

JUNE 2024

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Air quality in Invercargill –  
assessing the effectiveness of  
management options to reduce  
particulate concentrations

Envirolink Report 2435-ESRC302

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## EXECUTIVE SUMMARY

In Invercargill concentrations of PM<sub>10</sub> continue exceed the National Environmental Standard (NES) of 50 µg/m<sup>3</sup> (24-hour average, one allowable exceedance per year). Compliance with the NES for PM<sub>10</sub> in Invercargill was required by September 2020. In 2021 the NES was breached on two occasions with a total of three measured exceedances. The number of breaches has decreased from an average of 15 per year from 2008 to 2016 to six per year (2018-2023) with maximum measured concentrations reducing from around 140 µg/m<sup>3</sup> (2012) to around 81 µg/m<sup>3</sup> (2020) over the same period.

The Southland Regional Council Air Plan became operative in 2016 and contained a range of measures to improve concentrations of PM<sub>10</sub> in the Invercargill airshed. The last phase out date for solid fuel burners not meeting the specified emission criteria and installed prior to the operative date of the plan is 2029. Improvements in air quality were therefore anticipated beyond the current point in time.

In addition to compliance with the NES for PM<sub>10</sub> an evaluation of annual PM<sub>10</sub> and PM<sub>2.5</sub> and daily PM<sub>2.5</sub> was carried out relative to a range of targets. The annual average PM<sub>2.5</sub> 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 µg/m<sup>3</sup> (Ministry for Environment, 2020) and the WHO (2021) guideline of 5 µg/m<sup>3</sup>.

Analysis suggests that the existing air plan provisions are unlikely to result in compliance with the NES for PM<sub>10</sub> in Invercargill without additional management measures. Whilst the transition from multifuel burners to lower emission wood burners appears to have occurred faster than anticipated, the reduction in total households using solid fuel burners for home heating has fallen short of the 40% target that Environment Southland had hoped to achieve.

The addition of a ULEB criteria for new wood burner installations combined with a behaviour change programme targeting burner operation may be sufficient to meet the NES for PM<sub>10</sub>.

The most difficult air quality target to meet in Invercargill is the WHO (2021) annual PM<sub>2.5</sub> guideline of 5 µg/m<sup>3</sup>. The measures required to achieve the WHO (2021) guideline would likely be:

- Limit all new installations of solid fuel burners in Invercargill to those meeting the ULEB criteria.
- Phase out older burners not meeting the new ULEB criteria for wood burners.
- Behaviour change programme targeting operation of wood burners that can improve overall domestic heating emissions by 10%.
- Prohibiting the installation of solid fuel burners in new dwellings and existing dwellings not currently using solid fuel.
- More stringent measures targeting industrial dischargers (e.g., fuel switching from coal or wood to pellet burners for schools).
- Prohibiting outdoor rubbish fires all year around.

It is unclear what standard will be adopted in New Zealand for annual average PM<sub>2.5</sub>. Health benefits are anticipated with improved annual average PM<sub>2.5</sub> concentrations, however.

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# 1 INTRODUCTION

In Invercargill, concentrations of PM<sub>10</sub> breach the National Environmental Standards (NES) of 50 µg/m<sup>3</sup> (24-hour average). Breaches occur during the winter months when increased emissions from domestic home heating combine with meteorological conditions conducive to elevated concentrations. Compliance with the NES for PM<sub>10</sub> in Invercargill was required by September 2020. In 2021 the NES was breached on two occasions with a total of three measured exceedances. The number of breaches has decreased from an average of 15 per year from 2008 to 2016 to six per year (2018-2023) with maximum measured concentrations reducing from around 140 µg/m<sup>3</sup> (2012) to around 81 µg/m<sup>3</sup> (2020) over the same period.

The Southland Regional Council Air Plan became operative in 2016 and contained a range of measures to improve concentrations of PM<sub>10</sub> in the Invercargill airshed. Rules relating to solid fuel burning for domestic home heating were as follows:

Discharges to air from an open fire in the Invercargill and Gore Airsheds are a prohibited activity after 1 September 2015 except:

- (a) from an open fire in an industrial or trade premises where the open fire is used exclusively for the smoking and cooking of food for wholesale or retail sale;
- (b) where the open fire(s) is located within a recorded heritage building; or
- (c) the open fire may be used for the burning of wood only until 1 January 2017.

The discharge to air in the Invercargill airshed from a small scale solid fuel burning appliance, excluding pellet burners and wood fired cooking stoves, that was lawfully installed:

- (a) before 1 January 1997, is a prohibited activity after 1 January 2017 except the appliance may be used for the burning of wood only until 1 January 2019;
- (b) between 1 January 1997 and 1 January 2001, is a prohibited activity after 1 January 2022;
- (c) between 1 January 2001 and 1 September 2005, is a prohibited activity after 1 January 2025;
- (d) between 1 September 2005 and 1 January 2010, that does not meet the criteria specified in Appendix A is a prohibited activity after 1 January 2030;
- (e) between 1 January 2010 and 6 September 2014 that does not meet the criteria specified in Appendix A is a prohibited activity after 1 January 2034.

