# Management of $PM_{10}$ in Reefton

## An assessment of management options to achieve National Environmental Standards

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# Executive Summary

Concentrations of $PM_{10}$ exceed National Environmental Standards (NES) for $PM_{10}$ in Reefton. The NES is set at 50 µg $m^{-3}$ (24-hour average) with one allowable exceedence per year.

The maximum measured $PM_{10}$ concentration in Reefton is 129 µg $m^{-3}$ and was recorded on 24 June 2007. The second highest concentration is 104 µg $m^{-3}$, recorded on 18 July 2007. In 2008 the highest recorded $PM_{10}$ concentration was 78 µg $m^{-3}$ (24 hour average) and there were 18 exceedences of the NES. The highest $PM_{10}$ concentrations are measured during the winter months. Reductions in $PM_{10}$ concentrations required to meet the NES are 52% based on the second highest $PM_{10}$ concentration measured during 2007.

An emission inventory (2005) shows the main source of $PM_{10}$ emissions in Reefton is solid fuel burning for domestic home heating. Domestic heating contributes around 93% of the daily winter $PM_{10}$ with 5% from outdoor burning, 1% from motor vehicles and less than 1% from industry.

The emission inventory indicates that 53% of winter $PM_{10}$ emissions are from burning coal on multi fuel burners, 30% of $PM_{10}$ emissions are from wood burnt on multi fuel burners and 10% from wood and coal on open fires (Wilton, 2006).

The impact of management options to reduce $PM_{10}$ concentrations in Reefton are examined in this report and air shed modelling is undertaken to determine the meteorological characteristics of Reefton.

Results suggest that the introduction of a multi fuel burner with a real life emission rate of 5g/kg, insulation measures to reduce coal consumption and a ban on outdoor burning are likely to ensure that the NES is met. All multi fuel burners installed before 2005 would need to be replaced with low emission multi fuel burners by 2013 if NES compliance by this date were important.

Emissions projections show that another option to meet the NES could be that by 2012 there was a ban on the use of coal, open fires, and outdoor burning and a 15 year phase out of solid fuel burners from the date of installation. This management option assumes that wood would be used during the solid fuel burner phase out period.

The report recommends that further testing of coal in multi fuel burners, in the laboratory, tested to AS/NZS4013 and AS/NZS4012 and real life testing is needed to provide greater certainty on the emissions from burning coal in multi fuel burners. In addition, it also recommends that the proportion of TSP that is $PM_{10}$ be assessed for domestic coal burners in New Zealand.

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# 1 Introduction

Air quality monitoring in Reefton shows $PM_{10}$ concentrations exceed the National Environmental Standard (NES) for $PM_{10}$ on up to 23 occasions during the winter months. The maximum recorded concentration of $PM_{10}$ is 129 µg $m^{-3}$ and was recorded on the 24 June 2007, the second highest concentration is 104 µg $m^{-3}$, recorded on 18 July 2007.

The Ministry for the Environment (MfE) requires the NES to be met by 2013 or the West Coast Regional Council (WCRC) will be unable to grant resource consents for discharges to air in Reefton or any other non-complying airshed. The NES for $PM_{10}$ is set at 50 µg $m^{-3}$ (24-hour average). Councils are required to set a straight line path (SLiP) to demonstrate compliance with the NES requirement of 50 µg $m^{-3}$ (24-hour average).

West Coast Regional Council has undertaken previous work to manage $PM_{10}$ concentrations in Reefton. In 2005 an emissions inventory was commissioned to determine the sources of $PM_{10}$ and other contaminants (Wilton, 2006), and in 2007 a report was completed to investigate options for reducing $PM_{10}$ to meet the NES, whilst retaining coal burning as a home heating choice for households (Smith & Wilton, 2007).

This report builds on previous work towards managing $PM_{10}$ in Reefton. It is based on more comprehensive data for $PM_{10}$ concentrations from 2005 to 2008. This data allows for greater certainty to determine the likely maximum $PM_{10}$ concentrations in Reefton. Based on air quality monitoring data between 2005 and 2008 the required reductions in $PM_{10}$ to meet the NES have been revised from around 60% (Smith & Wilton, 2007) to 52%.

Emission projections for a number of management scenarios designed to reduce $PM_{10}$ concentrations have been undertaken for Reefton. The purpose of this report is to analyse the effectiveness of these management options for reducing $PM_{10}$.

# 2 Air quality monitoring

Air quality monitoring for $PM_{10}$ has been carried out in Reefton since 2005. During 2005, monitoring was based on a one day in three sample regime and only a small number of exceedences of the NES for $PM_{10}$ were recorded. The maximum measured $PM_{10}$ concentration during 2005 was 55 μg $m^{-3}$.

In 2006 a Thermo Scientific FH 62 Beta Attenuation Monitor (BAM) was installed at the Reefton monitoring site. The BAM continuously monitors $PM_{10}$ and therefore provides a more reliable estimate of the number of exceedences and greater certainty around the magnitude of worst case concentrations. During 2006 $PM_{10}$ concentrations exceeded 50 μg $m^{-3}$ (24-hour average) on 16 days and the maximum measured $PM_{10}$ concentration was 86 μg $m^{-3}$. Monitoring results from 2007 show that were 23 days with concentrations above 50 μg $m^{-3}$ (24-hour average) and the highest recorded concentration was 129 μg $m^{-3}$. The highest recorded $PM_{10}$ concentration for 2008 was 78 μg $m^{-3}$ and there were 18 exceedences of the NES. Figure 2.1 shows $PM_{10}$ data for Reefton for 2007, being the year when both the number of exceedences and concentrations were highest.

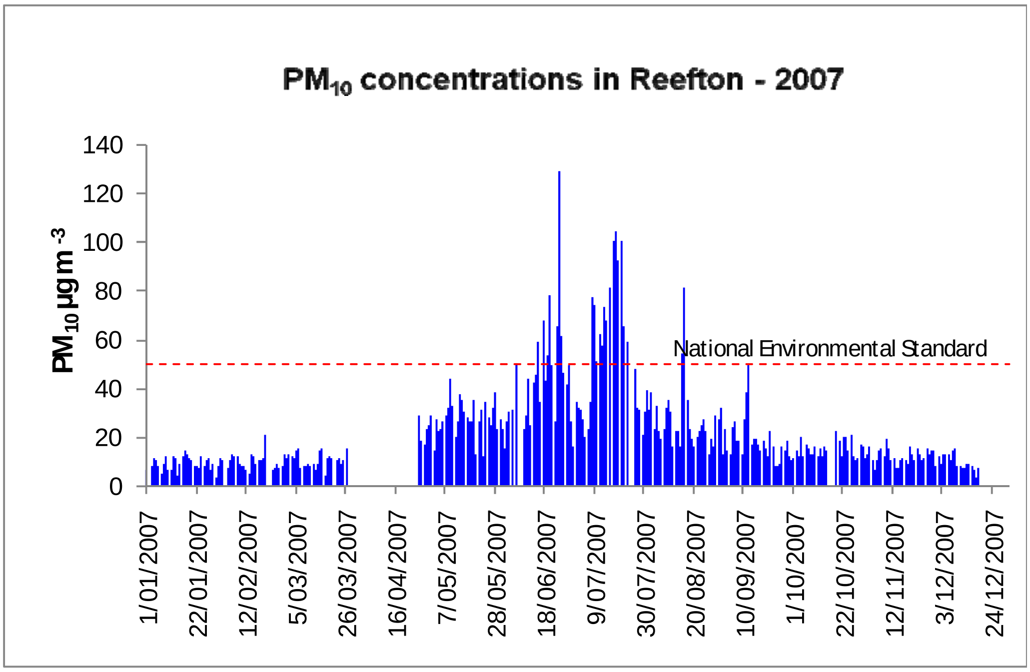



Figure 2.1: $PM_{10}$ data for Reefton in 2007.

# 3 Reductions required in $PM_{10}$ concentrations

The reductions required in $PM_{10}$ concentrations to meet the NES can be estimated based on existing monitoring data. This is the most robust method, particularly in locations where many years of monitoring results are available. The more data that are available, the higher the probability that the data captures the worst case meteorological conditions that give rise to elevated $PM_{10}$ concentrations. In Reefton, there is sufficient monitoring data to evaluate the starting point for the SLiP.

The recommended approach is to exclude the maximum $PM_{10}$ concentrations measured each year and to then evaluate the highest remaining concentration. The maximum concentration is excluded because the NES allows for one breach of 50 µg $m^{-3}$ (24-hour average) per year.

The reduction required in $PM_{10}$ concentrations in Reefton was calculated by Wilton (2006) as 9%. This was based on the limited amount of monitoring (one day in three) for $PM_{10}$ carried out during 2005 which resulted in only a small number of breaches of the NES for $PM_{10}$ and a maximum $PM_{10}$ concentration of 55 µg $m^{-3}$. More regular monitoring was carried out during 2006 and 2007 and a maximum $PM_{10}$ concentration of 129 µg $m^{-3}$ was measured. In 2007 Smith & Wilton (2007) assessed the reduction required in $PM_{10}$ concentrations to meet the NES as around 60% based on the maximum $PM_{10}$ concentration for 2007. Since the preparation of Smith & Wilton (2007) an additional year of $PM_{10}$ data are available, giving three years of continuous $PM_{10}$ data. This increases the probability that worst case $PM_{10}$ concentrations have been captured, allowing the option to base the reductions required in $PM_{10}$ concentrations on the highest second highest $PM_{10}$ concentration.

In Reefton it is now recommended that a value of 104 µg $m^{-3}$ be used to determine the required reductions in $PM_{10}$ emissions and the starting point for the SLiP. This is based on the highest second highest $PM_{10}$ concentration which was measured during 2007.

The reduction required in $PM_{10}$ concentrations to meet an air quality target of 50 µg $m^{-3}$ (24-hour average), can be calculated using Equation 3.1.

$$R = 100(1 - \frac{t}{c}) \qquad \text{Equation 3.1}$$

where

R = the percentage reduction

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

c = the concentration identified as representing the starting point of the SLiP

Based on Equation 3.1 the required reduction to meet the NES in Reefton is 52%.

# 4 Sources of $PM_{10}$

An emission inventory was carried out for Reefton during 2005. The inventory quantified emissions to air of particles less than 10 microns ($PM_{10}$), carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), volatile organic compounds (VOC), carbon dioxide ($CO_2$), fine particles ($PM_{2.5}$) and benzene and included domestic home heating, motor vehicles, outdoor burning and industry. The contribution of natural sources such as soil and sea spray cannot be identified in a robust manner using an inventory approach.

Figure 4.1 shows the domestic heating contribution to daily winter $PM_{10}$ emissions in Reefton is 93%, with outdoor burning producing around 5% of the $PM_{10}$ emissions, motor vehicles 1% and industry less than 1%.

Results from the emission inventory showed that 53% of winter $PM_{10}$ emissions were from burning coal on multi fuel burners, 30% of $PM_{10}$ emissions were from wood burnt on multi fuel burners and 10% from wood and coal on open fires (Wilton, 2006). Overall, 60% of households use coal on a multi fuel burner and 7% of households use coal on open fires in Reefton.

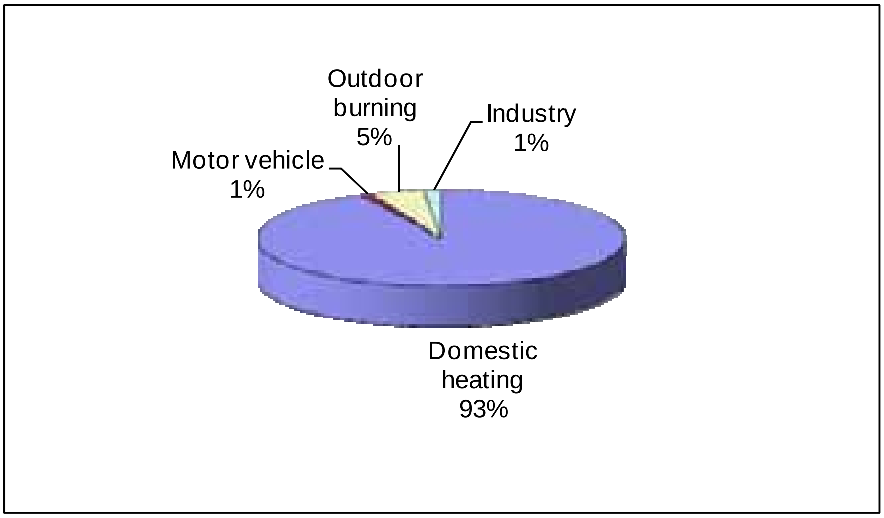



Figure 4.1: Sources of $PM_{10}$ emissions in the urban areas of Reefton in 2005.

