Air quality in the Wellington region

State and trends

Quality for Life

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Main cover photo: The morning after – smoke clearing from domestic fires in Masterton

Executive summary

Greater Wellington monitors air quality at selected residential and traffic-related locations in the Wellington region for key contaminants produced by domestic fires, motor vehicles and certain industrial processes. Emissions from these sources can cause air quality to be degraded under meteorological conditions that restrict the dispersion of pollutants.

This report assesses the results of State of the Environment (SoE) air quality monitoring undertaken in the region over the period 2000 to 2010 inclusive, describing both the current state of air quality[1] and spatial and temporal trends in air quality. Information from targeted investigations and source apportionment studies, such as emission inventories and receptor modelling, are also presented.

Routine SoE air quality monitoring at eight sites shows that, overall, the Wellington region has good air quality most of the time for three indicator pollutants: PM_{10}, carbon monoxide and nitrogen dioxide. At residential monitoring sites in Lower Hutt, Upper Hutt, Wainuiomata, Masterton and Tawa, concentrations of carbon monoxide and nitrogen dioxide were relatively low and well within national standards and guidelines. PM_{10} concentrations at these sites were also low, apart from during the winter months in Masterton and Wainuiomata when the National Environmental Standard for Air Quality (NES-AQ) daily limit was approached or exceeded on some occasions; this was limited to cold, calm and clear nights which restrict the dispersal of particulate matter.

Average concentrations of PM_{10} declined in Masterton, Wainuiomata and in Upper Hutt during the past 10 years – but there was no apparent trend in the number of high pollution nights experienced each year. A closer examination of the relationship between meteorology and high pollution episodes is needed in order to understand the impact of inter-annual variation in meteorology on air quality trends.

Air quality at monitoring sites located next to heavily trafficked roads in central Wellington, Ngauranga (Wellington city) and Melling (Lower Hutt), although poorer than that measured at the residential sites, met all national standards and guidelines for the three indicator pollutants measured. Pollutant concentrations measured at the long-term monitoring site in central Wellington city declined over 2004[2] to 2010, although the trends were in part influenced by a major change in traffic flows due to the completion of the inner city bypass in early 2007 as well as improvements in data quality since 2008.

Despite full compliance with air quality guidelines at transport monitoring sites, a national screening programme carried out by the New Zealand Transport Authority has shown that nitrogen dioxide concentrations may be elevated on some heavily trafficked local roads which are surrounded by buildings that interfere with the dispersal of pollutants. There may also be potential for some impact on air quality in areas adjacent to the Port of Wellington as a result of sulphur dioxide emissions from shipping activities in Wellington Harbour.

Emissions from domestic fires used for home heating are the major source of PM_{10} contributing to poor winter air quality in some parts of the region, including Masterton,

[1] Based on a shorter, more recent period (2008 to 2010 for most sites).

[2] 2005 to 2010 for nitrogen dioxide.

Upper Hutt, Wainuiomata, Carterton, Featherston and Raumati South. Most of this PM_{10} is emitted in the form of $PM_{2.5}$ – a finer fraction (and a component of PM_{10}) which is more strongly associated with adverse health effects than PM_{10} – which, on cold, calm and clear nights, is likely to exceed both the WHO (2006) guideline and the MfE (2002) reporting limit. $PM_{2.5}$ may contain other hazardous air pollutants such as polycyclic aromatic hydrocarbons and, in areas such as Wainuiomata where CCA-treated timber is used as an intermittent fuel source, arsenic.

The Wairarapa airshed (containing the Masterton monitoring site) was the only airshed in the region to officially breach the NES-AQ, which it did in 2006, 2008 and in 2010. Based on the number of high PM_{10} nights over 2008 to 2010 alone, on 1 September 2012 the Wairarapa airshed will be deemed as 'polluted' under the NES-AQ. While natural attrition of the older and more polluting wood burners may assist with reducing PM_{10} emissions in this airshed, it is unclear from the 2008 Masterton emission inventory whether this alone will be sufficient to ensure compliance with the NES-AQ by 2016. A further complicating factor is that screening studies undertaken at other locations in urban Masterton during winter 2010 suggest that the existing monitoring site at Wairarapa College may not represent the worst air quality in the Wairarapa airshed (as required by the NES-AQ).

Recommendations for future monitoring and investigations are listed in Section 8.1.

Contents

1. Introduction

Clean, fresh air is one of the fundamental resources for supporting healthy living. Greater Wellington monitors air quality at selected locations in the Wellington region for key contaminants produced by domestic fires, motor vehicles and certain industrial processes. Emissions from these sources can cause air quality to be degraded under meteorological conditions that restrict the dispersion of pollutants.

This report assesses the results of state of the environment air quality monitoring undertaken in the Wellington region over the period 2000 to 2010 inclusive. Specifically, it assesses the state of air quality and examines trends in air quality and emissions over the reporting period. Monitoring the state of the environment is a specific requirement for regional councils under Section 35(2)(a) of the Resource Management Act (RMA) 1991.

1.1 Report purpose

This technical report is one of eight covering air, land and water resources prepared with the primary purpose of informing the review of Greater Wellington's five regional plans. These plans were established to sustainably manage the region's natural resources, including the quality of the region's air. The review of the regional plans follows the recently completed review of the overarching Regional Policy Statement (RPS) for the Wellington region (GWRC 2010a).

The focus of the eight technical reports is on providing an up-to-date analysis of monitoring information on state and trends in resource health as opposed to assessing the effectiveness of specific policies in the existing RPS (WRC 1995) or regional plans. Policy effectiveness reports were prepared in 2006 following the release of Greater Wellington's last formal State of the Environment (SoE) report, *Measuring up* (GWRC 2005).

The last technical report on state and trends in air quality was prepared by Davy (2005a); this report focussed on the results of air quality monitoring carried out between 1999 and 2004.[3]

1.2 Report scope

The report focuses largely on data gathered through routine air quality monitoring and targeted investigations carried out since 2000. The report also includes information on source apportionment studies, such as emission inventories and receptor modelling, and targeted investigations into contaminants of concern.

[3] Greater Wellington also prepares annual summary reports documenting SoE monitoring results obtained in the last financial year (calendar year in the case of air quality). Refer to Mitchell (2012) for the most recent annual air quality monitoring report.

1.3 Report outline

The report comprises eight sections:

- Section 2 outlines Greater Wellington's air quality monitoring network, sampling methods and air quality indicators.
- Section 3 provides an overview of emissions of pollutants in the Wellington region and key pressures likely to impact on air quality.
- Section 4 presents an analysis of the current state of air quality at urban residential and roadside sites in the Wellington region based on routine monitoring between 2008 and 2010. Available information on hazardous air pollutants is also presented.
- Section 5 provides an overview of receptor modelling identifying the sources of particulate matter in the region.
- Section 6 assesses spatial and temporal trends in air quality in selected airsheds across the Wellington region between 2000 and 2010.
- Section 7 discusses the main findings from Sections 3 to 6 and the implications for future monitoring and compliance with the NES-AQ. The estimated social costs associated with exposure to PM_{10} in the region are also outlined.
- Section 8 presents conclusions and recommendations.

1.4 Terms and definitions

A number of air quality variables and reference documents have been abbreviated in this report. Generally, the names are mentioned in full on their first use in each section. The principal acronyms used are listed in Table 1.1.

Table 1.1: List of main acronyms used in this report

Acronym	Definition
CO	Carbon monoxide
MfE	Ministry for the Environment
NES-AQ	Resource Management (National Environmental Standards for Air Quality) Regulations 2004
NO_2	Nitrogen dioxide
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate matter
PM_{10}	Particulate matter with aerodynamic diameter of 10 microns or less
$PM_{2.5}$	Fine fraction of particulate matter with aerodynamic diameter of 2.5 microns or less
$PM_{2.5-10}$	Coarse fraction of particulate matter with aerodynamic diameter between 2.5 and 10 microns
RAQMP	Regional Air Quality Management Plan for the Wellington region (2000)

2. Overview of air quality monitoring in the Wellington region

2.1 Background

Designing a monitoring programme to accurately characterise pollutant concentrations in the Wellington region is challenging due to the spatial and temporal variations in air quality. The region has complex topography and non-uniform climatology – ranging from exposed coastal areas to sheltered valleys – resulting in highly variable air quality on a daily and seasonal basis. Air quality monitoring is technically specialised and requires considerable financial investment, meaning that only a limited number of sites can be monitored at any one time.

The development of the Wellington region's air quality monitoring programme was initially driven by Greater Wellington's Regional Policy Statement (RPS, WRC 1995) which identified various air quality issues, including a lack of information on the state of air quality in the region. An air quality monitoring strategy developed by Davy (1997) directed a series of 'screening studies' to identify areas where air quality may be degraded. The results of these studies, together with a regional emissions inventory (Air and Environmental Sciences 2001), were used to develop plans for a regional air quality monitoring network.

The Regional Air Quality Management Plan (RAQMP), operative since 2000, mandated the development and implementation of an ambient air quality monitoring plan sufficient to provide appropriate information on which to base future air quality management decisions. A five-year air quality monitoring strategy was developed in 2000 (Davy 2000a) to provide for the staged introduction of five permanent air quality stations in order to monitor trends in air quality over time.

2.2 Monitoring purpose and objectives

2.2.1 Purpose

Greater Wellington's ambient air quality monitoring programme seeks to provide scientifically sound and relevant information in the most cost-effective and efficient manner for the following purposes:

- to manage the region's air quality resource;
- to protect human health;
- to fulfil the statutory requirements of the RMA 1991; and
- to determine compliance with the national environmental standards for air quality (NES-AQ).

Monitoring alone cannot fully characterise air quality and complementary assessment tools such as source apportionment studies (including emission inventories and receptor modelling) and possibly atmospheric pollution dispersion models are also required to satisfy the monitoring purpose and objectives.

2.2.2 Objectives

Ambient air monitoring objectives have evolved in response to local and national developments. The following objectives are currently identified for Greater Wellington's ambient air monitoring programme:

(a) State of the environment reporting (SoE) and trends analysis to accurately characterise air quality (independent of meteorological factors) and to alert policy makers and regulators to any change in air quality;

(b) Determine regulatory compliance with national ambient air quality standards (NES-AQ) and national guidelines for key contaminants;

(c) Identify, apportion and detect changes over time in air pollution sources to provide the weight-of-evidence for policy intervention to improve air quality and to assess the effectiveness of any such intervention;

(d) Identify potential health risks from exposure to air toxics and other non-NES-AQ pollutants in response to local issues and in light of new international findings and standards; and

(e) Provide air quality information that is appropriate to:

- assist regulators to assess the effects of industrial discharges to air on air quality by providing information on air quality of the receiving environment affected by industrial discharges
- inform regional transport planners about the impact of transport emissions on air quality and contribute towards the assessment of environmental sustainability as defined in the Regional Land Transport Strategy
- inform the public and raise awareness in a way that allows people to manage their exposure to air pollutants and encourage participation in any emissions reductions campaigns.

2.3 Air quality management areas (airsheds)

The Wellington region is divided into eight airsheds, constrained by valleys between steep hills or mountains: Kapiti Coast, Porirua Basin (including Tawa valley and Pauatahanui Inlet), Karori, Wellington city, Wainuiomata, Lower Hutt Valley, Upper Hutt Valley and Wairarapa Valley (Figure 2.1). Each airshed has a distinct microclimate, meteorological conditions and air quality pressures. Terrain maps showing airshed boundaries are presented in Appendix 1. These airsheds were formally Gazetted in 2005 in accordance with the national standard for air quality[4] (Davy 2005). The national standard only requires air quality to be monitored in airsheds where the standard is likely to be breached. Therefore, not all airsheds in the Wellington region will be necessarily monitored on a permanent basis.

[4] Resource Management (National Environmental Standards for Air Quality) Regulations 2004.

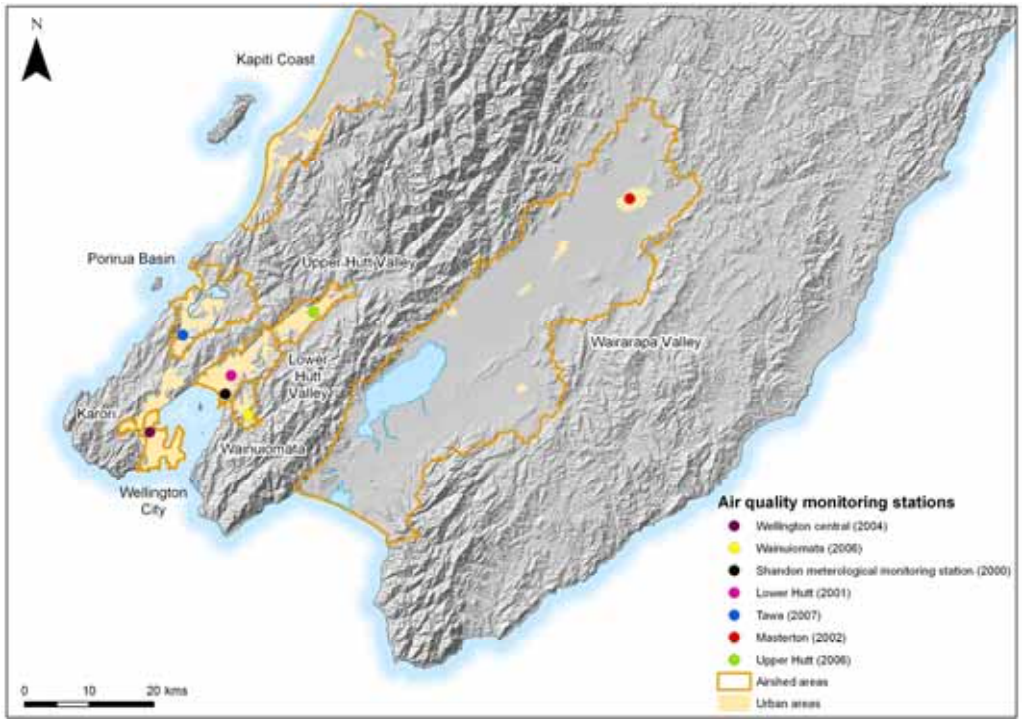


Figure 2.1: Location of Greater Wellington air quality and meteorological monitoring sites (as at 2010) and airshed boundaries established in 2006

2.4 Monitoring sites

Long-term continuous air quality monitoring in the Wellington region commenced in Upper Hutt in 2000[5], with a stand-alone meteorological monitoring station established in Petone, Lower Hutt, in the same year. Additional long-term air quality monitoring sites were subsequently established in Lower Hutt (2001), Masterton (2002), inner Wellington city (2004), Wainuiomata (2006) and the Wellington suburbs of Karori[6] and Tawa (both 2007). A full list of Greater Wellington's current and past monitoring sites is provided in Appendix 2.

Monitoring sites are established for a variety of purposes as outlined in Section 2.2. Some monitoring sites are able to serve multiple purposes and their monitoring duration is determined by the requirements of the monitoring programme and resource constraints. Where it is likely that the NES-AQ will be breached in an airshed, monitoring must be undertaken in that part of the airshed where the standard is breached by the greatest margin or breached most frequently – whichever is the most likely. Essentially this equates to monitoring the area in the airshed that has the 'worst' air quality. The Masterton, Lower Hutt and Wainuiomata monitoring sites were established prior to the NES-AQ coming into force in 2005 and were originally sited to represent 'broad-scale' exposure as opposed to 'worst-case' exposure, which may occur in a very localised area. MfE (2011) have recommended that councils review each of their NES-AQ compliance monitoring sites to determine what type of exposure is happening at each site and to justify the location of the monitoring site.

[5] Site relocated in 2006.
[6] Site disestablished in early 2009

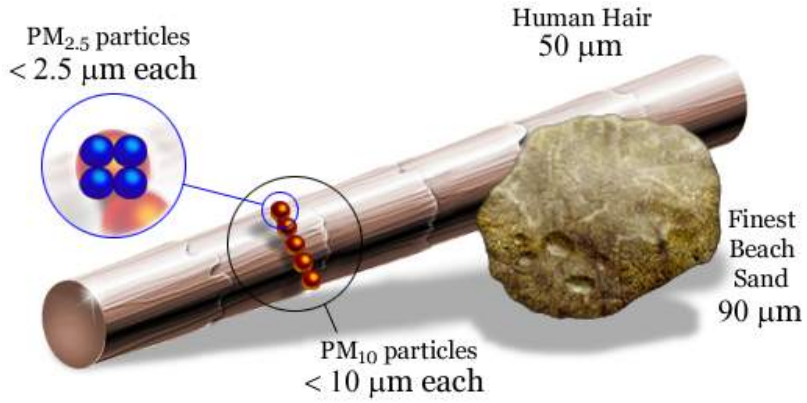
2.5 Air quality indicators

The core monitoring programme is focussed on measuring three contaminants: $PM_{10,}$ carbon monoxide and nitrogen dioxide. These three pollutants, together with ozone and sulphur dioxide, were proposed as environmental indicators by MfE (1997), and came into force as national environmental standards (NES-AQ) on 1 September 2005. Ozone, a secondary pollutant formed through a photochemical reaction in air, is not measured as Wellington was not identified as a city with atmospheric conditions favourable for formation of this pollutant (McKendry 1996). Sulphur dioxide is not measured as major industrial sources are not present in the region.