In addition, the proposed rules require installation of all solid fuel burners meet an emission criteria of 1.5 g/kg of particulate when tested to NZS4013. From the date of notification of the plan (September 2014) no higher emitting coal burners would be allowed to be installed.

Outdoor burning in the Invercargill and Gore Airsheds was also prohibited during the months of May to August inclusive.

An evaluation of the effectiveness of these measures was carried out in 2015 to update previous evaluations with more recent census data on home heating methods (Wilton, 2015). That report included the impacts of an incentives programme in addition to the above regulatory options with an objective of reducing the number of households using solid fuel burning for home heating by 40%. That report predicted compliance with the NES for PM<sub>10</sub> in Invercargill by 2021. In contrast air quality monitoring data for Invercargill recorded several breaches each year from 2021 to 2023. This report integrates results from a 2022 air emission inventory including revised household solid fuel burner heating methods and fuels and prepares updated projections based on these data.

Additional objectives of this report are to assess the whether the NES for PM<sub>10</sub> is likely to be met using the current suite of regulations (noting that some are yet to be effective) and what additional measures may be required to meet this and other air quality targets for PM<sub>2.5</sub>. These targets include the proposed NES PM<sub>2.5</sub> values of 25 µg/m<sup>3</sup> (24-hour average) and 10 µg/m<sup>3</sup> (annual average) and the World Health Organization (2021) guidelines of 15 µg/m<sup>3</sup> (24-hour average) and 5 µg/m<sup>3</sup> (annual average).

## 2 REDUCTIONS REQUIRED TO MEET AIR QUALITY TARGETS

Air quality monitoring data were examined to determine the reductions in PM<sub>10</sub> and PM<sub>2.5</sub> concentrations in Invercargill required to meet different air quality targets. A 2022 base year was used as this coincides with the most recent assessment of sources contributing to these contaminants. The air quality targets included in this evaluation are shown in Table 2.1.

**Table 2-1: Potential air quality targets for PM<sub>10</sub> and PM<sub>2.5</sub>**

PM <sub>10</sub> daily		PM <sub>2.5</sub> daily	
○	Current NES (50 µg/m <sup>3</sup> )	○	Proposed NES (2020) (25 µg/m <sup>3</sup> )*
		○	WHO 2021 guideline (15 µg/m <sup>3</sup> )*
PM <sub>10</sub> annual		PM <sub>2.5</sub> annual	
○	Current Ambient Air Quality Guidelines (AAQG) (20 µg/m <sup>3</sup> )	○	Proposed National Environmental Standard (NES) (2020) (10 µg/m <sup>3</sup> )
○	World Health Organisation (WHO) 2021 guideline (15 µg/m <sup>3</sup> )	○	WHO 2021 guideline (5µg/m <sup>3</sup> )

\* 99.7 percentile concentration – which allows for approximately three exceedances per year

The reductions required in daily winter PM<sub>10</sub> and PM<sub>2.5</sub> concentrations were estimated based on the second or fourth highest concentration (depending on the allowable number of breaches for the standard) adjusted for worst case meteorological conditions.

### 2.1 PM<sub>10</sub> - 2022 update

The NES for PM<sub>10</sub> is a daily average concentration of 50 µg/m<sup>3</sup> with one allowable exceedance per year. The NES was introduced in 2005 and Invercargill was required to be fully compliant by September 2020. A previous assessment found a 56% reduction in 2012 daily winter PM<sub>10</sub> was required to meet the NES. In 2021, 2022 and 2023 the NES for PM<sub>10</sub> was breached in the Invercargill airshed on two, one and four occasions respectively. Monitoring for PM<sub>10</sub> is carried out using an FH62 beta attenuation monitor (BAM).

The reductions required to meet the NES for PM<sub>10</sub> (24-hour average) are based on the second highest PM<sub>10</sub> concentrations measured per year, whilst also considering year to year variability in meteorology (impact of worst case meteorology). The second highest PM<sub>10</sub> concentrations measured during 2021, 2022 and 2023 were 58, 51 and 59 µg/m<sup>3</sup> respectively. Adjusting the data for these years by an estimated increased potential for worst case meteorology<sup>1</sup> indicates a likely worst case value of around 86 µg/m<sup>3</sup> for current concentrations. The reduction still required to meet the PM<sub>10</sub> NES based on this value is estimated at around 42% of the 2022 concentrations.

There is no annual average NES for PM<sub>10</sub>. The WHO (2021) air quality guideline for PM<sub>10</sub> (annual average) is 15 µg/m<sup>3</sup> and the ambient air quality guideline value is 20 µg/m<sup>3</sup> (Ministry for the Environment, 2002). The annual

<sup>1</sup> The worst case peak (second highest daily PM<sub>10</sub>) to mean PM<sub>10</sub> concentrations at Invercargill are around 4.7 (as recorded in 2012, 2014 and 2016). Adjusting the annual average PM<sub>10</sub> in 2022 by this ratio gives a second highest concentrations of 86 µg/m<sup>3</sup>.

average PM<sub>10</sub> concentrations in Invercargill in 2021 to 2023 ranged from 16 – 18 µg/m<sup>3</sup>. The reduction required to meet the WHO (2021) guideline for annual average PM<sub>10</sub> is estimated at 17%.