# 5 Analysis of the use of multi fuel burners in Reefton

In 2007 WCRC undertook research to evaluate options for retaining coal burning as a home heating option for households in Reefton whilst reducing $PM_{10}$ to meet the NES (Smith & Wilton, 2007).

The research included a study of emissions ratings for multi fuel burners in New Zealand to determine if any burners were available that met the NES design criteria for wood burners of 1.5 g/kg of total suspended particulate (TSP).

The report found that laboratory tests for some multi fuel burners using a mix of wood and coal have been undertaken in New Zealand. Emission test results of 3.9g/kg for the Woodsman Matai RMF have been recorded, the retail price for this burner is $1,899. The Logaire Hestia recorded 2.56g/kg and is priced at $2,399. The Logaire Kronos achieved 3.6g/kg and is priced at $2,699. All prices include GST. Smith & Wilton, note that only the actual test emission data for the Woodman Matai RMF was cited, and brochures for the Logaire multi fuel burners claimed to have the emission rates cited above.

These burners were tested to AS/NZS4013 and AS/NZS4012. Due to the differences between testing appliances in real life compared to the controlled laboratory situation, it is believed that the real life emissions from these multi fuel burners may be considerably higher.

Although two multi fuel burners were identified that had low emission rates, use of them in Reefton was considered cost prohibitive. These multi fuel burners are produced by McKenzie Heating Design Ltd and Allan's Sheet Metal & Engineering Ltd and are central heating systems and were estimated to cost between $7,000 and $15,000. The laboratory testing results for these appliances were 1.46g/kg and 1.49g/kg when tested to AS/NZS4013. As the fuel is delivered through an automated process, it is expected that there would be little variation between laboratory and real life testing.

Emissions projections were undertaken to determine if an appropriate standard for wood and coal could be established that would allow for achievement of the NES by 2013.

The report found that a real life emission limit of less than 1 g/kg of $PM_{10}$ for both wood and coal emissions would be required to achieve the NES for $PM_{10}$ in Reefton (Smith & Wilton, 2007). However, because of the limited monitoring data available at the time the research was undertaken, the reduction required to meet the NES was based on the maximum measured $PM_{10}$ concentration and was calculated to be around 60%.

This report evaluates management options relative to a lower required reduction of 52%. This revised reduction allows for more flexibility to determine emission limits than the Smith & Wilton report.

# 6 Management options for $PM_{10}$

Estimates of trends in $PM_{10}$ concentrations by source are shown in Figure 6.1. These are based on the assumptions outlined in Table 6.2. This indicates little variation in emissions over time due the significant impact that multi fuel burners have on the Reefton emission profile. This is different to many other urban areas that show a large decrease in $PM_{10}$ emissions from domestic home heating as a result of households replacing older more polluting burners with NES authorised wood burners. For Reefton, the magnitude of this improvement relative to the reduction required in $PM_{10}$ is shown in Figure 6.2.

The emission projections include a natural attrition rate for burners of either 15 or 20 years. The average life span of a burner is considered to be around 15 years. However some households will replace their burners beyond 15 years. The assumption of a 20 year phase out for burners is likely to provide more certainty for determining emission reductions.

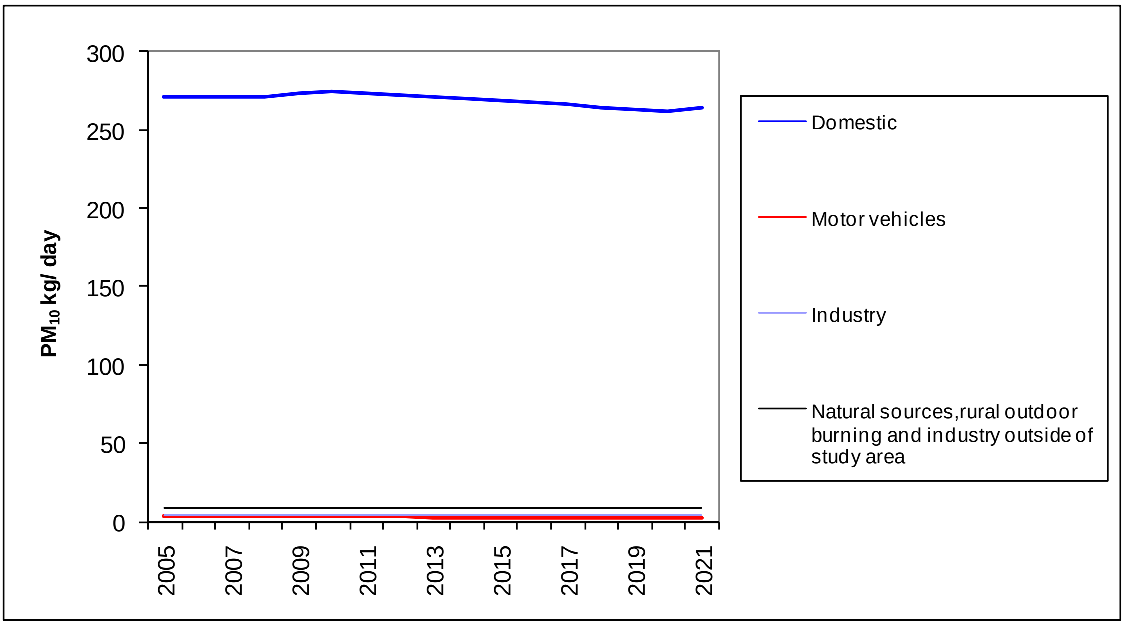



Figure 6.1: Estimates in trends in $PM_{10}$ concentrations by source for Reefton.

Figures 6.3 and 6.4 show the impact of different management options in achieving the NES. Small reductions of $PM_{10}$ concentrations are likely to be achieved if only outdoor burning and open fires were banned and the NES would not be met. The reason for the minimal reduction of $PM_{10}$ emissions from these management approaches is the large contribution that multi fuel burners have on $PM_{10}$ emissions in Reefton.

Figure 6.5 shows the impact of introducing a standard in 2010 of 5g/kg for multi fuel burners tested to real life conditions and phasing out all non complying wood burners, multi fuel burners and open fires by 2013. The projections indicate that this management option is overly stringent and more flexibility for reducing $PM_{10}$ emissions could be perused. Figures 6.6 to 6.11 show the effect of different emission limits for multi fuel burners for reducing $PM_{10}$.

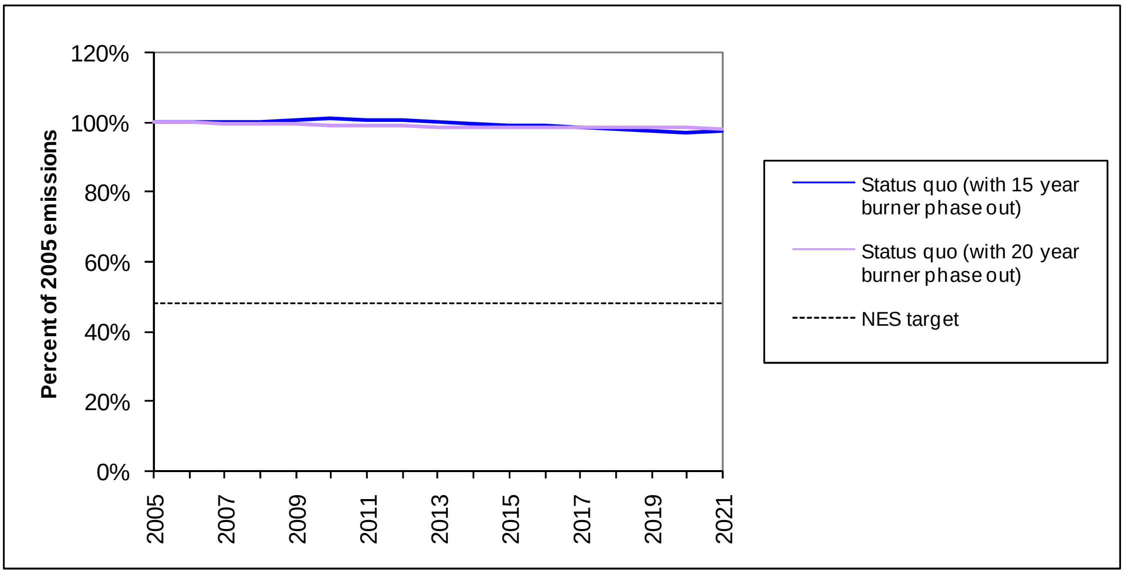



Figure 6.2: Status quo projections for Reefton.

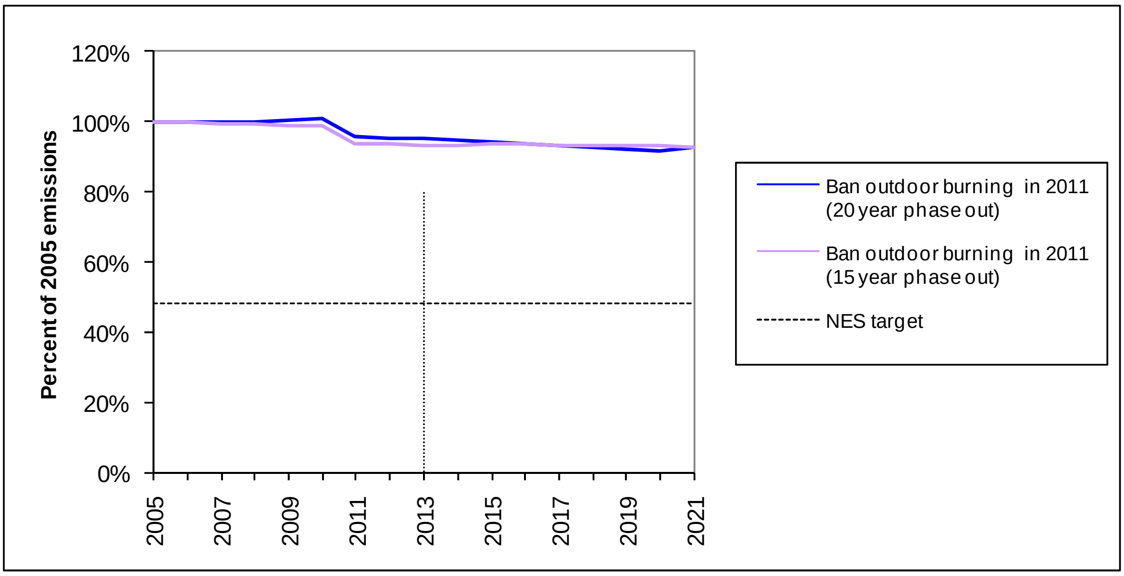



Figure 6.3: Ban outdoor burning in 2011.

