The impact of rural burning on PM_{10} concentrations in Blenheim

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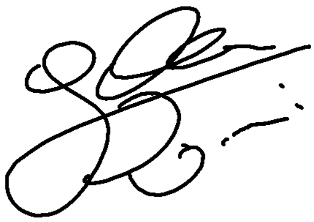

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Executive summary

Marlborough District Council's designated airshed of Blenheim is failing to meet the national air quality standard for PM_{10} and a number of different management strategies are being considered to improve the air quality in the town. One factor suspected of contributing to the problem is the release of emissions from burning events in Blenheim's rural surrounds, which drift into the airshed.

The purpose of this analysis is to identify factors that influence the contribution rural biomass burning makes to PM_{10} concentrations in Blenheim and illustrate the impact of these variables using case studies. Also, based on an analysis of the local meteorological data, landuse and basic principles of atmospheric dispersion, advice on the management of rural burning activities in proximity to Blenheim is put forward.

Analysis of the meteorological data from 2006 to 2011 shows marked seasonal differences. There is evidence that Winter (in particular) has more hours of very stable air, indicating the formation of inversion layers. Autumn and Winter show similar patterns that increase the risk of inadequate pollutant dispersion within the Blenheim airshed, and also increase sensitivity to pollutant sources directly west of Blenheim.

The case studies use real meteorological conditions to describe how dispersion from a rural burn directly west of Blenheim may affect the town on a partcular day. The factors which influence the impact of a burn are varied and to a great extent, unknown quantities.

Further data collection is required to better inform any proposed changes in the management of rural burning. An example of placing restrictions upon the timing of any rural burning directly west of Blenheim is given, but to allow an adequate assessment of the efficacy of any changes in management of rural burning on ambient concentrations, baseline data must be collected. Establishing a register of burning activities within the Wairau Valley is an important first step.

1 Introduction

Marlborough District Council (MDC) is responsible for the management of the quality of the air in its designated airsheds, ensuring it complies with the National Environmental Standards set out for Air Quality (the NESAQ) by the Ministry for the Environment (MfE).

Marlborough's only designated airshed is the town of Blenheim and it is of concern due to its failure to meet the NESAQ for PM_{10}, that is for particulate matter less than ten micrometres in aerodynamic diameter. The Standard mandates a maximum daily average concentration of 50 µg m^{-3}, which may be exceeded once a year. MDC has until 2016 to meet this. As Figure 1.1 shows, the number of exceedances of this threshold recorded in Blenheim has been increasing in recent years, throwing into question the efficacy of current air quality management plans and necessitating the consideration of wider measures to ensure compliance. In 2012 there were eight exceedances.

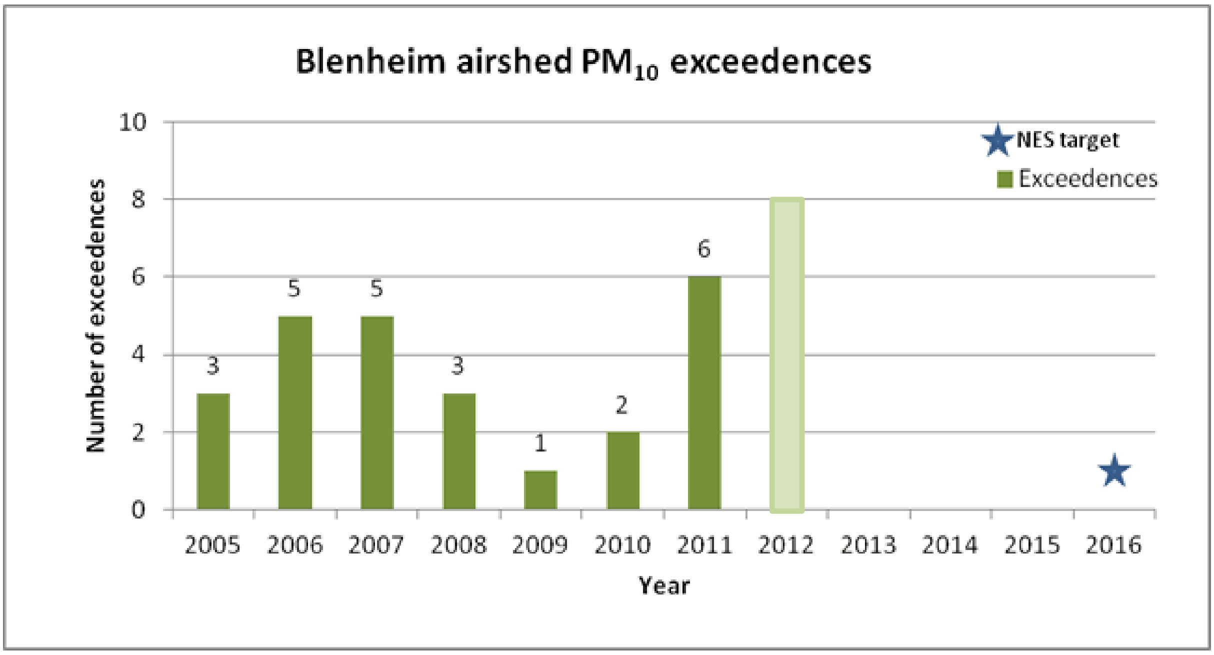

Figure 1-1 Number of NESAQ exceedances in Blenheim. Retrieved from: http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/nes/marlborough/blenheim.html **The lighter bar has been added by the author to bring the figure up to date.**

It is in this context that the effects of 'rural burning', that is outdoor biomass burning beyond the geographical limits of the urban centre, are investigated. This report identifies factors that influence the contribution rural burning makes to PM_{10} concentrations in Blenheim and illustrates the impact of these variables using case studies. It also provides advice on the management of rural burning activities in proximity to Blenheim, in particular upwind of the town, to the west.

2 Rural burning in Marlborough

In general, rural burning activities fall into three main types:

1. Seasonal stubble burning of remnant arable crops, conducted after harvest.
2. Seasonal burning of waste from pruning of orchards, vineyards etc.
3. Periodic burning of general farming waste, from maintenance of shelterbelts and other stands of vegetation.

There is little if no arable farming in the vicinity of Blenheim and so the practise of stubble burning, though common in other areas, is not relevant to this investigation.

Seasonal burning of prunings is common however, as the principal land use around Blenheim is vineyards. Grapes are harvested from late summer to autumn (February to April) and pruning is left until the plants are dormant, in winter. It is assumed by the author that disposal of the waste is carried out quickly after pruning in order to minimise any reservoirs of disease on the property, that may affect new spring growth. The waste burned at these times will be relatively uniform; small sized dormant wood and vegetation that will not be dry or seasoned, but will not be in leaf.

General farming waste may build up throughout the year, with waste-generating activities like pruning hedges, topping shelterbelts occurring in between more time-sensitive, core activities. These kinds of activities will produce more mixed fuel – often green or with a high moisture content. There may also be contaminants, such as damaged horticultural netting and films, silage wrap or feed bags and maybe treated timber, from re-fencing.