## 2.2 PM<sub>2.5</sub> – 2022 update

Concentrations of PM<sub>2.5</sub> have been measured in Invercargill since 2016. Whilst there have been interruptions in the record of data over the last few years, the estimated annual average PM<sub>2.5</sub> concentration for Invercargill has been consistently around 11 µg/m<sup>3</sup> with a maximum of 11.7 µg/m<sup>3</sup> for the year 2021. The reduction required to meet the proposed NES (annual average) for PM<sub>2.5</sub> of 10 µg/m<sup>3</sup> based on this value is 14%. The reduction required to meet the WHO (2021) PM<sub>2.5</sub> guideline based on this value is 57%.

The proposed NES for PM<sub>2.5</sub> also includes a daily standard of 25 µg/m<sup>3</sup>. The reduction required to meet this guideline is estimated at around 51% based on the highest fourth highest PM<sub>2.5</sub> concentration from 2021 to 2023<sup>2</sup>. This was a value of 51 µg/m<sup>3</sup> which was measured in 2021. The WHO (2021) guidelines also include a daily standard for PM<sub>2.5</sub> of 15 µg/m<sup>3</sup>. The reduction required in daily winter PM<sub>2.5</sub> to meet this in Invercargill was estimated at 71%.

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<sup>2</sup> A longer period was used owing to the extent of missing data for the period 2021-2023.

## 3 MANAGING PM<sub>10</sub> CONCENTRATIONS IN INVERCARGILL

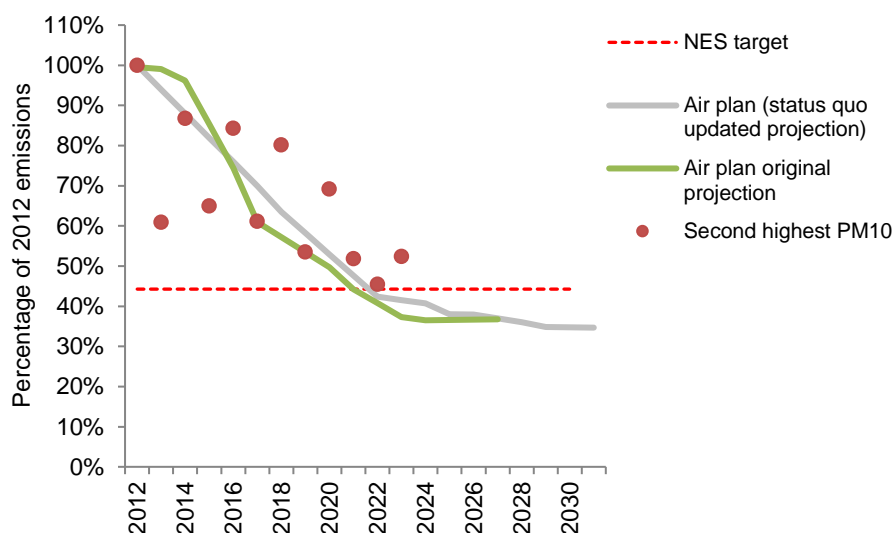
### 3.1 Impact of air plan on heating methods and projections

The 2022 air emission inventory assessed home heating methods and fuels for Invercargill. The impact of changes in solid fuel burning for domestic heating and prohibitions on the use of outdoor fires during winter months on worst case PM<sub>10</sub> concentrations is shown in Figure 3.1. This also compares the estimated impact relative to the original projections and the second highest PM<sub>10</sub> concentrations per year. The updated projections suggest PM<sub>10</sub> emissions have decreased at a similar rate to what was anticipated.

Notwithstanding this there are some significant differences in the reason for the decrease. In the 2022 inventory it was estimated less than 500 households used multi fuel burners in Invercargill compared with the original projected 1600 households for 2022 (Wilton, 2015). This has brought forward reductions that would have been expected to occur post 2025 in the original projection. The offsetting variable (why the 2022 emissions are not therefore much lower than the original projections at 2022) is that the air plan, and 2015 projections (Wilton, 2015), had assumed that 40% of households that were using solid fuel burners would move to a non-solid fuel alternative and that an incentives programme would assist with that. Analysis of the proportion of households using solid fuel burning in 2022 suggests that this reduction is less than 20%.

The monitoring data indicates that the Invercargill airshed is unlikely to have reached compliance with the NES for PM<sub>10</sub>. Figure 3.1 shows that the second highest PM<sub>10</sub> concentrations measured between 2012 and 2020 alternate between a higher and lower value with the years 2021 and 2022 both having lower value concentrations. A comparison of the peak (second highest PM<sub>10</sub> concentration each year) to mean ratios for each years suggest that worst case meteorological conditions were occurring in 2012, 2014, 2016, 2018 and 2020. Thus the 2022 concentration for a worst case meteorology year would likely be around the value indicated in Figure 3.1 for 2020.

Potential reasons for the overestimation of impact of regulatory measures include a greater than anticipated contribution from natural sources to PM<sub>10</sub> concentrations, the monitoring site being unduly influenced by a non domestic heating source, reporting bias in home heating methods (e.g., households under reporting coal use) and poorer than average operation of wood burners (e.g., burning of wet wood).



