x PM_{10} -2.5

The extent to which the relationship between $PM_{2.5}$ and PM_{10} in Arrowtown applies to other towns in the Region will largely depend on the sources of coarse mode particulate in those areas. Sources of coarse mode particulate include natural sources such marine aerosols and wind-blown fugitive dusts as well as anthropogenic sources such as handling of bulk solid materials and other industrial sources. It would be likely that the inland towns such as Clyde, Cromwell and Clyde would have similar $PM_{2.5}$ to PM_{10} ratios as Arrowtown whereas Dunedin, Mosgiel and Milton would all be more affected by marine aerosols and anthropogenic sources of coarse mode particulate such as the handling of materials. It is proposed that the Arrowtown $PM_{2.5}$ to PM_{10} ratios be used in conjunction with PM_{10} data to estimate concentrations of $PM_{2.5}$ in Clyde, Cromwell and Clyde. Currently $PM_{2.5}$ monitoring in these areas is inadequate for the purposes of assessing reductions required, either because of the duration of the monitoring or because the monitoring method is not of the standard required for this type of evaluation.

Alexandra

Concentrations of PM_{10} in Alexandra

Air quality monitoring for PM_{10} has been carried out in Alexandra since 2005 with monitoring carried out using a beta attenuation monitor (BAM). The airshed is polluted under the National Environment Standards as the NES for PM_{10} (50 µg/m^3, 24-hour average, one allowable exceedance) is breached during the winter in Alexandra. Figure 0-6 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Alexandra since 2012.

In 2017 the monitoring site in Alexandra was relocated and the new monitoring site has much lower frequency of exceedances than the earlier monitoring site. The impact on maximum PM_{10} concentrations is unclear as the same step change at 2017 is not as distinct, although it seems likely that the new site measures lower peak concentrations also. Figure 0-7 shows the daily PM_{10} concentrations over the same period by air quality indicator category. This reiterates that the new site has a lower proportion of days when PM_{10} concentrations were 33 µg/m^3 (66% of the NES). The NES requires that PM_{10} be monitored in a location that experiences the worst case PM_{10} concentrations or the greatest frequency of high PM_{10} concentrations. It seems likely that the new monitoring site is less suitable in terms of NES requirements.

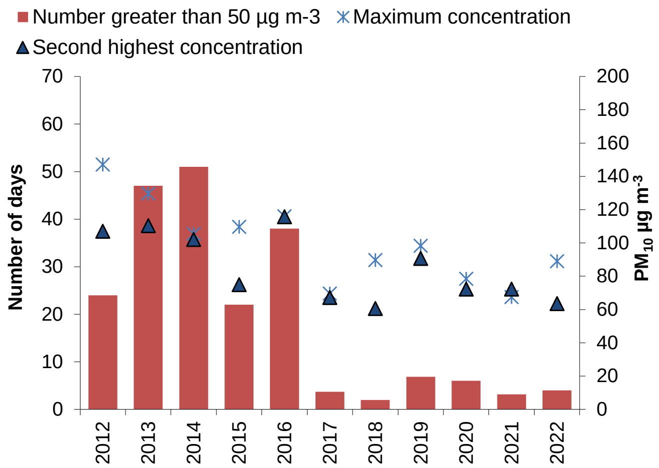


Figure 0-6: Annual exceedances of daily PM_{10} NES (50 µg/m^3), maximum and second highest 24-hour PM_{10} concentration.

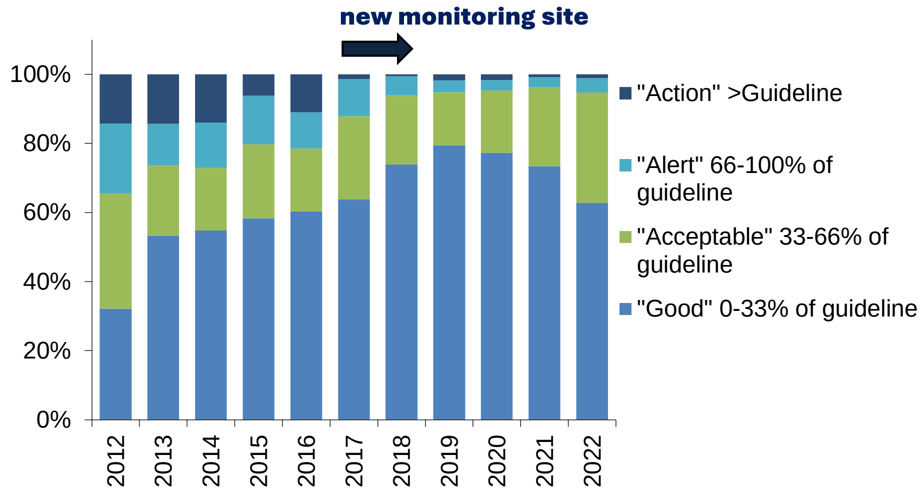


Figure 0-7: Distribution of daily PM_{10} concentrations in Alexandra from 2012 to 2022

Figure 0.3 shows the annual average PM_{10} concentrations at the new Alexandra site over a six-year period from 2017 to 2022.

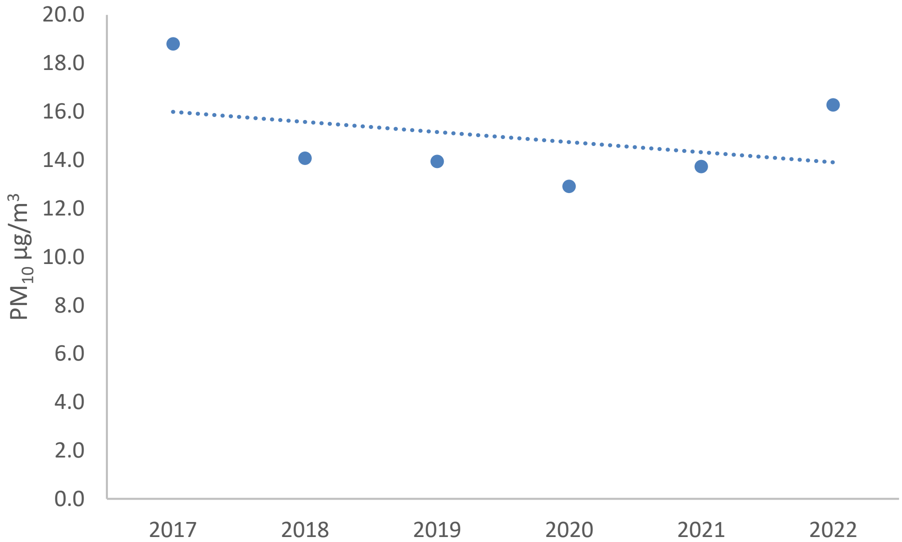


Figure 0-8: Annual average PM_{10} concentrations in Alexandra from 2017 to 2022

Table 0.3: Summary of PM_{10} concentrations measured at Alexandra from 2012-2022

	2012*	2013*	2014*	2015*	2016*	2017	2018	2019	2020	2021	2022
Monitoring method											
"Good" 0-33% of guideline	32%	53%	55%	58%	60%	64%	74%	79%	77%	73%	63%
"Acceptable" 33-66% of guideline	33%	21%	18%	21%	18%	24%	20%	15%	18%	23%	32%
"Alert" 66-100% of guideline	20%	12%	13%	14%	10%	11%	6%	3%	3%	3%	4%
"Action" >Guideline	14%	14%	14%	6%	11%	1%	1%	2%	2%	1%	1%
Percentage of valid data	46%	89%	100%	97%	94%	59%	99%	95%	97%	96%	99%
Annual average (µg m^{-3})	19.3	23.4	24.1	20.0	21.1	18.8	14.1	13.9	12.9	13.7	16.3
Measured PM_{10} concentrations above 50 µg m^{-3}	24	47	51	22	38	3	2	6	6	3	4
Second highest PM_{10} concentration (µg m^{-3})	107	110	102	75	116	67	61	91	72	72	64
Annual maximum (µg m^{-3})	147	130	106	110	116	70	90	98	79	68	89
Number of records	168	326	365	355	344	215	360	346	355	349	360

* Old monitoring site

The reduction required to meet the proposed daily NES for PM_{10} (50 µg/m^3, one allowable exceedance) and WHO (2021) daily PM_{10} guideline (45 µg/m^3, three allowable exceedances) were calculated based on the worst case year for meteorology of 2019 (second highest PM_{10} of 91 µg/m^3 and fourth highest of 58 µg/m^3). The reduction required was calculated at 45% and 23% respectively. No reduction in annual PM_{10} concentrations is required to meet the AAQG (annual of 20 µg/m^3). A reduction of around 8% is required to meet the WHO (2021) annual average guideline (15 µg/m^3) based on the 2022 annual average of 16.3 µg/m^3.

If the old site equivalent concentrations were to be used then the reductions required would be as follows:

- Daily PM_{10} – 58% and 40% for the NESAQ and WHO (2021) guideline respectively
- Annual PM_{10} – 29% reduction

Concentrations of $PM_{2.5}$ in Alexandra

Concentrations of $PM_{2.5}$ have been measured in Alexandra since September 2022. The monitoring method is a Met One ES642 sampler. This is an optical method of measurement which does not have equivalency status under the USEPA CFR 50 Appendix J "*Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere*". Given the limited data available and the measurement method not being wholly reliable, estimates of $PM_{2.5}$ concentrations for Alexandra have been made based on the relationship to PM_{10} concentrations from the Arrowtown monitoring site in winter 2022 (daily averages) and using a combination of summer and winter relationships for annual averages.