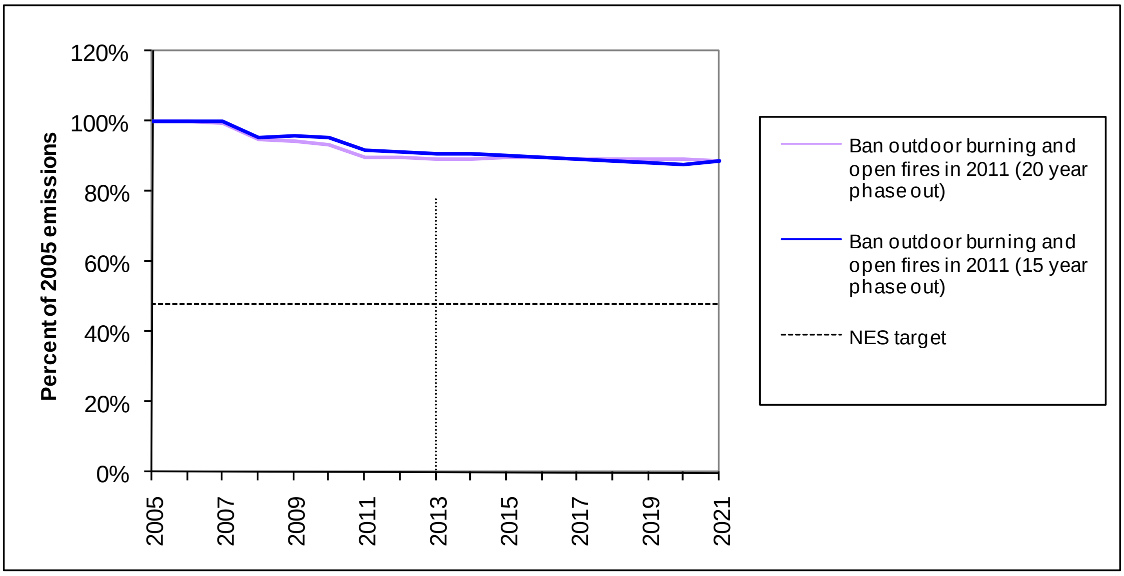



Figure 6.4: Ban open fires and outdoor burning in 2011.

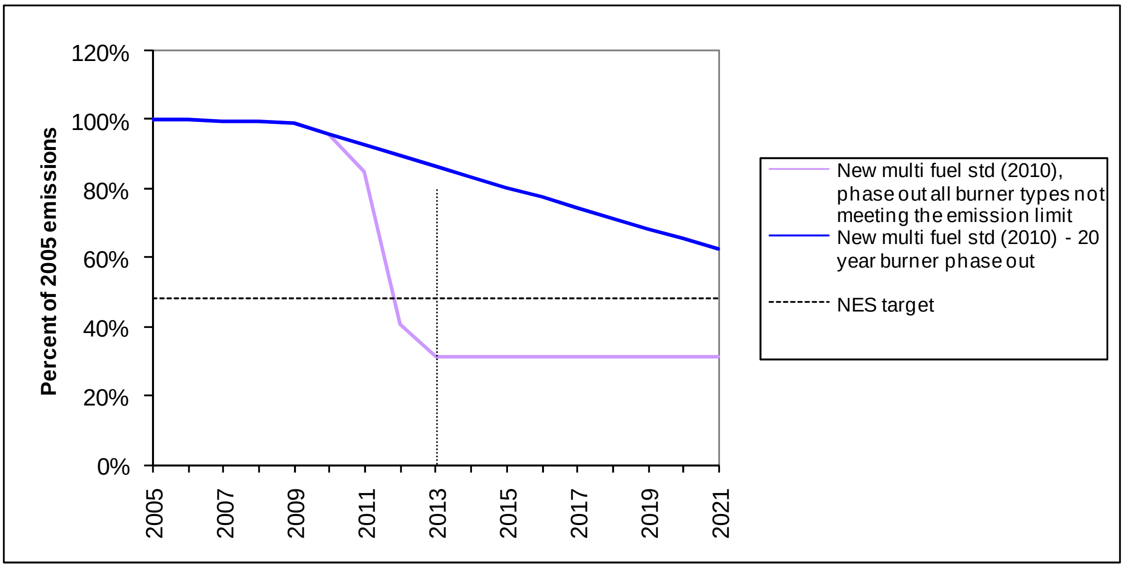



Figure 6.5: New standard in 2010 for multi fuel burners (equivalent to 5 g/kg real life) and phase out of all wood burners, multi fuel burners and open fires not meeting the emission limit by 2013.

## 6.1 Management options for the introduction of a 6g/kg standard for multi fuel burners

In order to determine the level of flexibility for emission limits for Reefton, emissions projections were made for two scenarios based on emission limits of 6g/kg and 5g/kg for multi fuel burners tested under real life conditions.

Figure 6.6 shows that if a new standard was introduced for multi fuel burners in 2010 with emissions equivalent to 6g/kg real life and that all multi fuel burner installed prior to 2005 were converted to the new standard, the NES is unlikely to be met. Projections for the same scenario but without the phase out of burners installed pre 2005 is also illustrated in Figure 6.6 and subsequent figures.

Figure 6.7 shows that in addition to the management options outlined in Figure 6.6 that if a 10% reduction in fuel use through insulation was also achieved that it is still unlikely that the NES would be met by 2013.

Figure 6.8 indicates that the introduction of a new standard for multi fuel burners equivalent to 6g/kg real life, ensuring that all multi fuel burners installed before 2005 were converted to the new standard, a 10% reduction in fuel use achieved through insulation improvements and a ban on outdoor burning may achieve the NES by 2013.

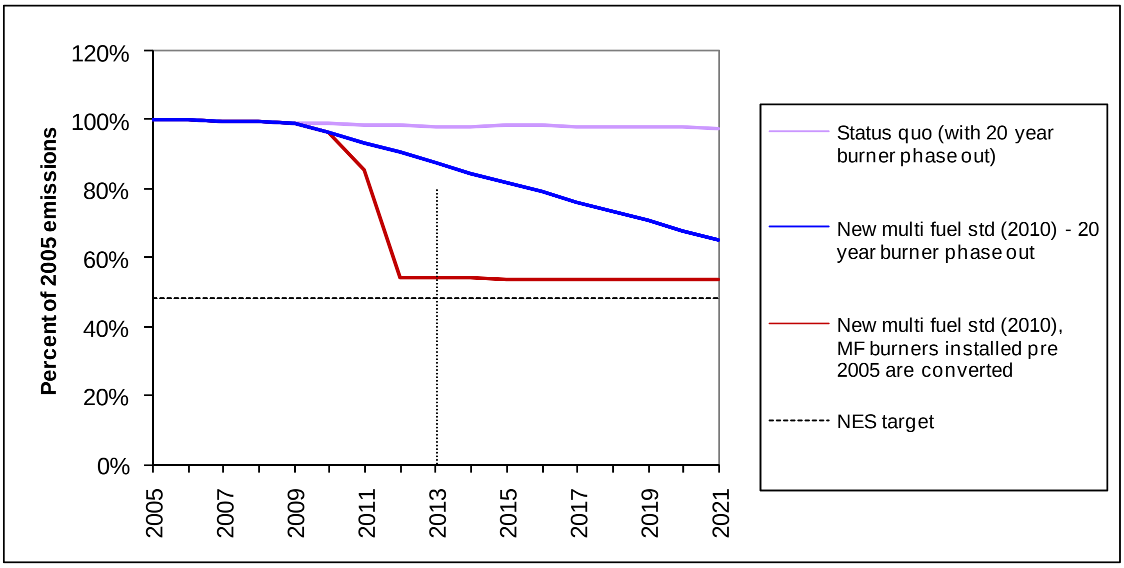



Figure 6.6: New standard for multi fuel burners (equivalent to 6 g/kg real life), all multi fuel burners installed before 2005 are converted to the new standard.

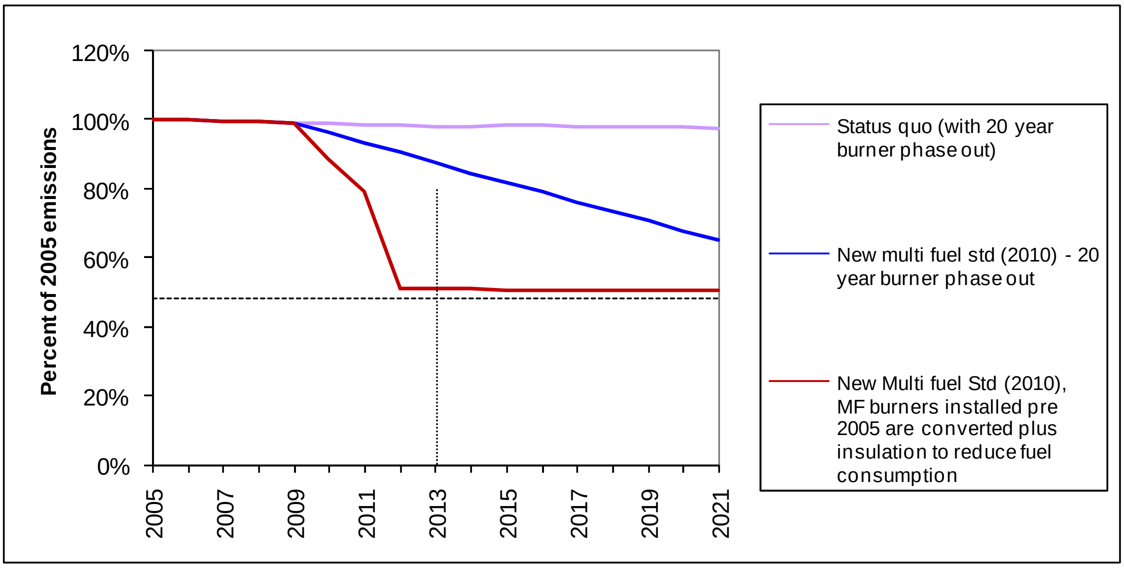



Figure 6.7: New standard for multi fuel burners (equivalent to 6 g/kg real life) all multi fuel burners installed before 2005 are converted to the new standard and a 10% reduction in fuel use is achieved through insulation improvements.

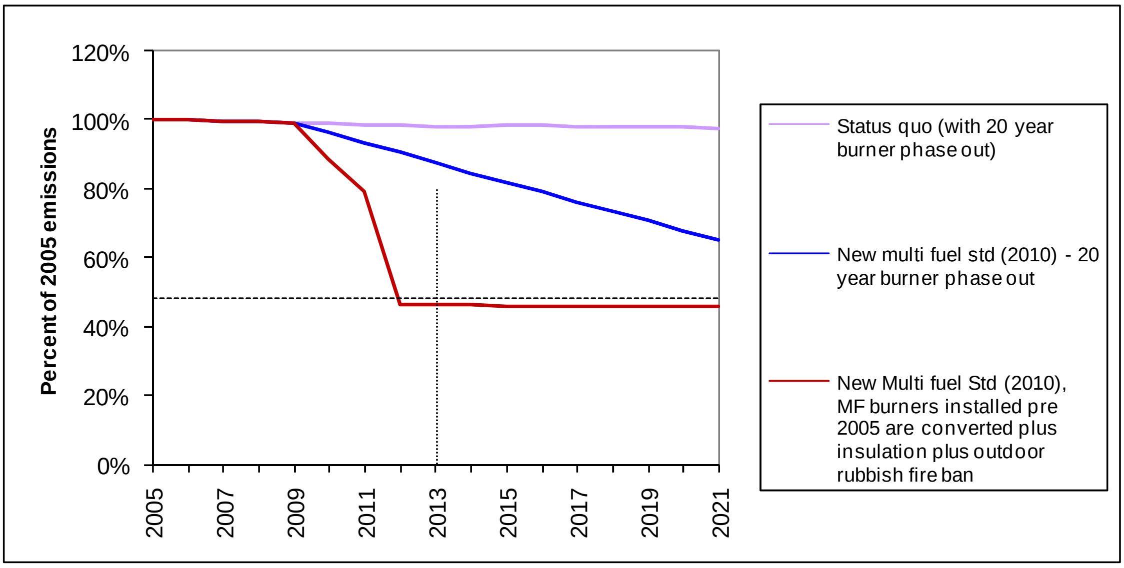



Figure 6.8: New standard for multi fuel burners (equivalent to 6 g/kg real life), all multi fuel burners installed before 2005 are converted to the new standard, a 10% reduction in fuel use is achieved through insulation improvements and a ban on outdoor burning.

## 6.2 Management options for the introduction of a 5g/kg standard for multi fuel burners

Further emissions projections were undertaken to assess the effect of introducing a lower emissions standard equivalent of 5g/kg for multi fuel burners when tested to real life conditions. Figures 6.9 to 6.11 show a number of management options that are based on the introduction of this emission limit in 2010. Multi fuel burners installed before 2005 would need to be converted to burners meeting the 5g/kg standard. Figure 6.10 shows the additional benefit if a 10% reduction in fuel use could be achieved through the insulation of houses. More certainty for meeting the NES could be achieved through an additional ban on outdoor burning (Figure 6.11).