The NES-AQ requires that monitoring be undertaken using continuous and standard methods (see Appendix 3 for a summary of the methods used). The results of Greater Wellington's monitoring are reported nationally by the Ministry for the Environment (MfE). Standard methods are used to aid inter-comparability of monitoring results between regions.

2.5.1 Particulate matter

Particulate matter (PM) is a complex mixture of organic and inorganic aerosols that are dispersed in air. PM occurs in a range of sizes with diverse chemical and physical properties depending on the emission source and atmospheric transformations. PM_{10} is that portion of particulate matter with an equivalent aerodynamic cross section less than 10 micrometres. This size fraction is small enough to be inhaled into the respiratory system (Figure 2.2).



Source: www.mfe.govt.nz

Figure 2.2: Particulate matter particle sizes shown relative to the width of a human hair and a grain of sand

Airborne particles commonly occur in two distinct sizes – 'fine' (less than 2.5 µm) denoted as $PM_{2.5}$ and 'coarse' (2.5 to 10 µm) or $PM_{2.5\text{-}10}$. PM_{10} consists of all particles less than 10 µm, ie, the fine and coarse fraction combined. Fine and coarse PM typically differ in their origin, dispersal properties and site of deposition within the human respiratory tract.

Epidemiological studies show adverse health effects from both short-term and long-term exposure to PM_{10}. Moreover, a threshold below which there are no observed adverse effects has not been reliably established to date (WHO 2006).

Fine particles ($PM_{2.5}$) mainly arise from combustion processes, such as vehicle exhaust and wood and coal burning. Fine PM includes inorganic species, organic aerosols, metals and black carbon (soot). Many of the inorganic species (eg, sulphate, nitrate and ammonia) are not emitted directly, but arise as secondary particles formed when sulphur oxides, nitrogen oxides and ammonia are chemically converted in the atmosphere. Fine particles can remain suspended in air for long periods and may be transported across large distances (hundreds to thousands of kilometres). $PM_{2.5}$ causes the most harm to people's health because these smaller particles can penetrate deeper into the lungs.

In contrast, coarse particles are largely produced by mechanical processes, such as crushing, abrasion and wind action. Anthropogenic sources include re-suspended dust from roads and industrial activities. Natural sources, such as marine aerosol and wind-blown soils, are often a major component of the coarse fraction. Coarse PM tends to settle out more quickly after being formed or emitted than the finer $PM_{2.5}$.

2.5.2 Carbon monoxide

Carbon monoxide is a colourless and odourless gas produced by the incomplete combustion of carbon-containing fuels such as petrol and diesel used by motor vehicles, or wood and coal used by domestic appliances or industrial boilers. Motor vehicles and domestic home heating are the main sources of carbon monoxide in urban areas.

When inhaled, carbon monoxide reduces the oxygen carrying capacity of the blood and, depending on its concentration, causes a range of adverse health effects.

2.5.3 Nitrogen dioxide

Nitrogen dioxide arises from combustion processes, with vehicle emissions being the main source in urban areas. Vehicle exhausts contain a mixture of nitrogen dioxide and nitric oxide (NO), collectively known as oxides of nitrogen (NOx). Most of the NOx discharged from vehicle exhausts is in the form of nitric oxide which is subsequently converted to nitrogen dioxide by oxidation.

Nitrogen dioxide appears as a brown and acidic gas in the atmosphere. Nitrogen dioxide has adverse health effects such as lung inflammation and eye, nose and throat irritation.

2.6 Hazardous air pollutants (HAPs)

In addition, to the core NES-AQ monitoring programme, limited monitoring has been carried out for some hazardous air pollutants (HAPs) which are also identified as priority contaminants (MfE 2002). HAPs refer to the large number of airborne chemical substances with toxic or carcinogenic properties. Usually the levels of HAPs in air are very low, but under some circumstances they can accumulate to levels that are harmful for human health. Sources of HAPs include industrial discharges (e.g. chemical and paint manufacture), domestic

activities (eg, solid fuel burners), vehicles, and natural sources (eg, vegetation and geothermal activity).

2.6.1 Volatile organic compounds (VOCs)

VOCs are characterised by having high vapour pressure at room temperature which means they evaporate rapidly into the air. VOCs are highly reactive and are precursor gases in atmospheric reactions with other pollutants – for example, VOCs react with NOx to produce ozone. Plant foliage is also a natural source of VOCs such as isoprene and monoterpenes.

Benzene and toluene are volatile hydrocarbons produced by activities using solvents and are also found in vehicle emissions. Major sources of the aldehydes acetaldehyde and formaldehyde are vehicle exhaust emissions, domestic solid-fuel fires and some industrial processes. Formaldehyde, in particular is associated with the manufacture of particleboard, plywood, fabrics and furnishings.

2.6.2 Metals (arsenic, chromium and lead)

Inorganic arsenic is classified by the USEPA as a Group A carcinogen of high potency. Volatile arsenic oxides, either in gaseous form or associated with particulate matter are produced when timber that has been treated with copper-chrome-arsenate (CCA) is burnt.

Chromium is also classified by the USEPA as a Group A carcinogen of high potency. Chromium emissions are mostly associated with particulate matter produced during the combustion of fossil fuels and is produced directly by some industrial processes. Chromium is also produced when CCA-treated timber is burnt.

Lead is a heavy metal that accumulates in the environment and can have a range of chronic and acute health effects depending on community exposure levels. Nationally, the ambient air concentration of lead has fallen dramatically since the phase-out of lead in petrol was completed in 1996. Non-occupational exposure to lead can still occur during to the renovation of houses or premises containing lead-based paint.

2.6.3 Polycyclic aromatic hydrocarbons (PAHs)

Benzo(a)pryene (BaP) is an indicator species for PAHs which are a large group of organic semi-volatile compounds that can occur in the gas phase or become attached to particulate matter. PAHs arise from incomplete combustion of fuels with the main sources being domestic fires, vehicle exhaust emissions and some industrial processes. BaP is highly toxic with carcinogenic properties.

2.7 Air quality assessment criteria

2.7.1 National standards and guidelines for air quality indicators

National ambient air quality guidelines (national guidelines) were established by MfE (1994) and were revised in 2002 (Table 2.1). Some of these guideline values were adopted as national environmental standards in 2004. The National

Environmental Standards for Air Quality (NES-AQ) specify minimum requirements for outdoor air quality that provide a consistent level of protection for human health and the environment. Details of how measured indicators are averaged for comparison to assessment criteria are provided in Appendix 7.

Table 2.1: National standard and guideline values for air quality indicators

Indicator		Threshold concentration	Averaging period	Permissible exceedences per year
PM_{10}	Standard	50 µg/m^3	24-hour	One 24-hour period
	Guideline	20 µg/m^3	Annual	–
$PM_{2.5}$	Monitoring value	25 µg/m^3	24-hour	–
Carbon monoxide	Standard	10 mg/m^3	8-hour moving	One 8-hour period
	Guideline	30 mg/m^3	1-hour	–
Nitrogen dioxide	Standard	200 µg/m^3	1-hour	9 hours
	Guideline	100 µg/m^3	24-hour	–

2.7.2 World health guidelines (WHO)

It is now widely recognised that the adverse health effects associated with exposure to $PM_{2.5}$ are greater than those associated with PM_{10}. For this reason, various agencies, including the World Health Organisation (WHO), US Environmental Protection Agency (US EPA) and the European Union (EU) have all adopted targets or standards for $PM_{2.5}$. $PM_{2.5}$ is now becoming the air quality indicator of choice internationally due to its widespread use in epidemiological studies; it is more ubiquitous in the environment and is typically anthropogenic in origin and therefore more easily controlled by intervention measures (Air Quality Technical Advisory Group 2009).

WHO (2006) recommends guidelines for both short and long term exposure to PM_{10} (Table 2.2) because the coarse fraction (between 2.5 and 10 µm) cannot be considered harmless. The WHO daily and annual guidelines for PM_{10} have the same numerical values as the national environmental standard – however, the WHO PM_{10} guidelines are based on the assumption that a $PM_{2.5}$:PM_{10} ratio of 0.5 exists. Therefore, the PM_{10} guideline may not afford the same intended level of protection if the actual $PM_{2.5}$:PM_{10} ratio is higher than 0.5.

Table 2.2: WHO (2006) guideline values for air quality indicators

Indicator	Threshold concentration	Averaging period
$PM_{2.5}$	25 µg/m^3	24-hour[7]
	10 µg/m^3	Annual
Nitrogen dioxide	40 µg/m^3	Annual

[7] 99th percentile (3 days/year).

WHO also have an annual average guideline for nitrogen dioxide which is useful for comparing against the results of screening studies, such as passive diffusion tubes, which can only provide data at monthly resolution.

2.7.3 National guidelines for hazardous air pollutants (HAPs)

National guidelines exist only for a limited number of HAPs (Table 2.3) – selected on the basis of their heath effects, likelihood of being discharged, potential for public exposure and ultimate fate in the environment (Chiodo & Rolfe 2000).

Table 2.3: MfE (2002) guideline values for selected hazardous air pollutants

Contaminant	Threshold concentration	Averaging period
Lead	0.2 µg/m^3	3-month moving average calculated monthly
Benzene (year 2002)	10 µg/m^3	Annual
Benzene (year 2010)	3.6 µg/m^3	Annual
Benzo(a)pyrene	0.3 ng/m^3	Annual
Arsenic (inorganic)	5.5 ng/m^3	Annual
Formaldehyde	100 µg/m^3	30 minutes
Acetaldehyde	30 µg/m^3	Annual
Chromium VI	0.0011 µg/m^3	Annual

2.8 Meteorological variables

Core meteorological variables relevant to air quality monitoring – temperature, wind speed and direction, and relative humidity – are measured continuously at each of Greater Wellington's air quality monitoring sites. Additional variables, such as global and net solar radiation, soil temperature, soil moisture and rainfall are also measured at some sites (refer Appendix 4 for details). Local information on meteorology is critical for the interpretation of air quality data, in particular, to confirm exceedences of standards and guidelines and trends. Wind direction information can help us understand higher level synoptic conditions as well as the likely sources of contaminants. Wind speed and temperature play a crucial role in the dispersion of air pollutants.

Meteorological data collected at Shandon Golf Course (Lower Hutt) (Figure 2.3) and at the Masterton air quality monitoring site are measured at heights of 5, 10 and 15 m and are therefore suitable for use as inputs for meteorological model development and/or air dispersion models. The Shandon data provide useful information for assessing windflows in the nearby Seaview industrial area which has the highest density of discharge to air consents in the region. The Masterton data are critical for understanding the relationship between meteorology and episodic degraded air quality due to domestic emissions (ie, residential fires).

Figure 2.3: Greater Wellington meteorological monitoring station with 15 m mast located at Shandon Golf course, Petone

3. Emissions and impact of climatology on air quality

Air is the receiving environment for emissions arising from many day-to-day activities, such as driving, heating homes with wood or coal, lawn mowing and outdoor burning, as well as industrial and commercial activities. These emissions contain contaminants such as particulate matter, carbon monoxide, nitrogen oxides, reactive organic compounds and heavy metals which, if at high enough concentrations in air, will adversely affect the health of exposed populations.

This section outlines the major sources of anthropogenic emissions that, on occasion, place pressure on the air resource in some areas of the Wellington region. These emission sources include home heating, outdoor burning, industry and transport. Information on domestic home heating sources has been obtained from local emissions inventories and from census data. As there is little up-to-date information readily available on the quantity of emissions from industry and transport sectors, other indirect measures have been used to assess the relative emissions from these sources.

Climatology factors that influence air quality at an airshed level in the region are also briefly outlined. While the day-to-day impact of emissions on air quality depends on local meteorology or the weather conditions at the time the emissions are occurring, the long-term susceptibility of an area to air pollution is determined by its climatology.

3.1 Emissions from home heating

The regional emissions inventory (Pacific Air and Environment 1998) found that residential heating (based on 1996 census information) was responsible for 43% of the total annual PM_{10} emitted. During the winter months the contribution of domestic heating sources to PM_{10} emissions rises to 65%. This finding is consistent with national data which show that home heating is the main cause of elevated PM_{10} in populated areas during winter with, on average, 45% of households burning solid fuels (ie, wood and coal).

More up-to-date regional estimates of PM_{10} (g/ha/day) were obtained through the application of emission and fuel use factors[8] to data on household heating methods obtained from the 2006 census (Wilton et al. 2010). This analysis showed the proportion of households using solid fuels for home heating in the Wellington region was lower than the national average, apart from rural areas in the Wairarapa, which were among the highest in the country (Table 3.1). To enable comparisons between census area units (CAU), emissions were divided by CAU area to provide an estimate of emissions density. Figure 3.1 shows the variation in emissions density (per winter day) from domestic sources across the Wellington region in 2006.

[8] PM_{10} from burning wood (kg/day) = no. households using wood x (emission factor (8g/kg) x weight of fuel burned per day (20 kg/day)).
PM_{10} from burning coal (kg/day) = no. households using coal x (emission factor (25g/kg) x weight of fuel burned per day (16 kg/day)).

Table 3.1: Household solid fuel use for domestic heating and PM10 emissions density by local territorial authority in the Wellington region in 2006

(Source: Statistics NZ and Wilton et al. 2010)

Territorial authority	No. houses using wood	No. houses using coal	PM_{10} g/day/ha (wood)	PM_{10} g/day/ha (coal)
Wellington City	13,695 (20%)	2373 (3.5%)	76	32
Lower Hutt City	10,203 (29%)	1551 (4.3%)	43	16
Upper Hutt City	5,142 (36%)	435 (3.1%)	15	3
Porirua City	5,367 (35%)	831 (5.4%)	49	19
Kapiti Coast District	7,509 (39%)	609 (3.2%)	37	7
Masterton District	6,558 (73%)	384 (4.3%)	5	1
Carterton District	2,283 (82%)	123 (4.4%)	3	0
South Wairarapa District	2,967 (81%)	162 (4.4%)	9	0

Nationally, the use of wood and coal to heat dwellings decreased between 1996 and 2006 – from 48.7% to 40.9% for wood and from 13% to 7% for coal. However, in the Wairarapa, the percentage of households using wood for home heating did not change between 1996 and 2006, although there was a reduction in coal from 7.1% to 4.3% (Statistics NZ). In Upper Hutt, the use of wood and coal to heat dwellings decreased between 1996 and 2006 – from 39.2% to 36.1% for wood and from 5.3% to 3.0% for coal. In Wainuiomata, wood to heat dwellings decreased slightly from 39.1% to 38.1% between 1996 and 2006. Coal use declined more substantially – from 6.8% in 1996 to 4.0% in 2006 (Statistics NZ).

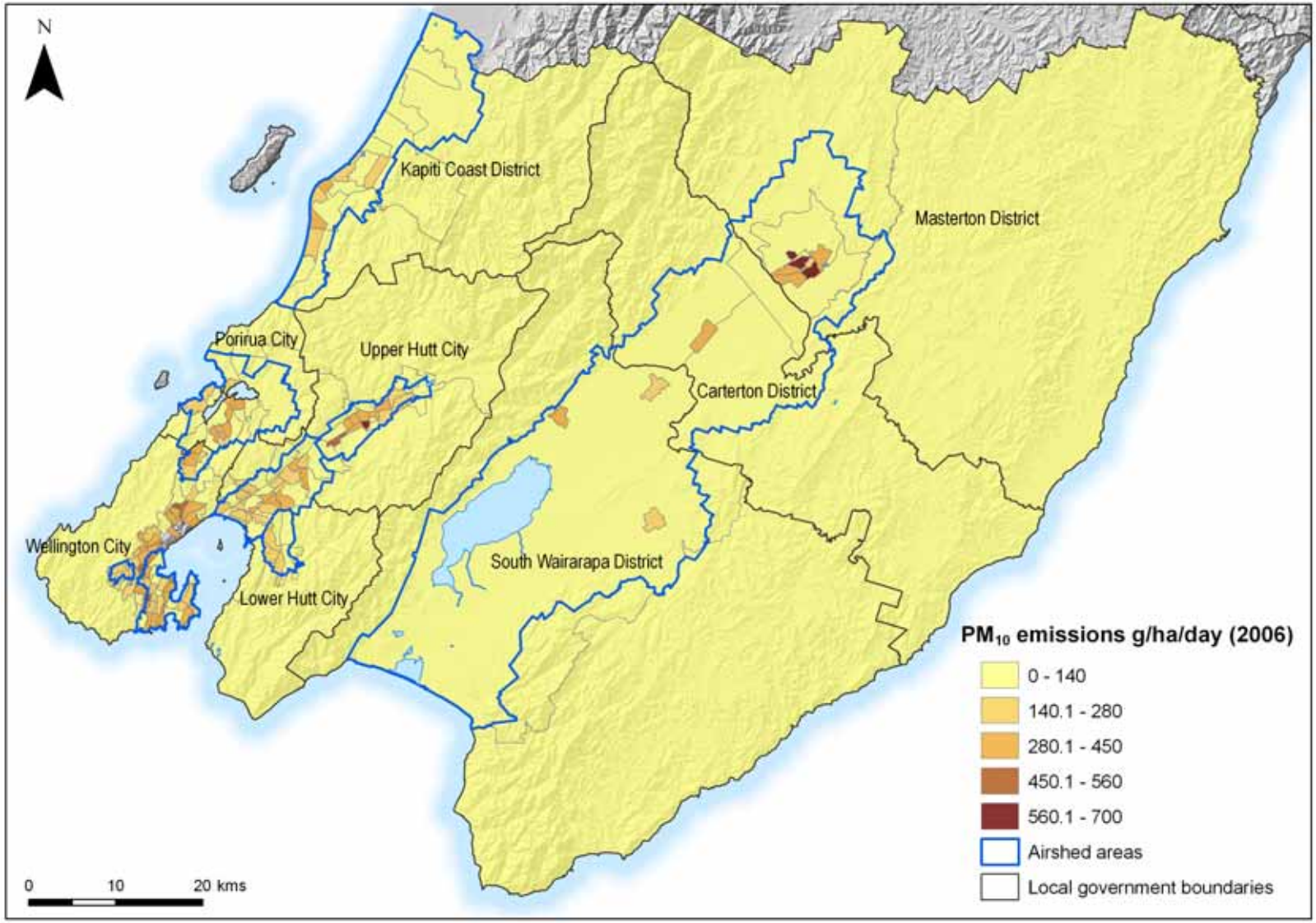
3.1.1 Home heating surveys

To provide more detailed information on domestic emissions, in areas where air quality is degraded during winter, telephone surveys were carried out in Wainuiomata and Upper Hutt airsheds (Wilton 2006) and in the Masterton urban area (Wilton & Baynes 2008a). Estimates of PM_{10} emissions by day and season were obtained by applying emission factors to data collected from a sample of households on heating methods, heating appliance type and fuel use.