In both cases accelerants may be used to start the fire. This will increase the burn temperature and so should decrease smoke generation. However, the by-products of the accelerants will also be added to the generated pollutants.

Another purpose for burning which should be mentioned is frost protection. Historically, growers have lit fires close to vines and orchards to produce heat and smoke to minimise risk of frost. (Although producing heat in an area may be helpful, the belief that the smoke will act similarly to cloud or water vapour, in trapping heat close to the ground is dubious.[1]) More controlled methods of this principle include the use of smudge or smoke pots to produce heat and smoke. These are now banned in Marlborough. An alternative are return stack burners, which minimise smoke while creating heat. The use of these is a controlled activity and requires consent from MDC (Smart, 2006).

[1] Smoke does not act like fog because smoke particles are too small to block long-wave radiation loss the way water vapour does. So it cannot 'trap' heat close to the ground. In fact, smoke not only has no effect on outgoing long-wave radiation; it actually impedes warming in the morning, because smoke particles *are* the right size to block the incoming shortwave solar energy

2.1 Current regulations for rural burning

Although we are approaching rural burning as an air quality hazard, it is usually seen as a fire hazard and is regulated as such. Generally, it should be noted that the conditions that facilitate good dispersion (i.e., high winds and low humidity) are the same conditions that increase the risk of a rural burn getting out of control and so are, to a degree, avoided.

The Marlborough-Kaikoura Rural Fire Authority determines the level of fire-risk depending upon climatic conditions and designates a fire season accordingly. The following details are sourced from MDC's website, accessed February 2013.

Open fire season means no permit is required to light a fire. Apart from some localities where restrictions are permanently in place (fire protection zones), between May and October there are usually no restrictions and no permits to burn are necessary.

A restricted fire season means a permit is required to be issued for any rural burning. MDC administer the fire permits but it is the responsibility of the Administration Fire Zone Rural Fire Officer to approve a permit and carry out any site inspections deemed necessary. Approval is given after considering a range of factors which affect the safety of the burn. These include:

- The location and vehicle accessibility of the proposed burn
- The type of fuel to be burned
- The prevailing weather, long-term forecast and the local exposure to wind
- The location and size of any fire breaks and on-site availability of fire-fighting resources
- The proximity of scrub, buildings, overhead wires, trees, silage and other potential hazards

Most permits will be issued for a period that allows the applicant to wait for ideal conditions before lighting. For large burns a burn plan may be required. Failure to obtain a permit before burning is an offence which carries a fine of $1500.

A burn plan will set out specific stipulations to ensure the burn is safe and of minimal nuisance. It may include details that are pertinent to air quality impacts, such as checking for inversion layers on the morning of the burn and delaying if present, managing the smoke by burying residue in pre-dug holes and stopping the fire early if an inversion is expected that night.

A Prohibited Fire Season or Total Fire Ban means no burning at all is allowed and any issued permits are revoked for the duration.

3 The relative contribution of rural burning to Blenheim air quality

The relative impact rural burning has upon ambient concentrations very much depends upon the time of year. Pruning in winter of vines will generate waste to be burned then. Burning of waste vegetation from property maintenance will be less predictable in timing, however Total Fire Bans over hotter, drier months will also push the occurrence of these activities into the autumn, winter and spring.

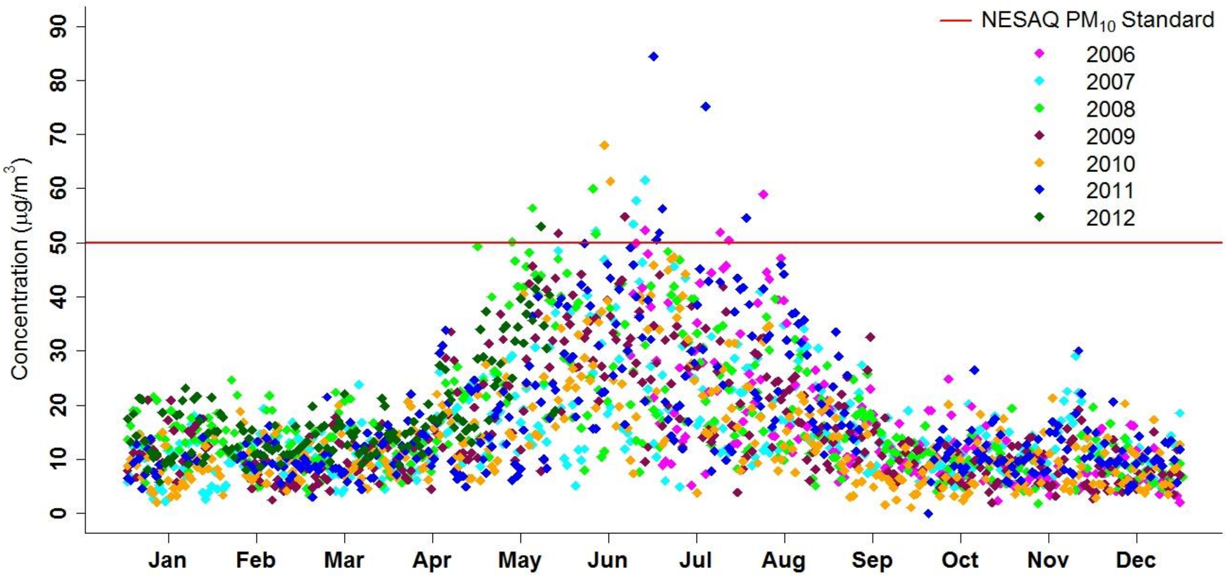

Figure 3-1: Daily average PM_{10} concentrations for the years 2006 to 2012.

Figure 3-1 shows the daily PM_{10} concentrations recorded in Blenheim at the Redwoodtown site over six years. For most of the year, ambient air quality in Blenheim is good, with 24 hour average PM_{10} concentrations beginning to show elevation in April, reaching maxima in June or July and decreasing back to 'background' levels by September. This pattern is caused by increased PM_{10} emissions from wood-burning for domestic heating by the residents of Blenheim, and an increased frequency of atmospheric inversion layers which prevents the adequate dispersion of air pollutants.

Although the absolute pollutant concentrations caused by rural burning are unknown, the relative contribution to ambient concentrations can be described. Outside of this wintertime pattern, the relative contribution of any rural burning on the ambient concentration may be high as there are few other sources, but the background concentration is low enough that there is no risk of an exceedance. During this pattern the relative contribution of rural burning will be small. As a parallel, Wilton (2012) estimates the contribution of outdoor burning within Blenheim during winter is approximately 5%. Although a rural burn is potentially a larger source than a 'backyard' burn, the greater distance the pollution must travel and therefore will disperse over before it reaches the Blenheim airshed means that its contribution is unlikely to be greater than the 5% from local outdoor burning. However, with concentrations already elevated by local emissions during winter, the drift of smoke from rural burning may be an extra burden that tips the ambient concentration beyond the threshold of 50 µg m^{-3} and so contribute to exceedances.