The two equations used to calculate $PM_{2.5}$ in Alexandra were:

Summer – $PM_{2.5} = 0.77 \times PM_{10} – 2.4$

Winter – $PM_{2.5} = .97 \times PM_{10} -2.5$

Table 0.4 shows the estimated annual average $PM_{2.5}$ concentrations in Alexandra of around 9-10 µg/m^3. The fourth highest daily $PM_{2.5}$ concentrations are shown as well as the estimated number of exceedances of the AAQG of 25 µg/m^3 (around 20-30 days per year).

The reduction required to meet the proposed daily NES for $PM_{2.5}$ (25 µg/m^3) and WHO (2021) daily $PM_{2.5}$ guideline (15 µg/m^3) were calculated based on the worst case year for meteorology of 2019 (estimated $PM_{2.5}$ concentration of 93 µg/m^3). The reduction required was calculated at 73% and 84% respectively. The reduction required to meet the proposed NES (annual of 10 µg/m^3) is around 15% and the WHO (2021) annual average (5 µg/m^3) is around 57% and has been calculated based on the 2022 average of 11.7 µg/m^3.

The relationship between the old and new monitoring site in Alexandra was evaluated using monitoring data collected by NIWA at both sites concurrently for a period of just over a month commencing June 2023. The strongest relationship between the two sites was described by the relationship new site = 28 x Ln(old site) – 55.46. The estimate of the impact of the site change on annual average $PM_{2.5}$ concentrations is shown in Table 0.4 by adjusting winter concentrations according to this relationship.

Table 0.4: Estimates of $PM_{2.5}$ concentrations in Alexandra from 2017-2022

AAQG – 25 µg/m^3	2017	2018	2019	2020	2021	2022
Monitoring method						
"Good" 0-33% of guideline	49%	62%	70%	64%	62%	47%
"Acceptable" 33-66% of guideline	23%	19%	15%	21%	20%	33%
"Alert" 66-100% of guideline	13%	10%	6%	8%	10%	10%
"Action" >Guideline	15%	8%	8%	6%	7%	9%
Percentage of valid data	59%	99%	95%	97%	96%	99%
Annual average (µg m^{-3})	11.3	10.0	9.9	9.0	9.6	11.7
Annual average (µg/m^3) adjusted for monitoring site		12	11	11	12	14
Measured $PM_{2.5}$ concentrations above 25 µg m^{-3}	33	29	26	21	25	33
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	46	44	54	51	37	48
Annual maximum (µg m^{-3})	65	85	93	74	63	84
Number of records for PM_{10}	215	360	346	355	349	360

Based on the old site equivalent $PM_{2.5}$ annual average concentrations the reduction required to meet the WHO (2021) guideline would be around 64%.

The reductions required for the purposes of this work have been calculated based on the current monitoring site in Alexandra. Additional reductions in $PM_{2.5}$ concentrations would be required to meet the WHO (2021) guideline, and other air quality guidelines, at the old Alexandra monitoring site.

Clyde

Concentrations of PM_{10} in Clyde

Air quality monitoring for PM_{10} has been carried out in Clyde since 2008 with monitoring carried out using a eBAM. Results from the monitoring indicate that the airshed is polluted under the National Environment Standards as the NES for PM_{10} (50 µg/m^3, 24-hour average, one allowable exceedance) is breached during the winter in Clyde. Figure 0-9 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Clyde since 2012. A reduction in the frequency of exceedances is apparent from 2018. No monitoring of PM_{10} concentrations has been carried out since 2020 and no monitoring data were available for 2014 and 2015.

Figure 0-10 shows the daily PM_{10} concentrations over the same period by air quality indicator category. It is noted that the monitoring period is typically May to September and does not include summer months.

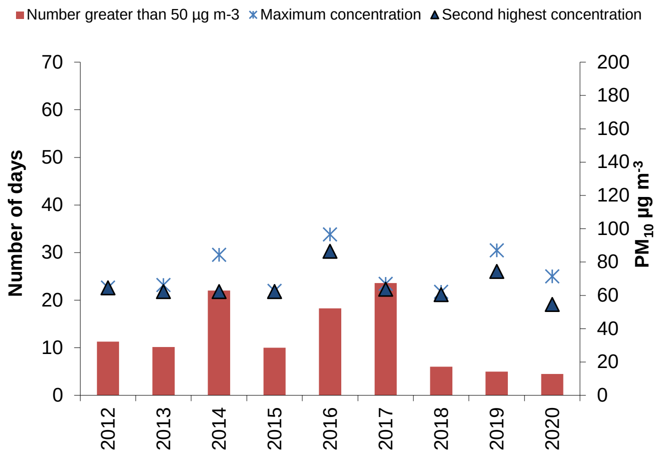


Figure 0-9: Annual exceedances of daily PM_{10} NES (50 µg/m³), maximum and second highest 24-hour PM_{10} concentration.

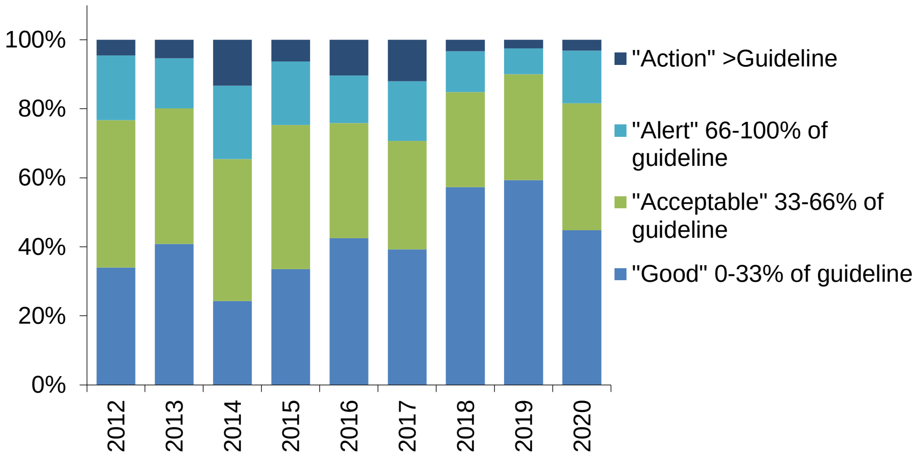


Figure 0-10: Distribution of daily PM_{10} concentrations in Clyde from 2012 to 2020

Figure 0-11 shows a potential decrease in winter average PM_{10} concentrations at Clyde site from 2012 to 2020. Summary PM_{10} data from 2012 to 2020 is shown in Table 0-5.

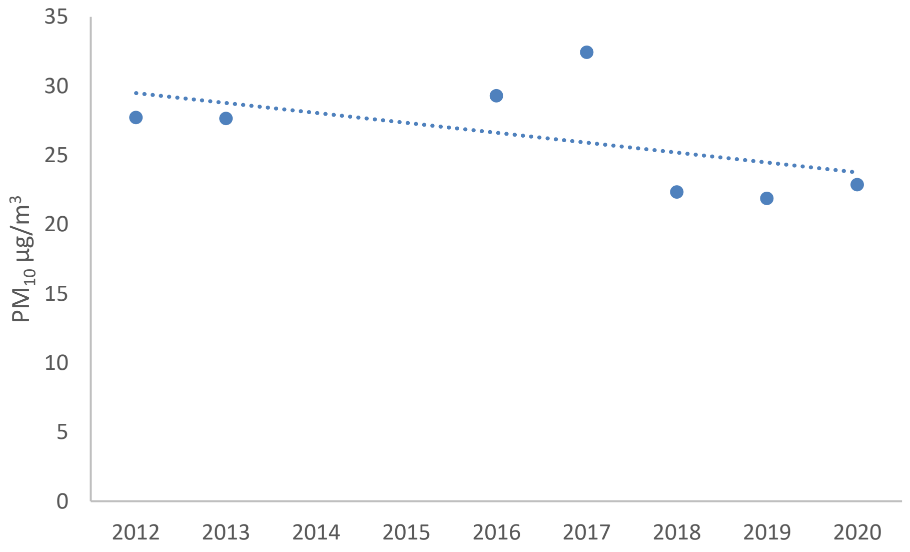


Figure 0-11: Winter average PM_{10} concentrations in Clyde from 2012 to 2020

Table 0.5: Summary of PM_{10} concentrations measured at Clyde from 2012-2020

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Monitoring method									
"Good" 0-33% of guideline	34%	41%	24%	34%	43%	39%	57%	60%	45%
"Acceptable" 33-66% of guideline	43%	39%	41%	42%	33%	31%	28%	31%	37%
"Alert" 66-100% of guideline	19%	15%	21%	18%	14%	17%	12%	8%	15%
"Action" >Guideline	5%	5%	13%	6%	10%	12%	3%	3%	3%
Percentage of valid data	54%	51%	45%	43%	48%	52%	49%	54%	34%
Winter average (µg m^{-3})	28	28	32	27	29	32	22	22	23
Measured PM_{10} concentrations above 50 µg m^{-3}	9	10	22	10	18	23	6	5	4
Second highest PM_{10} concentration (µg m^{-3})	65	62	62	62	87	64	61	74	55
Annual maximum (µg m^{-3})	65	66	84	63	97	67	62	87	72
Number of records	197	186	164	158	174	191	178	198	125

The reduction required to meet the proposed daily NES for PM_{10} (50 µg/m^3, one allowable exceedance) and WHO (2021) daily PM_{10} guideline (45 µg/m^3, three allowable exceedances) were calculated based on the worst case year for meteorology of 2019 (second highest PM_{10} of 74 µg/m^3 and fourth highest of 55 µg/m^3). The reduction required was calculated at 33% and 18% respectively. Annual average PM_{10} concentrations were estimated using summer average PM_{10} of 10.7 µg/m^3 from Alexandra. The annual average PM_{10} concentration for 2020 was estimated at around 14.7 µg/m^3. No reduction in annual PM_{10} concentrations is required to meet the AAQG (annual of 20 µg/m^3) or the WHO (2021) guideline of 15 µg/m^3.