Households generally use more than one method for heating their main living area. The main methods of home heating in Wainuiomata during winter 2006 were electricity and gas with 51% and 41% of households respectively using these methods to heat their main living area. Solid fuels were also used by around 39% of households – with about two-thirds of these households using wood burners.

In Upper Hutt during 2006, electricity, gas and wood burners were the most commonly used home heating methods with 48%, 38% and 34% of households respectively using these methods to heat their main living area. Solid fuels were used for heating by around 43% of households – with just over three quarters of these households using wood burners.

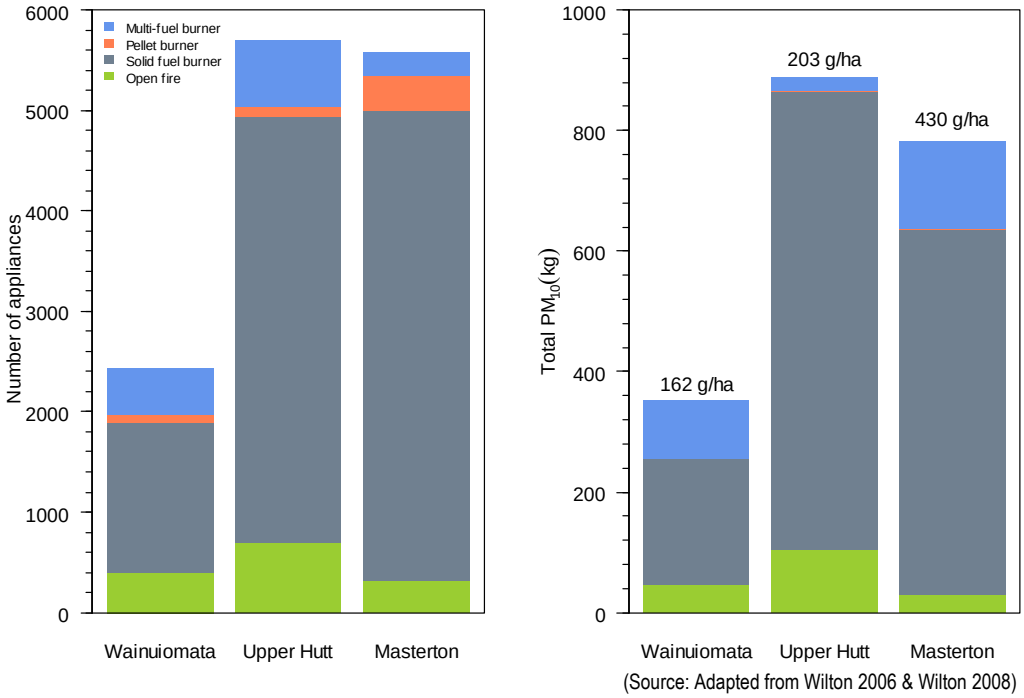
The most common method for heating the main living area in Masterton during 2008 was wood burners (66% of households). Electricity was the second-most popular method (32%), followed by gas (18%). Solid fuels were used for heating by around 76% of households – with most (87%) of these households using wood burners.



(Source: Adapted from Emission and Socio-Economic Spatial Model (Wilton et al. 2010))

Figure 3.1: Winter PM_{10} emissions density for the Wellington region due to domestic heating using wood by census area unit (2006)

Figure 3.2 shows the number and type of solid fuel appliances, the total mass of PM_{10} emitted and the emissions density by survey area. Although Upper Hutt and Masterton have similar numbers of appliances, the emissions density in Masterton is double that of Upper Hutt because the Masterton urban area is much smaller than the Upper Hutt airshed area.

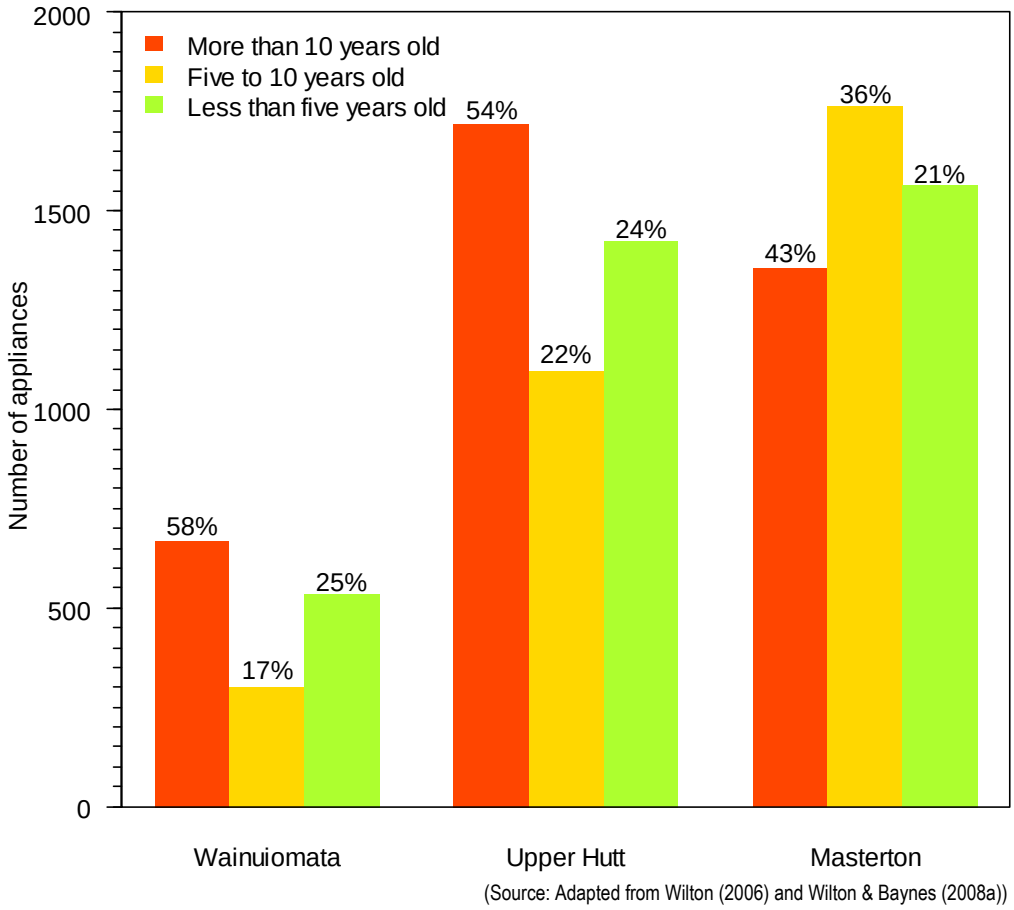


(Source: Adapted from Wilton 2006 & Wilton 2008)

Figure 3.2: Number of households with solid fuel appliances in Wainuiomata (2006), Upper Hutt (2006) and Masterton (2008) (left), and total PM_{10} (kg) emitted by home heating appliance type on an average winter day with the emissions density shown at the top of each bar (right)

PM_{10} emission rates from solid fuel appliances vary by appliance type (ie, open fire, wood burner, multi-fuel, pellet burner, etc), appliance design standard and appliance age. Figure 3.3 shows the breakdown of wood burner age in each area surveyed. The older wood burners contribute proportionally more to overall PM_{10} emissions than younger appliances that are designed to be cleaner burning. The NES-AQ requires new wood burners installed (on properties less than two hectares) after 1 September 2005 to meet an emissions standard of less than 1.5 grams of particles for each kilogram of dry wood burnt.

It is expected that households will replace their wood burners once they reach the end of their useful working life – estimated to be about 15 years on average – and that this will result in a reduction in PM_{10} kg/day emitted into the airshed. Overall a reduction of about 30% in PM_{10} emissions in Wainuiomata and Upper Hutt (between 2006 and 2016) and in Masterton (between 2008 and 2016) is expected under 'business as usual' (Wilton & Baynes 2008b). However, there are uncertainties around these projections, in particular the impact of the recent economic recession on households' ability to replace burners after 15 years as well as ongoing issues with deriving a representative emission rate for NES-AQ compliant wood burners. There are many factors affecting emissions, such as wood burner operation, installation, fuel type, fuel



(Source: Adapted from Wilton (2006) and Wilton & Baynes (2008a))

Figure 3.3: Relative ages of wood burners in households in Wainuiomata and Upper Hutt (as at 2006) and Masterton (as at 2008). The relative contribution to total PM_{10} emitted on an average winter day by wood burner age is shown at the top of each bar.

moisture content and fuel quality which cannot easily be accounted for in emission projection scenarios. Nevertheless, emissions of PM_{10} from domestic home heating are expected to decrease with time resulting in a reduction in pressure on air quality from this source.

3.2 Emissions from outdoor burning

The telephone surveys showed that urban outdoor burning during winter was carried out by five per cent of houses in Wainuiomata, 7% of houses in Upper Hutt and 14% in Masterton. This activity equated to around 4% of total winter PM_{10} emissions in Wainuiomata, 9% in Upper Hutt (Wilton 2006) and 4% in Masterton (Wilton & Baynes 2008a).

There are insufficient data available to estimate the level of emissions from rural burning associated with farming and horticultural activities. The regional emission inventory estimated that controlled burning produced 104.8 tonnes/year of PM_{10}, representing 4% of all anthropogenic emissions (Air and Environmental Sciences Ltd 2001). The impact of rural outdoor burning on local and regional air quality has not been quantified, although it does result in visible haze in the Wairarapa Valley from time to time (Figure 3.4).

Figure 3.4: Smoke haze in the Wairarapa Valley due to rural burning

3.3 Emissions from industry

Emissions arising from industrial and trade premises operating throughout the region are controlled by Greater Wellington's RAQMP (WRC 2000) and require a discharge permit for their activities. Some discharges from industrial and commercial activities are permitted (subject to meeting specified conditions) and do not require resource consent. As at the end of 2010, the Wellington region had 203 activities operating with discharge to air permits, ranging from landfills and wastewater treatment plants to school boilers.

Up-to-date industrial emissions data are not available but, according to the region-wide emissions inventory (compiled between 1997 and 2001 by Pacific Air and Environment (1998)), industrial emissions were estimated to contribute 2% of both carbon monoxide and nitrogen oxides, 29% of PM_{10}, 5% of sulphur dioxide and 18% of volatile organic compounds (VOCs). While not regionally significant as a whole, individual industries may have significant effects on their immediate surroundings, particularly with respect to odour and localised discharges of hazardous air pollutants. Table 3.2 presents the industrial categories that contribute most significantly to inventoried pollutants (Air and Environmental Sciences 2001). It is likely that the contribution of industrial sources to region-wide levels of emissions has declined since the inventory was compiled as some industries are no longer in operation.

Table 3.2: Major industrial contributors (in bold type) to pollutant emissions in the Wellington region (base year 1997/98), based on information reported by Air and Environmental Sciences (2001)

Industry	VOC	NOx	CO	SO_2	PM_{10}
Mining & quarrying					**68%**
Landfill	**9%**	6%	**16%**	5%	1%
Food & agriculture		7%	9%	**17%**	2%
Wood products	1%	**20%**	**18%**	4%	9%
Asphalt		2%	1%	1%	
Batteries		2%		6%	4%
Cement					5%
Abrasive blasting	1%	2%			
Spray painting	4%	5%	1%		
Organic chemical products	**39%**	**23%**	7%	4%	8%
Metal products					1%
Incineration		2%		2%	
Textiles		5%	1%		
Fuel storage	**44%**	3%	1%		
Miscellaneous combustion	1%	**23%**	**46%**	**61%**	2%
Total (tonnes/yr)	1,827	215	834	129	611

3.3.1 Localised industrial emissions and amenity effects

Complaints about air pollution are a qualitative measure of local pressures on the air resource. Emissions, such as dust, smoke and odour from industrial activities, can lead to complaints from nearby residents or workers. Greater Wellington typically receives complaints about dust soiling outdoor and indoor surfaces, smoke emissions, and odours associated with industrial activities, such as waste treatment or panel beating. Most incidents are triggered by either plant process failure or meteorological conditions unfavourable for the dispersion of air pollutants at source.

Up until 2005, air pollution incidents made up well over half of all reported pollution issues in the region. Greater Wellington records show the number of reported air pollution incidents peaked in 2001, with 90% of these complaints relating to ten industrial sites in the western half of the region. Total reported air pollution incidents subsequently declined and since 2006 have plateaued to around 400 to 500 incidents per year (Figure 3.5). The decline in reported odour incidents is attributed to the closure of some sites (a fish processing plant in 2007, an asphalt plant in 2001, and a biosolids composting plant in 2008), improved odour control at some plants (at a meatworks and a landfill) as well as a proactive odour monitoring programme carried out by Greater Wellington. According to Greater Wellington's Incidents Database, as at June 2010, air pollution incidents made up just over a third of all environmental pollution incidents recorded by Greater Wellington.

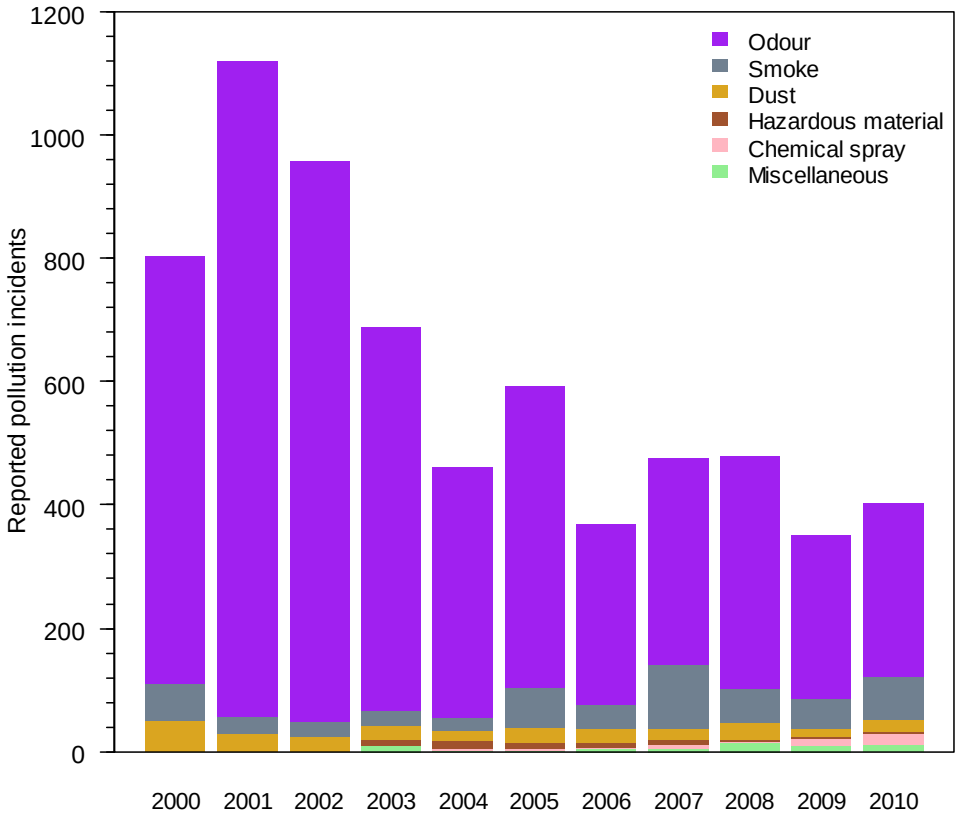


Figure 3.5: Reported air pollution incidents for the Wellington region by end of financial year, based on records in Greater Wellington's Incidents Database

3.4 Emissions from transportation

Emissions from motor vehicles that can affect health include carbon monoxide, nitrogen oxides, VOCs, and sulphur dioxide, as well as particulate matter. Additionally, other gases (such as ozone) and particles (sulphates and nitrates) can form in the atmosphere from photochemical reactions involving some of those primary emissions.