4 Analysis of local meteorological measurements

The factors that determine the dispersion of outdoor burning emissions are the wind direction and wind speed and the stability of the atmosphere into which the pollutant is being released. Wind speed and direction are directly measured, whereas atmospheric stability is not. These meteorological factors are determined in part by the location of the area of interest and its surrounding topography. Figure 4-1 shows the siting of Blenheim within the channel of the Wairau River, with the Wither Hills directly south of the town.

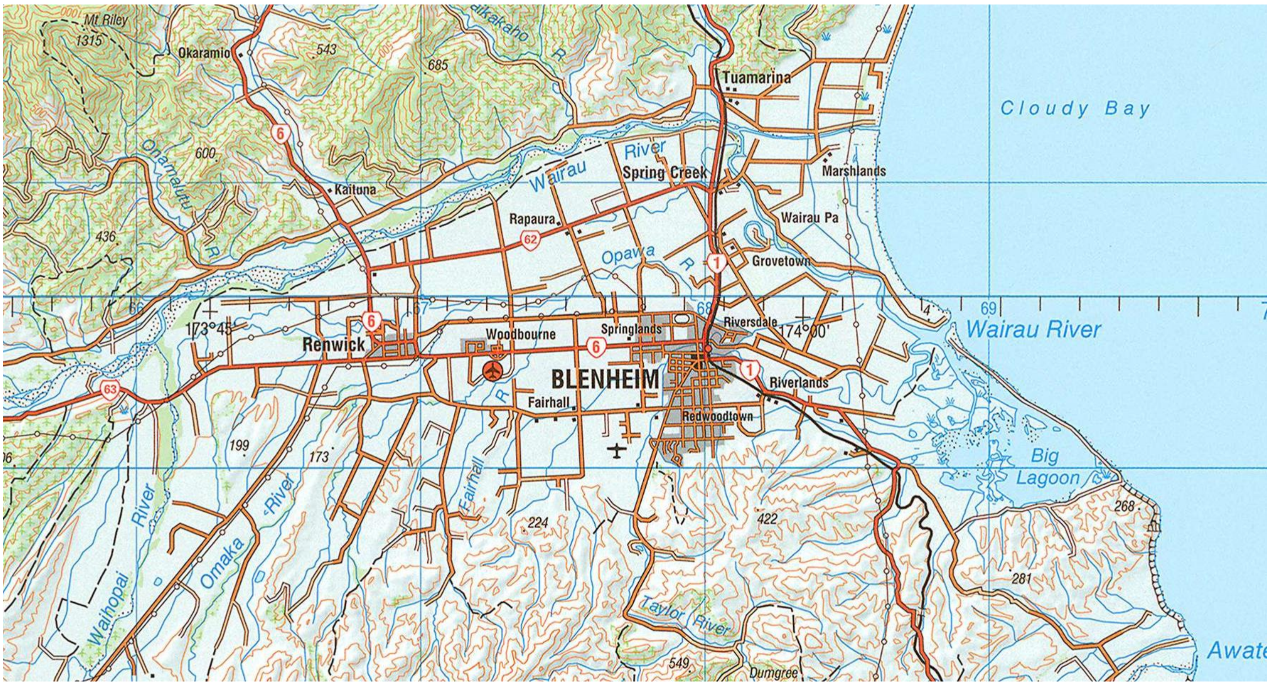

Figure 4-1: Map of Blenheim and surrounds. (Generated by Maptoaster)

This suggests that winds will be channelled down this valley and an analysis of the hourly wind data measured at the Blenheim EWS site from 2006 to 2011 show this. Figure 4-2 shows the winds at Blenheim for each season. Autumn and winter in particular show westerlies predominating, that is flow down the valley to the sea. The windspeeds are generally low, often 2 – 4 m/s. Spring has the strongest winds, with the westerly less dominant but still a feature. In summer, winds are more variable in direction.

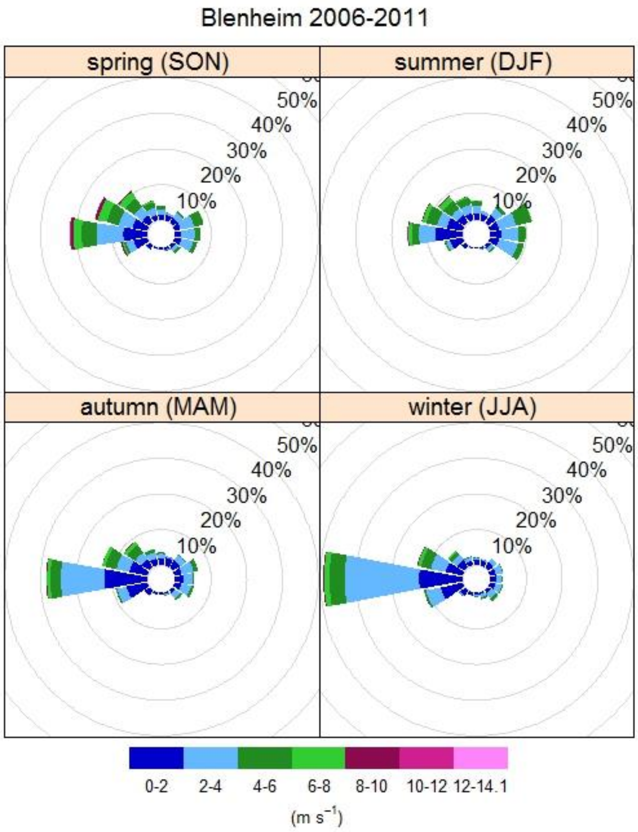

Figure 4-2: Wind roses by season for 2006 to 2011.

This description gives an indication of the seasonal patterns, but a rural burn takes place over a day, or maybe a few if left burning. The patterns that have an immediate impact are what happens throughout the day and the next sections seek to describe these.

4.1 Daily wind direction

In Figure 4-3 the sequence of plots give an indication of the distribution of wind directions measured hourly from 2006 to 2011, over the diurnal cycle, for each season. Each 'ladder' shows the distribution of the wind directions for one hour of the day, with the distance between 'rungs' of the ladder equalling 10% of the data points for that hour. This means that if the rungs are bunched together, there are more data for that hour with that wind direction. Where the rungs are spaced out there are fewer data and so that wind direction is less prevalent. Of course, wind direction is circular and so the 'top' and 'bottom' 10%s are artificially separated on this plot, where in reality, they are adjacent to each other. The plots give an indication of how wind directions change throughout the day each season, from Spring to Winter.

Firstly, there is an obvious difference in the morning between Spring and Summer, and Autumn and Winter, which show a much stronger grouping of measurements within a tight band of 30-40 degrees around 270º – west. This continues up until 10-11am and means smoke from fires lit during this time is most likely to drift west. During Spring and Summer over 50% of measurements are still westerly (as opposed to 80% for winter), but there is more variation in general.