Concentrations of $PM_{2.5}$ in Clyde

Concentrations of $PM_{2.5}$ have been measured in Clyde since May 2021. The monitoring method is a Met One ES642 sampler. This is an optical method of measurement which does not have equivalency status under the USEPA CFR 50 Appendix J "*Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere*". Estimates of daily winter $PM_{2.5}$ concentrations for Clyde have been made for the years 2017 - 2020 based on the relationship to PM_{10} concentrations from the Arrowtown monitoring site in winter 2022 (daily averages). The summer $PM_{2.5}$ concentrations for year 2017 – 2020 are based on the 2022 Clyde summer average $PM_{2.5}$ concentration of 3.7 µg/m^3.

The equation used to calculate winter $PM_{2.5}$ in Clyde for 2017 to 2020 were:

Winter – $PM_{2.5}$ = .97 x PM_{10} - 2.5

For 2021 and 2022 $PM_{2.5}$ data are from the ES642 sampler located in Clyde.

Table 0.6 shows the estimated annual average $PM_{2.5}$ concentrations in Clyde of around 8-10 µg/m^3 for the period 2018 to 2022. The 2017 annual average concentration, also based on that approach, is higher as this year had a much greater frequency of meteorological conditions conducive to elevated concentrations (as evidenced by the increased frequency of exceedance for PM_{10} and $PM_{2.5}$). The fourth highest daily $PM_{2.5}$ concentrations are shown as well as the estimated number of exceedances of the AAQG of 25 µg/m^3 (around 30 days per year).

The reduction required to meet the proposed daily NES for $PM_{2.5}$ (25 µg/m^3) and WHO (2021) daily $PM_{2.5}$ guideline (15 µg/m^3) were calculated based on the 2021 and 2022 fourth highest $PM_{2.5}$ concentration of 43 µg/m^3). Note that this was the same value as extrapolating the worst case year (2019 for estimates based on PM_{10}) to the 2022 equivalent value. The reduction required was calculated at 42% and 65% respectively. The reduction required to meet the WHO (2021) annual average (5 µg/m^3) is around 38% and has been calculated based on the average annual $PM_{2.5}$ concentrations from 2020 to 2022 average of 8.7 µg/m^3.

Table 0.6: Estimates of $PM_{2.5}$ concentrations in Clyde from 2017-2022

AAQG – 25 µg/m^3	2017**	2018**	2019**	2020**	2021*	2022*
Monitoring method						
"Good" 0-33% of guideline	73%	83%	78%	83%	86%	85%
"Acceptable" 33-66% of guideline	14%	12%	16%	11%	9%	12%
"Alert" 66-100% of guideline	8%	5%	4%	5%	5%	3%
"Action" >Guideline	5%	1%	1%	1%	1%	0%
Percentage of valid data	96%	100%	75%	95%	94%	100%
Annual average (µg m^{-3})	13.0	9.3	9.8	9.1	8.8	8.2
Measured $PM_{2.5}$ concentrations above 25 µg m^{-3}	66	36	28	33	30	26
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	58	51	51	50	43	43
Annual maximum (µg m^{-3})	63	58	82	67	53	54
Number of records for PM_{10}	352	365	274	347	344	365

*non reference method sampler

** extrapolated from PM_{10}

Cromwell

Concentrations of PM_{10} in Cromwell

Air quality monitoring for PM_{10} has been carried out in Cromwell since 2008 using an eBAM. Monitoring data shows that the airshed is polluted under the National Environment Standards as the NES for PM_{10} (50 µg/m^3, 24-hour average, one allowable exceedance) is breached during the winter in Cromwell. No PM_{10} monitoring was carried out in Cromwell during 2022. Figure 0-12 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Cromwell since 2012 and suggests a reduction in the frequency of exceedance from an average of 35 for the five years from 2012 to 2016 to an average of 21 for the five years from 2017 to 2021. Figure 0-13 shows the daily PM_{10} concentrations over the same period by air quality indicator category. This shows an increase in the proportion of days when air quality was less than 33% of the guideline value (16 µg/m^3) from 2012 to 2021.

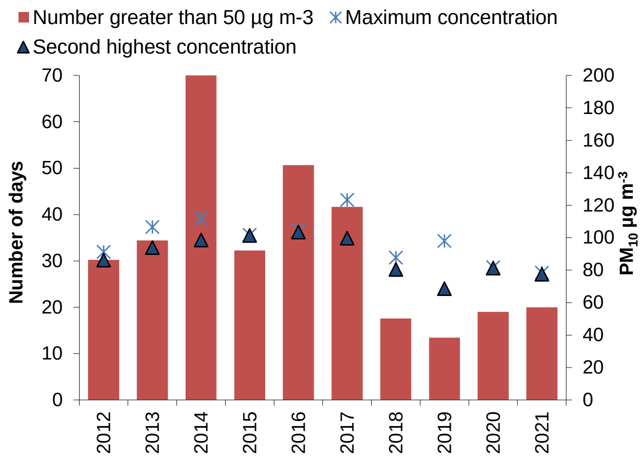


Figure 0-12: Annual exceedances of daily PM_{10} NES (50 µg/m^3), maximum and second highest 24-hour PM_{10} concentration.

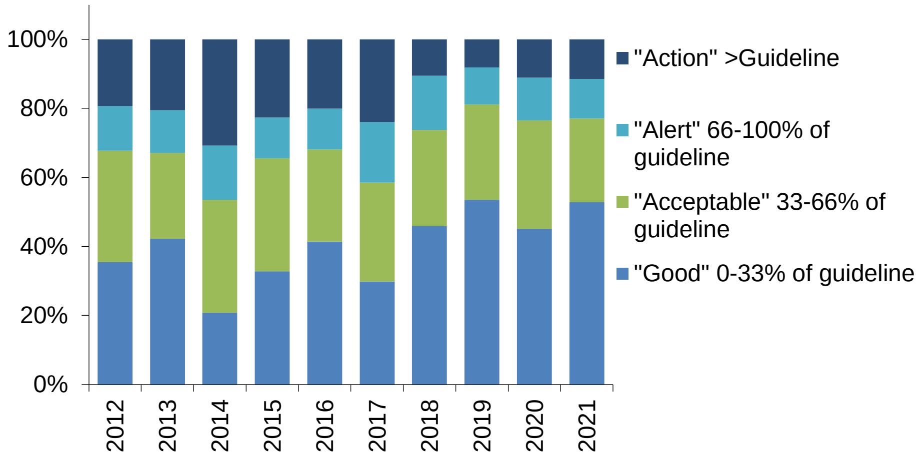


Figure 0-13: Distribution of daily PM_{10} concentrations in Cromwell from 2012 to 2022

No evaluation of annual average PM_{10} concentrations in Cromwell was possible as PM_{10} sampling was limited to the winter months. Figure 2.3 shows the winter average PM_{10} concentrations from 2012 to 2021. Summary PM_{10} data for the period from 2012 to 2021 is shown in Table 0-7.

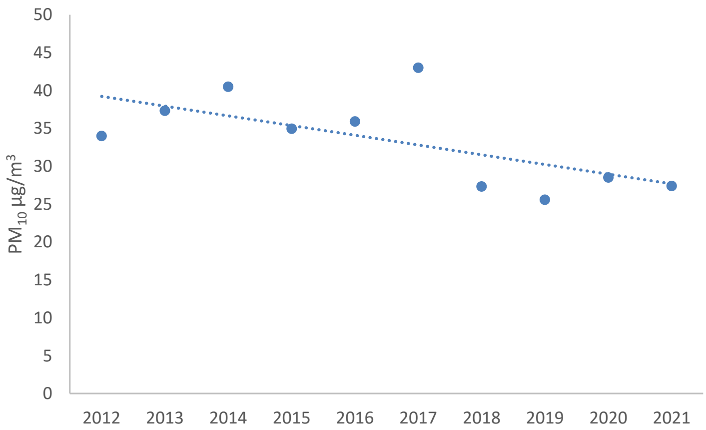


Figure 0-14: Winter average PM_{10} concentrations in Cromwell from 2017 to 2022

Table 0.7: Summary of PM_{10} concentrations measured at Cromwell from 2012-2021

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Monitoring method										
"Good" 0-33% of guideline	35%	42%	21%	33%	41%	30%	46%	53%	45%	53%
"Acceptable" 33-66% of guideline	32%	25%	33%	33%	27%	29%	28%	28%	31%	24%
"Alert" 66-100% of guideline	13%	12%	16%	12%	12%	18%	16%	11%	12%	11%
"Action" >Guideline	19%	20%	31%	23%	20%	24%	11%	8%	11%	11%
Percentage of valid data	42%	44%	44%	33%	46%	47%	36%	44%	42%	48%
Winter average (µg m^{-3})	34	37	41	35	36	43	27	26	29	27
Measured PM_{10} concentrations above 50 µg m^{-3}	30	33	49	27	34	41	14	13	17	20
Second highest PM_{10} concentration (µg m^{-3})	94	99	101	104	100	81	69	81	78	94
Annual maximum (µg m^{-3})	107	112	102	105	123	88	98	82	79	107
Number of records	161	159	119	169	171	132	159	153	174	161

The reduction required to meet the proposed daily NES for PM_{10} (50 µg/m^3, one allowable exceedance) and WHO (2021) daily PM_{10} guideline (45 µg/m^3, three allowable exceedances) were calculated based on the worst case year for meteorology of 2015 adjusted for 2021 concentrations. The reduction required was calculated at 37% and 41% based on concentrations of 79 µg/m^3 and 76 µg/m^3 respectively.