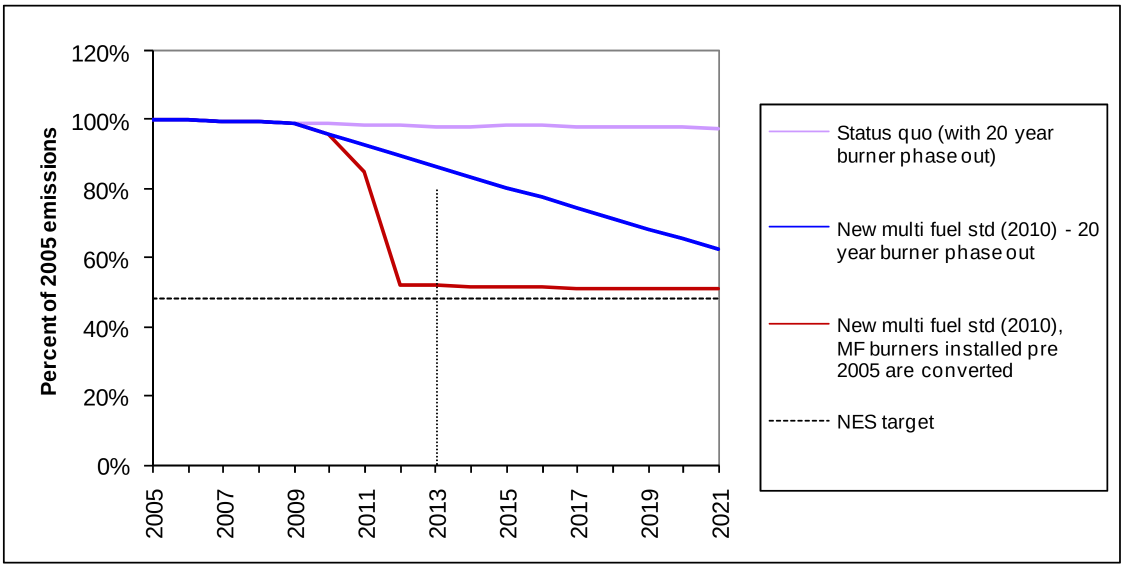



Figure 6.9: New standard for multi fuel burners (equivalent to 5 g/kg real life), all multi fuel burners installed before 2005 are converted to the new standard.

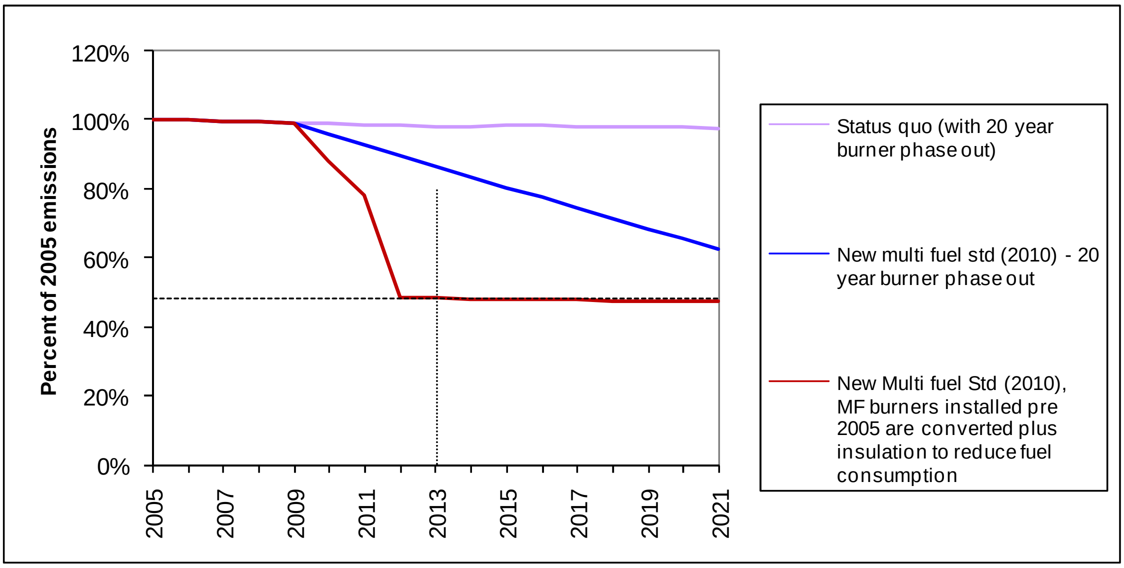



Figure 6.10: New standard for multi fuel burners (equivalent to 5 g/kg real life), all multi fuel burners installed before 2005 are converted to the new standard and a 10% reduction in fuel use is achieved through insulation improvements.

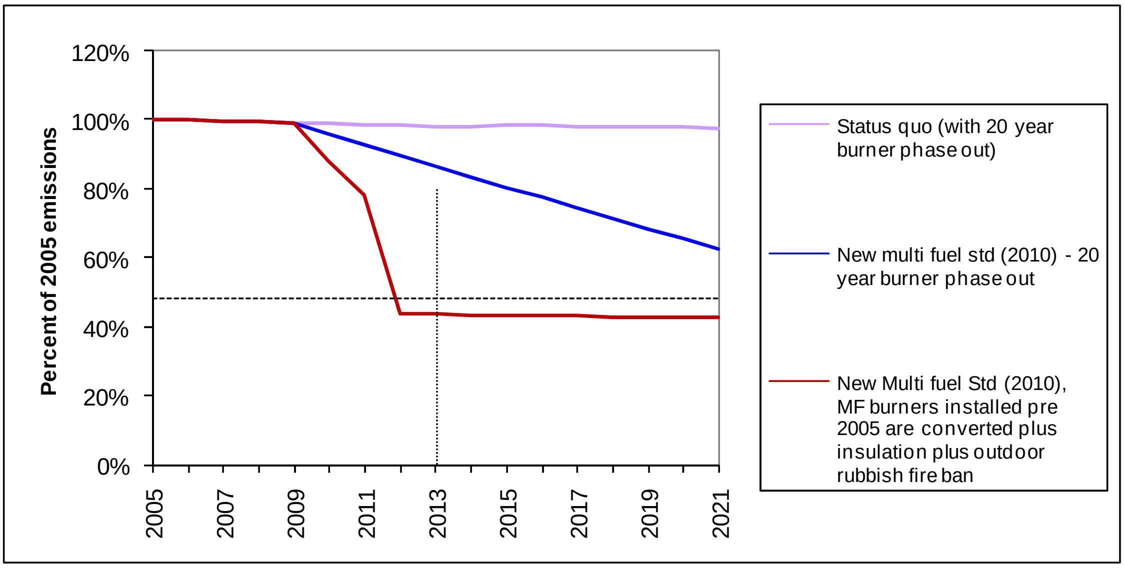



Figure 6.11: New standard for multi fuel burners (equivalent to 5 g/kg real life), all multi fuel burners installed before 2005 are converted to the new standard, a 10% reduction in fuel use is achieved through insulation improvements and a ban on outdoor burning.

## 6.3 Management options for achieving the NES in Reefton without the use of coal

Further analysis was undertaken to determine possible management options to meet the NES by 2013 in Reefton without using coal. Figure 6.12 indicates that if by 2012 there was a ban on the use of coal, open fires, and outdoor burning and a 15 year phase out of solid fuel burners from when they were installed then the NES is likely to be achieved. This management option assumes that wood would be continued to be used in multi fuel burners during the phase out period.

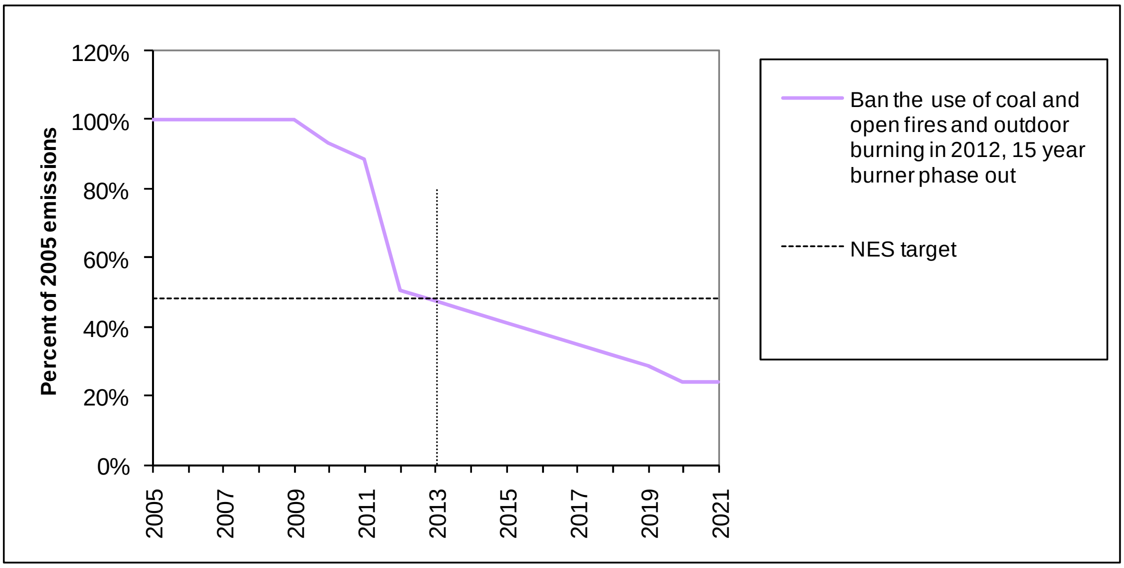



Figure 6.12: Ban the use of coal, open fires, and outdoor burning in 2012 and replacement of solid fuel burners 15 years after installation with NES wood burners.

## 6.4 Assumptions

Table 6.1 outlines the average fuel use and emission factors used for different appliance and fuel type categories. The emission factor used in the emission inventory for multi fuel burners burning coal is 28 g/kg. This emission factor has a high degree of uncertainty because it is based on limited testing of coal burners.

Further testing of coal in multi fuel burners, in the laboratory, tested to AS/NZS4013 and real life testing is recommended to provide greater certainty on the emissions from burning coal in multi fuel burners. In addition, the proportion of TSP that is $PM_{10}$ should be assessed for domestic coal burners in New Zealand. Table 6.2 specifies further assumptions underpinning the emissions projections and management options assessments.