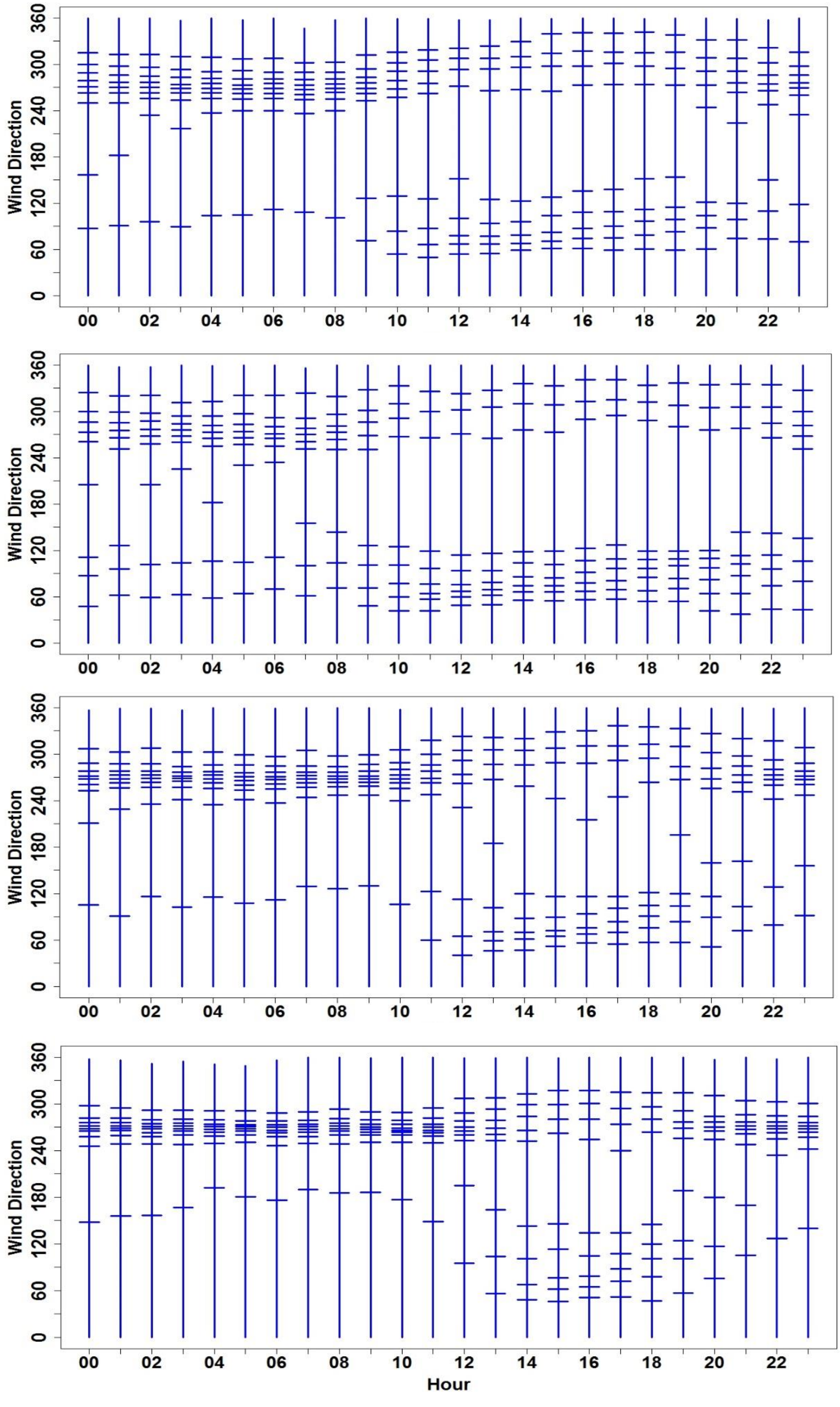

Figure 4-3: Diurnal patterns of wind direction. (Spring, Summer, Autumn, Winter)

Secondly, there is a 'shift' in pattern in all season that begins to occur around midday or later. Westerlies become far less common and measurements focus in more easterly directions (say 40^o to 90^o). In Summer this shift in pattern is sharp at hour 11 as is the return to the morning pattern, which occurs in hour 23. Fifty percent of data in the morning are westerly and in the afternoon, around 50% are easterly. This shifting pattern may be explained by a land-sea breeze system. The pattern is less pronounced in other seasons (as are sea breezes), or occurs more gradually.

4.2 Daily windspeed

Figure 4-4 shows similar plots produced for windspeed, from Spring to Winter. With box and whisker plots, the median value is given by the horizontal black bar. The boxes directly below and above the bar show the extent of the central 50% of data around the median. The extent of the upper and lower 25% of data are shown by the 'whiskers'.

In general, the patterns confirm what the seasonal wind roses showed. Windspeeds are generally low, particularly in the morning, with a rise as the day progresses. The winds then subside in the late evening. During winter, there is barely a diurnal pattern present, with at least 75% of winds under 4m/s for all hours of the day. This most certainly hinders dispersion during this period, and with variable wind directions in the afternoon-evening, means that plumes may drift one way and then return with a change in wind direction, and never adequately disperse.