The reduction in annual average PM_{10} was estimated using summer average PM_{10} concentrations from Alexandra of 10.7 µg/m^3. This gave estimated annual average concentrations for Cromwell for 2019 top 2021 of 16. 2. Based on these estimates no reduction in annual PM_{10} concentrations is likely required to meet the AAQG (annual of 20 µg/m^3) in Cromwell. A reduction of around 7% is likely to be required to meet the WHO (2021) annual average guideline (15 µg/m^3).

Concentrations of $PM_{2.5}$ in Cromwell

Concentrations of $PM_{2.5}$ have been measured in Cromwell since May 2021. The monitoring method is a Met One ES642 sampler. This is an optical method of measurement which does not have equivalency status under the USEPA CFR 50 Appendix J "*Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere*". Given the limited data available and the measurement method not being wholly reliable, estimates of daily winter $PM_{2.5}$ concentrations for Cromwell have been made based on the relationship to PM_{10} concentrations from the Arrowtown monitoring site in 2022 (daily averages).

The two equations used to calculate $PM_{2.5}$ in Cromwell were:

Summer – $PM_{2.5} = 0.77 \times PM_{10} - 2.4$

Winter – $PM_{2.5} = .97 \times PM_{10} - 2.5$

Table 0.8 shows the estimated annual average $PM_{2.5}$ concentrations in Cromwell of around 11-17 µg/m³. The fourth highest daily $PM_{2.5}$ concentrations are shown as well as the estimated number of exceedances of the AAQG of 25 µg/m³ (around 30-75 days per year).

Table 0.8: Estimates of $PM_{2.5}$ concentrations in Cromwell from 2012-2021

AAQG – 25 µg/m³	2017	2018	2019	2020	2021
Monitoring method					
"Good" 0-33% of guideline	68%	77%	74%	74%	74%
"Acceptable" 33-66% of guideline	6%	8%	10%	9%	9%
"Alert" 66-100% of guideline	5%	6%	5%	6%	4%
"Action" >Guideline	21%	9%	11%	12%	13%
Percentage of valid data	99%	93%	99%	96%	100%
Annual average (µg m^{-3})	16.8	11.6	11.2	12.0	11.7
Measured $PM_{2.5}$ concentrations above 25 µg m^{-3}	75	31	38	41	47
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	89	68	58	72	68
Annual maximum (µg m^{-3})	117	83	93	77	74
Number of records for PM_{10}	363	339	361	352	365

The reduction required to meet the proposed daily NES for $PM_{2.5}$ (25 µg/m³) and WHO (2021) daily $PM_{2.5}$ guideline (15 µg/m³) were calculated based on 2021 $PM_{2.5}$ estimates. The reduction required was calculated at 63% and 78% respectively. The reduction required to meet the proposed NES (annual of 10 µg/m³) is around 14% and the WHO (2021) annual average (5 µg/m³) is around 57% and has been calculated based on the 2021 average of 11.7 µg/m³. Given the extent of extrapolation in annual average concentrations, the reductions required should be treated with caution and as indicative of likely scale of reduction required.

Milton

Air quality monitoring for PM_{10} has been carried out in Milton from 2008 to 2021 using an eBAM. The airshed is polluted under the National Environment Standards as the NES for PM_{10} (50 µg/m³, 24-hour average, one allowable exceedance) is breached during the winter in Milton. Figure 0-15 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Milton since 2012 and suggests a reduction in the frequency of exceedance from an average of 33 for the five years from 2012 to 2016 to an average of 24 for the five years from 2017 to 2021. Figure 0-16 shows the daily PM_{10} concentrations over the same period by air quality indicator category. This shows an increase in the proportion of days when air quality was less than 66% of the guideline value (16 µg/m^3) from around 2019.

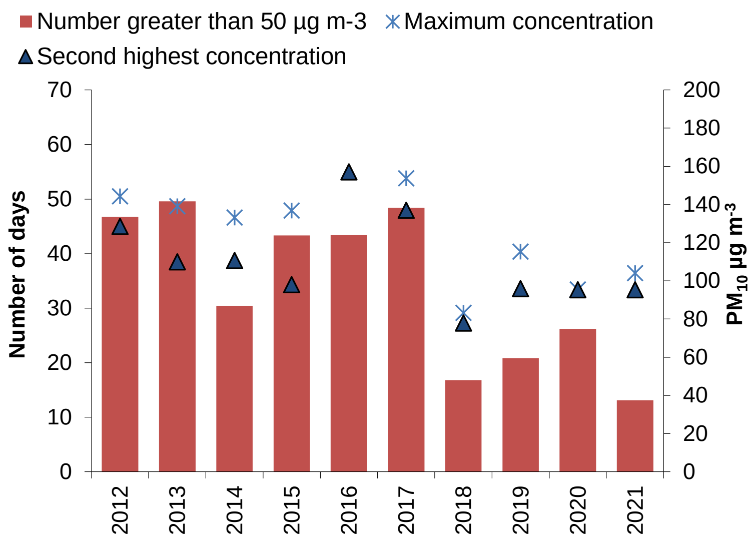


Figure 0-15: Annual exceedances of daily PM_{10} NES (50 µg/m^3), maximum and second highest 24-hour PM_{10} concentration.

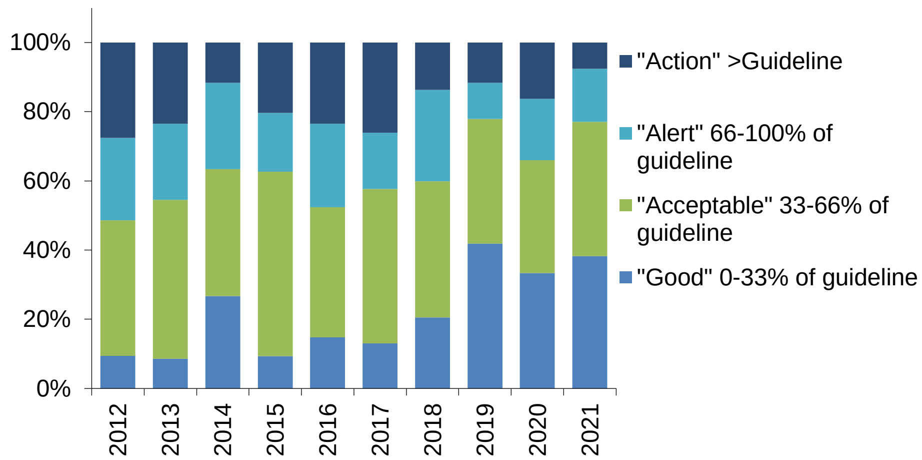


Figure 0-16: Distribution of daily PM_{10} concentrations in Milton from 2012 to 2021

No evaluation of annual average PM_{10} concentrations in Milton was possible as PM_{10} sampling was largely limited to the winter months. Figure 0-17 shows the winter average PM_{10} concentrations from 2012 to 2021. Summary PM_{10} data for the period from 2012 to 2021 is shown in Table 0-9.

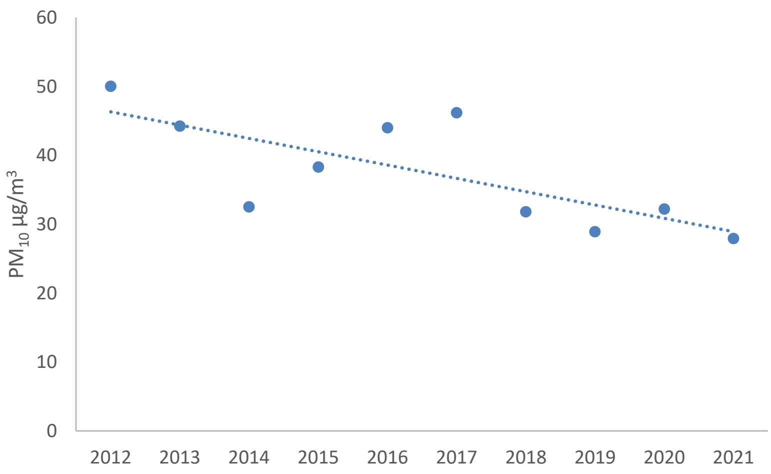


Figure 0-17: Winter average PM_{10} concentrations in Milton from 2012 to 2021

Table 0.9: Summary of PM_{10} concentrations measured at Milton from 2012-2021

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Monitoring method										
"Good" 0-33% of guideline	9%	9%	27%	9%	15%	13%	21%	42%	33%	38%
"Acceptable" 33-66% of guideline	39%	46%	37%	54%	38%	45%	39%	36%	33%	39%
"Alert" 66-100% of guideline	24%	22%	25%	17%	24%	16%	26%	10%	18%	15%
"Action" >Guideline	28%	24%	12%	20%	23%	26%	14%	12%	16%	8%
Percentage of valid data	38%	51%	33%	50%	41%	50%	32%	47%	39%	47%
Winter average (µg m^{-3})	50	44	33	38	44	46	32	29	32	28
Measured PM_{10} concentrations above 50 µg m^{-3}	38	44	14	37	35	48	16	20	23	13
Second highest PM_{10} concentration (µg m^{-3})	129	110	111	98	157	137	78	96	95	95
Annual maximum (µg m^{-3})	144	139	133	137	203	154	83	115	96	104
Number of records	137	187	120	181	149	184	117	172	141	170

The reduction required to meet the proposed daily NES for PM_{10} (50 µg/m^3, one allowable exceedance) and WHO (2021) daily PM_{10} guideline (45 µg/m^3, three allowable exceedances) were calculated based on the worst-case year for meteorology of 2016 adjusted for 2021 concentrations. The reduction required was calculated at 50% and 45% based on concentrations of 100 µg/m^3 and 83 µg/m^3 respectively.