Table 6.1: Average emission factors and fuel use.

| | Emission Factor g/ kg | Fuel Use kg |
|---|---|---|
| **Open fire - wood** | 10 | 28 |
| **Open fire - coal** | 21 | 27 |
| **Wood burner -pre 1995** | 11 | 28 |
| **Wood burner - 95-00** | 7 | 27.6 |
| **Wood burner -Post 2000** | 5 | 27.6 |
| **Woodburner 1.5 g/kg** | 3 | 27.6 |
| **Multifuel – wood** | 13 | 22.3 |
| **Multifuel – coal** | 28 | 20.5 |
| **Oil** | 0.3 | 2 |
| **Gas** | 0.03 | 1.0 |
| **Pellet** | 2 | 8 |

Table.6.2: Assumptions underlying the assessment of the effectiveness of management options for reducing $PM_{10}$ emissions.

| | |
|---|---|
| 1 | A decrease in $PM_{10}$ emissions from motor vehicles of around 31% by 2021 based on projected increases in VKTs combined with NZTER predictions on $PM_{10}$ emission reductions from motor vehicles. |
| 2 | The industry contribution to $PM_{10}$ emissions is less than 1% and a 10% increase in emissions from industry over time. |
| 3 | Current outdoor burning emissions occur throughout the week and weekend. |
| 4 | Emission factors for burners as per Table 6.1. |
| 5 | Average fuel use for NES authorised burners of 18 kg per night as per the 2005 Reefton emission inventory survey. |
| 6 | Average fuel use for other burners as per the 2005 Reefton emission inventory survey (Table 6.1). |
| 7 | A proportional reduction in concentrations for any given reduction in emissions. |
| 8 | No variations in the impact of emissions occurring at different times of the day. |
| 10 | A 1% decrease in population in Reefton between 2001 and 2021. |

| | |
|---|---|
| 11 | Only 50% of households replacing open fires, if prohibited, will install solid fuel burners*. |
| 12 | An emission factor for NES authorised wood burners of 3 g/kg. |
| 13 | A 10% reduction in the number of open fires from 2005 to 2021. |
| 14 | The weight of an average outdoor rubbish fire is 150 kilograms per burn. |
| 15 | A small proportion (0.25% per year) of houses currently using other heating methods will convert to solid fuel |
| 16 | For options including an open fire or outdoor burning ban these are effective from 2011 |
| 17 | 79% of new burner installations will be multi fuel burners. |
| 18 | All houses replacing wood burners and multi fuel burners replace with solid fuel |

*This is based on an evaluation of heating method in households that use open fires which shows a reasonable proportion (40%) also have an alternative solid fuel burner

### 6.4.1 Summary

The community in Reefton relies heavily on coal burning for solid fuel heating. Management measures to reduce $PM_{10}$ in most areas of New Zealand typically focus on reducing the use of higher emission fuels (such as coal) and appliances. However, this type of solution would have ongoing costs to the Reefton community as coal is sourced locally for minimal cost. As a result two approaches to managing $PM_{10}$ have been considered.

a) Traditional approach of tackling high emitting fuels and appliances (namely coal burning and older wood burners).
b) Allowing for the ongoing use of coal burning assuming a sufficiently low emitting coal burner is available.

The second option poses problems from policy viewpoint in that additional scientific work is required to establish average real life emissions from low emission coal burners. Moreover, it is currently uncertain if the technology would be available to achieve the required reductions.

Results of this study suggest that the NES could be met if there was a ban on the use of coal, open fires, and outdoor burning in 2012 and phase out of solid fuel burners 15 years after installation. Alternatively the science around emissions from multi fuel burners could be progressed to determine if any existing technology were likely to result in emissions sufficiently low as to allow for ongoing use of low emission multi fuel burners. This study suggests that a real life emission rate of around 5 g/kg (TSP) may be appropriate. Achievement of the NES by 2013 for the latter option would require the replacement of a large proportion of existing multi fuel burners (e.g., all multi fuel burners installed prior to 2005). Additional measures that may increase certainty include insulation of homes (if this results in a reduction in fuel use) and a ban on outdoor burning.

# 7 Air Shed Modelling

## 7.1 Model setup and methodology

The Air Pollution Model (TAPM) version 3.0.7 was used to examine two different emission scenarios for Reefton. TAPM is a three-dimensional incompressible, nonhydrostatic, primitive equations model, which uses a terrain-following coordinate system (Hurley, 2002). The meteorological component of the model is supplied with a dataset derived from the Limited Area Prediction System (LAPS) analysis data from the Australian Bureau of Meteorology while the sea surface temperature is derived from Rand's global long term means at a resolution of 100 kilometers, although the prescribed values can be changed. The simulations presented here use four nested grids with a grid spacing of 10.8, 2.7, 0.9 and 0.3 kilometres, respectively. The meteorological model grid is configured with 50 zonal and meridional grid nodes while pollution model of TAPM is configured with 99 zonal and meridional grid nodes. To improve the accuracy of the meteorological model of TAPM, observational data was assimilated from the meteorological station at Reefton. Default model options were used, except that more realistic monthly varying deep soil temperature and deep soil moisture was used.

To predict $PM_{10}$, the air pollution module of TAPM was used in a tracer mode (with no chemistry). Since 90 percent of the total emissions are from domestic heating, only one tracer was allocated to represent all emissions from all sources that include domestic heating, traffic, industry, outdoor burning and natural emissions. TAPM was integrated for the month of July for two scenarios to examine compliance with national environmental standards. In the first simulation baseline emissions for 2005 were used to predict $PM_{10}$ concentrations for July 2007, while in the second simulation; the same meteorology for July 2007 was used with the reduced emission scenario for 2013. Emission inventory data was obtained from the Reefton Air Emission Inventory report (Wilton, 2005). This data was modified to hourly estimates by Environet Limited for the purposes of this study. The baseline emissions are based on the air emissions for the main populated area of 201 hectares within Reefton (Wilton, 2005). The model setup is summarized in Table 7.1.

Table 7.1: Model Setup.

| **Meteorological Model Setup** | | | | |
|---|---|---|---|---|
| Simulation period | 1st to 31st July 2007 | | | |
| | Grid-1 | Grid-2 | Grid-3 | Grid-4 |
| Grid spacing(metres) | 10800 | 2700 | 900 | 300 |
| Grid points | 50 | 50 | 50 | 50 |
| Vertical levels | 35 | 35 | 35 | 35 |
| | | | | |
| Deep soil moisture | 45% | | | |
| Sea surface temperature | 275.5 | | | |
| Deep soil temperature | 275.5 | | | |
| Observational data assimilated for wind speed and wind direction | | | | |
| | | | | |
| **Pollution Model Setup** | | | | |
| Grid spacing(metres) | 5400 | 1350 | 450 | 150 |
| Grid points | 99 | 99 | 99 | 99 |
| Surface emission mixing in vertical levels | 1 | 1 | 1 | 1 |
| | | | | |
| Extent of area source | 201 hectares = 2km$^2$ | | | |
| Base line emissions: | 302.3 kg/day | | | |
| 2013 emissions: | 146.7 kg/day | | | |

## 7.2 Model results and discussion

The small town of Reefton is located on the west coast of South Island in the Inangahua River valley, covered from three sides by small hills up to 400 metres. TAPM was run with and without data assimilation. However, given the complexity of terrain and very low wind speeds (less than 2 ms$^{-1}$) TAPM was unable to predict basic meteorological variables such as wind speed, wind direction, temperature and relative humidity with reasonable accuracy. The final TAPM simulations were, therefore, run with data assimilation to more realistically represent the meteorology of this area to better predict concentrations of $PM_{10}$ in the Reefton airshed.

The model predictions were extracted at the nearest grid point from the location of the Reefton air quality monitor on the inner most grid (300 metres spacing for the meteorological model and 150 metres for the pollution model) at the lowest model level of 10 metres above the ground. The hourly data (both observed and model predicted) were then converted to 24 hour average data to get a daily average profile of meteorology and $PM_{10}$ concentration at Reefton. Statistics of 24 hour average observations and model predictions are shown in Table 7.2, and are based on recommendations by Willmott (1981). Since the observational data was assimilated in the model to nudge the wind speed and direction towards the observed values, the Index of agreement (IOA) of observed and model predicted values wind speed, U and V component is 1.0 with no significant biases, and low RMSE which basically means that the data assimilation was successful. Index of agreement is a measure of how well predicted variations about the observed mean are represented. A value greater than 0.50 is considered to be good (Hurley et al., 2003).

Table 7.2: Model evaluation statistics for near surface meteorology.

| Meteorological Variable | MEAN OBS | MEAN MOD | STD OBS | STD MOD | CORR | RMSE | IOA |
|---|---|---|---|---|---|---|---|
| Wind speed $ms^{-1}$ | 0.5 | 0.5 | 0.5 | 0.5 | 1.00 | 0.04 | 1.00 |
| U-Comp $ms^{-1}$ | -0.1 | -0.1 | 0.3 | 0.3 | 0.99 | 0.04 | 1.00 |
| V-Comp $ms^{-1}$ | 0.2 | 0.2 | 0.6 | 0.5 | 1.00 | 0.04 | 1.00 |
| Temp degree C | 3.9 | 6.9 | 3.8 | 2.0 | 0.65 | 4.13 | 0.63 |

MEAN OBS: Mean values of observed data; MEAN MOD: Mean values of model predicted data; STD OBS: Standard Deviation of observed data; STD MOD: Standard deviation of model predicted data; CORR: Correlation Coefficient; RMSE: Root mean square error; IOA: Index of agreement.

The time series of the 24 hour average observed wind speed, wind direction and temperature at 10 metres above ground level at Reefton for July 2007 are shown in Figure 7.1. With data assimilation, wind speed and wind direction were predicted with an obvious high Index of agreement of almost 1.0, however, TAPM over predicted temperature for almost the entire simulation period. The bias in the observed and predicted temperatures was largest in the second and third week of July 2007. The qunatile-quantile plots of the observed and modelled data (Figure 7.2) shows that TAPM significantly over predicted low temperatures, however, the model's prediction for high observed temperatures (>8$^{o}$C) was good.

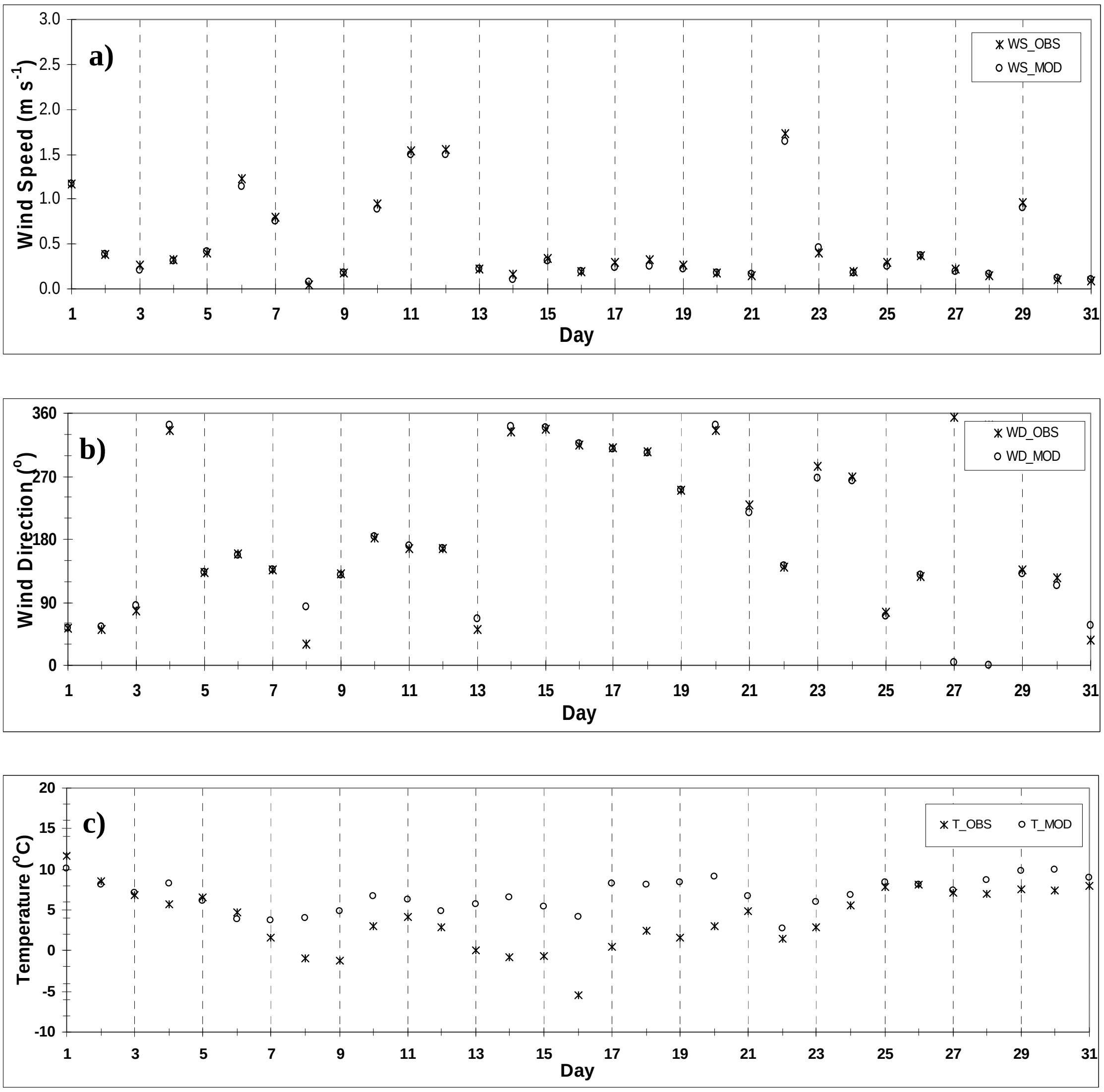



Figure 7.1: Average daily time series plots of observed and model predicted data for a) wind speed, b) wind direction and c) temperature at Reefton.