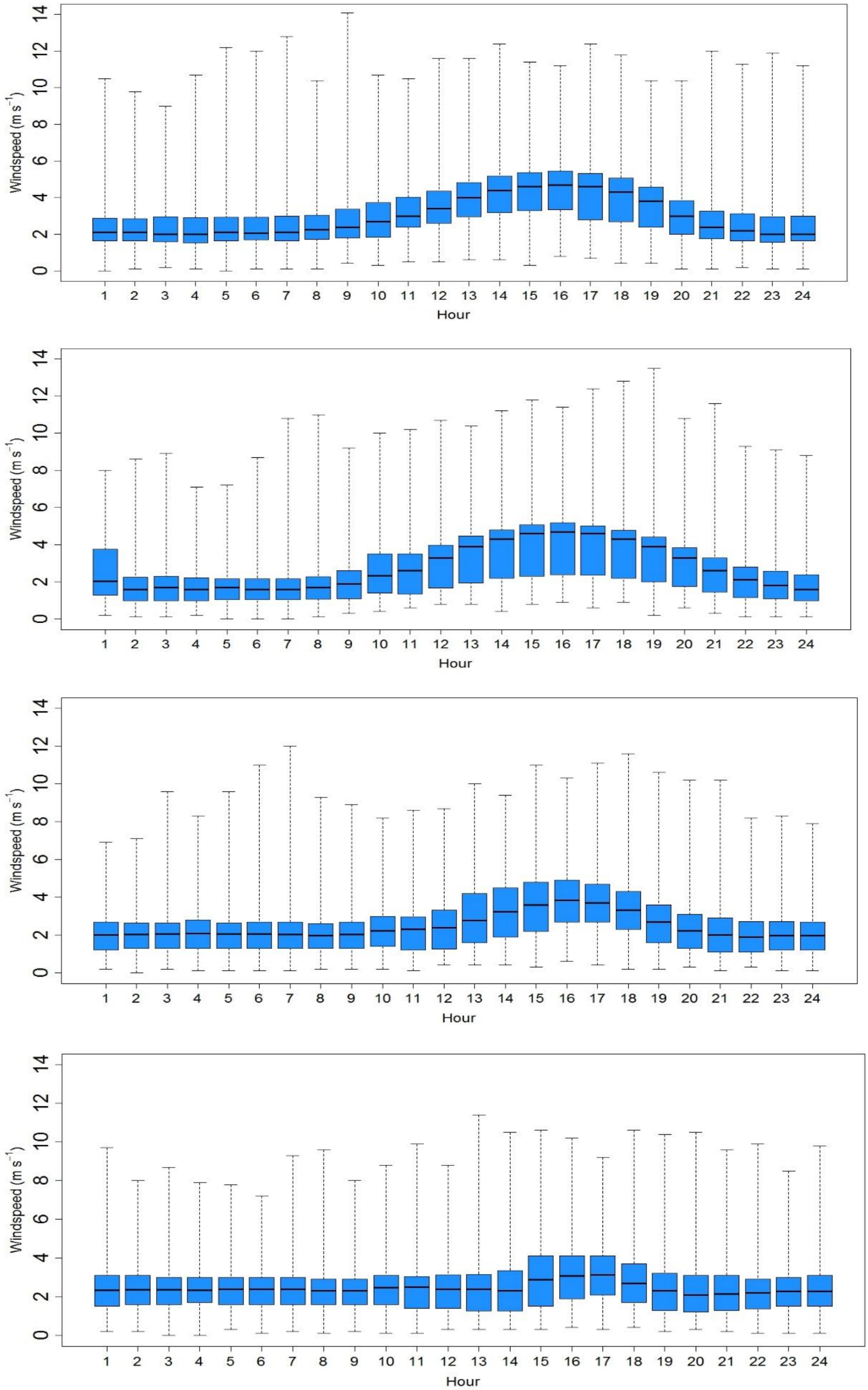

Figure 4-4: Diurnal patterns of windspeed. (Spring, Summer, Autumn, Winter)

4.3 Stability

Although stability is not directly measured, certain meteorological measurements may be combined to generate an indicative measure or categorisation of the stability (the Pasguill-Gifford (P-G) stability). They are: solar radiation, cloud cover and wind speed. These data are collected within Blenheim at the EWS climate station or directly west of the town at Woodbourne airport. The matrix used to categorise each hour of data into a P-G stability is given in Appendix A and follows the method described in the Auckland Council report AUCRCAKL02 (Golder, 2009).

The P-G stability classes are as follows:

- A – very unstable
- B – unstable
- C – slightly unstable
- D – neutral
- E – slightly stable
- F – stable

Essentially, the more unstable the atmosphere, the greater the dispersion of any pollutant emitted. Conversely, the more stable the atmosphere the harder it is for adequate dispersion to take place.

Figure 4-5 shows the seasonal differences in the abundance of the different P-G classes. All season show high numbers of neutral (D) hours, which is not unusual and should not hinder dispersion. Spring and Summer show more unstable (A-C) hours than Autumn or Winter, which have greater stable hours (E-F). It is this shift to more stable conditions that increases the risk of an inversion layer forming and trapping pollutants close to the ground.

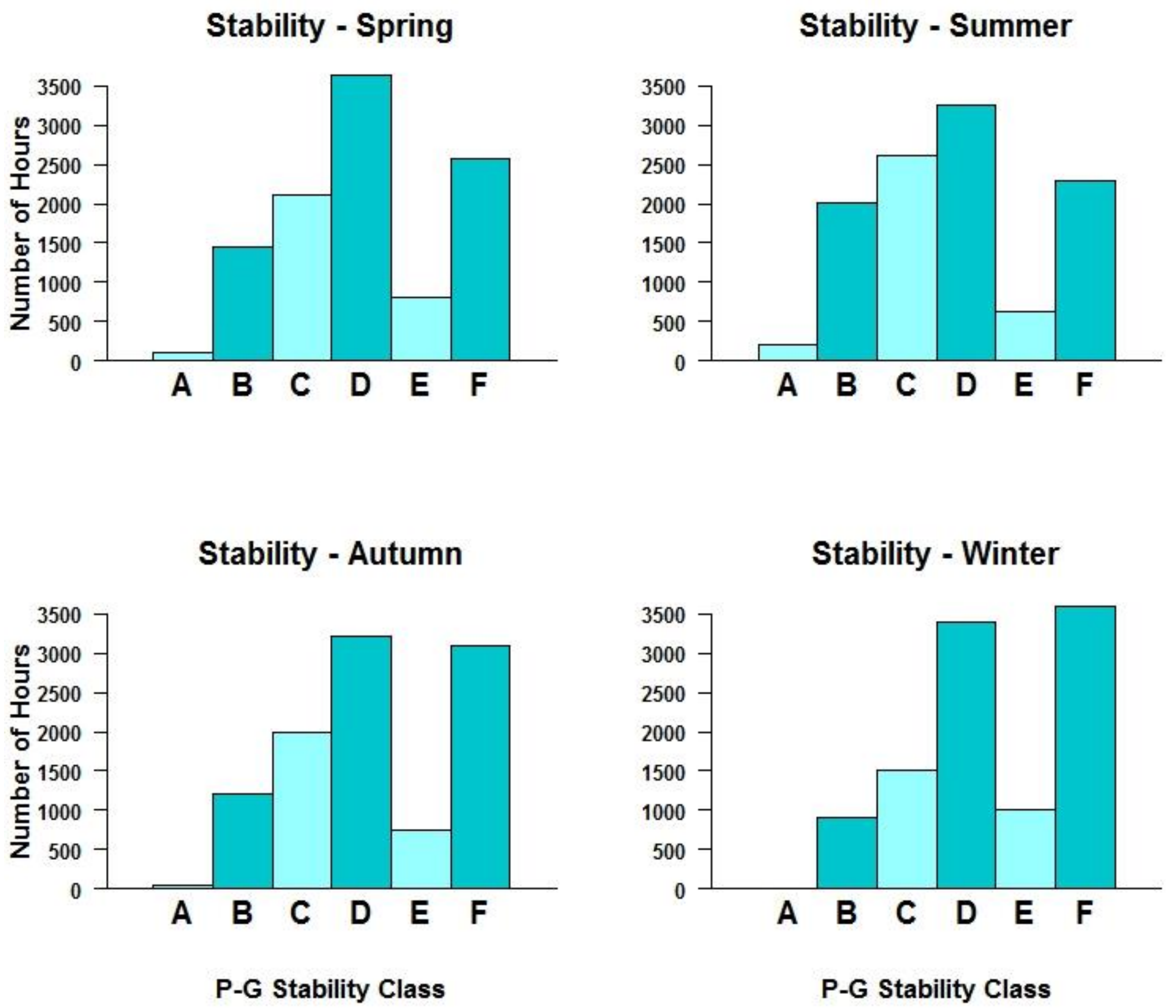

Figure 4-5: Seasonal frequency of P-G stability classes over 2006-2011.