The region-wide inventory (compiled between 1997 and 2001 by Pacific Air and Environment (1998)) found that motor vehicles were the predominant source of carbon monoxide, estimated to contribute three-quarters of all carbon monoxide produced in the region. Over 80% of regional emissions of nitrogen oxide were attributed to transport sources, with around two thirds from motor vehicles and the remainder from commercial shipping. Commercial shipping activities were also identified as the principal source of sulphur dioxide emissions in the region.

3.4.1 Fuel consumption

The quantity of fuel used in the region is an indirect measure of the contribution of the transport sector to emissions of carbon monoxide and nitrogen oxides. Some fuel sales will include non-transport related uses, such as mowers, chainsaws, generators and so on. There will also be fuel purchased outside the region but used in it (and vice versa). According to local authority records, in 2010/11, 444 million litres of fuel was sold in the region (66% petrol and 33% diesel). Overall fuel consumption increased between 2000 and

2008, with a slight downward trend over the last few years when sales have lagged behind population growth. Therefore, fuel use per capita has decreased. It is likely that increased fuel prices, improved vehicle fleet fuel efficiency, and the current economic recession have combined to curb fuel sales (GWRC 2010b).

3.4.2 Vehicle fleet age, state highway traffic volumes and VKT

Vehicle emissions are heavily influenced by the age of the vehicle, its level of maintenance, type of fuel used, etc. Therefore, as the vehicle fleet modernises, the level of pollutants produced per vehicle is expected to reduce.

On-road emissions testing of the Auckland light vehicle fleet found that emissions of all pollutants per vehicle, on average, decreased significantly between 2003 and 2009 despite an increase in average vehicle age (Bluett et al. 2011). Much of the improvement observed in fleet emissions was attributed to lower emitting vehicles entering the fleet as a result of the 2003 vehicle exhaust emissions rule requiring emission standards for New Zealand-new vehicles (Bluett et al. 2011). It should be noted that improvements in emissions per vehicle may not translate into reductions in overall emissions, if vehicle numbers, kilometres travelled (VKT) and congestion increase. Figure 3.6 shows the average heavy vehicle age in the Wellington region has gradually increased, reaching 12 years in 2010. The average light vehicle age fluctuated over the past decade and reached 13.6 years in 2010.

The annual average state highway traffic volumes increased by 7% across NZTA-monitored sites in the Wellington region from 2000 to 2010. All of this growth was observed between 2000 and 2004 and since this time annual average daily traffic volumes have remained relatively unchanged (GWRC 2010b).

In 2010, VKT on the state highway network and local roads in the region totalled 3,745 million kilometres. The majority of the region's roads are classified as local roads with only 6% of the road length classified as state highway – although just under half of all VKT in the region were on state highways. Figure 3.7 shows there has been little change in VKT on the region's roads over the last 10 years – with some increase in 2010.

In future, VKTs may increase in areas with population growth and it is uncertain whether predicted reductions in emissions (per vehicle) due to improving vehicle technology will occur because of the aging vehicle fleet. Future pressures from transportation on air quality are therefore unknown and will require ongoing assessment.

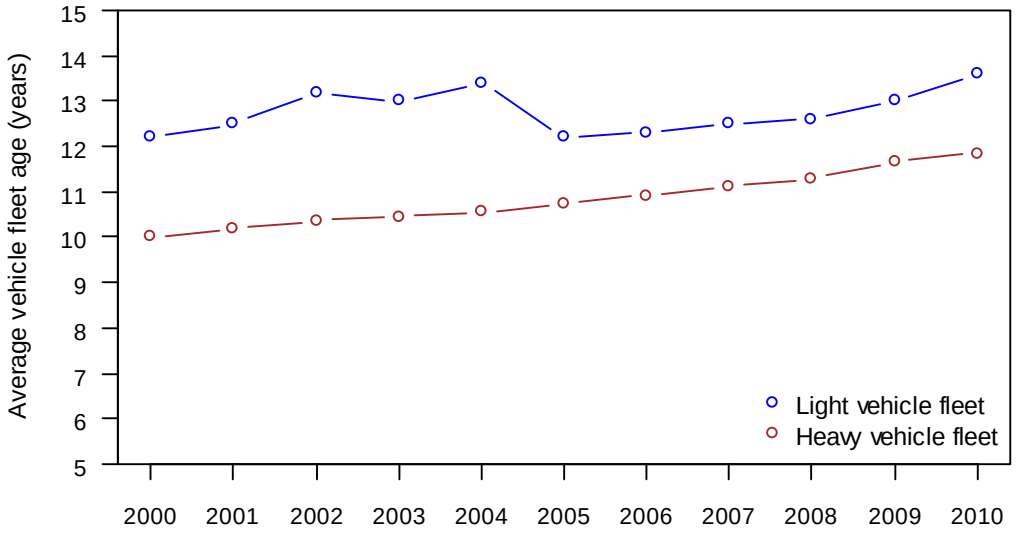


Figure 3.6: Annual average vehicle fleet age for the Wellington region between 2000 and 2010 based on Ministry of Transport data[9]

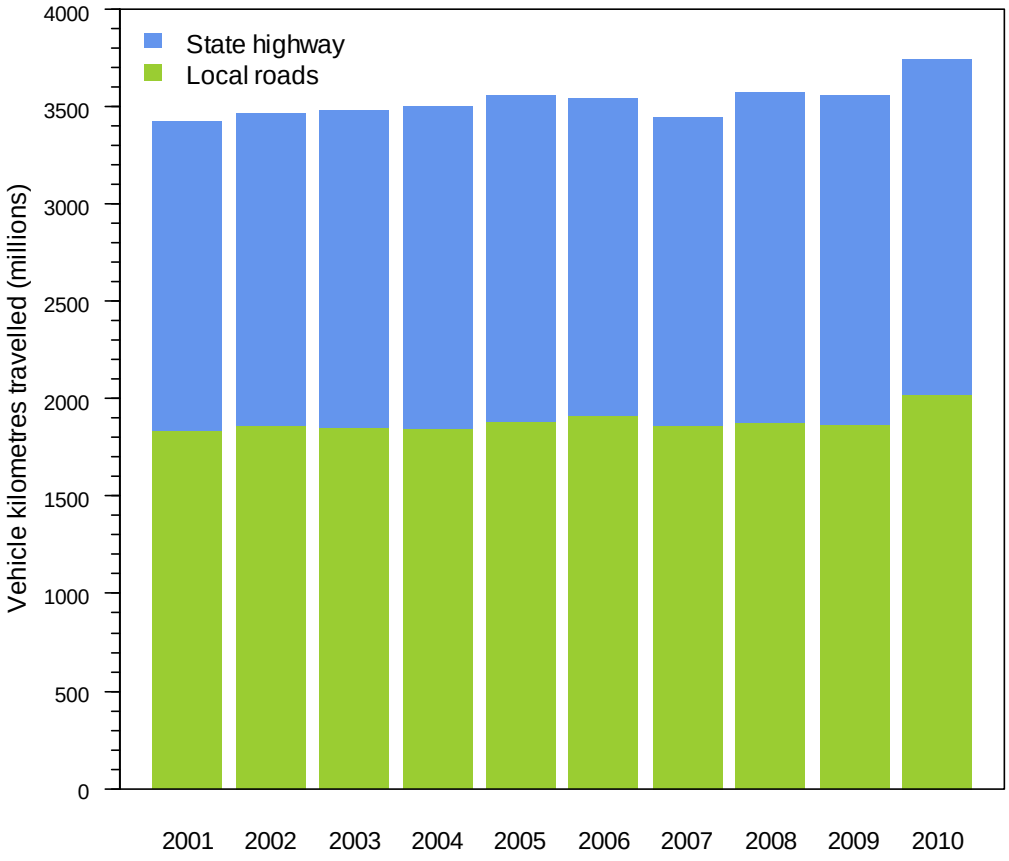


Figure 3.7: Vehicle kilometres travelled (VKT) on state highway and local roads in the Wellington region between 2001 and 2010 based on Ministry of Transport data[10]

[9] http://www.transport.govt.nz/ourwork/TMIF/Pages/TV006.aspx accessed on 4 August 2011.
[10] http://www.transport.govt.nz/ourwork/TMIF/Pages/TV001.aspx accessed 4 August 2011.

3.4.3 On-road vehicle emissions testing in Wellington

Greater Wellington measured exhaust emissions from about 6,500 vehicles at five roadside sites in the region during March to April 2006 to provide baseline information about Wellington's vehicle fleet and raise awareness about the importance of vehicle maintenance for reducing emissions (Bluett & Dey 2007). Using remote sensing, tailpipe emissions were tested for levels of carbon monoxide, nitric oxide, unburned hydrocarbons and opacity (as an indicator of fine particulate matter) as the vehicle passed by on-road monitoring equipment. Motorists were able to view a display monitor indicating whether their vehicle's emissions were rated as 'good', 'fair' or 'poor'.

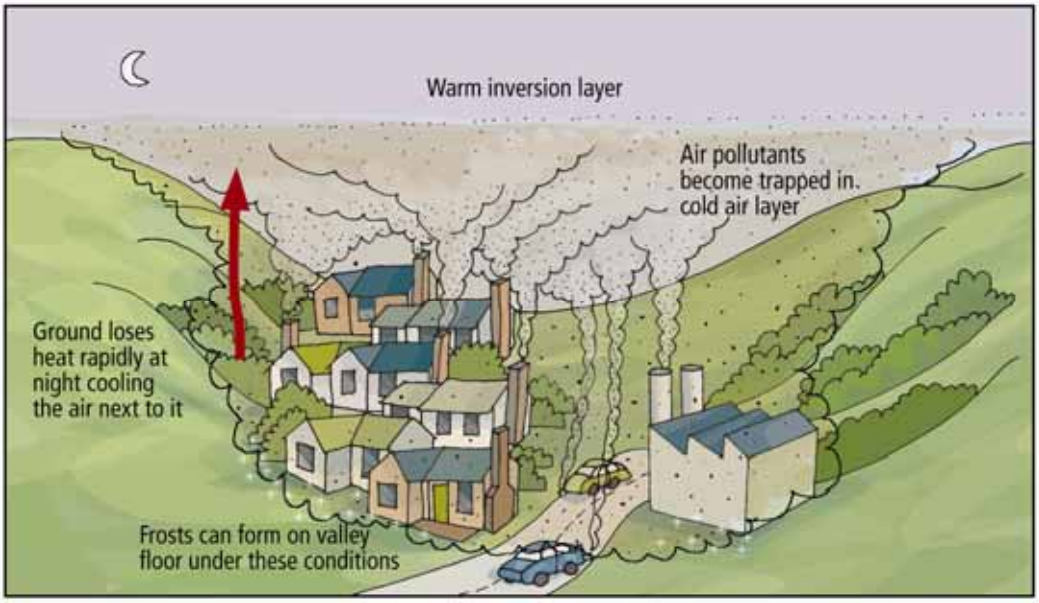
The study found that the most polluting 10% of vehicles (gross emitters) were responsible for 55% of the total carbon monoxide emissions and of the total unburned hydrocarbon emissions, 35% of the total nitric oxide emissions, and 45% of the total smoke emissions. The registered owners of approximately 900 vehicles, which were the worst polluting of those tested, were contacted by letter and encouraged to have their vehicle serviced. As an incentive, these vehicle owners were offered the chance to be reimbursed up to $250 towards the cost of their vehicle service.

The study also found that of the tested vehicles, 17% were diesel and 83% were petrol. The average age of the vehicles tested in the 2006 study was 10 years (ie, manufactured in 1996) and there was a steady increase in emissions per vehicle for all four pollutants with vehicle age.

Figure 3.8: Free vehicle emissions check at Westpac Stadium (March 2006) in Wellington city offered as part of the publicity and education campaign running in tandem with the on-road vehicle emissions testing study

3.5 Airshed climatology

Short-term meteorological events are largely responsible for air pollution episodes. For example under still conditions, fine particles ($PM_{2.5}$) and other contaminants are trapped near to the ground because low wind speeds restrict horizontal mixing and temperature inversions restrict vertical mixing (Figure 3.9). Climatology examines weather conditions averaged over longer periods of time and this assists our understanding of why some areas are more susceptible to poor air quality than others.



(Source: Greater Wellington publication GW/RP-G-03/57)

Figure 3.9: Night time temperature inversion trapping pollutants near the surface

In the Wellington region, topography strongly influences airshed climatology. The presence of Cook Strait means westerly gradient (large-scale) air flows are turned to northwest or northerly flows over the western part of the Wellington region and, to a lesser extent, in the Wairarapa. The proximity to Cook Strait leads to high frequencies of strong winds, also observed in both the ranges and coastal locations of the Wairarapa (although mean wind speeds over the inland plain from Lake Wairarapa to Masterton are lower). Winds can also be very gusty across Wellington and the Wairarapa due to local channelling of winds around the hills and ranges. Seasonal wind flow variation is not large, although there is a small maximum in late spring. Wind roses for air quality monitoring sites are shown in Appendix 5. These wind roses primarily show local conditions at the monitoring site – especially where the meteorological mast is less than 10 m in height.

Total rainfall strongly mimics the region's topography and increases with elevation. In central Wellington and the CBD, as well as on the Miramar Peninsula and along the western coast from Makara to Kapiti Island including Porirua, around 1,200 mm of annual rainfall is typically observed. In comparison, the inland Wairarapa plains from about Lake Wairarapa to Masterton receive close to 800 mm of rainfall being sheltered from westerly rain by the Tararua Range and from southeasterly rain by the Aorangi Range. Across much of the remainder of the coastal Wairarapa hills and coastal

settlements, annual rainfall varies between about 1,000 and 1,400 mm (Griffiths 2011).

The windiness of the Wellington region as well as the maritime effect of the nearby sea moderates temperatures, so that extremes of temperature are reasonably rare. There are exceptions though, in the Hutt Valley (especially Upper Hutt) and the Wairarapa inland plain (from Lake Wairarapa to Masterton), where the increased distance from the sea coupled with the degree of sheltering from the wind, means that the diurnal temperature range in these valleys is markedly larger than that observed in coastal locations or at elevation in the Rimutaka and Tararua ranges. Cold air pooling into the valleys/plains also occurs during autumn and winter mornings. Therefore, both hotter afternoons and much cooler mornings are observed in the Hutt Valley and Wairarapa plains than elsewhere in the region.

Griffiths (2011) examined meteorological data collected at both Greater Wellington and NIWA air quality monitoring sites between 2005 and 2010 to classify local climatology of the eight regional airsheds (Appendix 6). Wellington city, Porirua and Kapiti airsheds were defined as coastal in nature indicating they are windy, close to the sea and rarely experience frosts. These conditions mean that formation of temperature inversions that restrict vertical dispersion of pollutants are unlikely and therefore air quality is usually good. However, there may be local 'pockets' of poor air quality in these airsheds during winter under light-wind, clear sky situations in low lying areas. In contrast, Lower Hutt, Upper Hutt, Wainuiomata and Wairarapa airsheds have a climatology described as 'valley', meaning they are less windy and experience a greater range of temperatures. During light-wind, clear sky winter conditions cold air drainage/ponding into the valleys occurs, leading to the formation of low-level temperature inversions which can result in poor air quality.

4. State of the region's air quality

This section presents an analysis of the current state of air quality in the Wellington region, based on three years of continuous PM_{10}, carbon monoxide and nitrogen dioxide data collected between 2008 and 2010 at six long-term (permanent) monitoring sites. In addition to comparing the results for these principal air quality indicators against national standards and guidelines designed to protect public health, information gained from investigations into hazardous air pollutants (HAPs), such as industrial discharges or area sources such as domestic fires, is also summarised.

4.1 Key indicator air pollutants

4.1.1 Approach to analysis

Three years of continuous monitoring data collected between 2008 and 2010 have been aggregated to describe the current state of air quality at six long-term (permanent) sites across the region. A three-year period was used to accommodate inter-annual variation in air quality due to meteorology and is short enough not to be affected by any longer term trends that may be present.

The monitoring sites have been divided into two types:

- 'neighbourhood sites' (Lower Hutt, Upper Hutt, Wainuiomata, Masterton and Tawa) – these sites are located in areas that broadly typify residential land use and are used to assess urban air quality trends and compliance with air quality guidelines and standards.
- 'peak sites' (Wellington central and short-term sites at Melling intersection[11] (Lower Hutt) and at Ngauranga[12] (Wellington)) – these sites are located near busy roads where high pollutant concentrations are expected and are used to assess the impact of traffic emissions on local air quality.