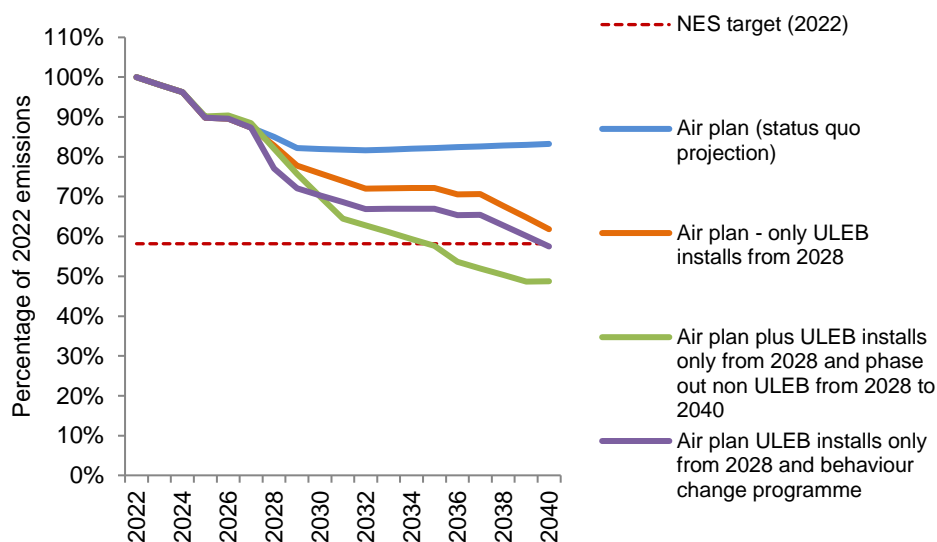
**Figure 3-1: Baseline projections for daily winter PM<sub>10</sub> updated with the 2022 data, comparison with original projections and second highest PM<sub>10</sub> concentrations.**



## 3.2 Management measures to meet the NES for PM<sub>10</sub> in Invercargill

The reduction in PM<sub>10</sub> concentrations required to meet the NES for PM<sub>10</sub> has been estimated at 42% of the 2022 concentrations.

A range of management measures were assessed to observe impact on daily winter PM<sub>10</sub> concentrations. Figure 3.2 shows the updated (with 2022 data) impact of the status quo (existing air plan measures) in achieving this reduction as well as the introduction of the ULEB emission criteria for new burner installations and a behaviour change programme.



**Figure 3-2: Updated management options assessment for achieving the NES daily PM<sub>10</sub> target**

It is likely that the introduction of a ULEB criteria for new burner installations would result in compliance with the NES for PM<sub>10</sub> over time. Figure 3.2 suggests that this could occur by around 2040 if done in conjunction with a behaviour change programme that was effective in reducing wood burner emissions by 10%. These programmes aimed at reducing the prevalence of high emitters by assisting households with high emissions to burn better. They require significant and ongoing resourcing to be effective but can be implemented relatively quickly. A behaviour change programme implemented in Nelson appears to have been effective in reducing PM<sub>10</sub> concentrations although quantification of the specific impact of the programme is difficult.

Earlier compliance with the NES for PM<sub>10</sub> may also be possible with the introduction of a ULEB criteria for new burner installations and the phase out of older burners not meeting this requirement.

### 3.2.1 Method, assumptions and limitations

The method for assessing the projected PM<sub>10</sub> is as detailed in Wilton (1998). The base assumptions underpinning the projections analysis are:

- A reduction in PM<sub>10</sub> concentrations based on the second highest PM<sub>10</sub> concentrations.
- Households using heating methods and fuel quantities and other source emissions based on 2022 air emission inventory.
- Emission factors for burners as per the 2022 air emission inventory.
- Natural source contributions based on source apportionment data provided by Southland Regional Council of 4% of winter PM<sub>10</sub> for 2014.

- Emission factors for ULEB of 2.0 g/kg. This is based on an evaluation of four studies of real life testing of ULEB wood burners which are summarised in (Webley, 2023). The average particulate emissions from these four studies range from 1.58 g/kg (dual combustion burners only) to 2.05 g/kg.
- Outdoor burning emissions quantified as part of the inventory are included as a source in the non winter months.

Introduction of a ULEB criteria requires reliance on the existing testing regime for ULEB being implemented by Environment Canterbury. A limitation to the application of this is limited ongoing investment in post implementation validation including the real-life testing of authorised burners to ensure anticipated outcomes are realised.

### 3.3 Management measures to meet annual average PM<sub>10</sub> targets in Invercargill

Figure 3.3 shows the estimated impact of the status quo (current air plan) on annual average PM<sub>10</sub> concentrations. This suggests that the WHO (2021) air quality target (15 µg/m<sup>3</sup>) could be achieved by around 2034 in the absence of any further intervention.