4.4 Implications of meteorology on dispersion

The analysis of the meteorology shows clearly the role meteorology plays in elevated winter-time concentrations. The conditions for inversion layers are more frequent and windspeeds low. Winter and Autumn display many of the same patterns in wind flows, while Spring and Summer are more closely aligned.

5 Case Studies

Three examples have been chosen to illustrate the effect of meteorology upon dispersion. The meteorological data presented here are real but their effects are described in relation to a theoretical burn event taking place directly west of Blenheim. The periods are a day and a half long, in order to describe the conditions on the morning of ignition and overnight into the following morning. The effects described are plausible but only indicative. The magnitude of any effects would depend upon the nature of the fire and its proximity to Blenheim.

The plots used to illustrate these examples hold a great deal of information. Temperature (red) and windspeed (pink) are given on the left axis, while rainfall (blue) and relative humidity (cyan) are on the right axis. Along the top, for each hour, a pink arrow indicates the wind direction and the P-G stability classification calculated for that hour is also given.

5.1 2-3 November 2009 (Spring)

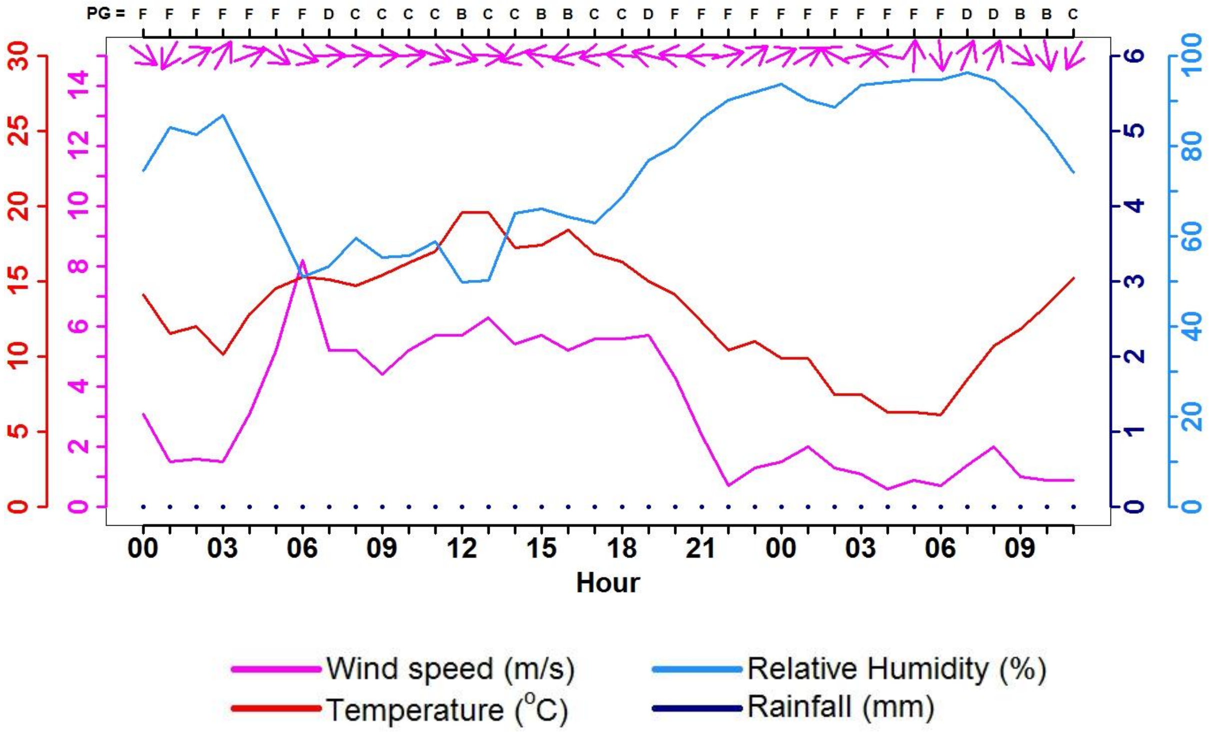

Figure 5-1: Case Study 1: 2-3 November, 2009.

In the early morning the air is very stable, but the windspeed increases steadily and an inversion layer is unlikely. From around 06 hour the wind direction is westerly and ignition at this time will send pollutant towards Blenheim. The windspeed is relatively good for Blenheim, i.e., above 4m/s. At around 14 hour there is a reversal in wind direction. This means new emissions will not be travelling towards Blenheim, but emissions that have already passed over Blenheim may drift back. During the day, up until around 19 hour, conditions are unstable and favourable for good dispersion. After 19 hour the atmosphere becomes stable, the windspeed drops away to under 2m/s and the wind direction turns back to a westerly. If the fire is still smouldering, there is a danger of inadequate dispersion and an accumulation of emissions from this fire over Blenheim. The wind direction overnight becomes variable, meaning the pollutants may drift back and forth over the town.

5.2 3-4 April 2010 (Autumn)