Inadequate summer data were available to accurately determine annual average PM_{10} concentrations in Milton. An estimate of annual average concentrations was made using summer PM_{10} data from Mosgiel (2017 – 2021 average of 14.3). This suggested annual average concentrations in Milton might be around 19-26 µg/m^3 with concentrations from 2018 all being around 19-20 µg/m^3. As data are potentially indicative of a downward trend use of recent annual averages is appropriate. Based on this assessment it is unlikely that a reduction in annual PM_{10} concentrations is required to meet the AAQG (annual of 20 µg/m^3). A reduction of around 30% is likely required to meet the WHO (2021) annual average guideline (15 µg/m^3).

Concentrations of $PM_{2.5}$ in Milton

Concentrations of $PM_{2.5}$ have been measured in Milton since May 2021. The monitoring method is a Met One ES642 sampler. This is an optical method of measurement which does not have equivalency status under the USEPA CFR 50 Appendix J "*Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere*". Figure 0-18 illustrates the correlation between $PM_{2.5}$ and PM_{10} concentrations measured in Milton from May to December 2021. This gives a coefficient of determination (r^2) of 0.93 suggesting the measured $PM_{2.5}$ and PM_{10} concentrations are well correlated and that around 75% of the PM_{10} is in the $PM_{2.5}$ size fraction.

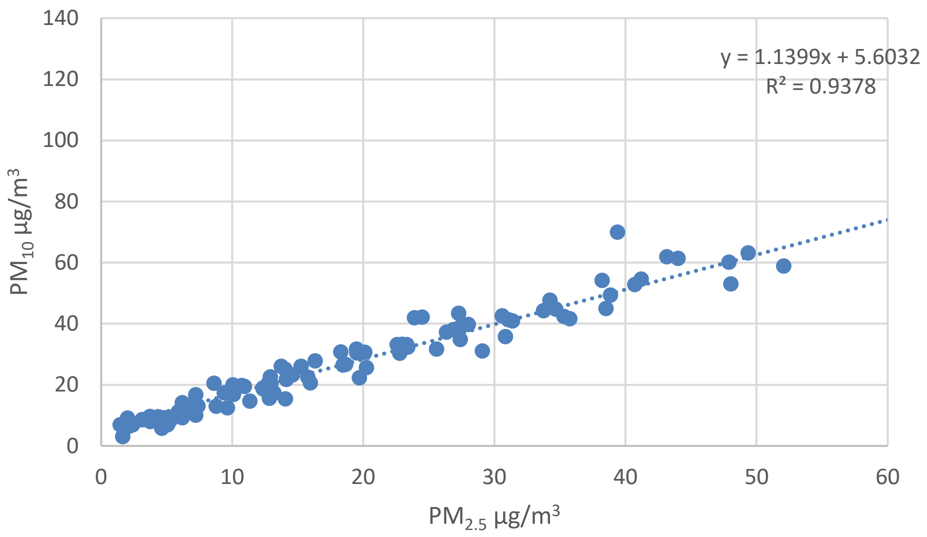


Figure 0-18: Comparison of PM_{10} and $PM_{2.5}$ concentrations measured in Milton during 2021

Concentrations of $PM_{2.5}$ were estimated for the years 2017 to 2021 based on PM_{10} measurements and the relationships derived from the 2022 data comparison. These showed winter and summer correlations as follows:

Winter $PM_{2.5}$ = 0.82 PM_{10} – 3.3

Summer $PM_{2.5}$ = 0.62 PM_{10} – 3.2

Table 0.8 shows the estimated annual average $PM_{2.5}$ concentrations in Milton of around 9-10 µg/m^3 for the period 2018 to 2021 and a slightly lower concentration of 7.8 for 2022. The fourth highest daily $PM_{2.5}$ concentrations are shown as well as the estimated number of exceedances of the proposed NES of 25 µg/m^3.

Table 0.10: Estimates of $PM_{2.5}$ concentrations in Milton from 2017 to 2022

PROPOSED NES – 25 µg/m^3	2017	2018	2019	2020	2021	2022
Monitoring method						
"Good" 0-33% of guideline	72%	90%	83%	82%	84%	87%
"Acceptable" 33-66% of guideline	12%	7%	10%	10%	10%	10%
"Alert" 66-100% of guideline	9%	2%	6%	6%	5%	2%
"Action" >Guideline	7%	1%	1%	2%	1%	1%
Percentage of valid data	99%	100%	98%	99%	100%	100%
Annual average (µg m^{-3})	15.1	6.7	9.8	9.8	9.0	7.8
Measured $PM_{2.5}$ concentrations above 25 µg m^{-3}	72	20	34	43	34	21
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	80	57	62	60	52	58
Annual maximum (µg m^{-3})	123	65	92	75	103	78
Number of records for PM_{10}	362	365	358	361	365	365

The reduction required to meet the proposed daily NES for $PM_{2.5}$ (25 µg/m^3) and WHO (2021) daily $PM_{2.5}$ guideline (15 µg/m^3) were calculated based on the 2022 fourth highest $PM_{2.5}$ concentration of 58 µg/m^3. The reduction required was calculated at 57% and 74% respectively. The reduction required to meet the WHO (2021) annual average (5 µg/m^3) is around 43% and has been calculated based on the 2020 - 2022 average of 8.8 µg/m^3.

Mosgiel

Air quality monitoring for PM_{10} has been carried out in Mosgiel since 2005 using a BAM. The airshed is polluted under the National Environment Standards as the NES for PM_{10} (50 µg/m^3, 24-hour average, one allowable exceedance) is breached during the winter in Mosgiel. Figure 0-19 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Mosgiel since 2013. Data for 2012 are not reported as the monitoring this year did not commence until September.

Figure 0-20 shows the daily PM_{10} concentrations over the same period by air quality indicator category. Data are not indicative of obvious improvements in PM_{10} concentrations in Mosgiel from 2013 to 2022.

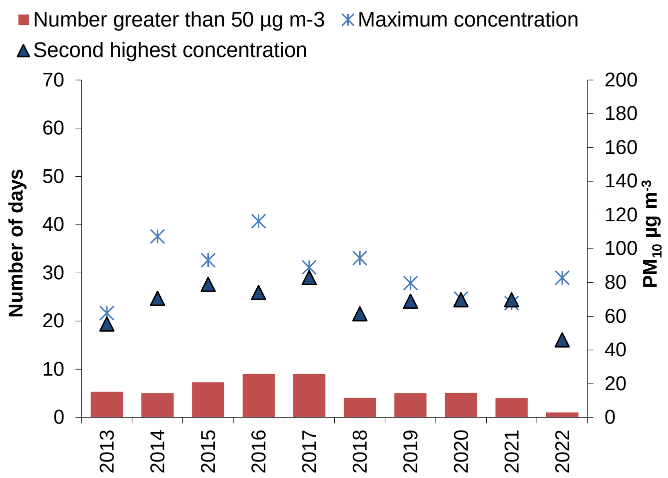


Figure 0-19: Annual exceedances of daily PM_{10} NES (50 µg/m^3), maximum and second highest 24-hour PM_{10} concentration.

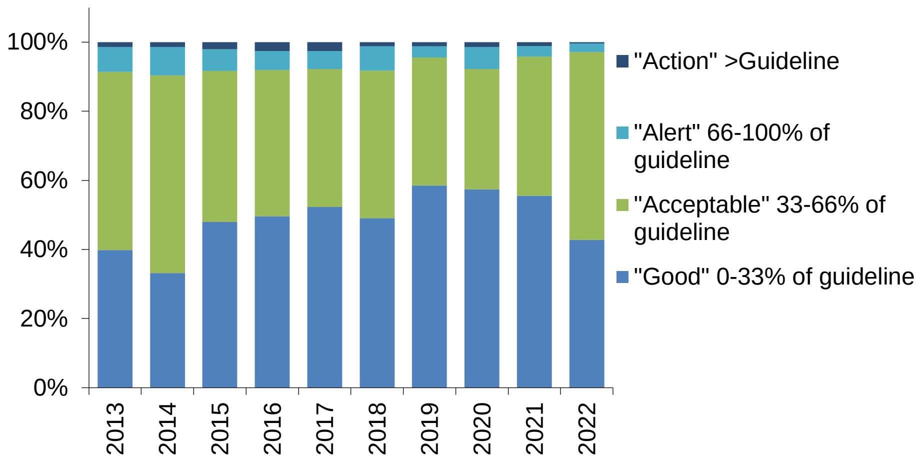


Figure 0-20: Distribution of daily PM_{10} concentrations in Mosgiel from 2013 to 2022

Trend assessment in PM_{10} data typically requires a minimum period of 10 years of monitoring data. No statistical evaluation of trend was carried.