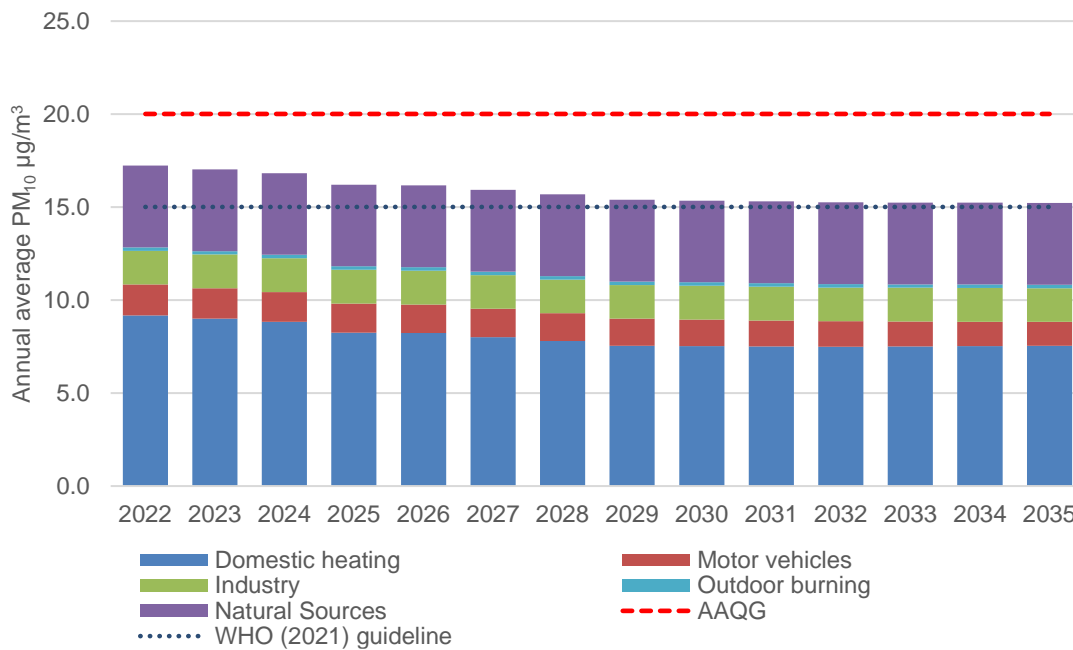
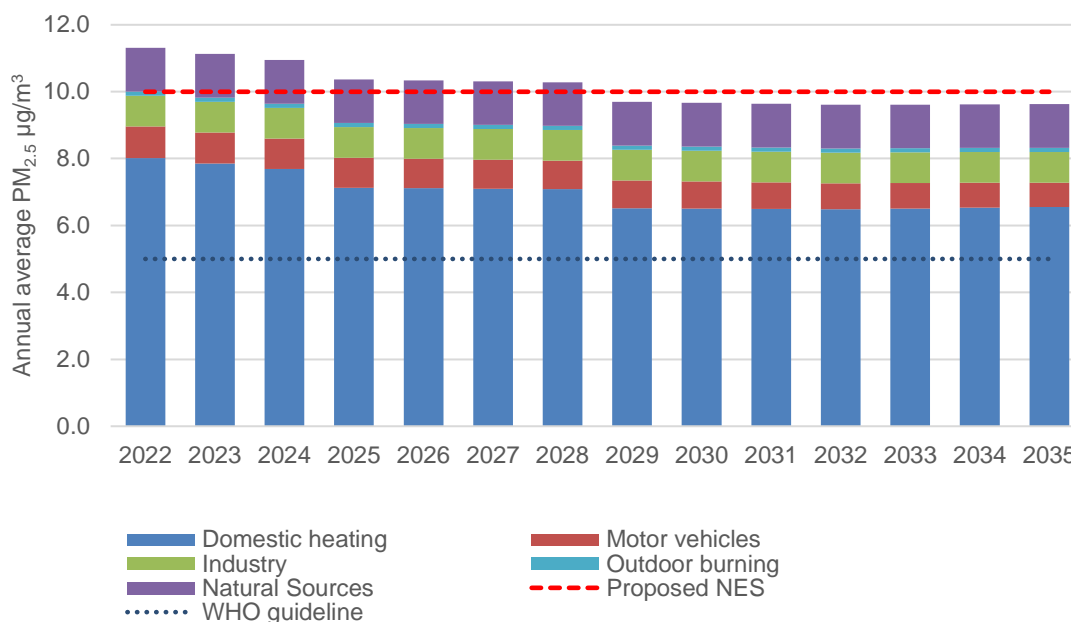


Figure 3-3: Estimated annual average PM<sub>10</sub> concentrations for the status quo (current air plan provisions)

## 4 MANAGING PM<sub>2.5</sub> CONCENTRATIONS IN INVERCARGILL

### 4.1 Annual average PM<sub>2.5</sub> concentrations

The annual average PM<sub>2.5</sub> target is most significant from a health viewpoint and is therefore prioritised in the PM<sub>2.5</sub> assessment. Figure 4.1 shows the projected impact of the current air plans measures on annual average PM<sub>2.5</sub> concentrations. It is noted that the proposed NES was based on the original WHO (2006) guideline which has been superseded by the WHO (2021) guideline. It is unclear what value for annual average PM<sub>2.5</sub> will be adopted in any revised NES for New Zealand.