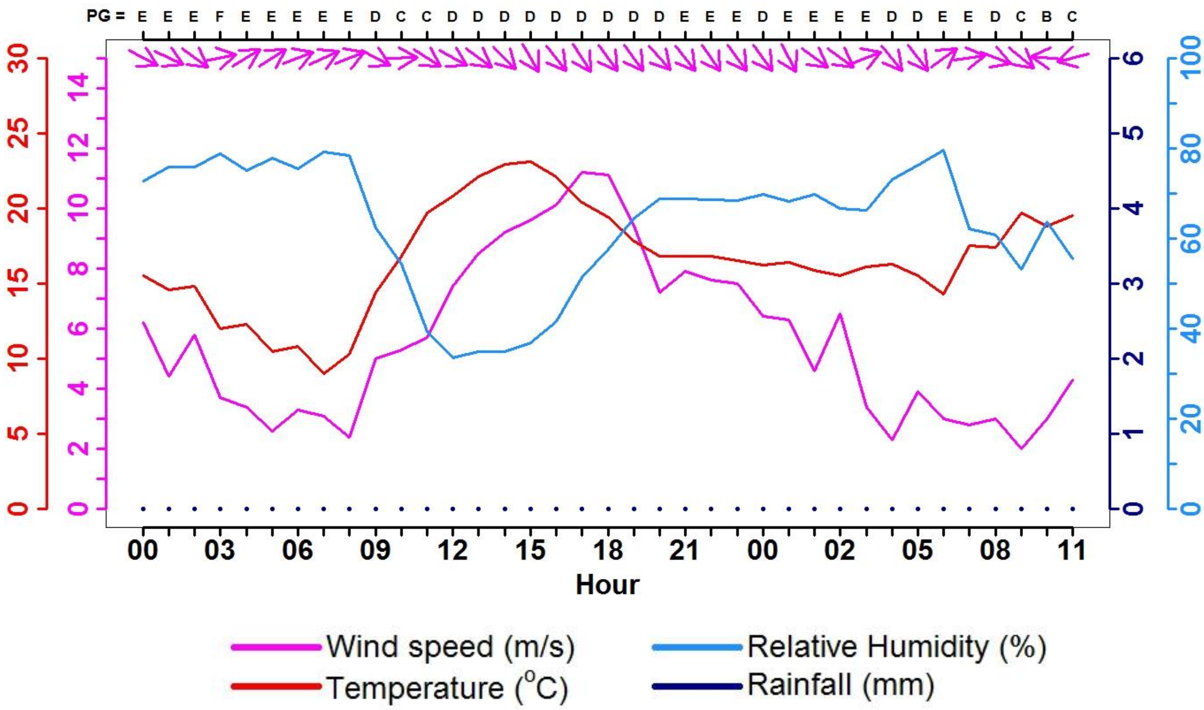

Figure 5-2: Case Study 2: 3-4 April, 2010.

The early morning is slightly stable with low windspeeds and a westerly direction. This changes around 09 hour, so any ignition before then may affect Blenheim, with emissions drifting towards the town and less than ideal conditions for dispersion. After 9:00 hour the wind increases in strength and moves around to the northwest. This means the emissions will be moving up and over the Wither Hills, however there is a risk that part of the plume may follow the contour of the hills west instead and affect Blenheim. Nevertheless, strong winds mean dispersion will be adequate. The windspeed gradually decreases throughout the night with a few hours of light and variable winds from 03 where any residual smouldering may send smoke back and forth across Blenheim. However, the atmosphere remains relatively unstable, so dispersion should remain adequate overnight and the following morning.

5.3 14-15 August 2009 (Winter)

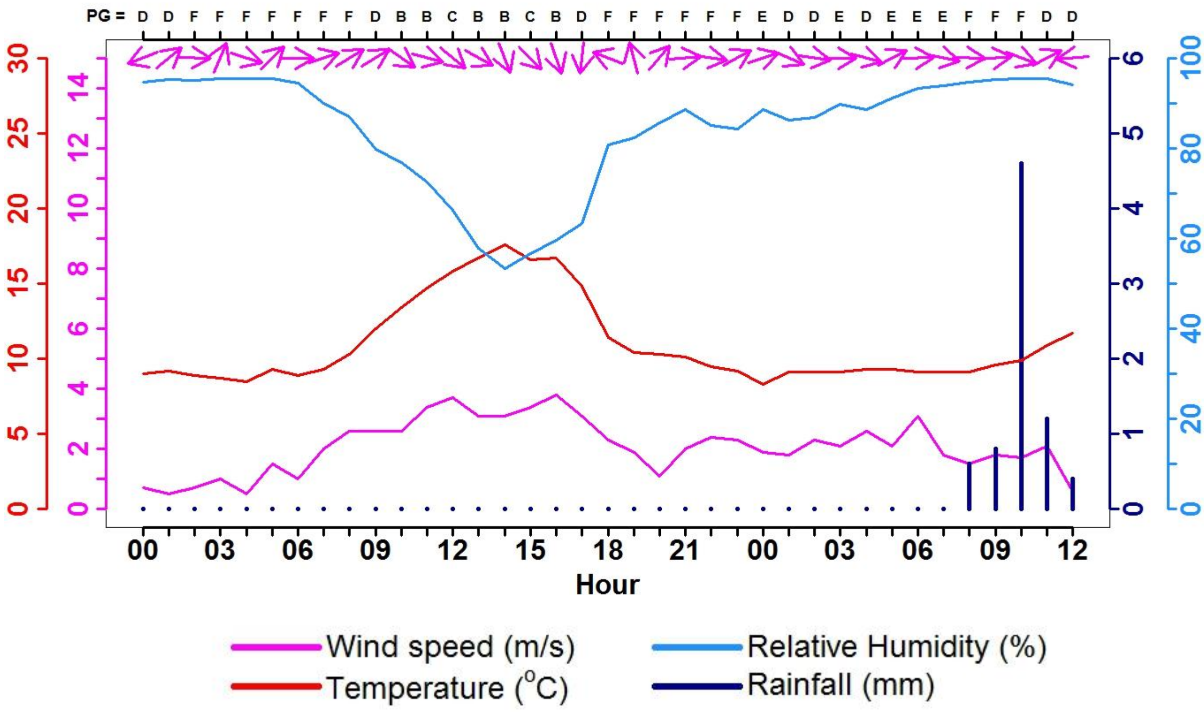

Figure 5-3: Case Study 3: 14-15 August, 2009.

The third example is a typical winter period. The P-G stability remains stable from the early hours of the morning until around 09 hour. Windspeeds are low and direction variable, but generally westerly between 06 and 09. An inversion layer is quite likely. Ignition during this time would lead to very poor dispersion of smoke over Blenheim. The windspeed picks up a little throughout the morning and the direction swings to a more northerly. With windspeeds lower than the second example, there is a greater risk that the plume will follow the contours of the Wither Hills rather than being pushed over them. The atmosphere becomes stable again around 17 hour. This is when the windspeed decreases and direction becomes variable for a few hours before settling into a westerly flow until the next morning. The atmosphere is neutral or slightly stable for the night, so it is unclear if an inversion layer would form. However any residual emissions will be drifting into Blenheim on low windspeeds, so dispersion will not be ideal. An inversion layer may form the next morning with 08 to 10 hours having P-G stability of F, however the rainfall will have a positive effect on ambient concentrations by washing pollutants out of the atmosphere.

5.4 Effect of distance from source

In an attempt to demonstrate the effects of proximity to source, an artificial case study has been modelled using Ausplume, a steady state model based on Gaussian dispersion, using very primitive assumptions. This is not intended to give any indication of the effect of a real fire on ambient concentrations, simply to demonstrate the difference in amplitude of an effect, depending upon the distance between a fire and a measurement site. The meteorological data used in Ausplume was a range of windspeeds and stabilities, with wind direction constant at 270^{o} so that receptors directly east of the source were constantly exposed. The emission strength was purely nominal and constant for all hours of the run.

Thus there is no indication of actual concentrations in Figure 5-4; the results are purely relative to each other. Within one hour's results, the difference is solely dependent upon distance to source. Between hours (for the same receptor) the difference is a combination of windspeed and stability.