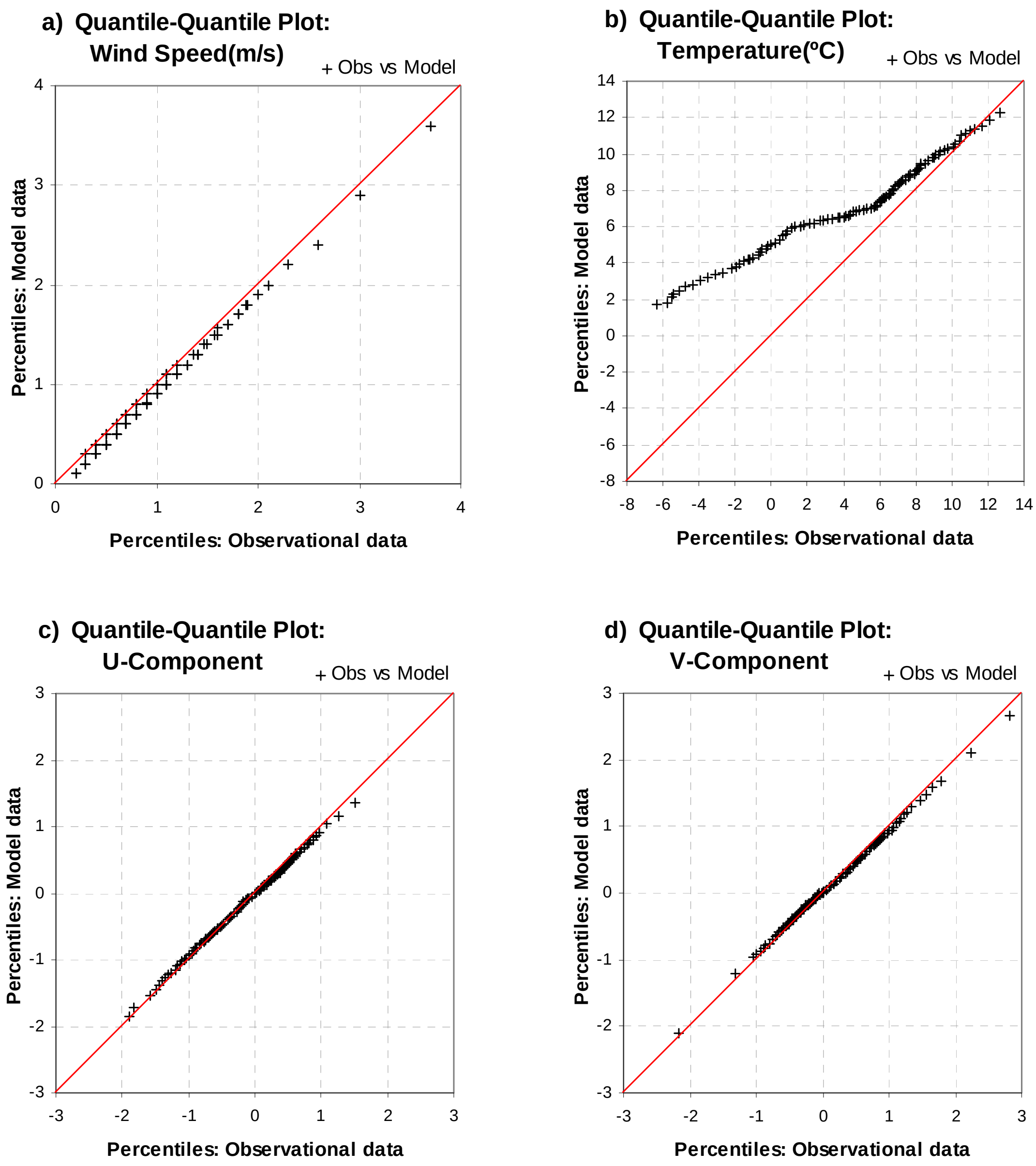



Figure 7.2: Quantile-Quantile Plots of observed and predicted values for wind speed, U and V component of wind and temperature.

The predictions of TAPM for $PM_{10}$ were extracted at the nearest grid point to the $PM_{10}$ monitoring site at Reefton on the inner most grid (150 metre spacing). The $PM_{10}$ sampler is located at the centre of Reefton at a primary school building. The height of the sampler inlet is 1.8 metres above the ground while the predicted $PM_{10}$ concentrations were extracted from model's lowest level that was 10 metres above the ground.

Results of the predicted $PM_{10}$ concentrations were compared with the observed $PM_{10}$ data. The robust high concentration (RHC) method was used to compare the observed and predicted concentrations. The RHC is preferred to the actual peak value because unlike percentiles it eliminates the undesirable influence of unusual events while still representing the magnitude of the maximum concentrations (Hurley et al., 2003). Table 7.3 shows the model significantly under predicted $PM_{10}$. The RHC ratio for the average 24 hour $PM_{10}$ concentration indicates less $PM_{10}$ than the observed values ($RHC_R$ =1.00 means perfect match and no bias at the extreme end of the observed and predicted concentrations).

Although the IOA was within acceptable limits, the bias between the observed and the modelled mean was almost 50% of the observed mean concentration. The RHC ratio for the 24 hour maximum $PM_{10}$ concentration was slightly better with an RHC ratio of 0.63 and a much lower bias compared to the average daily $PM_{10}$ concentration, although there is no change in correlation coefficient of average and maximum $PM_{10}$ with the observed $PM_{10}$ concentration.

Table 7.3: Model evaluation statistics for 24-hour averaged ground level $PM_{10}$.

| | **MEAN** | **STD** | **CORR** | **RMSE** | **IOA** | **Bias** | **Fb** | **$RHC_R$** |
|---|---|---|---|---|---|---|---|---|
| OBS. $PM_{10}$ (μg $m^{-3}$):2007 | 54.0 | 25.7 | 1 | 0 | 1 | 0 | 0 | 1 |
| TAPM.Avg.$PM_{10}$ (μg $m^{-3}$) | 27.8 | 13.7 | 0.44 | 34.78 | 0.53 | 26.22 | 0.64 | 0.53 |
| TAPM.Max.$PM_{10}$ (μg $m^{-3}$) | 37.2 | 18.6 | 0.44 | 29.21 | 0.59 | 16.8 | 0.37 | 0.63 |

STD: Standard Deviation; CORR: Correlation Coefficient; RMSE: Root mean square error; Bias= Mean observed concentration – Mean modelled concentration; Fb: Fractional bias; $RHC_R$: Robust highest concentration ratio of the predicted to observed.

Figure 7.3 shows that most of the under prediction occurred at high concentrations while at low $PM_{10}$ concentrations TAPM performed well. TAPM mostly under predicted $PM_{10}$ concentrations in the middle of the month when observed temperatures and wind speeds were the lowest (Figure 7.5). One likely explanation for this is that during strong inversion conditions emissions from domestic chimneys may be mixed down to the level of the sampler intake (1.8 metres above ground) within shorter distances, giving higher concentrations while the lowest level TAPM could reach was 10 metres above ground.

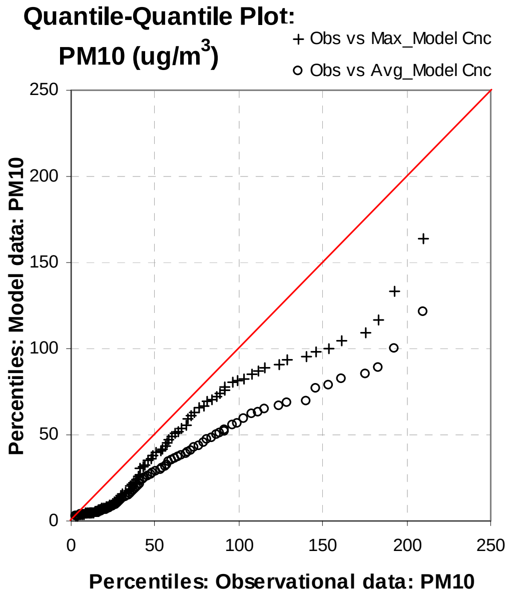



Figure 7.3: Quantile-Quantile plot of hourly observed and predicted (average and maximum) $PM_{10}$ concentrations.

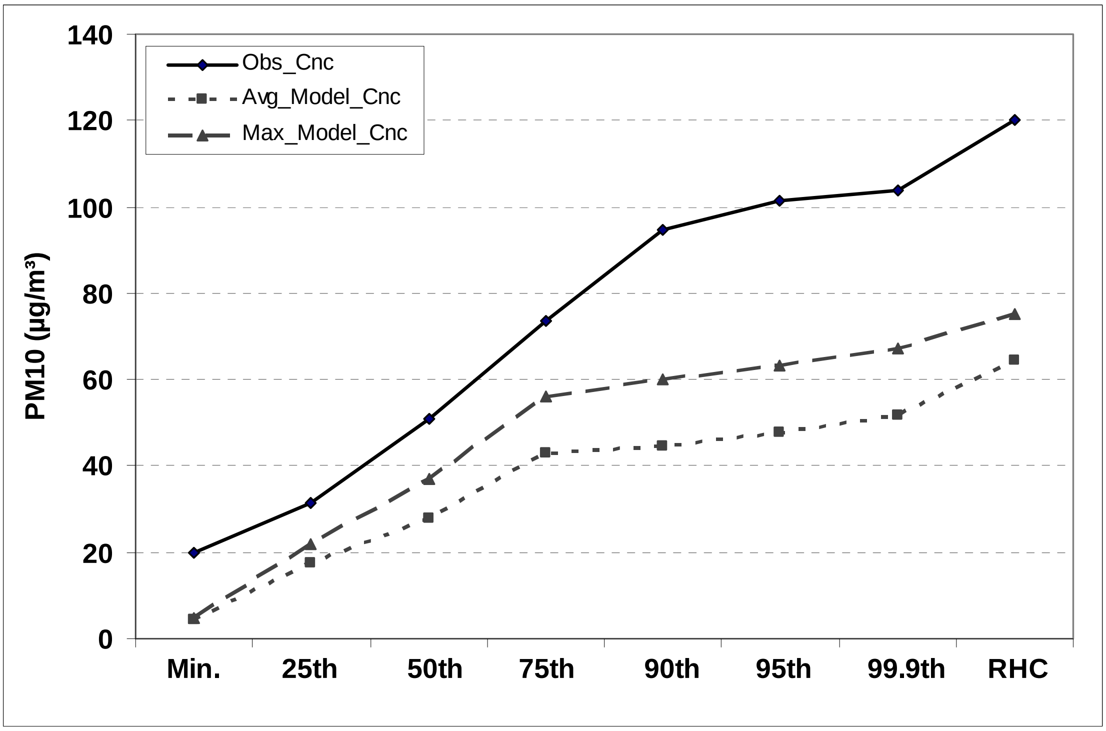



Figure 7.4: 24 hour average observed and predicted $PM_{10}$ concentrations, percentiles, minimum value and Robust Highest Concentration.