Details on the data analysis and presentation methods are outlined in Appendix 7 and the summary statistics for each monitoring site are provided in Appendix 8. Refer to Section 2.7 for information on the national standards and guidelines used in this section.

4.1.2 Neighbourhood air quality monitoring sites

Figure 4.1 shows the distribution of particulate matter (PM_{10}), carbon monoxide and nitrogen dioxide measured at five sites located in residential areas (note only PM_{10} was measured at Wainuiomata). The average concentration of PM_{10} measured across the five sites ranged from 11.0 $\mu g/m^3$ (Upper Hutt) to 13.7 $\mu g/m^3$ (Masterton). All residential monitoring stations recorded PM_{10} concentrations below the annual average guideline of 20 $\mu g/m^3$ (Figure 4.1(A)). Both Masterton and Wainuiomata experienced a higher frequency of days with elevated PM_{10} than the other residential sites resulting in occasional winter-time exceedences of the daily limit of 50 $\mu g/m^3$ set by the National Environmental Standards for Air Quality (NES-AQ).

[11] From November 2006 to January 2010.
[12] From November 2005 to July 2008.

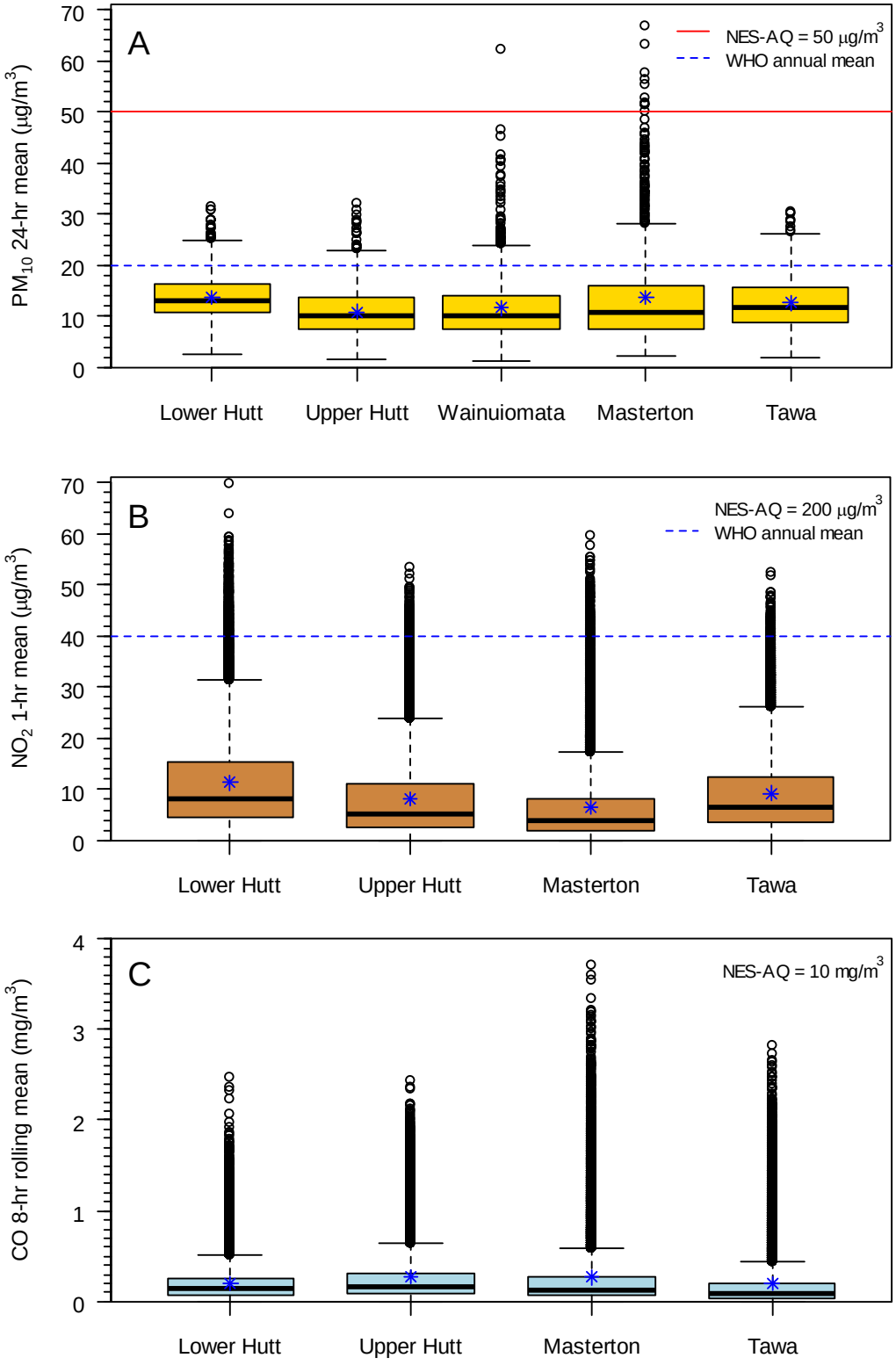


Figure 4.1: The distribution of A) daily mean PM_{10} concentrations, B) hourly mean nitrogen dioxide (NO_2) concentrations and C) 8-hour moving mean carbon monoxide (CO) concentrations, based on continuous measurements at residential monitoring sites from 2008 to 2010 (2009 to 2010 for Tawa). The blue stars show the mean concentration for each site over the three-year period.

The concentrations of nitrogen dioxide measured across the residential areas were relatively low and well within the maximum 1-hour average of 200 μg/m^3 set by the NES-AQ (Figure 4.1(B)). Average concentrations ranged from 6.5 μg/m^3 (Masterton) to 11.3 μg/m^3 (Lower Hutt), well below the WHO (2006) annual average guideline of 40 μg/m^3. The average concentration measured at Lower Hutt was slightly higher than at the other residential sites reflecting the site's proximity to commercial activities and busier local roads connecting Lower Hutt CBD to the eastern suburbs.

The concentrations of carbon monoxide measured across the residential monitoring sites were extremely low, with average concentrations ranging from 0.2 to 0.3 mg/m^3 – less than one tenth of the 8-hour moving average limit of 10 mg/m^3 set by the NES-AQ (Figure 4.1(C)). Higher peak values measured at the Masterton site can be attributed to the contribution of domestic fires on some winter evenings.

4.1.3 Peak (road side) air quality monitoring sites

Figure 4.2 shows the distribution of PM_{10}, carbon monoxide and nitrogen dioxide measured at three sites located near heavily trafficked roads. In terms of PM_{10} all three transport-impacted sites recorded concentrations lower than the annual average guideline of 20 μg/m^3 (Figure 4.2(A)). The Ngauranga Gorge site experienced the highest PM_{10} concentration and this was due, in part, to aggregate stock piles and quarrying activities located nearby. There was one exceedence of the NES-AQ daily limit of 50 μg/m^3 recorded at Wellington central and at Ngauranga. These elevated concentrations were attributed to non-vehicle exhaust emission sources, as they occurred during off-peak traffic times and did not coincide with high levels of other pollutants monitored at the site associated with vehicle emissions.

The concentrations of nitrogen dioxide measured at the transport-impacted sites were approximately 20 μg/m^3 higher than at the residential sites but still within the NES-AQ limit of 200 μg/m^3 (Figure 4.2(B)). The median concentration measured at central Wellington was slightly higher than the other transport sites. Annual average concentrations at all sites were all below the WHO (2006) annual average guideline of 40 μg/m^3.

Carbon monoxide concentrations measured were also low, although about 0.4 mg/m^3 higher than those measured at residential sites, with average levels less than one tenth of the NES-AQ limit of 10 mg/m^3 (Figure 4.2(C)).

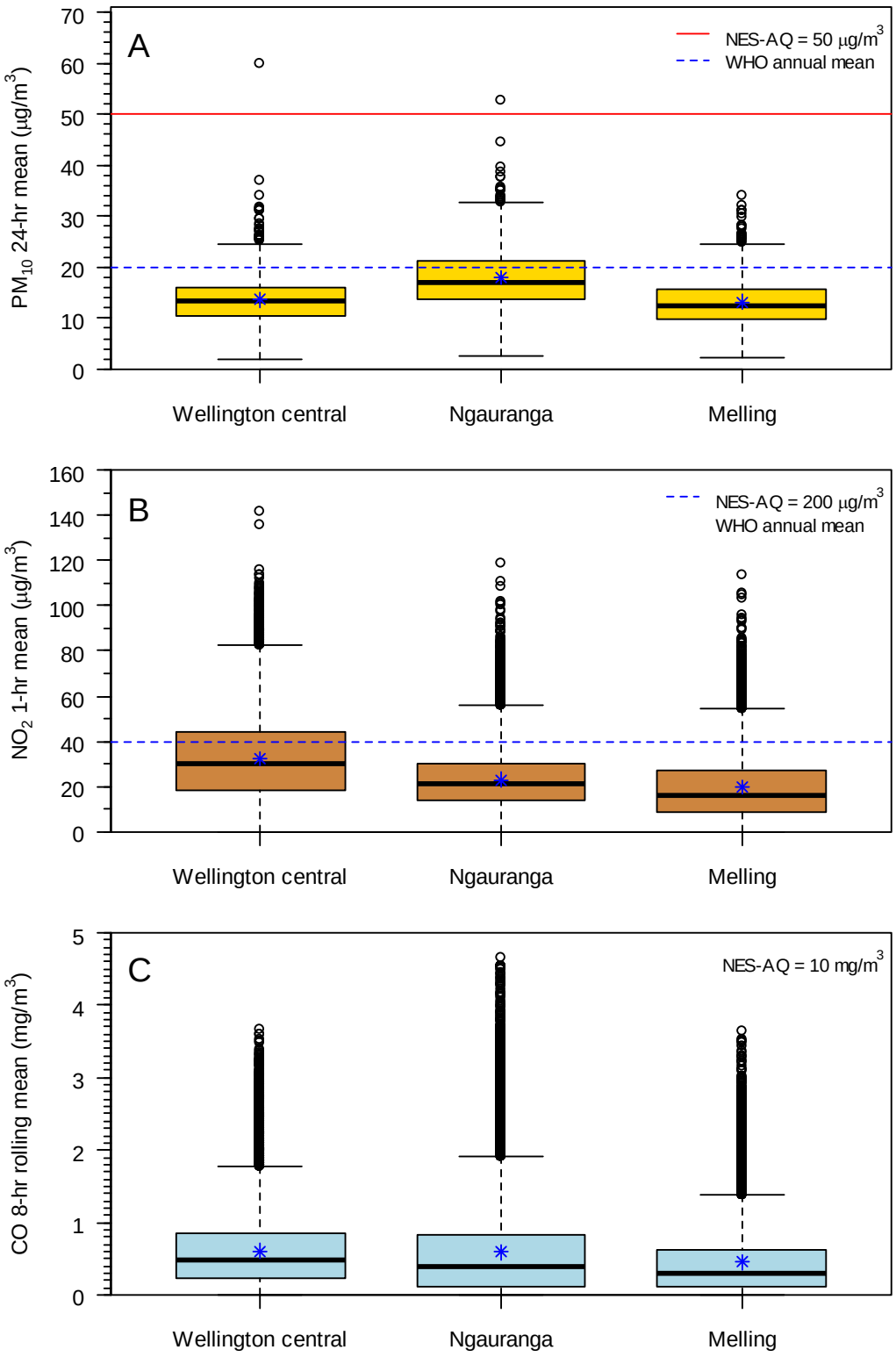


Figure 4.2: The distribution of A) daily mean PM_{10} concentrations, B) hourly mean nitrogen dioxide (NO2) concentrations and C) 8-hour moving mean carbon monoxide (CO) concentrations at based on continuous measurements at Wellington central (2006 to 2010), Ngauranga (2006 to 2008) and Melling (2006 to 2009). The blue stars show the mean concentration for each site over their respective monitoring periods.

4.1.4 Compliance with NES-AQ

Overall, there was a high degree of compliance with the NES-AQ at the monitored sites. The sites where there were exceedences of the NES-AQ threshold for PM_{10} are shown in Table 4.1. The exceedences in Masterton, Carterton and Tawa occurred during winter and were attributed to emissions from domestic fires. The exceedences at Wellington central and Ngauranga were attributed to non-vehicle emission sources. The Wairarapa was the only airshed to breach the NES-AQ, which it did in 2006, 2008 and 2010. A list of the dates and concentrations recorded for these events is provided in Appendix 9.

Table 4.1: Exceedences of the NES-AQ for PM_{10} recorded in the Wellington region by year, 2006 to 2010 (monitoring instrument indicated in brackets)

Site	2006	2007	2008	2009	2010
Masterton	3 (TEOM)	0 (TEOM)	3 (TEOM)	1 (FH62)	4 (FH62)
Carterton	Not monitored	Not monitored	Not monitored	Not monitored	1 (FH62)
Wainuiomata	Not monitored	1	0	0	0
Wellington central	0	0	1	0	0
Tawa	Not monitored	1 (TEOM)	0	0	0
Ngauranga	0	1 (FH62)	0	Not monitored	Not monitored

4.1.5 Passive nitrogen dioxide monitoring

In 2010, the NZ Transport Agency (NZTA) monitored nitrogen dioxide at 29 sites throughout the Wellington region as part of their national passive monitoring network[13]. These sites were located next to state highways and local roads and in urban background locations. Details for the five sites that measured the highest annual concentration are listed in Table 4.2. Some of the highest concentrations were recorded on local roads, which carry less traffic than state highways but may have high nitrogen dioxide levels due to confinement of vehicle emissions as a result of street canyon effects. Another reason for the higher concentrations is the proximity of the passive monitoring device to the roadside (Figure 4.3). Monitoring of nitrogen dioxide using standard methods (as utilised at Greater Wellington SoE monitoring stations) requires a greater distance between the monitoring instrument and the roadside in accordance with AS/NZS 3580.1.1:2007[14].

Table 4.2: Top five annual average concentrations of nitrogen dioxide (µg/m^3) measured by passive monitoring in the Wellington region (2010)

(Source: NZTA)

Monitoring site	Site classification	Distance to road	Annual concentration
Riddiford St/Hall St, Newtown, Wellington	Local road	1 m	40.3 µg/m^3
Rugby Street, Basin Reserve, Wellington	SH	1.5 m	35.5 µg/m^3
Knights Road, Bloomfield Tce, Lower Hutt	Local road	1 m	30.5 µg/m^3
Wellington central (Greater Wellington site)	SH	5 m	27.5 µg/m^3
Western Hutt Rd / Manor Park Rd	SH	1 m	26.1 µg/m^3

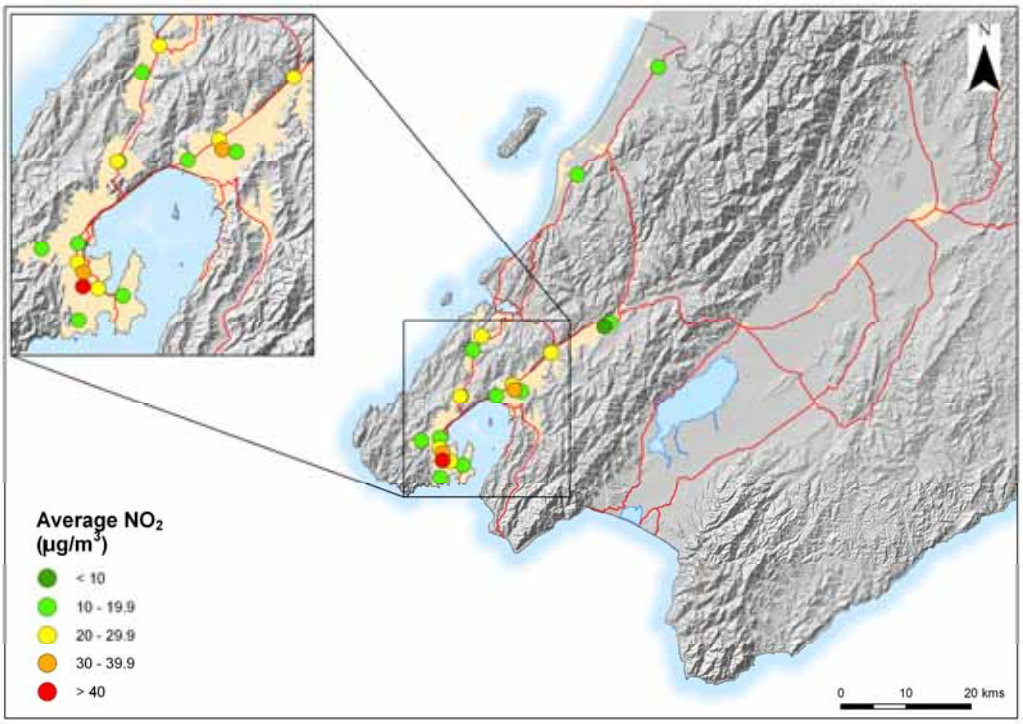
[13] Nitrogen dioxide (NO_2) is a widely used indicator of pollution from motor vehicles. NZTA established a national NO_2 passive monitoring network in 2007 in order to determine the impact of vehicle emissions on air quality across the state highway network (NZTA 2011). Diffusion tubes are an indicative monitoring technique that is ideal for examining spatial variability in long-term (ie, annual) NO_2 concentrations across a wide area.