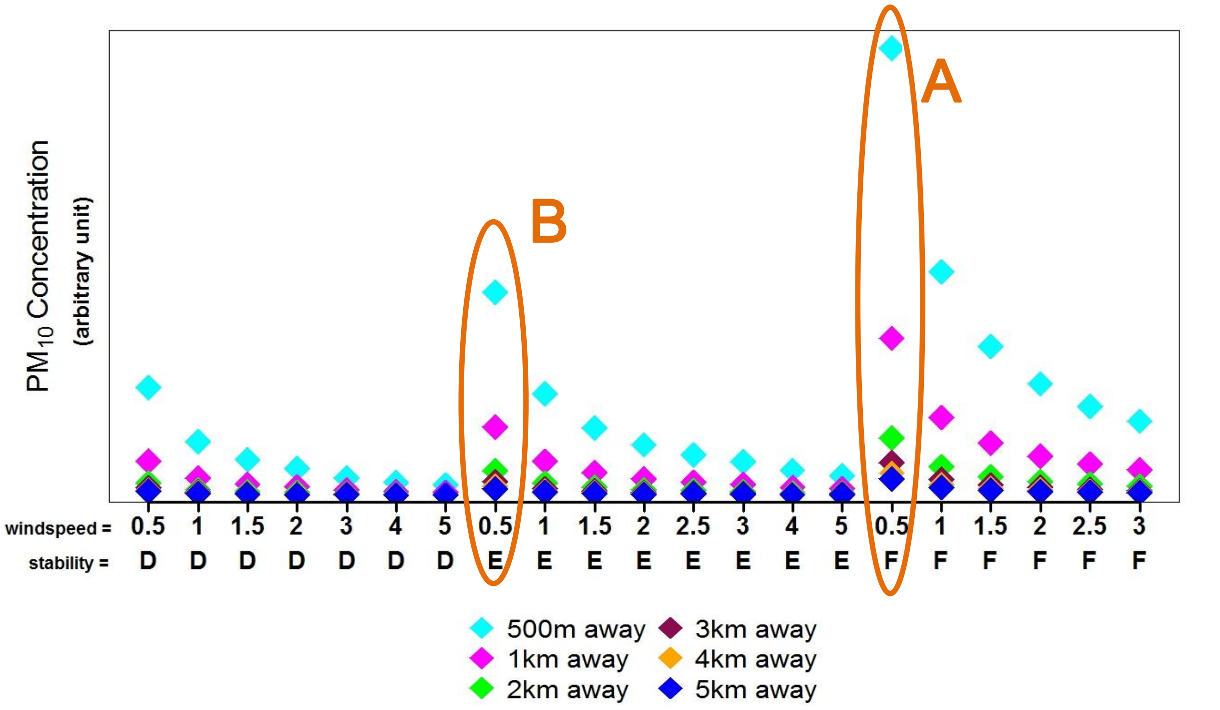

Figure 5-4: Ausplume output for a single receptor at varying distances from emission source.

For each hour, it can be clearly seen that closest receptor 500m away (cyan coloured) is exposed to largest concentrations. The next receptor (pink) is twice as far away and is exposed to about 30% of the concentration the first is. The differences between the receptors further away are very small and are only apparent under worst meteorological conditions – the hour labelled "A". Under these conditions, the concentrations 5km away are about 4% of the concentrations 500m away from the emission source.

By comparing the hours labelled "A" and "B", the effect of stability can also be seen. These two hours have same windspeed, but by shifting the atmospheric stability from E – slightly stable to F – stable, the concentrations at the receptors effectively double.

By comparing the hours directly after "A" and "B", the effect of greater wind speed can be seen. Doubling the windspeed form 0.5 m/s to 1.0 m/s halves the concentration. The concentrations taper off as windspeed increases, effectively halving in strength as windspeed doubles.

This example serves as an indication only, of the relative effect of these factors, in a simplified form. Ausplume also does not account for the effects of the terrain on the plume trajectory, washout from rain, or the cumulative effects of poor dispersion upon ambient concentrations. It calculates each hour independently from the next. It does not take into account wind variability or gustiness. However, the general principles of Gaussian dispersion are sound and informative.

6 Conclusions and Recommendations

The decision of when to burn will always be dominated by when is it safe in terms of low risk of a fire getting out of control and becoming a hazard. Within the periods that those concerns leave, the next concern is when is there a risk that the smoke from a rural fire will not disperse adequately and become a nuisance, and what practices can reduce the creation of smoke. These are adequately addressed by the current guidance (see MDC's rural burning guide), which can be found on the MDC website, and which failure to comply with can result in penalties.

This analysis has focussed solely on the effects rural burning may have on ambient PM_{10} concentrations. Other contaminants have not been considered.

This analysis has used hourly averaged meteorological data. In reality, the atmosphere is far more variable than shown here and the patterns described may be interrupted intermittently and repeatedly for better or worse plume dispersion than expected.

The analysis shows that both Winter and Autumn have an increased risk of both:

- inadequate pollutant dispersion in Blenheim
- sensitivity to pollutant sources directly west of Blenheim.

There is little understanding of the current magnitude of the effect of rural burning. One way to start to quantify this would be to require all land-owners along the Wairau Valley to register the date of any burns they have with MDC, so that the concentrations measured on these dates, at the Springlands site (on the western edge of Blenheim), can be compared with dates of non-burning events in order to see if there is any significant difference. It is recommended that data be collected at least for one year, in order to discern any seasonality in results and to confirm that assumptions stated here about the timing of burning practises hold true.

In regards to minimising the risk rural burning poses to contributing to an exceedance of the NESAQ for PM_{10}, Figure 3-1 shows that the months of concern are April to August, when the ambient concentrations are already elevated.

Based upon this risk, a possible management plan could be:

- A Total Fire Ban within the Wairau Valley up to 5km from Blenheim for the months April to July inclusive
- Have a Restricted Fire Season for the month of August for the same area. Require a permit for burning which takes into consideration the clearing of any inversion layer in the morning before ignition and the burying of any residue in pre-dug pits before any inversion forms on the day, so there is no overnight smouldering

It is unclear what effect these measures would have on ambient concentrations in Blenheim. Without baseline data collected before the implementation, attributing any changes in ambient pollutant concentrations to a new management plan could only be speculative.

7 References

Golder Associates, 2009, "Meteorological Data sets for the Auckland Region", Report number AUCRCAKL024

Smart, Joanne, October 2006, "Burning for frost protection", Marlborough District Council Presentation accessed March 2013 at http://wineinf.nzwine.com/research_outputs.asp?id=124&cid=2&type=r

MDC http://www.marlborough.govt.nz/Services/Permits-and-Licences/Fire-Permits.aspx accessed February 2013

Wilton, E., 2012, "Blenheim Emission Inventory – 2012", Marlborough District Council Report.

Appendix A Assigning P-G Stability Classes

Wind Speed (m/s)	Day time				1h before sunset and after sunrise	Night time		
	Solar Radiation (W/m²)					Cloud cover (okta)		
	Strong >925	Moderate 675-900	Slight 175-675	Overcast <175		0-3 cloud	4-7 cloud	8 cloud
<2	A	A	B	D	D	F	F	D
<3	A	B	C	D	D	F	E	D
<5	B	B	C	D	D	E	D	D
5-6	C	C	D	D	D	D	D	D
>6	C	D	D	D	D	D	D	D

Table 9 from Golder (2009): Stability class assignments used by VicEPA.