Annual average PM_{10} concentrations in Mosgiel from 2013 to 2022 is shown in Figure 0-21. Summary PM_{10} data for the period from 2013 to 2022 is shown in Table 0-11.

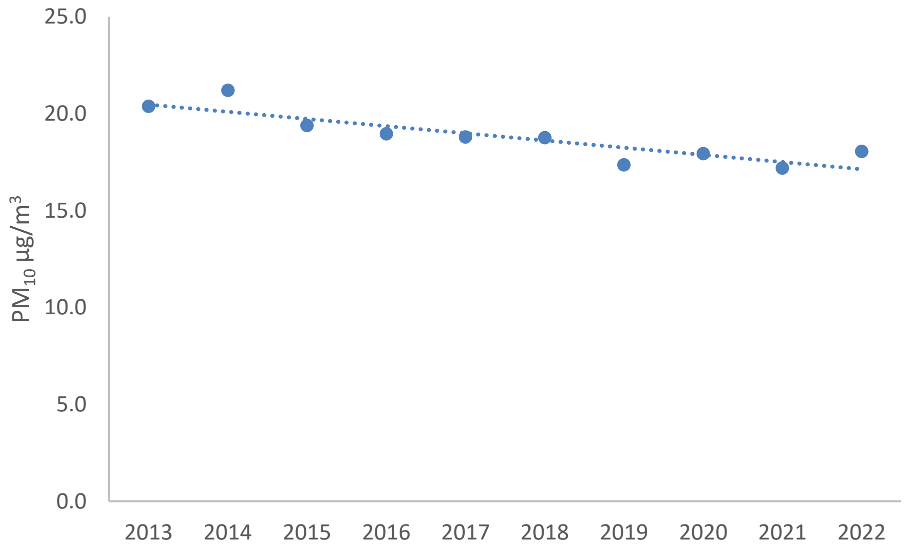


Figure 0-21: Winter average PM_{10} concentrations in Mosgiel from 2013 to 2022

Table 0.11: Summary of PM_{10} concentrations measured at Mosgiel from 2012-2021

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Monitoring method										
"Good" 0-33% of guideline	40%	33%	48%	50%	52%	49%	59%	58%	55%	43%
"Acceptable" 33-66% of guideline	52%	57%	44%	42%	40%	43%	37%	35%	40%	54%
"Alert" 66-100% of guideline	7%	8%	6%	5%	5%	7%	3%	6%	3%	3%
"Action" >Guideline	1%	1%	2%	3%	3%	1%	1%	1%	1%	0%
Percentage of valid data	95%	99%	92%	95%	95%	89%	92%	98%	97%	76%
Annual average (µg m^{-3})	20.4	21.2	19.4	19.0	18.8	18.8	17.4	17.9	17.2	18.1
Measured PM_{10} concentrations above 50 µg m^{-3}	5	5	7	9	9	4	4	5	4	1
Second highest PM_{10} concentration (µg m^{-3})	56	71	79	74	83	62	69	70	58	46
Annual maximum (µg m^{-3})	62	107	93	116	89	95	80	71	68	83
Number of records	347	362	334	346	347	326	335	358	355	278

The reduction required to meet the proposed daily NES for PM_{10} (50 µg/m^3, one allowable exceedance) and WHO (2021) daily PM_{10} guideline (45 µg/m^3, three allowable exceedances) were calculated based on the worst-case year for meteorology of 2017 adjusted for 2022 concentrations. The reduction required was calculated at 37% and 31% based on concentrations of 80 µg/m^3 and 65 µg/m^3 respectively.

No reduction in annual PM_{10} concentrations is required to meet the AAQG (annual of 20 µg/m^3). A reduction of around 17% is likely required to meet the WHO (2021) annual average guideline (15 µg/m^3) based on the 2022 annual average of 18.12 µg/m^3.

Concentrations of $PM_{2.5}$ in Mosgiel

Concentrations of $PM_{2.5}$ have been measured in Mosgiel since April 2023 using a T640 which measures both the $PM_{2.5}$ and PM_{10} size fractions. This is an optical method of measurement which does have equivalency status under the USEPA CFR 50 Appendix J "*Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere*". Reliance on this method to give $PM_{2.5}$ is appropriate.

Estimates of $PM_{2.5}$ concentrations in Mosgiel were made for the period 2017 to 2022 using the summer average $PM_{2.5}$ concentration from Milton of 3.7 µg/m^3 and the relationship between PM_{10} and $PM_{2.5}$ established for Mosgiel during winter 2023. That relationship can be defined as follows:

Winter – $PM_{2.5}$ = .78 x PM_{10} -2.05

Table 0.12 shows the estimated annual average $PM_{2.5}$ concentrations in Mosgiel of around 6-9 µg/m^3. The fourth highest daily $PM_{2.5}$ concentrations are shown as well as the estimated number of exceedances of the Proposed NES of 25 µg/m^3 (around 30-75 days per year). Data are indicative of improving $PM_{2.5}$ concentrations with a consistent decrease in annual average concentrations since 2017 and a reduction in exceedances of 25 µg/m^3 from around 20 in 2018-2018 to six in 2022 and 2023.

Table 0.12: Estimates of $PM_{2.5}$ concentrations in Mosgiel from 2017-2023

Proposed NES– 25 µg/m^3	2017	2018	2019	2020	2021	2022	2023
Monitoring method							
"Good" 0-33% of guideline	69%	70%	76%	71%	72%	75%	88%
"Acceptable" 33-66% of guideline	15%	14%	12%	15%	17%	17%	9%
"Alert" 66-100% of guideline	10%	11%	9%	8%	8%	7%	1%
"Action" >Guideline	6%	5%	4%	6%	4%	2%	2%
Percentage of valid data	100%	100%	93%	99%	100%	98%	88%
Annual average (µg m^{-3})	8.6	8.5	8.3	8.4	7.7	7.0	6.0
Estimated $PM_{2.5}$ concentrations above 25 µg m^{-3}	21	18	12	23	15	6	6
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	51	43	44	45	38	39	39
Annual maximum (µg m^{-3})	67	71	60	53	51	62	44
Number of records for PM_{10}	365	364	340	363	365	358	321

The reduction required to meet the proposed daily NES for $PM_{2.5}$ (25 µg/m^3) and WHO (2021) daily $PM_{2.5}$ guideline (15 µg/m^3) were calculated based on 2023 $PM_{2.5}$ concentrations as these were measured rather than estimated. The reduction required was calculated at 36% and 62% respectively.

The annual average $PM_{2.5}$ is less than the proposed NES (annual of 10 µg/m3). A reduction of around 23% is required to meet the WHO (2021) annual average (5 µg/m3) and is based on the 2022 and 2023 average of 6.5 µg/m3. Given the extent of extrapolation in annual average concentrations, the reductions required should be treated with caution and as indicative of likely scale of reduction required.

Dunedin

Air quality monitoring for PM_{10} has been carried out in Dunedin since 2005 using a BAM and additionally since 2018 using a T640x which also measures $PM_{2.5}$. Dunedin is not polluted under the National Environment

Standards as the NES for PM_{10} (50 µg/m^3, 24-hour average, one allowable exceedance). Figure 0-22 shows changes in NES exceedances and maximum daily PM_{10} concentrations at Dunedin since 2012.

Figure 0-23 shows the daily PM_{10} concentrations over the same period by air quality indicator category. Data suggest some improvements in PM_{10} concentrations in Dunedin from around 2016 to 2021. During these years a greater proportion of the PM_{10} concentrations were in the “good” less than 33% of the guideline category. In 2022 a construction site was operating near to the monitoring station which likely impacted on the concentrations of PM_{10} measured at the site.

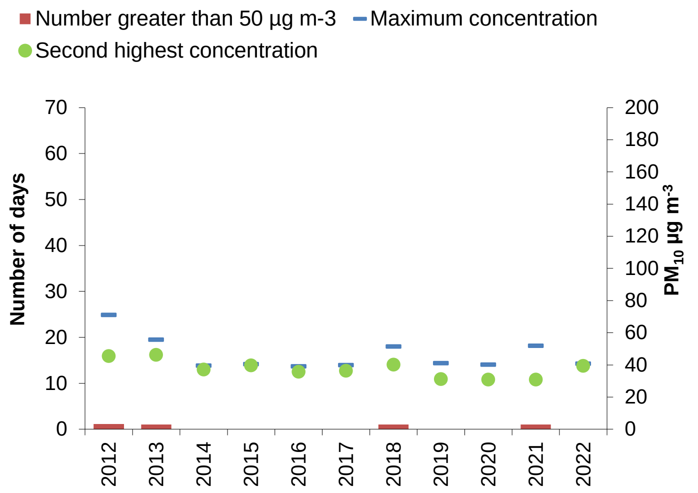


Figure 0-22: Annual exceedances of daily PM_{10} NES (50 µg/m^3), maximum and second highest 24-hour PM_{10} concentration.