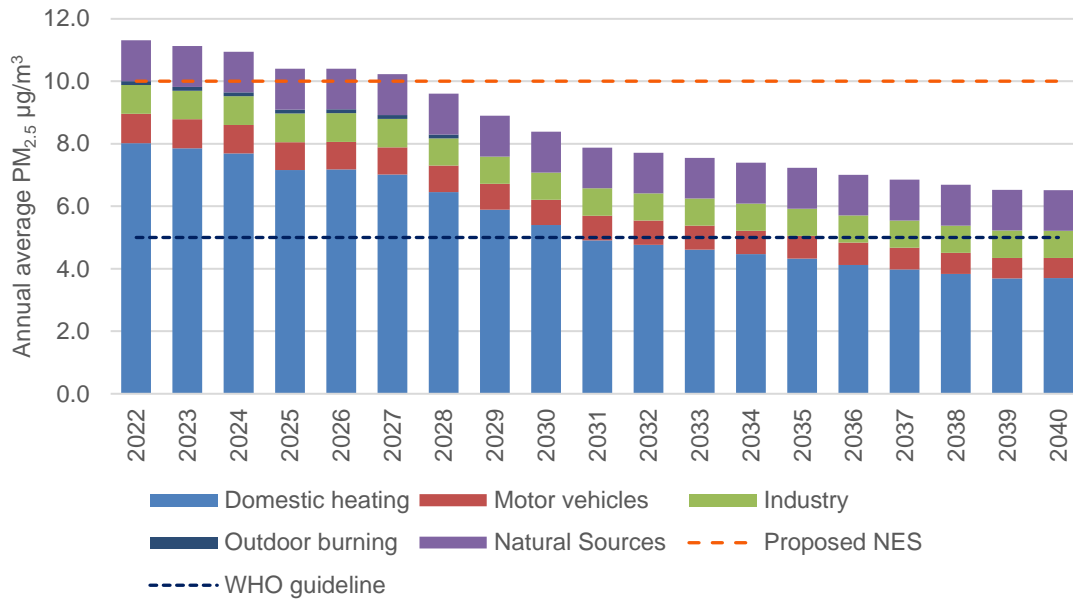


**Figure 4-1: Projected annual average PM<sub>2.5</sub> for the status quo – existing air plan measures**

Management measures to reduce annual PM<sub>2.5</sub> concentrations are similar to those targeting the daily PM<sub>10</sub> and PM<sub>2.5</sub> concentrations with the following two additional options which have been integrated into the assessment:

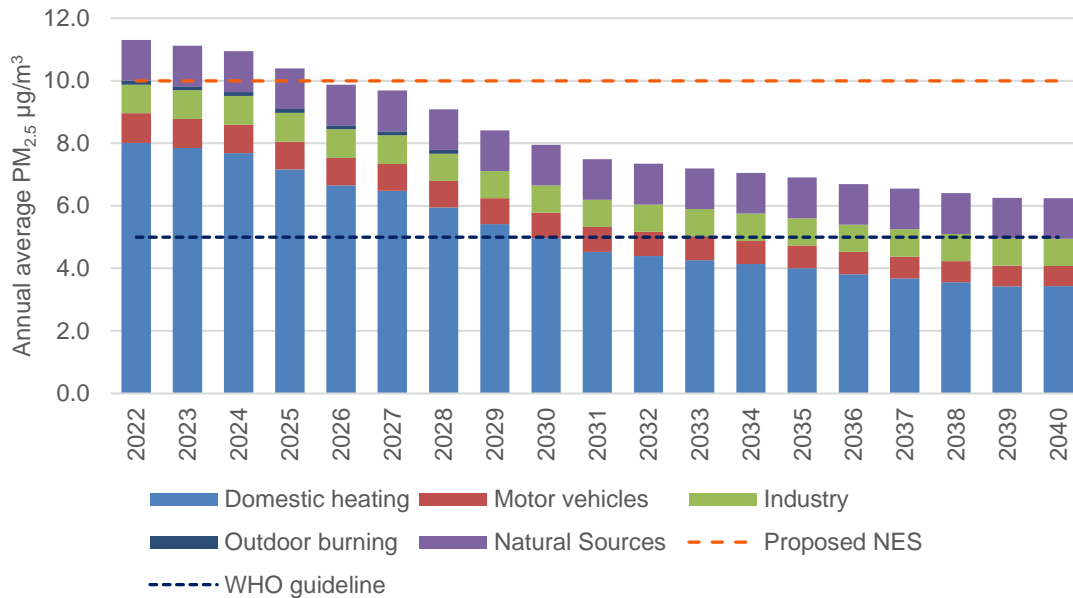
- a prohibition on outdoor burning during non-winter months
- a 5% reduction in annual PM<sub>2.5</sub> from industry (note much of this could be achieved through the conversion of school coal and wood boilers to pellet boilers).

The estimated impact of introducing a ULEB criteria for new burner installations, phasing out burners not meeting this standard in addition to these measures on annual average PM<sub>2.5</sub> is shown in Figure 4.2. This suggests a significant reduction in concentrations would occur as a result of this option but that additional measures would likely be required to meet the WHO (2021) guideline. This combination of options could reduce annual average PM<sub>2.5</sub> concentrations in Invercargill to less than 7 µg/m<sup>3</sup>. Whilst this option is unlikely to achieve the WHO (2021) guideline it is noted that any improvement in annual average PM<sub>2.5</sub> concentrations will result in health benefits.