[14] Methods for sampling and analysis of ambient air. Part 1.1: Guide to siting air monitoring equipment.

Figure 4.3: Location of passive nitrogen dioxide monitoring tubes (red square) at NZTA's monitoring site on the corner of Riddiford and Hall streets, Newtown, Wellington

NZTA's monitoring results for all Wellington sites monitored in 2010 are presented in Figure 4.4 where the annual concentration has been 'banded' relative to the WHO (2006) annual average guideline for nitrogen dioxide of 40 μg/m^3.

To enable comparisons to be made between continuous monitoring using a reference method and the passive screening method, NZTA has co-located diffusion tubes at four of Greater Wellington's permanent air quality monitoring sites. The co-location results to date indicate the passive monitoring method over-estimates the nitrogen dioxide concentration relative to the standard method by up 27%. The relationship between the two monitoring methods appears to be site-specific and a longer period of monitoring is needed to better understand this relationship.



(Source: NZTA)

Figure 4.4: Annual average nitrogen dioxide (NO_2) concentration (2010) measured by NZTA at sites in the Wellington region

4.2 Hazardous air pollutants (HAPs)

As outlined in Section 2.6, HAPs are not routinely measured as part of Greater Wellington's air quality SoE monitoring programme; the monitoring necessary to furnish results that can be compared to national health guidelines (refer Section 2.7.3) is expensive and resource-intensive. However, some HAPs, notably volatile organic compounds (VOCs) and metals (lead and arsenic), have been monitored using standard methods as part of short-term targeted investigations in areas of the Wellington region where significant industrial sources exist. There are also limited data available on concentrations of polycyclic aromatic hydrocarbons (PAHs) that have been collected as part of other studies in Wainuiomata and Masterton.

4.2.1 Volatile organic compounds (VOCs)

(a) Seaview industrial area

In 2003 18 months of targeted VOC monitoring was undertaken in the Seaview industrial area in Lower Hutt. This area was selected for investigation because of the presence of numerous sources of VOCs – the area has a high density of discharges to air with activities that include light manufacturing, engineering workshops, paint manufacture, hazardous waste processing, freight storage, oil and fuel tank farms and wastewater treatment (Davy & Day 2001).

VOC monitoring was undertaken from March 2003 to November 2004 at 158 Hutt Park Road, Gracefield on a one-day-in-six sampling regime (midnight to

midnight).[15] Samples were analysed for the presence of a comprehensive suite of 81 VOCs. Annual data capture rates of 75% (46 samples) and 82% (50 samples) were achieved for 2003 and 2004 respectively. Only half of the VOCs tested had at least one result above the analytical level of detection. VOCs with at least 20% of samples above the detection limit were summarised using regression on order statistics (Table 4.3) as the data fitted a log-normal distribution reasonably well.

VOC monitoring campaigns typically focus on BTEX compounds which are group of aromatic hydrocarbons consisting of benzene, toluene, ethylbenzene and xylene (which has three isomers: o-xylene, m-xylene and p-xylene). In this study concentrations of o-xylene and p,m-xylene were summed and reported as xylene total. The BTEX monitoring results shown in Figure 4.5 indicate that concentrations in 2004 were less than those measured in 2003.

Monitoring of benzene in 2003 and 2004 produced annual average concentrations of 4.06 $\mu g/m^3$ (2003) and 1.33 $\mu g/m^3$ (2004), both of which were compliant with the 10 $\mu g/m^3$ MfE (2002) guideline current at the time. However, the average benzene concentration guideline was reduced to 3.6 $\mu g/m^3$ in 2010 and comparing the 2003 and 2004 monitoring results against this more stringent guideline indicates that only the 2004 average complied with it. Monitoring of benzene concentrations at roadside sites in Hamilton from 2003 to 2004 shows concentrations decreased by about 50% during this period as a result of changes to petrol formulation (www.waikatoregion.govt.nz). A similar reduction in benzene concentrations in Wellington region over this period is also likely.

There are no national ambient air quality guidelines for toluene, ethylbenzene or xylene. An annual average guideline for toluene of 190 $\mu g/m^3$ and for xylene of 950 $\mu g/m^3$ was recommended by a technical review of the 1994 MfE guidelines (Rolfe 2000). However, these recommendations were not carried through to the final Ministry for the Environment guidelines published in 2002. Concentrations of toluene and xylene measured in Seaview were well below the levels recommended by Rolfe (2000).

[15] Monitoring was undertaken in accordance with USEPA Method TO-17 'Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes.

Table 4.3: Summary of volatile organic compound (VOC) monitoring results for Seaview collected over 2003 and 2004 (LOD = level of detection)

VOC (µg/m³)	Whole data set			2003				2004			
	Median	Mean	Std deviation	Median	Mean	Std deviation	% >LOD	Median	Mean	Std deviation	% >LOD
Toluene	6.90	19.26	35.89	11.50	30.57	48.48	6.5	3.50	8.86	10.41	8.0
Trichlorofluoromethane	2.20	4.57	5.34	6.95	7.92	6.12	6.5	1.50	1.57	0.79	16.0
p,m-xylene	2.35	4.51	5.70	3.95	6.51	7.22	10.9	1.70	2.68	2.81	18.0
Benzene	1.35	2.64	4.64	2.50	4.06	6.24	13.0	0.75	1.33	1.54	32.0
o-xylene	0.85	1.51	1.75	1.30	2.08	2.16	19.6	0.60	0.99	1.03	32.0
Xylene Total	3.25	6.04	7.42	5.15	8.61	9.35	10.9	2.30	3.69	3.82	18.0
1,2,4-trimethylbenzene	1.15	2.17	2.70	1.60	2.92	3.27	15.2	0.80	1.49	1.83	36.0
Ethylbenzene	0.70	1.21	1.44	0.90	1.66	1.80	21.7	0.50	0.80	0.83	36.0
Pentane	2.75	5.90	8.81	2.35	5.89	8.94	37.0	3.25	5.82	8.78	30.0
Trichloroethene	1.00	3.31	7.92	1.20	4.97	11.00	39.1	0.70	1.80	2.35	48.0
1,3,5-trimethylbenzene	0.40	0.66	0.74	0.55	0.85	0.85	39.1	0.28	0.49	0.57	54.0
2-butanone	1.00	7.07	17.97	4.50	13.87	24.27	39.1	NA	NA	NA	>80
Acetone	0.85	9.97	26.25	3.20	19.79	35.53	43.4	NA	NA	NA	>80
n-propylbenzene	0.10	0.33	0.60	0.25	0.60	0.79	60.9	NA	NA	NA	>80
Hexane	1.01	1.83	2.22	1.32	2.00	1.91	73.9	0.59	1.58	2.51	78.0
Naphthalene	0.12	0.28	0.47	0.15	0.38	0.63	71.7	NA	NA	NA	>80

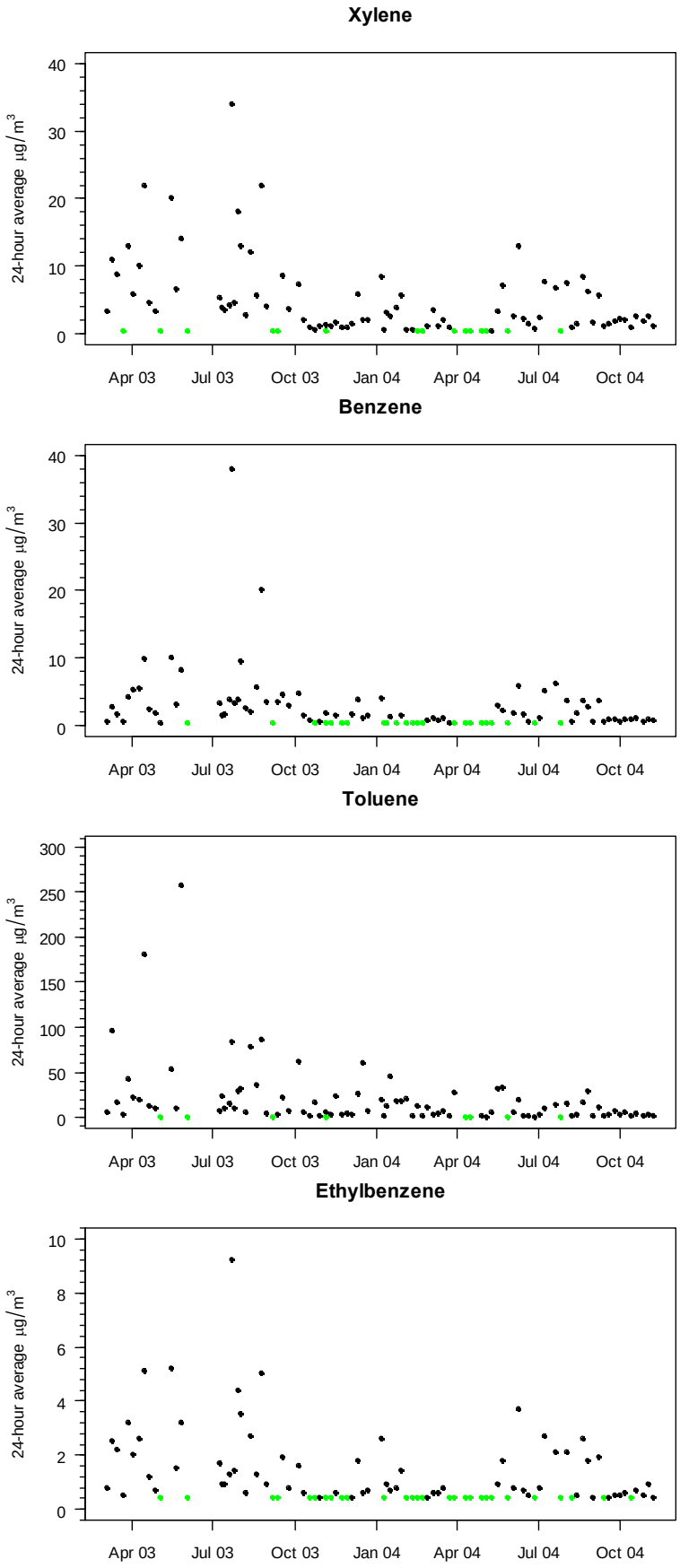


Figure 4.5: Time series of daily BTEX concentrations measured at Seaview during 2003 and 2004 (green points show values below the analytical level of detection)

(b) Masterton wood processing plant

In response to local concerns about air quality an investigation into levels of chromium and arsenic species associated with particulate matter arising from kiln drying of timber and re-drying of CCA-treated timber was undertaken at Railway Crescent, Masterton during the winter of 2004 (Davy 2005b). Ambient air was also sampled for formaldehyde and other aldehyde species associated with activities at the plant.

The monitoring results showed that CCA concentrations at Railway Crescent were similar to those measured at Greater Wellington's Wairarapa College air quality monitoring site over the same period. Chromium levels in air were likely to be below air quality guidelines for the protection of human health. Arsenic concentrations were elevated and at similar concentrations to that measured at Wairarapa College; however, this was attributed to domestic burning of CCA-treated timber for home heating rather than emissions from the wood processing and treatment plant.

Of the aldehydes monitored, only formaldehyde, acetaldehyde and acrolein were present at detectable concentrations. Formaldehyde and acetaldehyde levels were well below national guidelines (MfE 2002). Peak acrolein concentrations occurred during south-westerly winds, indicating that emissions from the timber mill are unlikely to be the source (there is no relevant New Zealand guideline for acrolein). Acrolein emissions (also formaldehyde and acetaldehyde) are known to be associated with wood combustion sources such as domestic fires.

4.2.2 Polycyclic aromatic hydrocarbons (PAHs)

Wood smoke contains a multitude of compounds with toxic, carcinogenic and inflammatory properties. Organic compounds, such as polycyclic aromatic hydrocarbons (PAHs), are released during the incomplete combustion of wood and other organic materials.

In the Wainuiomata receptor modelling study the organic carbon content of PM, determined by thermal optical reflectance, was found to be highly correlated with both $PM_{2.5}$ (r=0.82) and the biomass burning source (r=0.86) (Davy et al. 2009a). This indicated that most of the organic carbon found in PM was derived from hydrocarbon compounds emitted by solid fuel fires. During the winter months it was found that organic carbon made up, on average, 20% of measured PM_{10} mass. A semi-quantitative analysis of organic compounds present on a day with high source contribution of biomass burning identified several PAHs (eg, benzo(a)pyrene, pyrene, fluoranthene, anthracene). These findings are consistent with a study of particle-associated PAHs in air at Masterton (2003 to 2004) and Wainuiomata (2006) carried out by Victoria University (Xu 2007) that found elevated levels of BaP in Masterton and Wainuiomata during the winter months. These studies did not include enough monitoring data to determine an annual BaP concentration. However, similar studies carried out in Christchurch's woodsmoke-dominated airsheds have found annual average BaP concentrations 10 times higher than the MfE (2002) guideline value of 0.3 ng/m^3 (McCauley 2005). It is uncertain

whether management options to reduce PM_{10} concentrations to meet the NES-AQ will also achieve compliance with the BaP guideline.

4.2.3 Lead – industrial sources

In the Wellington region there is a local industrial source of airborne lead in Petone (lead-acid battery recycling) and, until 2006, there was also a source in Seaview (battery manufacture). A residential area lies to the west of the battery recycling plant in Petone. As the closest residential dwellings are within 50 m of the plant boundary, Greater Wellington investigated levels of lead in air and in dust to provide information for community health-risk assessments.

Levels of lead in air adjacent to the factory were measured in 1999 (Davy 2000a) and were re-measured in 2008 (Mitchell 2008) and in 2009 (Mitchell 2009). The most recent monitoring found three-month moving average lead concentrations in total suspended particulate (ranging from 0.019 $\mu g/m^3$ (Kirkcaldy Street) to 0.035 $\mu g/m^3$ (Waione Street), well below both the MfE (2002) national ambient air quality guideline of 0.2 $\mu g/m^3$ and the USEPA standard[16] of 0.15 $\mu g/m^3$. Overall, levels of lead in air have dropped by an order of magnitude between 1999 and 2009 due to improved pollution control equipment installed at the battery recycling plant.

Two research studies aimed at determining the sources of PM in Seaview (discussed further in Section 5) were carried out from 2003 to 2004 and from 2005 to 2007. Between 2003 and 2004 elevated lead levels were detected on some sampling days. When the study was repeated in 2005 to 2007 the peak values of lead detected in both the fine and coarse fractions were substantially lower than those measured between 2003 and 2004. Table 4.4 compares the values for the two periods. The reduction in lead in airborne particulate is attributed to the closure of the lead-acid battery manufacturing plant in Seaview in 2006. The average lead concentration for the 2005 to 2007 study period (measured as PM_{10}) was 0.025 $\mu g/m^3$ which is well below the MfE guideline of 0.2 $\mu g/m^3$ set to protect public health.

Table 4.4: Mean and maximum concentrations of lead in fine and coarse PM collected by GENT sampler at Seaview over 2003 to 2007, based on data presented in Davy (2007) and Davy et al. (2008)

Concentration ($\mu g/m^3$)	2003 to 2004			2005 to 2007		
	Mean	Max	% samples >LOD	Mean	Max	% samples >LOD
Coarse ($PM_{2.5–10}$)	0.044	1.447	97%	0.013	0.069	35%
Fine ($PM_{2.5}$)	0.020	0.427	64%	0.012	0.111	30%

4.2.4 Arsenic – domestic fires

Toxic inorganic compounds, such as arsenic, have been shown to be associated with residential wood burning in other parts of New Zealand due to the use of copper chrome arsenic (CCA) treated timber as a fuel source for domestic heating (Davy et al. 2011b). Similarly, the Wainuiomata receptor modelling study found arsenic was associated with the biomass source burning profile

[16] Effective 12 January 2009 (http://www.gpo.gov/fdsys/pkg/FR-2008-11-12/html/E8-25654.htm)

(r=0.68 [0.61, 0.75]) indicating that sufficient quantities of CCA-treated timber were burnt to cause peak arsenic concentrations during winter (Figure 4.6).