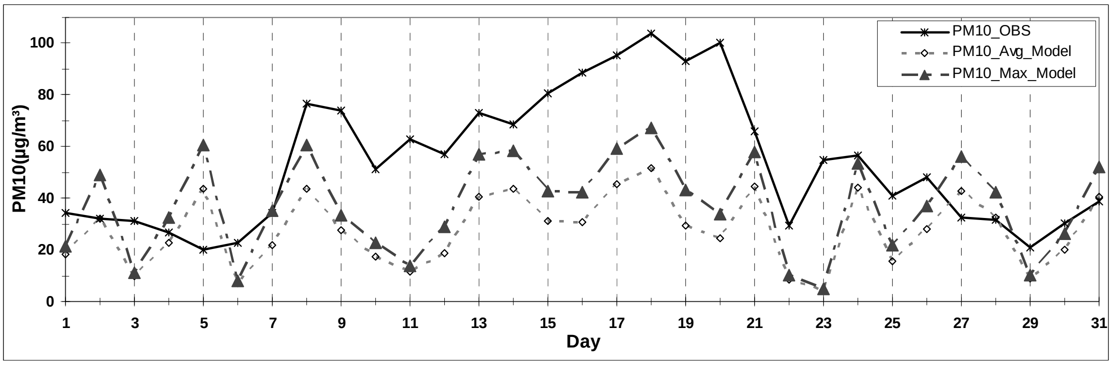



Figure 7.5: Time series plot of 24 hour average observed and predicted $PM_{10}$ concentrations.

Wind speeds at Reefton are generally very low. The 24 hour average wind speed was less than 2 $ms^{-1}$ for the entire simulation period. There are only 37 hours in the month when wind speed was above $2ms^{-1}$ and more than 60% of these hours were during day time between 7:00am and 5:00pm.

Wind roses from the metrological station at Reefton (Figure 7.6) show that winds are most frequently from the southeast (27%) and northwest (22%) quarters. During the day (between 12:00 noon to 4:00pm) north-westerly winds were dominant, while at night, and during morning hours (6:00pm to 12:00am and 1:00am to 10:00am) the highest frequency of winds were observed from the southeast quarter although moderate frequencies of winds from other directions were also recorded. The observed and predicted data suggests that except for the afternoon, the wind speed from northwest, and western quarters were the lowest ($=0.5ms^{-1}$) whereas the wind speed from the southeast, was greater than $1.2ms^{-1}$ almost throughout the diurnal cycle.

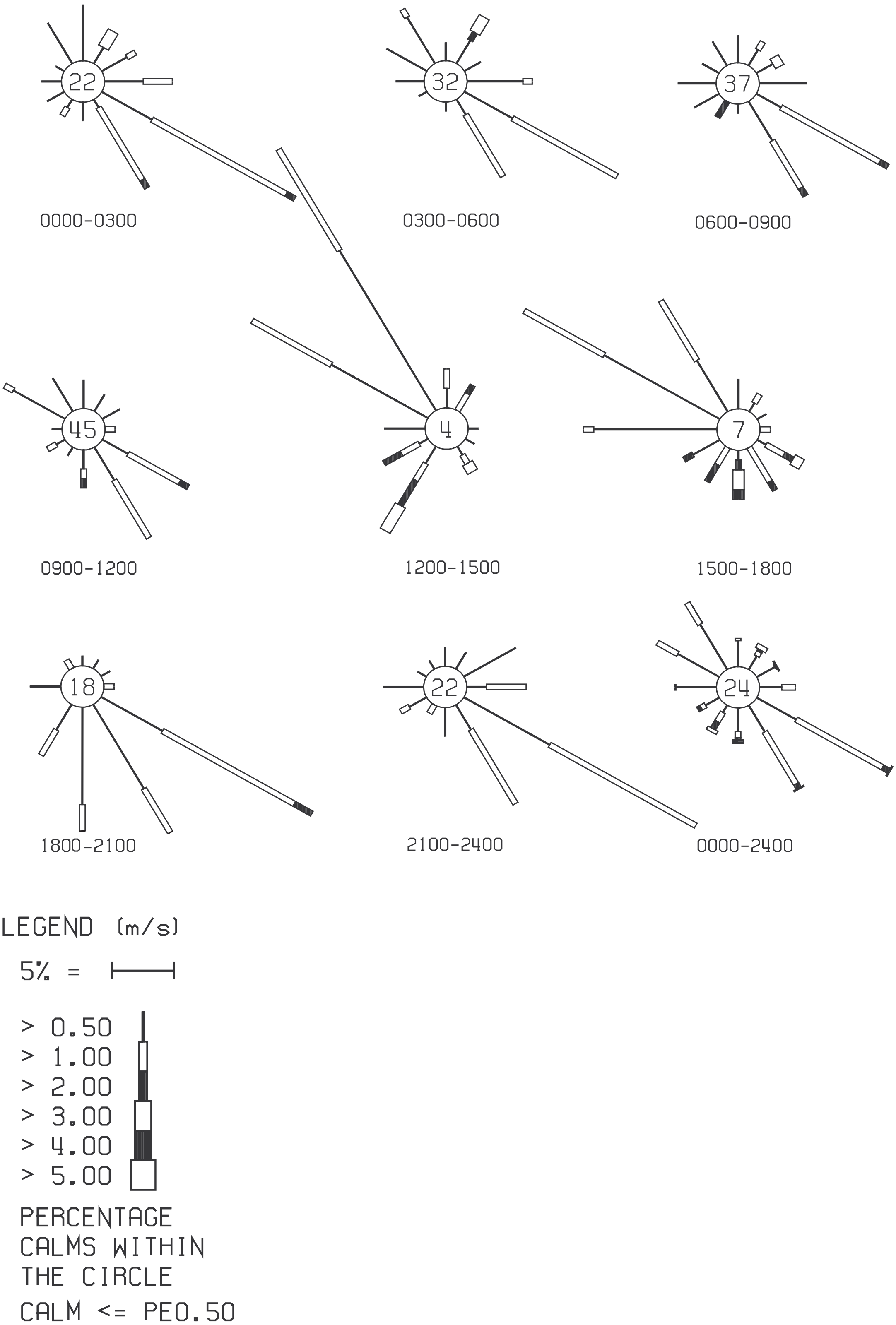


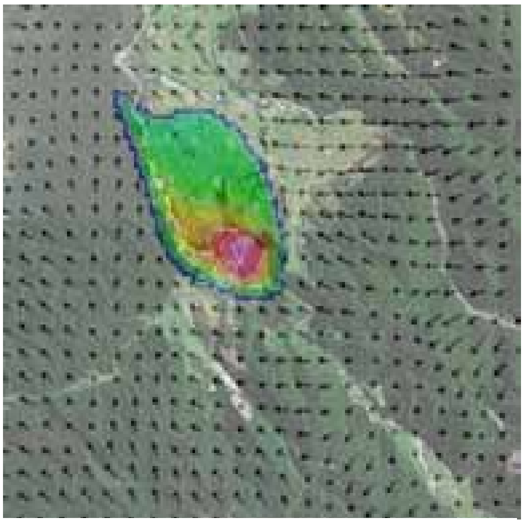

Figure 7.6: Three hourly wind roses for July 2007.

Observed and predicted $PM_{10}$ concentrations were the highest at night time under weak north-westerly wind flow. The maximum $PM_{10}$ (24 hour average) concentration of (104 $\mu gm^{-3}$) was observed on 18 July 2007 while TAPM predicted the highest $PM_{10}$ concentration (52 $\mu gm^{-3}$) on 18 July 2007. Model results of average and maximum $PM_{10}$ concentrations show dispersion of $PM_{10}$ to the north, northwest and south of Reefton (Figures 7.7 and 7.8). This is primarily due to the predominant northwest and southeast wind flow. The higher concentration of $PM_{10}$ depends on many factors including the intensity of emission, the size of the emission area and the local meteorology of the region. Reefton is surrounded by small hills up to 400 metres high from three sides that appear to have significant effects on local meteorology. The higher terrain especially to the east and southeast of Reefton obstructs dispersion of $PM_{10}$ in these quarters; the pollutant therefore disperses to the north or to the southwest.

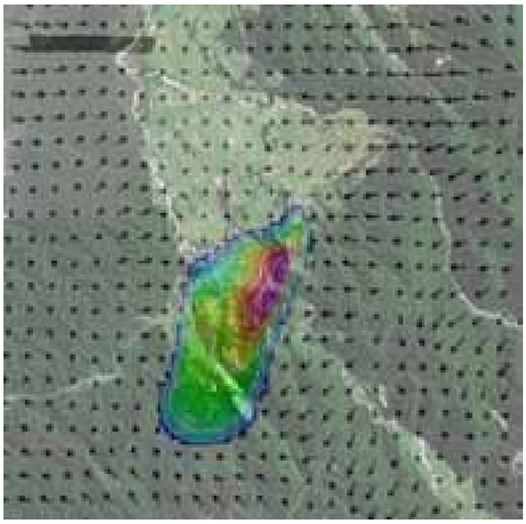
The pollutant dispersion at Reefton is a function of wind flows from different directions that simultaneously occur over this small area. To examine the pollutant's dispersion in and around Reefton, the wind field along with $PM_{10}$ is plotted for four different wind flows when TAPM predicted higher $PM_{10}$ levels at Reefton. The results of the modelling exercise (Figure 7.9) show that in addition to southeast and north-westerly winds, the down slope east-northeast winds also play an important role in pollutant dispersion. Observational data show that south easterlies are the dominant wind flow during the night time. When the relatively strong winds from the southeast combine with down slope winds from the eastern quarter, the pollutant is dispersed towards the north-northwest of Reefton (Figure 7.9a). However, under the usual very weak night time north westerly wind flow, the pollutant is dispersed towards the southwest/south by the accompanying northeast-easterly winds (Figure 7.9b). Under the dominant north-north-easterly down slope flow, the pollutant is pushed either towards the southwest or northwest of Reefton (Figure 7.9c), while strong south westerly winds with the opposing easterly down slope winds disperse the pollutant northward of Reefton (Figure 7.9d). The model results show that during night time the downward convergence of weak wind flows from different directions leading to calm conditions. Under these conditions TAPM predicted highest hourly $PM_{10}$ levels on 27 July at 06:00pm (177 $\mu g\ m^{-3}$).

Figure 7.7: Average $PM_{10}$ concentrations (µg $m^{-3}$) for July 2007.

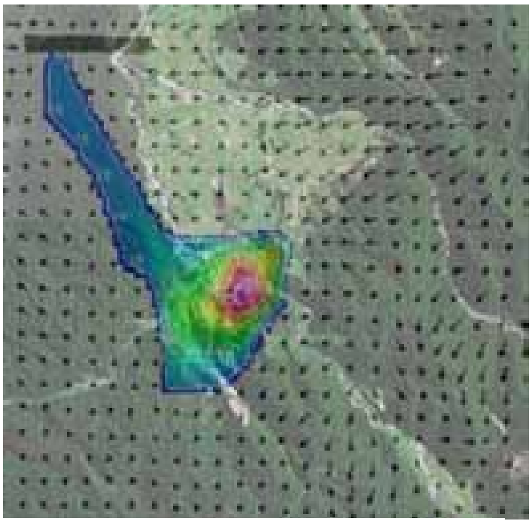

Figure 7.8: Maximum hourly $PM_{10}$ concentrations (µg $m^{-3}$) for July 2007.



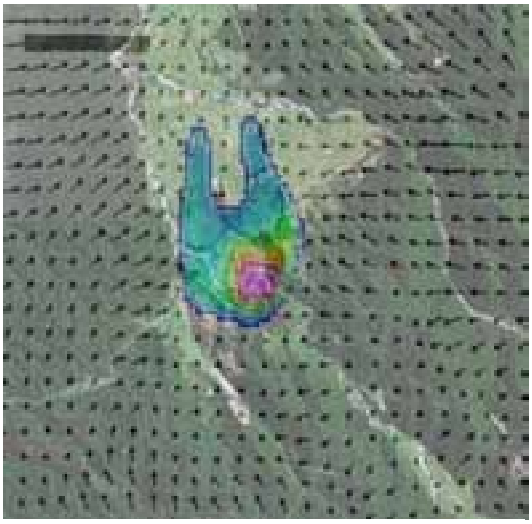
**a)** 26th Jul.2007: 19:00 hours; SE+N/NE flow



**b)** 4th Jul.2007: 22:00 hours; NW+N/NE flow



**c)** 2th Jul.2007: 22:00 hours; N+NE flow



**d)** 31st Jul.2007: 22:00 hours; SW + N flow

Figure 7.9: $PM_{10}$ dispersion under varying wind flow conditions at Reefton.