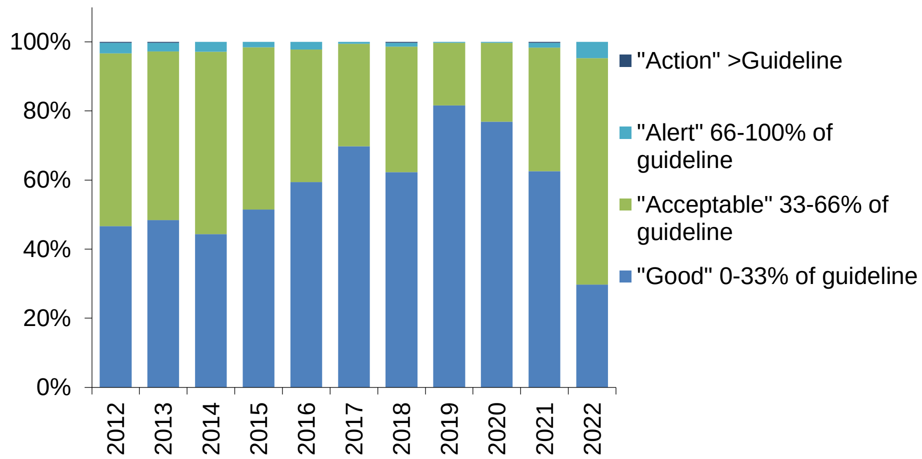


Figure 0-23: Distribution of daily PM_{10} concentrations in Dunedin from 2013 to 2022

Annual average PM_{10} concentrations in Dunedin from 2012 to 2022 is shown in Figure 0-24. Data may be indicative of a slight reduction in PM_{10} concentrations over this period if 2022 data are excluded. Summary PM_{10} data for the period from 2012 to 2022 is shown in Table 0-13.

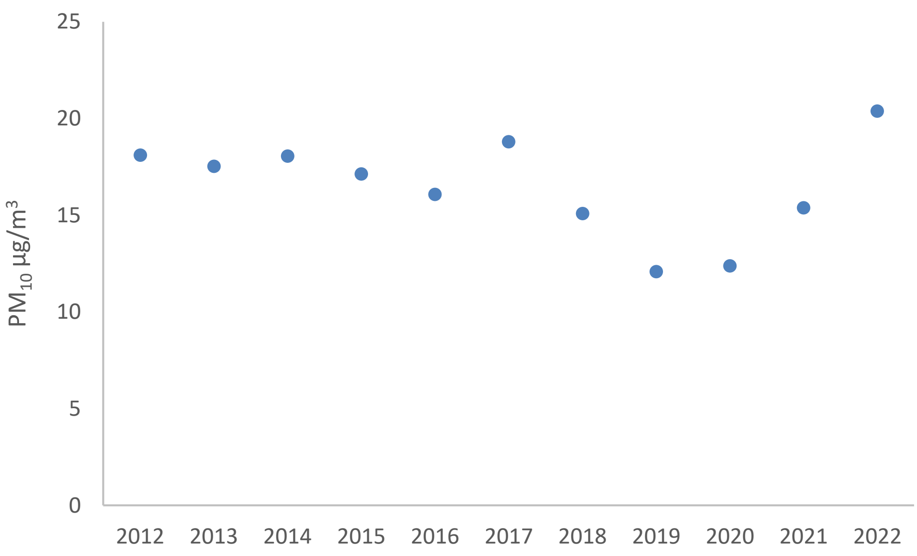


Figure 0-24: Annual average PM_{10} concentrations in Dunedin from 2012 to 2022

Table 0.13: Summary of PM_{10} concentrations measured at Dunedin from 2012-2022

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Monitoring method											
"Good" 0-33% of guideline	47%	48%	44%	51%	60%	70%	62%	82%	77%	63%	30%
"Acceptable" 33-66% of guideline	50%	49%	53%	47%	38%	30%	36%	18%	23%	36%	65%
"Alert" 66-100% of guideline	3%	3%	3%	2%	2%	1%	1%	0%	0%	1%	5%
“Action” >Guideline	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Percentage of valid data	90%	97%	95%	85%	85%	98%	97%	95%	93%	96%	98%
Annual average (µg m^{-3})	18	18	18	17	16	19	15	12	12	15	20
Measured PM_{10} concentrations above 50 µg m^{-3}	1	1	0	0	0	0	1	0	0	1	0
Second highest PM_{10} concentration (µg m^{-3})	46	46	37	40	36	37	40	31	31	31	39
Annual maximum (µg m^{-3})	71	56	40	41	39	40	52	41	40	52	41
Number of records	330	353	345	311	312	357	355	347	341	352	356

No reductions are required in Dunedin to meet the NES for PM_{10} or the WHO (2021) daily PM_{10} guideline. No reduction in annual PM_{10} concentrations is required to meet the AAQG (annual of 20 µg/m^3). It is also likely that the WHO (2021) annual average guideline (15 µg/m^3) will be met in Dunedin at the conclusion of the neighbouring construction activities.

Concentrations of $PM_{2.5}$ in Dunedin

Concentrations of $PM_{2.5}$ have been measured in Dunedin since 2018. The monitoring method is a T640x sampler which measures both PM_{10} and $PM_{2.5}$. This is an optical method of measurement that does have equivalency status under the USEPA CFR 50 Appendix J "*Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere*".

Table 0.14 shows the estimated annual average $PM_{2.5}$ concentrations in Dunedin of around 7 µg/m^3. The fourth highest daily $PM_{2.5}$ concentrations are below the Proposed NES of 25 µg/m^3 but in excess of the WHO (2021) daily $PM_{2.5}$ guideline.

Table 0.14: Estimates of $PM_{2.5}$ concentrations in Dunedin from 2018-2022

– 25 µg/m^3	2018	2019	2020	2021	2022
Monitoring method					
"Good" 0-33% of guideline	100%	98%	98%	74%	73%
"Acceptable" 33-66% of guideline	0%	2%	2%	24%	26%
"Alert" 66-100% of guideline	0%	0%	0%	2%	1%
"Action" >Guideline	0%	0%	0%	0%	0%
Percentage of valid data	36%	94%	52%	90%	98%
Annual average (µg m^{-3})		7.0	7.0	7.1	7.4
Measured $PM_{2.5}$ concentrations above 25 µg m^{-3}	0	0	0	0	0
Fourth highest $PM_{2.5}$ concentration (µg m^{-3})	11	18	18	18	18
Annual maximum (µg m^{-3})	13	21	25	22	22
Number of records for PM_{10}	130	344	191	327	356

The reduction required to meet the WHO (2021) daily $PM_{2.5}$ guideline (15 µg/m^3) was calculated based on the 2019 to 2022 fourth highest $PM_{2.5}$ concentrations of 18 µg/m^3. The reduction required was calculated at 18%. The reduction required to meet the WHO (2021) annual average (5 µg/m^3) is around 32% and has been calculated based on the 2022 average of 7.4 µg/m^3.

APPENDIX B: EVALUATION OF STANDARDS AND GUIDELINES FOR PM_{10} AND $PM_{2.5}$

In February 2020 the New Zealand Ministry for the Environment (MfE) released Proposed Amendments to the National Environmental Standards for Air Quality which covered both particulate (PM_{10} and $PM_{2.5}$) and mercury. The proposed amendments included standards for PM_{10} and $PM_{2.5}$ (daily and annual) which were based on the WHO (2005) air quality guidelines. At this point in time, it was clear that the WHO (2005) guidelines were out of date. The Ministry for the Environment received feedback. A decision on the NES for particulate was not made prior to the WHO (2021) guideline review and has not been made subsequently.

In September 2021 the World Health Organisation (WHO) released updated air quality guidelines (AQG) for PM_{10}, $PM_{2.5}$, nitrogen dioxide, sulphur dioxide, ozone and carbon monoxide. The objectives of the guidelines were to:

- Provide evidence-informed recommendations in the form of AQG levels, including an indication of the shape of the concentration–response function in relation to critical health outcomes for relevant averaging time periods.
- Provide interim targets to guide reduction efforts towards the ultimate and timely achievement of the AQG levels for those countries that substantially exceed the AQG levels.
- Provide qualitative statements on good practices for the management of certain types of particulate include dust from sandstorms, ultra fine particle numbers and elemental/ black carbon.

The review process included a framework which prioritised health outcomes. In the framework causality determination generally supersedes the strength of health outcome. By applying the prioritization framework, the following health outcomes were identified:

- all-cause (non-accidental) mortality:
- cause-specific mortality, as per the International Statistical Classification of Diseases and Related Health Problems, 10th edition (ICD 10, 2016 version WHO, 2016b): cardiovascular (ICD-10 codes I00-I99, lung cancer ICD-10 codes C30-C39 and respiratory (ICD-10 codes J00-J99);
- hospital admissions and emergency room visits related to asthma (ICD-10 code J45); and
- hospital admissions and emergency room visits related to ischemic heart disease (ICD-10 codes I20-I25; ultimately restricted to myocardial infarction, ICD-10 codes I21-I22).

Table 2.1 of the WHO (2021) review summarises the long term health outcomes by contaminant for both short and long term exposures. For PM_{10} and $PM_{2.5}$ the list of included health outcomes are similar between the duration periods with long term exposure also having a casual relationship with lung cancer that is not included in the short term exposures. Causality determinations are stronger for $PM_{2.5}$ than for PM_{10}.

The relationship between the health effects of long term exposures and short term exposures is of particular relevance in evaluating the guidelines for particulate because of the approach used by WHO (2021) to establish the short term (daily) guideline values. As indicated above there are no priority health outcomes identified for short term durations that do not also occur within the long term duration health outcomes.

The WHO (2021) approach to annual average guidelines (long term exposures) was to determine the level of particulate concentration for each indicator for which there were no studies that met their robustness criteria which demonstrated an effect below that value. That is the levels were set at the lowest concentration for which an effect had been demonstrated. This does not mean that there is no effect below this concentration as the limits may occur as a result of the absence of studies with lower concentrations. This approach is more protective than the 2005 guidelines which set guidelines and noting there were effects that occurred below those values and that there was no safe threshold for particulate.