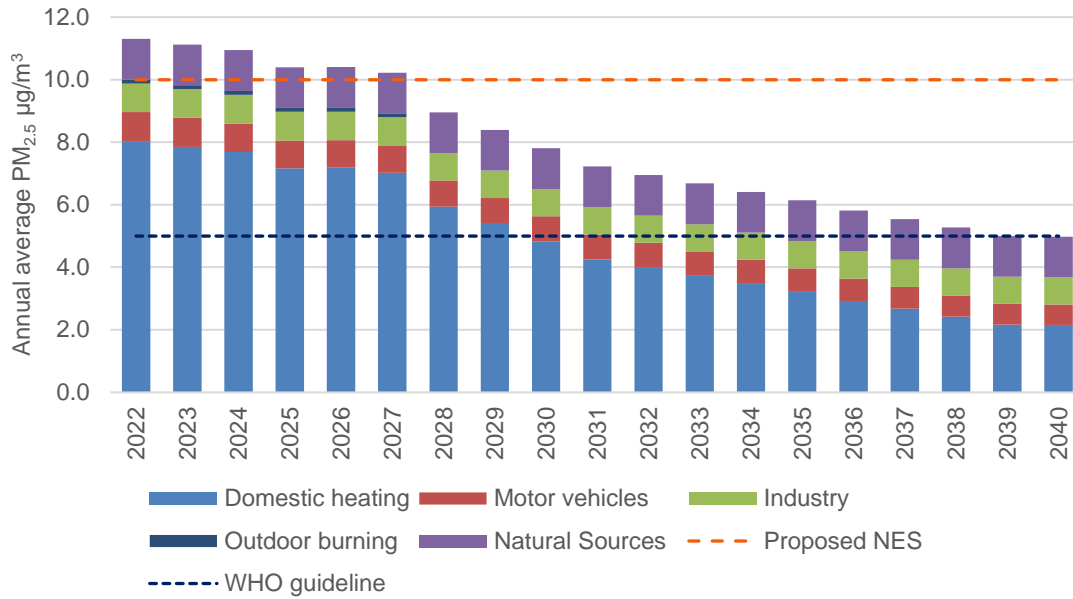


**Figure 4-2: Projected annual average PM<sub>2.5</sub> for introduction of a ULEB criteria for new burner installs and the phase out of burners not meeting this criteria plus prohibit outdoor burning.**

The addition of a behaviour change programme as well as the outdoor burning prohibition, industry improvement, ULEB requirement and burner phase out is shown in Figure 4.3. This is based on the assumption that the behaviour change programme was effective in reducing emissions by 10%. It is possible that a greater reduction could be achieved with an extensive programme, however. This combination of options could reduce annual average PM<sub>2.5</sub> concentrations in Invercargill to just over 6 µg/m<sup>3</sup>.



**Figure 4-3: Projected annual average PM<sub>2.5</sub> for the introduction of a ULEB criteria for new burner installs, the phase out of burners not meeting this criteria, prohibition on outdoor burning and a behaviour change programme**

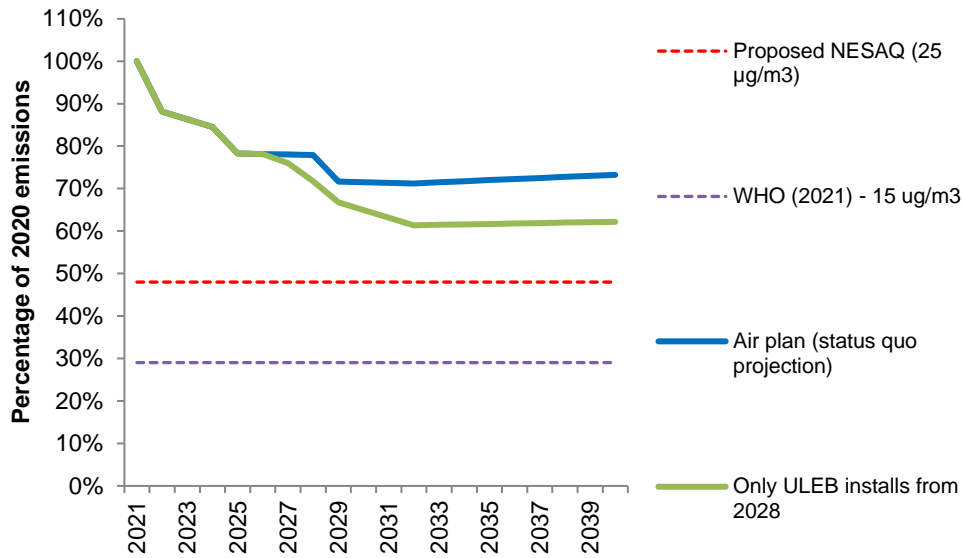


**Figure 4-4: Projected annual average PM<sub>2.5</sub> for the phase out of non ULEB burners, prohibition on outdoor burning, a behaviour change programme and no solid fuel burner installations in new dwellings.**

Figure 4.4 suggests that a combination on the introduction of a ULEB criteria for new installations, the phase out of burners not meeting that criteria, prohibition on outdoor burning, industry improvements, a behaviour change programme and restrictions on burner installation to replacements only (no burner installations in new dwellings or existing dwellings using other heating methods) may result in achievement of the WHO (2021) annual air quality target for PM<sub>2.5</sub>.