Temperature inversions frequently occur during cold winter nights in Reefton (Stevenson et al., 2004). Figure 7.10 shows the average vertical profile of potential temperature at 23:00 hours for July 2007. The figure indicates that in Reefton there is an inversion layer (air temperature increasing with height) in the first 50 metres of the stable boundary layer. The high concentrations of $PM_{10}$ are particularly associated with stable conditions when the inversion traps the pollutants close to the ground and restricts their vertical and horizontal mixing.

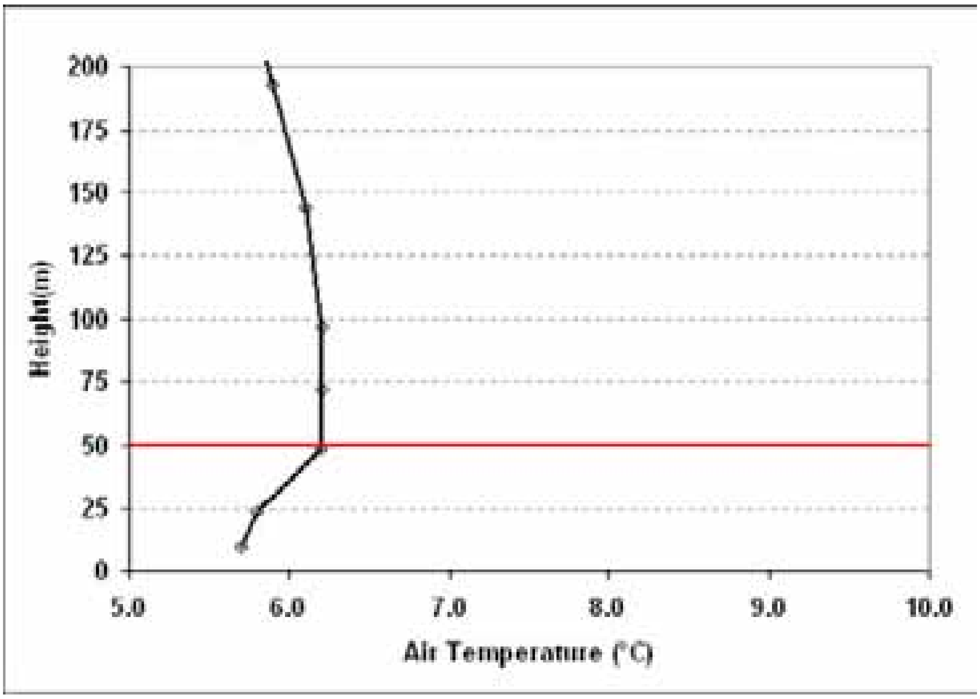



Figure 7.10: The average model predicted vertical profile of air temperature at 11:00pm for July 2007 at Reefton.

To examine the spatial extent of $PM_{10}$ concentrations within Reefton, the predicted $PM_{10}$ concentrations were extracted from five different locations. These locations were the centre of the town, and the northwest, northeast, southeast and southwest of the town. Figure 7.11 shows the 24 hour average $PM_{10}$ concentrations from these five locations. TAPM predicted that the highest concentrations were in the centre of the town followed by southwest corner with the second highest $PM_{10}$ concentration. TAPM predicted that the lowest $PM_{10}$ concentration was located to the southeast of Reefton. This is consistent with the average and maximum $PM_{10}$ concentrations and wind profile for Reefton as due to the dominant south easterly flow at Reefton, the pollutant dispersed to southwest and northwest quarters and increased the $PM_{10}$ concentrations at these locations.

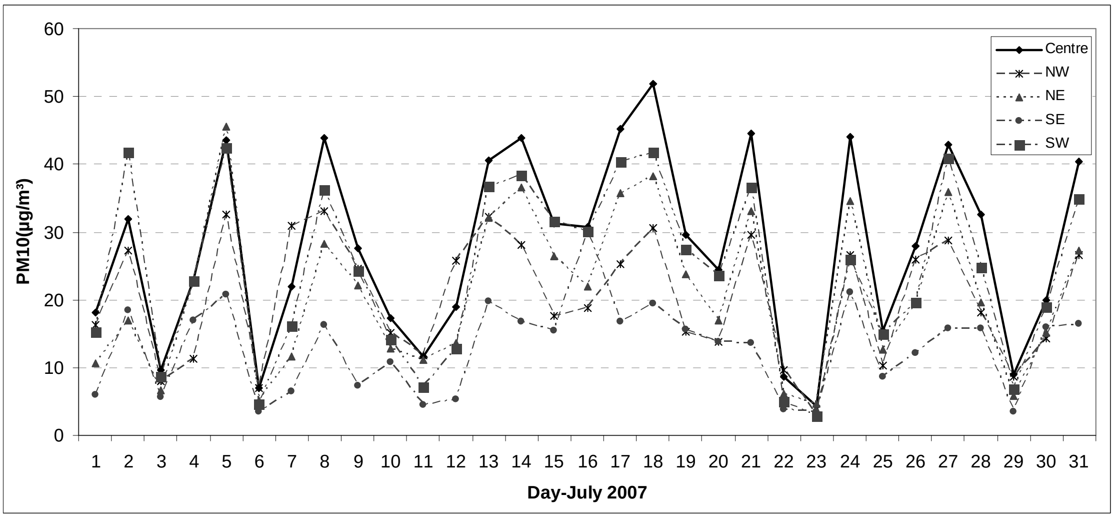



Figure 7.11: Time series plot of 24 hour average predicted $PM_{10}$ concentrations. The time series data is extracted from five locations in the 2km$^2$ Reefton area.

## 7.3 Compliance with emission reduction scenario 2013

TAPM was run using a reduced emission scenario for 2013 for the same July period to examine whether there would be any exceedences of the NES during this period. The maximum 24 hour average of maximum $PM_{10}$ predicted concentrations were examined for 2005 and 2013. Observational data shows 15 exceedences (24 average concentration > 50µg m$^{-3}$) in July 2007 (Figure 7.12), however, TAPM predicted only 10 exceedences for 2007 scenario. For the 2013 scenario with reduced $PM_{10}$ emissions, TAPM did not predict $PM_{10}$ concentrations in excess of the NES of 50µg m$^{-3}$.

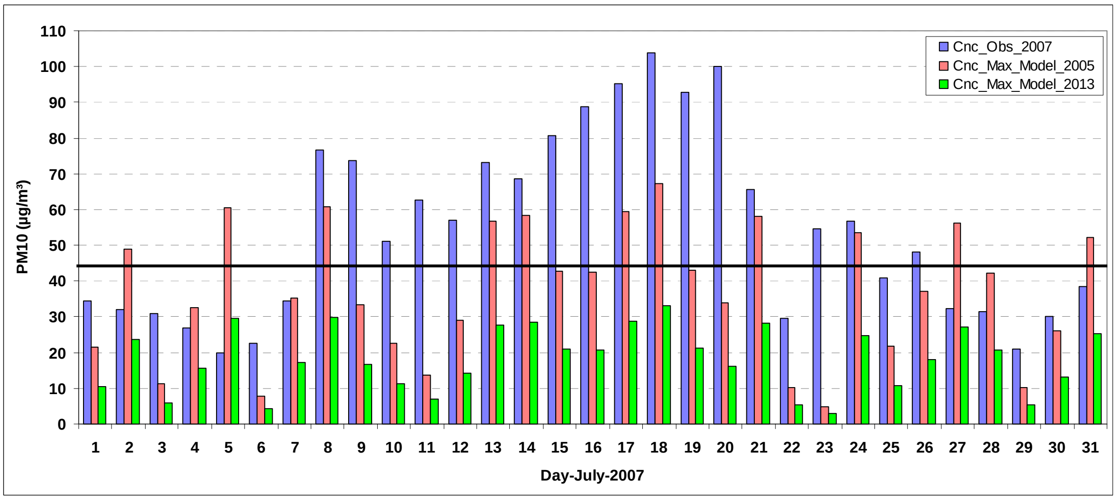



Figure 7.12: 24 hour average observed and maximum $PM_{10}$ concentrations using baseline emissions for 2005 and projected emissions for 2013.

# 8 Conclusions

This study provides more detail on meteorology in Reefton and its impact on $PM_{10}$ concentrations and on management options for reducing $PM_{10}$ to meet the NES.

The dominant wind flows are from the south-east and north-west with south easterlies accounting for more than 27% of the total time and north-westerlies prevalent 22% of the total time. South-easterly flows dominate the night time whereas north-westerlies are most prevalent during the day time. The night time north-northeasterly cold air drainage flow is also a regular feature of the local meteorology of Reefton.

Within the 2km$^2$ Reefton area TAPM predicted that the highest $PM_{10}$ concentration was in the centre of the town. This is because during calm conditions the dispersion of $PM_{10}$ is very slow and the vertical and horizontal movement of the air mass is restricted, resulting in high $PM_{10}$ concentrations. The lowest $PM_{10}$ concentrations were predicted to the southeast corner which is consistent with the dominant south-easterly wind flow that moves the $PM_{10}$ in a northward direction. Both observed and predicted $PM_{10}$ concentrations were highest at night and in the evening hours of the day under very weak north-westerly winds.

Terrain appears to be an important influence on local meteorology and in determining the dispersion path of the $PM_{10}$. The night time cold air drainage from low elevation hills, east, and southeast of Reefton displace the dispersion path of the $PM_{10}$ plume. Under calm conditions the cold air drainage from the east with the opposing wind flow forms a convergence zone and significantly increases $PM_{10}$ concentrations over Reefton, whereas southeast or northwest wind flow accompanied with cold air drainage flow disperses $PM_{10}$ either to the northeast–southwest direction or transports it to the northwest quarter.

Dispersion modelling using TAPM generally under predicted $PM_{10}$ concentrations on days when concentrations were highest at Reefton. For example, monitoring of $PM_{10}$ during July 2007 showed 15 exceedences whereas TAPM with the 2005 emissions data predicted only 10 exceedences. One potential reason for this is that emissions from chimneys are mixed at a height of around four metres with limited horizontal dispersion under strong inversion conditions. The $PM_{10}$ sampling is conducted at a height of 1.8 metres and is closer to the discharge height than the 10 metre height minimum in the TAPM model.

The model was run with a 2013 emission scenario to check that the estimated reduction in $PM_{10}$ emissions associated with different management options would result in compliance with the NES if meteorological conditions were similar to 2007. For this scenario, TAPM did not predict any exceedences. However, it is noted that the model is under predicting and unlikely to provide a reliable estimate of $PM_{10}$ concentrations for the 2013 revised emission scenario. The relationship between emissions and concentrations appears linear, however, indicating that a 52% reduction in $PM_{10}$ emissions will reduce concentrations by a similar proportion.

The Reefton community heavily relies on coal for domestic home heating during winter. An emission inventory suggests that 53% of winter $PM_{10}$ emissions are from burning coal on multi fuel burners. Management options in this report have focused around retaining coal use while meeting the NES and evaluating other options that would meet NES requirements.

The results of this study suggest that the introduction of a multi fuel burner with a real life emission rate of 5g/kg, insulation measures to reduce coal consumption and a ban on outdoor burning are likely to result in compliance with the NES. All multi fuel burners installed before 2005 would need to be replaced with low emission multi fuel burners prior to 2013 if achievement of the NES target date of 2013 is important.

There is uncertainty whether there are multi fuel burners that are available that have a real life emission rate of 5g/kg. Two burners, the Woodsman Matai RMF and the Logaire Hestia have recorded emission tests of 3.9g/kg and 2.56g/kg when tested to AS/NZS4013 and AS/NZS4012. However, real life emission rates have not been quantified and are likely to be higher than test results.

Alternatively, the results of this study indicate that the NES could be met if there was a ban on the use of coal, open fires, and outdoor burning in 2012 and phase out of solid fuel burners 15 years after installation.

Further testing of coal in multi fuel burners, in the laboratory, tested to AS/NZS4013 and AS/NZS4012 and real life testing is needed to provide greater certainty on the emissions from burning coal in multi fuel burners. In addition, it is also recommended that the proportion of TSP that is $PM_{10}$ be assessed for domestic coal burners in New Zealand.

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