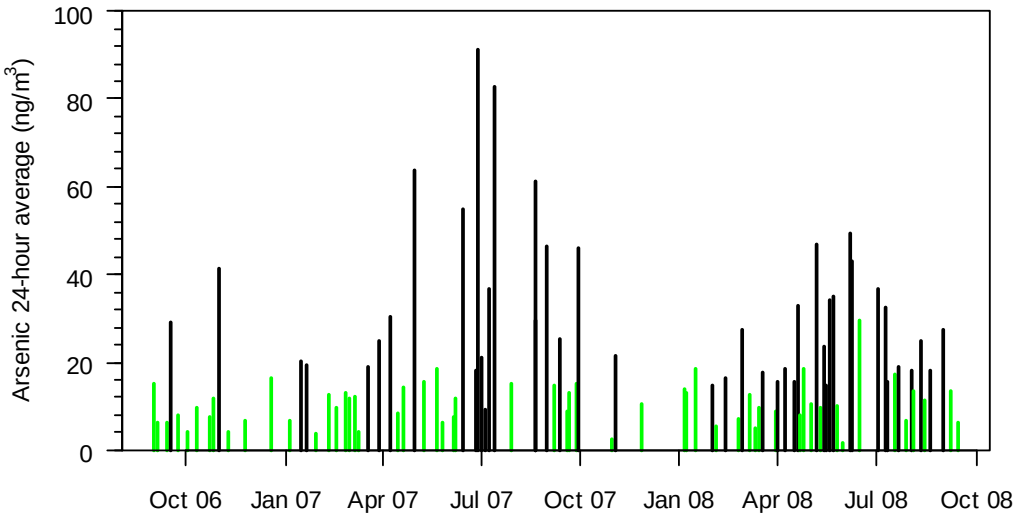


Figure 4.6: Time series of arsenic concentrations (ng/m^3) detected in $PM_{2.5}$ at Wainuiomata over 2006 to 2008. The green bars represent measurements below the analytical level of detection

Arsenic was detected on 115 fine PM filters, of which 59 were above the limit of detection (LOD) obtained by ion beam analysis. The exact LOD for the concentration of each element varies with each sample filter depending on the filter composition, sample composition, detector resolution and spectral interference from other elements in the sample.

Figure 4.7 shows that there was a tendency for elevated arsenic concentrations to occur on days where there was a high biomass burning contribution. The relationship between biomass burning and arsenic concentration was not consistent though, due in part to the intermittent nature of CCA-treated timber use (ie, presumably only used when timber off-cuts were available). The copper and chrome components of the treated timber were not associated with the biomass source profile as these are retained in the ash during combustion of CCA-treated timber (Davy et al. 2011b).

The annual average concentration of arsenic (occurring in the fine PM fraction) was estimated at 6.9 ng/m^3 in both 2007 and 2008 using only measurements above their limit of detection with all other values set to zero. Therefore, it is likely that the MfE (2002) annual average guideline for inorganic arsenic of 5.5 ng/m^3 was exceeded in Wainuiomata over the monitoring period.

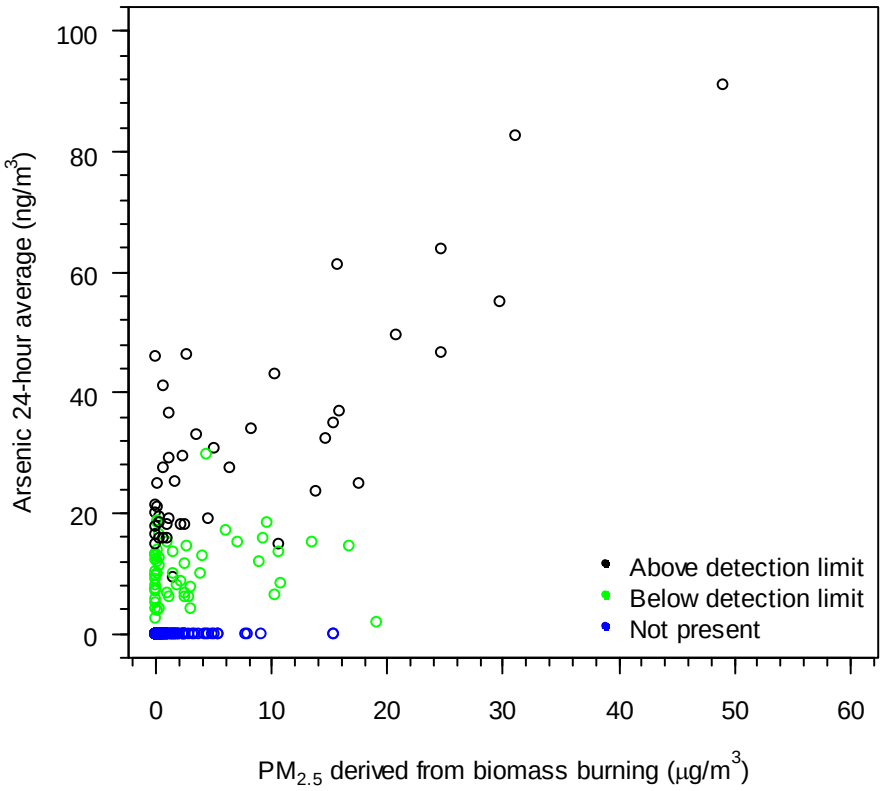


Figure 4.7: Scatter plot of $PM_{2.5}$ derived from biomass burning and arsenic concentrations (determined by ion beam analysis) measured at Wainuiomata over 2006 to 2008

4.2.5 Arsenic – industrial sources

As part of the lead in air study in Petone (Mitchell 2009), average arsenic concentrations measured in 2009 (March to July only) ranged from 3.9 ng/m^3 (Waione Street) to 4.4 ng/m^3 (Kirkcaldy Street).

4.3 Summary

The Wellington region experiences good air quality. Of the three key indicator pollutants measured over the reporting period, PM_{10} was the only pollutant to approach or exceed the NES-AQ limit and this was restricted to the winter months in Masterton, Carterton and Wainuiomata. These occasional episodes of elevated PM were attributed to emissions from domestic wood burners occurring under meteorological conditions that curtailed the dispersion of pollutants. Although concentrations of PM_{10} may be below the NES-AQ threshold of 50 µg/m^3 most of the time, the concentrations of other toxic contaminants associated with wood smoke, such as PAHs, $PM_{2.5}$ and inorganic arsenic, may exceed applicable health guidelines.

Information on PM_{10} concentrations is more useful for air quality management purposes and health studies if it also includes information on the composition of particulate matter and relative source contributions. Section 5 addresses this information need using source apportionment techniques for PM in the region.

The concentrations of key indicator pollutants measured at Greater Wellington's roadside monitoring sites during 2008 to 2010 were all well

below national standards and guidelines. NZTA's passive nitrogen dioxide monitoring programme indicates that there was high spatial variability in nitrogen dioxide concentrations throughout the region. Some local roads experienced higher nitrogen dioxide concentrations than the monitoring sites on heavily-trafficked state highways. The higher concentrations may arise because these particular local road monitoring sites are in highly built-up areas where the dispersal of pollutants may be restricted compared to the relatively well-ventilated state highway monitoring locations.

The Wellington region has relatively low numbers of industrial discharges to air. The area with the highest density of discharges to air is Seaview in Lower Hutt. Levels of volatile organic compounds measured in Seaview from 2003 to 2004 were extremely low, apart from benzene. Benzene concentrations are likely to have decreased significantly since 2004. Levels of lead in air near industrial sources in Petone and Seaview have declined markedly due to improvements in process control at the lead-acid battery recycling plant and the closure of a battery manufacture plant, respectively.

5. Sources of particulate matter and impacts on air quality

5.1 Introduction

The results of air quality monitoring presented in Section 4.1 highlight that particulate matter is the primary air quality indicator of concern for the Wellington region as it is the only indicator known to approach or exceed the NES-AQ. In order to manage air quality effectively, we need credible information of the sources of PM and how much each source contributes to air pollution. This is known as source apportionment.

A substantive source apportionment research programme was undertaken for the region between 2002 and 2010. Over this period, Greater Wellington participated in an international source apportionment programme in Australasia that was led by GNS Science under the umbrella of the Regional Cooperative Agreement and the International Atomic Energy Agency. The programme sought to determine the chemical and physical composition of ambient PM in order to apportion the measured PM to sources at the following locations (Table 5.1):

- Upper Hutt (Trentham), Seaview industrial area and Masterton (Davy 2007) using a receptor modelling technique;
- Wainuiomata (Davy et al. 2009a) using a receptor modelling technique; and
- Carterton, Featherston and Solway (Davy et al. 2009b) using a mass reconstruction technique.

Table 5.1: Location of PM monitoring sites for source apportionment studies undertaken between 2002 and 2010

Site	Location	Monitoring period
Upper Hutt	Trentham	June 2000 to February 2002
Masterton	Wairarapa College	April 2002 to November 2004
Seaview	158 Hutt Park Road, Lower Hutt	April 2002 to November 2004 July 2005 to July 2007
Wainuiomata	Wainiomata Bowling Club	July 2006 to September 2008
Wairarapa towns	Featherston, Carterton and Solway	June 2009 to July 2009
Raumati South	Glen Road	May 2010 to August 2010

5.2 Fine and coarse PM concentrations

As part of the research programme, concentrations of both $PM_{2.5}$ (fine) and $PM_{2.5-10}$ (coarse) particulate matter were identified at Upper Hutt (located at Trentham Fire Station), Masterton, Wainuiomata and Seaview (Figure 5.1 and Table 5.2). At these four sites, coarse PM concentrations ranged from 1.5 to 25 $\mu g/m^3$ – with no particular seasonality. In contrast, fine PM concentrations ranged from 1 to 46 $\mu g/m^3$ and showed distinct seasonality in Upper Hutt, Masterton and Wainuiomata; the largest peaks occurred during the winter months (May to September), particularly in Masterton and in Wainuiomata. Little or no seasonality in fine or coarse PM was observed in Seaview.

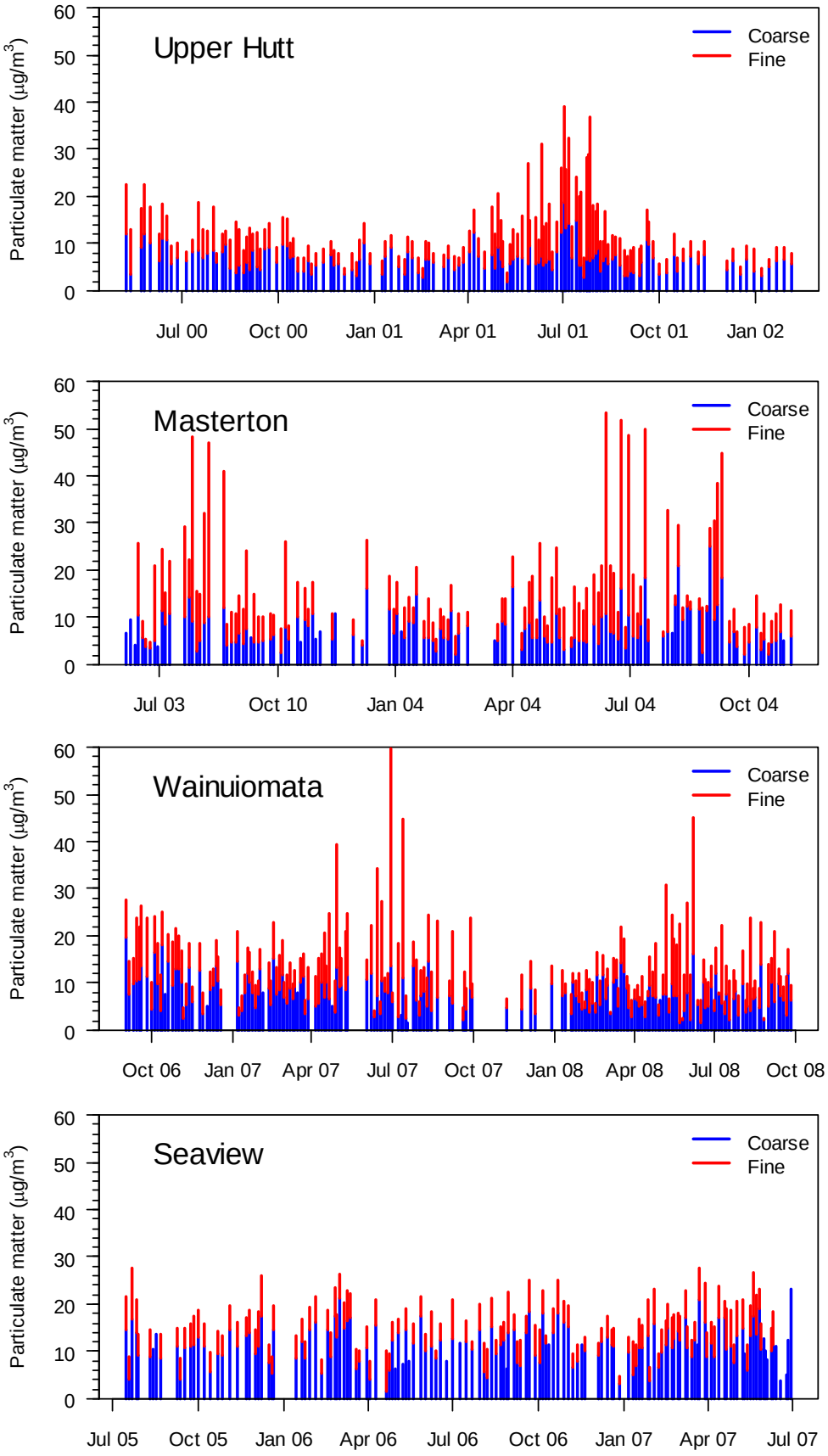


Figure 5.1: Time series of fine and coarse particulate matter measured at Upper Hutt (May 2000 to Feb 2002), Masterton (Jul 2002 to Nov 2004), Wainuiomata (Jul 2006 to Sep 2008) and Seaview (Jul 2005 to Jul 2007) by GENT sampler

Table 5.2: Summary of gravimetric concentrations (µg/m^3) of fine and coarse PM collected by GENT sampler at Upper Hutt (May 2000 to February 2002), Masterton (June 2003 to November 2004), Wainuiomata (July 2006 to September 2008) and Seaview (July 2005 to July 2007)

	Min	25th percentile	Median	Mean	75th percentile	Max	*n*
Upper Hutt							
$PM_{2.5}$	1.2	2.9	4.2	6.0	7.6	26.8	142
$PM_{2.5-10}$	2.0	5.1	6.3	6.7	7.9	18.6	142
PM_{10}	3.9	8.6	10.8	12.7	14.9	39.2	142
Masterton							
$PM_{2.5}$	0.8	3.9	5.7	9.0	10.8	42.3	119
$PM_{2.5-10}$	2.1	5.0	6.3	7.6	9.6	25.0	132
PM_{10}	4.4	10.0	13.0	16.7	19.2	53.2	119
Wainuiomata							
$PM_{2.5}$	0.1	3.3	4.9	6.4	7.2	46.2	229
$PM_{2.5-10}$	1.5	4.8	7.4	7.6	9.9	19.6	189
PM_{10}	2.5	9.7	12.6	14.5	18.3	59.7	181
Seaview							
$PM_{2.5}$	1.3	3.8	5.0	4.8	6.0	10.7	142
$PM_{2.5-10}$	1.5	8.8	11.3	11.4	13.9	23.3	150
PM_{10}	4.6	13.3	16.3	16.6	19.9	27.7	130

While these results are not directly comparable to guidelines and standards (because the monitoring method is not a standard method) the average annual $PM_{2.5}$ and PM_{10} concentrations were less than their respective annual average guidelines of 10 µg/m^3 (WHO 2006) and 20 µg/m^3 (MfE 2002).

5.2.1 Ratio of fine to coarse particulate matter

Fine PM is more strongly associated with adverse health effects than PM_{10} and consequently the numerical guidelines for average annual and daily PM_{10} concentrations are based on the assumption that no more than half of the measured PM_{10} is $PM_{2.5}$ (WHO 2006). The average $PM_{2.5}$:PM_{10} ratio was 0.44 at Wainuiomata, 0.47 at Upper Hutt and 0.54 at Masterton which are close to the assumed $PM_{2.5}$:PM_{10} ratio of 0.5 used to derive the WHO numerical guidelines for PM_{10}.

The $PM_{2.5}$:PM_{10} ratio measured in the areas with high biomass burning contributions was highly variable during the winter months, although the higher ratios (ie, above 0.7) only occurred during winter (Figure 5.2). Elevated winter PM_{10} concentrations (ie, above 30 µg/m^3) were associated with ratios of 0.5 and above. Consequently, the NES-AQ PM_{10} threshold of 50 µg/m^3 may not provide the envisaged level of health protection during the winter months, on days where PM_{10} is largely composed of $PM_{2.5}$.