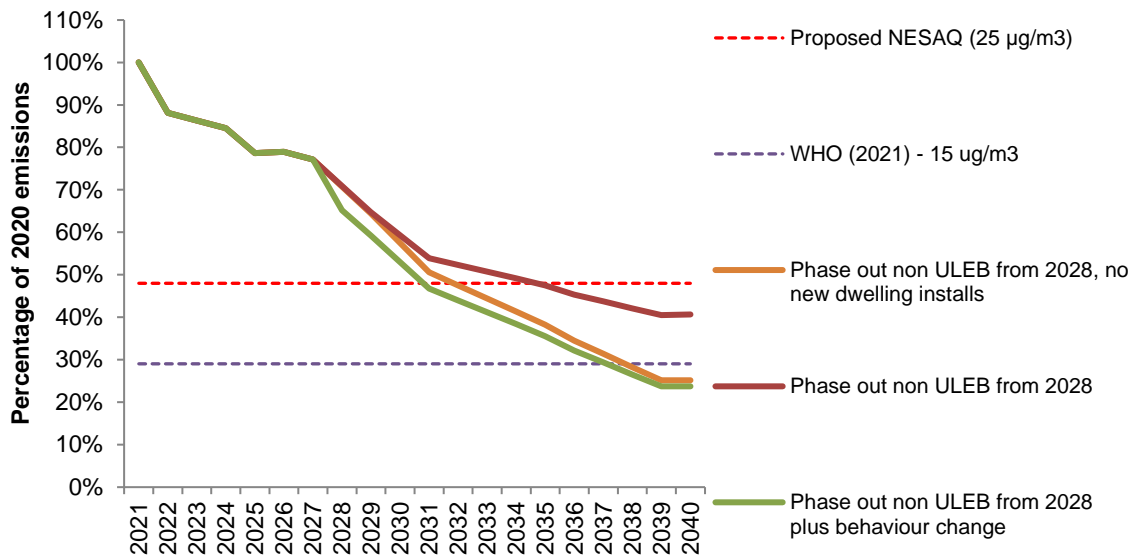
## 4.2 Daily winter PM<sub>2.5</sub> concentrations

Figure 4.5 shows the estimated impact of the existing air plan measures on daily winter PM<sub>2.5</sub> as well as the option of requiring that all new burner installation meet the ULEB criteria from 2028. This suggests that these options are not sufficient to meet the proposed NES of 25 µg/m<sup>3</sup> (three allowable exceedances) or WHO (2021) daily PM<sub>2.5</sub> guideline.



**Figure 4-5: Estimated impact of status quo and introduction of ULEB criteria on daily winter PM<sub>2.5</sub>**

Figure 4.6 shows the impact of the ULEB installation criteria, burner phase out options and either a behaviour change programme or no new dwelling installs. This suggests that either of these two options in addition to a burner phase out (of those not meeting the ULEB criteria) may be sufficient to meet the WHO (2021) daily PM<sub>2.5</sub> standard.



**Figure 4-6: Estimated impact of status quo and introduction of ULEB criteria on daily winter PM<sub>2.5</sub>**

Assumptions underpinning the evaluation are as detailed for PM<sub>10</sub> with the exception of the use of PM<sub>2.5</sub> (as opposed to PM<sub>10</sub>) emission estimates for all sources.

## 5 CONCLUSIONS

The evaluation suggests that the existing air plan provisions are unlikely to result in compliance with the NES for PM<sub>10</sub> in Invercargill without additional management measures. Whilst the transition from multifuel burners to lower emission wood burners appears to have occurred faster than anticipated, the reduction in total households using solid fuel burners for home heating has fallen short of the 40% reduction target that Environment Southland had hoped to achieve. Additional management measures that may be sufficient to achieve the NES for PM<sub>10</sub> include the addition of a ULEB criteria for new wood burner installations combined with a behaviour change programme targeting burner operation.

These are both relatively low-cost measures particularly in comparison to new burner phase requirements. Additionally, a behaviour change programme may be very effective in reducing PM<sub>10</sub> and PM<sub>2.5</sub> concentrations in Invercargill if households are burning wet wood and operating burners poorly.

The analysis shows that the most difficult air quality target to meet in Invercargill is the WHO (2021) annual PM<sub>2.5</sub> guideline of 5 µg/m<sup>3</sup>. This has not been adopted in New Zealand at this point in time and it is unclear what target the Ministry for the Environment will propose for PM<sub>2.5</sub>. It is noted that any improvements in annual average PM<sub>2.5</sub> concentrations will have health benefits and consequently any progress towards this target will be of value. The measures required to achieve the WHO (2021) guideline would likely be:

- Limit all new installations of solid fuel burners in Invercargill to those meeting the ULEB criteria.
- Phase out older burners not meeting the new ULEB criteria for wood burners.
- Behaviour change programme targeting operation of wood burners that can improve overall domestic heating emissions by 10%.
- Prohibiting the installation of solid fuel burners in new dwellings and existing dwellings not currently using solid fuel.
- More stringent measures targeting industrial dischargers (e.g., fuel switching from coal or wood to pellet burners for schools).
- Prohibiting outdoor rubbish fires all year around.

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