In comparison, the 2005 the annual PM_{10} and $PM_{2.5}$ guidelines were determined following a lengthy and thorough evaluation of health literature. Information pertaining to the derivation of the daily guidelines was minimal in comparison with the daily guidelines apparently based on an average data distribution relative to the annual guideline. That is, the daily guideline was really just implemented as a measure to achieve the annual guideline that would work for areas that had a similar distribution of data. Limited information was provided on the basis for the data distribution and with a daily PM_{10} value set at 50 µg/m^3 (a well used guideline at that point) and daily $PM_{2.5}$ set at 25 µg/m^3 compared with an annual guideline of 10 µg/m^3, it gave appearances of being poorly determined. This is confirmed by the WHO (2021) guidelines which note that the WHO guideline ratio of annual average $PM_{2.5}$ (10 µg/m^3) to daily $PM_{2.5}$ (25 µg/m^3) of 2.5 was not empirically determined.

The approach to establishing the daily PM_{10} and $PM_{2.5}$ (2021) guideline values is detailed in section 2.5.2 of World Health Organization, (2021). This outlines that short term guidelines are based on relationship of the 99th percentile concentration to the annual average concentration for an average distribution of data. Thus, the short term guideline specific value is not meaningful expect to the extent that it relates to annual concentrations effects.

WHO (2021) section 2.5.2 – annual versus daily guidelines

"Daily and hourly concentrations vary around the annual average, often in a lognormal distribution. If short-term AQG levels are derived based on lowest short-term exposures that are – with at least moderate certainty – associated with adverse health effects, then much lower values are obtained than those determined for long-term AQG levels. (The caveat about evidence of less than moderate certainty expressed in section 2.5.1 also applies here). Importantly, the short-term variation in air pollution concentrations is largely driven by meteorology, which cannot be controlled. Short-term guidelines are typically defined as a high percentile of the distribution of daily values, for example the 98th or 99th percentiles equivalent to seven or three days a year exceeding this value (i.e. exceedance days). The rationale for choosing a high percentile and not the maximum is that the maximum of daily values for a given year is a less stable statistic than the high percentiles. For locations in which concentrations are below the annual mean AQG level, days with such high daily mean concentrations will be rare and a large proportion of days will have concentrations below the annual mean AQG level. Thus, the health burden related to a few days with higher concentrations corresponds to a very small fraction of the total air pollution-related burden. In contrast, the long-term variation in air pollution concentrations is largely driven by spatial variation in air pollution sources and emissions, which can be controlled, although control for some sources such as desert dust, pose unique and much more considerable challenges. Typically, the magnitude of the health effects associated with variations in long-term exposure is larger, per mass unit, than the magnitude of the health effects associated with short-term variations. As a consequence, long-term AQG levels for most health outcomes are more health protective than short-term AQG levels. In such instances, the long-term AQG level is used to derive a short-term AQG level whenever the same health effect is considered (e.g. mortality) for both long- and short-term exposures. According to this line of reasoning, all eight steps outlined for long-term AQG level development remain valid for short-term AQG level development, except for step 3 (defining the minimal relevant increase in health outcomes. "

The rationale for having short term guidelines is given as:

The rationale for having short-term AQG levels next to long-term AQG levels for the same pollutant is based on the need to provide air quality managers, health-care providers, vulnerable patients and the general population with tools to communicate health risks and short-term emission controls. The GDG notes that there is substantial evidence that some susceptible groups may be harmed by short-term elevations of some pollutants: those with asthma, coronary heart disease, COPD and other chronic conditions and diseases. Overall, these susceptible groups represent a substantial proportion of the population in many countries.

Short term guidelines for particulate are derived based on the ratio of daily to annual concentrations from a large database of monitoring data. The ratios used to select the daily $PM_{2.5}$ and PM_{10} values were 3.05 and 2.85 respectively (WHO, 2021).

The WHO (2021) guideline development document recommends using the same ratio everywhere for the purpose of deriving a 24-hour average AQG level and this approach has been adopted by WHO (2021). They note that the primary motivation is that short-term effect estimates for $PM_{2.5}$ and all-cause mortality do not significantly vary between different regions of the world. They do acknowledge that there are differences in effect estimates depending on $PM_{2.5}$ concentrations, but are of the view that "*this is not important when deriving AQG levels for relatively low short-term concentrations; it is important when quantifying the health burdens associated with the higher interim target levels*".

The ratio of annual to daily $PM_{2.5}$ for the urban areas of Otago considered in this report based on the concentrations reported in Appendix A for 2022 are shown below. The estimated daily $PM_{2.5}$ guideline based on the actual distribution of data ranges from 12 µg/m^3 in Dunedin to 38 µg/m^3 in Milton and compares with the WHO (2021) guideline of 15 µg/m^3. This indicates that all towns examined with the exception of Dunedin lie well above the average used in the WHO database with respect to data distribution.

	Annual	Daily (99th)	Ratio	Estimated daily $PM_{2.5}$ guideline
Arrowtown	8.9	56	6.3	31
Alexandra	11.7	48	4.1	21
Clyde	8.2	43	5.2	26
Cromwell	8.5	54	6.4	32
Milton	7.7	58	7.5	38
Mosgiel	6	39	6.5	33
Dunedin	7.4	18	2.4	12

Whilst the approach taken by WHO (2021) is robust and justifiable with respect to annual average concentrations, in my view the setting of short term guidelines based on the long term effects and an average distribution of data is weak. The approach may be pragmatic for the purposes of developing guidelines at the world level but makes little sense when viewed through the lens of air quality management in areas where the distribution of particulate concentrations is as skewed as occurs in small towns in the Otago Region and throughout New Zealand.

It particular it is noted that the extent of management required to achieve the daily targets well outweighs the management required to achieve the annual guidelines. This is likely to occur in any areas of New Zealand where the ratio of daily (99th percentile) $PM_{2.5}$ to annual $PM_{2.5}$ is more than 3.05.

The most significant health indicator for particulate is the annual average $PM_{2.5}$ concentrations. The HAPINZ (2021) indicates a10.5% increase in all cause mortality per 10µg/m^3 increase in annual average $PM_{2.5}$. Short term exposures have typically given concentration response relationships of 1% per 10 µg/m^3 increase in daily concentrations. An air quality management regime that prioritises low annual average concentrations is likely to be the most effective from a cost benefit viewpoint.

The NES for PM_{10} and $PM_{2.5}$ in New Zealand is still to be reviewed in light of the WHO (2021) guidelines. It is therefore unclear what is currently required from Councils and whether the approach of WHO will be adopted and whether the standard would also include interim targets. In the absence of a NES for $PM_{2.5}$ Councils have some discretion on the level they set for air quality management and the evaluation approach is likely to require a section 32 analysis of costs and benefits under the Resource Management Act (1991).

One consideration in the selection of air quality management measures for Otago towns is the extent to which policy direction should be driven by the daily $PM_{2.5}$ guideline. This is because the additional health benefits of achieving that target are minimal in comparison to the health benefits associated with reducing annual average concentrations.

APPENDIX C: ADDITIONAL METHODOLOGY DETAIL

A key component of the management options design is the way that emissions and concentrations are related in the projections analysis.

The biggest issue with relating emissions and concentrations is that meteorological conditions are variable. The PM_{10} (24-hour) projections analysis has been designed to represent a meteorological condition, namely the worst case meteorology representative of the second highest PM_{10} concentrations in any year. This is because the NESAQ allows one exceedance per year and therefore the reductions required in PM_{10} concentrations are based on the second highest PM_{10}. The meteorology needs to be based on the worst case year to ensure that compliance, once achieved is ongoing.

Once the PM_{10} concentrations representative of the above meteorological conditions has been established, for the base (starting) year of the projection, the percentage reduction required to achieve compliance can be calculated as follows:

Equation A1: Reduction required % = $\frac{X-50}{x}$ x 100

Where x is the PM_{10} concentration representative of the second highest PM_{10} concentration for worst case meteorological conditions and for the base year of the projections (normally an inventory year).

The meteorological conditions are thus held constant (for a 24-hour period) enabling the assumption that (for the day represented) a percentage reduction in emissions will result in the same percentage reduction in concentrations. The y axis on the graph therefore represents both the percentage reduction in emissions and concentrations. The target line which represents a change in concentration required to meet the NES (1 - the value from equation A1 above) is therefore able to be expressed as a percentage of concentrations for the base year.

The emissions are quantified for the base year from an inventory and with the addition of natural sources (from source apportionment studies) converted to an emission estimate based on the percentage contribution. The estimated changes in emissions over time, as a result of natural attrition or regulatory measures are estimated for each source and results expressed as a percentage of the base year emissions to enable direct comparison to the air quality target.

One scientific limitation, not accounted for in the methodology is the relationship between variations in source emissions throughout the day and meteorological conditions. In particular it is noted that sources that are more prevalent at times during the day when the meteorological conditions are more conducive to elevated concentrations will have a slightly higher contribution to concentrations than indicated by their relative contribution to emissions. Thus, in theory, measures targeting early evening sources such as domestic heating, may underestimate the reductions that might be achieved.

For assessing the relative contributions of sources to annual average concentrations further assumptions regarding seasonal variability in the impact of meteorological conditions is required. Annual estimates are made based on monthly average concentrations and the relative contributions of sources (on an emission basis) to those concentrations. This allows for seasonal variation in the impact of meteorological conditions to be factored into the relative contributions assessment.