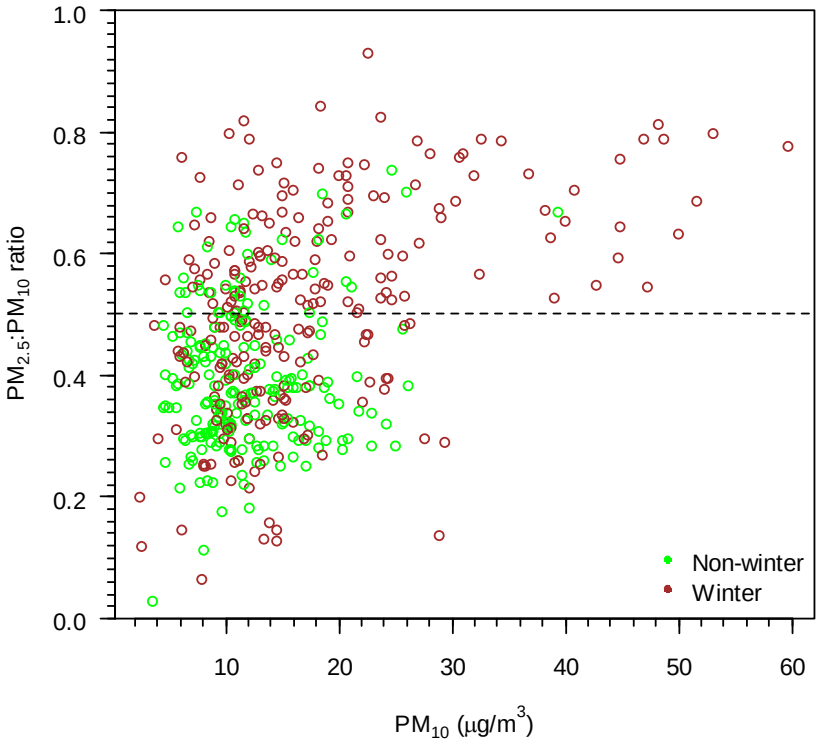


Figure 5.2: Scatter plot of PM_{10} and $PM_{2.5}$:PM_{10} ratios measured at Upper Hutt – Trentham (2000 to 2002), Masterton (2002 to 2004) and Wainuiomata (2006 to 2008) by GENT sampler

5.3 Sources of particulate matter in the region

There are six distinct sources of PM identified by receptor modelling (Davy 2007, Davy et al. (2008), (2009a), (2011a)) that are common to the region (Table 5.3).

Table 5.3: Sources of particulate matter identified in the Wellington region

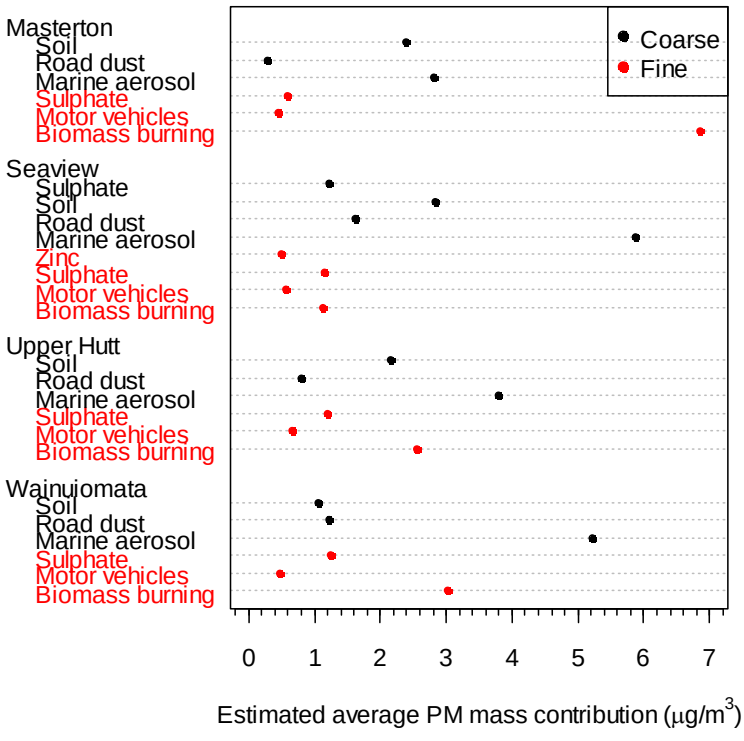
Source description	Size fraction	Origin	Elemental & chemical profile
Soil (crustal matter)	Coarse	Mechanical abrasion and weathering of the earths' crust. Sources include unsealed yards and open areas where soil particles can become disturbed by wind action	Typical components of crustal matter: aluminimum, silicon and iron, magnesium and calcium
Marine aerosol	Coarse	Long range transport from surrounding oceans	Sodium and chlorine along with other elements associated with sea water
Road dust	Coarse	Re-suspended dust from road surfacces due to vehicle movements	Sodium, sulphur, chlorine, calcium and iron
Biomass burning	Fine	Domestic fires	Black carbon and potassium (marker of wood combustion)
Motor vehicles	Fine	Exhaust emissions	Hydrogen, black carbon, calcium, iron, chloride, silica, aluminium
Sulphate	Fine	Gas to particle conversion of gases containing sulphur (eg, SO_2)	Dominated by sulphur

The contribution of each source to measured particulate matter in each of the four main study areas is shown in Figure 5.3. Soil (crustal matter) and marine aerosol are ubiquitous sources common to all areas studies. Marine aerosol originating from the oceans surrounding the region was a particularly significant contributor to PM measured in Seaview – most likely due to its exposed coastal location.

Levels of road dust and particulate from vehicle emissions were broadly similar in all four areas. One of the most striking differences between the study areas is the dominance of biomass burning source in Masterton.

The contribution of secondary sulphate, arising from the gas-to-particle conversion of gases containing sulphur, was also fairly uniform in the areas studied. There may however, be different sources of precursor gases. An analysis of wind direction suggests that emissions from high sulphur content marine-grade diesel used by vessels in Wellington Harbour may be the source of combustion-derived sulphur dioxide that contributed sulphur particles to the fine fraction at Seaview (Davy et al. 2008). Dimethyl sulphide produced by marine organisms may be a natural long-range source of sulphur-containing particles at Wainuiomata, Upper Hutt and to a lesser extent Masterton.

The Seaview industrial area was unique due to the presence of a coarse sulphate source, likely to have been associated with a local industrial activity. A zinc source made up 10% of the fine fraction and is thought to originate from emissions produced by a hot-dip galvanising operation northwest of the monitoring site.



(Source: Adapted from Davy (2007) and Davy et al. (2008) and (2009a))

Figure 5.3: Average source contribution to fine and coarse PM at Masterton (2003 to 2004), Upper Hutt (2000 to 2002), Wainuiomata (2006 to 2008) and Seaview (2005 to 2007) estimated by receptor modelling

5.3.1 Seasonality in source contributions

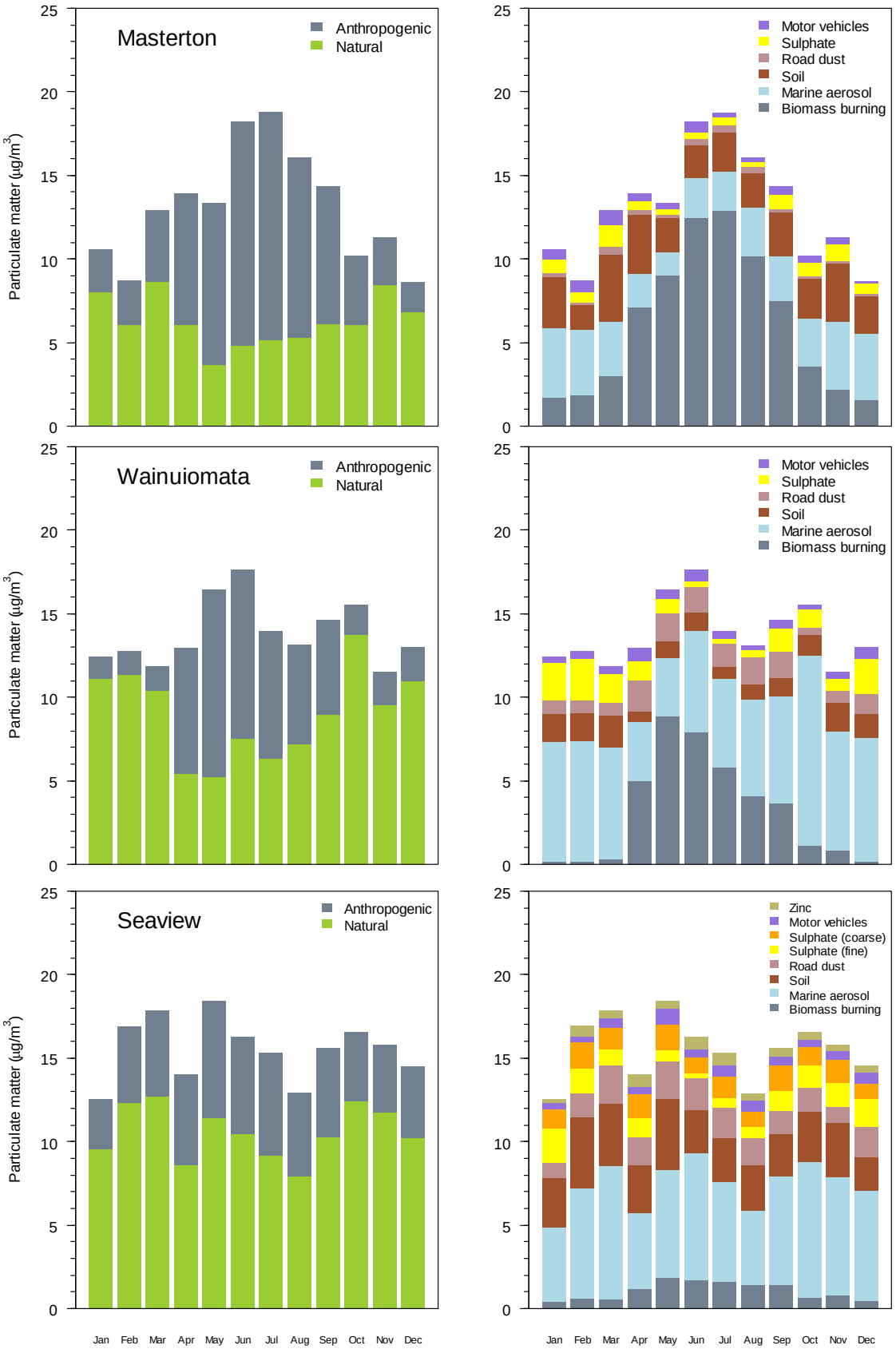
One of the key outcomes from receptor modelling is the identification of the relative contribution of natural sources and anthropogenic sources to ambient PM. Other methods of source apportionment, such as emission inventories, fail to account for natural sources, which can be substantial. Information on natural sources is critical for air quality management focussed on PM_{10} – as natural sources are uncontrollable and need to be factored into any emission reduction strategies.

Figure 5.4 shows that natural sources such as marine aerosol, crustal matter (soils) and secondary sulphate were significant contributors to measured PM_{10} in Masterton, Wainuiomata and Seaview (Upper Hutt could not be shown because only summary data were available at the time of preparing this report). In Masterton and Wainuiomata the ratio of anthropogenic source contributions to natural source contributions showed marked seasonality – with higher ratios during the winter months. Marine aerosol was a significant contributor to PM_{10} in Wainuiomata throughout the year.

A different pattern was observed in Seaview; little seasonality was evident in the relative source contributions to PM_{10}, apart from a tendency for fine sulphate contributions to be higher in the summer months largely due to increased atmospheric reactivity – which is also seen at the other sites. The biomass burning source contributions are slightly higher during the winter months on days with a north-westerly component and this is attributed to transport of domestic solid fuel emissions from the Hutt Valley by down-valley drainage flows on cold winter days.

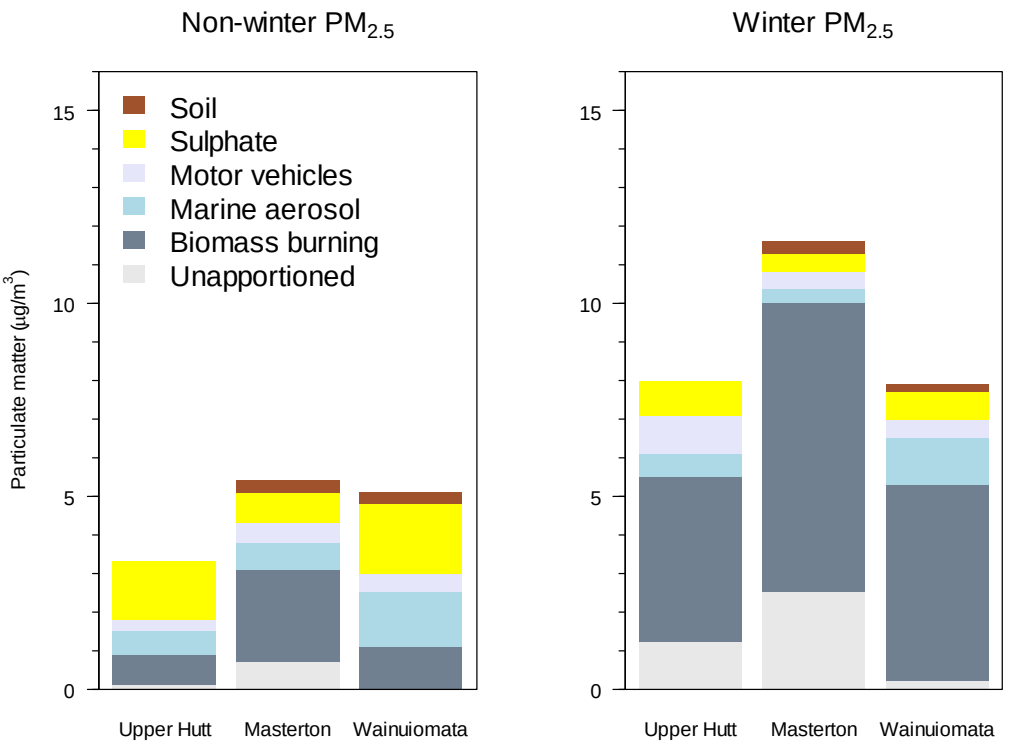
It should be noted that receptor modelling does not always account for all the gravimetrically measured mass – and in this case the concentrations in Figure 5.4 have not been scaled up to accommodate the un-apportioned mass.

The relative source contributions to $PM_{2.5}$ (including un-apportioned mass) measured at Upper Hutt, Masterton and Wainuiomata are shown in Figure 5.5. Masterton recorded the highest average winter $PM_{2.5}$ concentration, largely due to the contribution of fine PM produced by biomass burning. During the non-winter period, secondary sulphate was contributing the most of any source to $PM_{2.5}$ in Wainuiomata and Upper Hutt, although concentrations were low, averaging less than 2 $\mu g/m^3$. In Masterton biomass burning was the main source of $PM_{2.5}$ during the non-winter period.



(Source: Adapted from Davy (2007) and Davy et al. (2008) and (2009a))

Figure 5.4: Average monthly mass contribution of anthropogenic and natural sources (left) and relative source contributions to PM_{10} measured at Masterton, Wainuiomata and Seaview estimated by receptor modelling.



(Source: Adapted from Davy (2007) and Davy et al. (2009a))

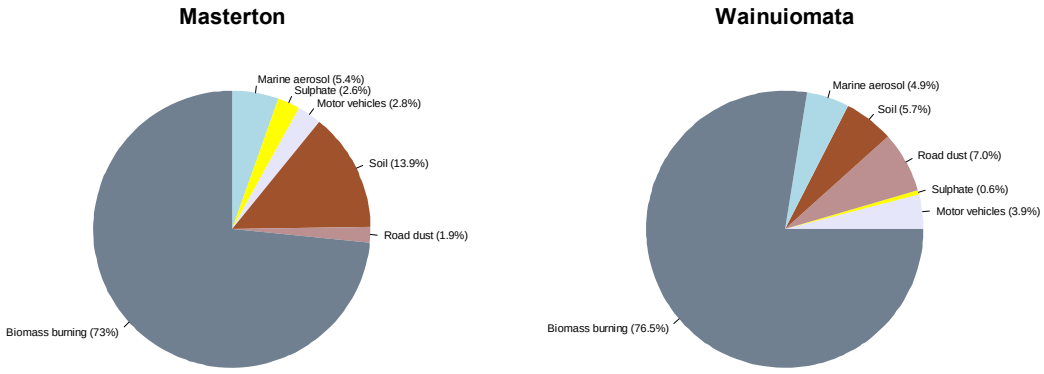
Figure 5.5: Relative non-winter (left) and winter (right) contribution of biomass burning, marine aerosol, motor vehicles, sulphate and soil to $PM_{2.5}$ measured at Upper Hutt (2000 to 2002), Masterton (2003 to 2004) Wainuiomata (2006 to 2008) estimated by receptor modelling

5.3.2 Source contributions to $PM_{2.5}$ pollution episodes

Pollution episodes are short periods of high PM concentration that generally exceed a standard or guideline. A PM2.5 pollution episode is defined by WHO (2006) as a 24-hour average greater than 25 µg/m3. During pollution episodes in Masterton and Wainuiomata, biomass burning accounted for almost three-quarters of the total estimated PM10 mass (Figure 5.6). On these days, emissions from solid fuel domestic fires, coupled with meteorological conditions unfavourable for the dispersion of air pollutants, resulted in elevated concentrations of $PM_{2.5}$ (Figure 5.7).

In Masterton, pollution episodes (recorded between 2003 and 2004) were characterised by the presence of a stable air mass (inversion conditions). Air mass back-trajectories indicate that the stable air masses originated from the southern ocean and this explained the presence of marine aerosol on high pollution nights (Davy 2007). In Wainuiomata, $PM_{2.5}$ pollution episodes (recorded between 2006 and 2008) were all associated with cold overnight temperatures and wind speeds less than 1 m/s.

There is no source apportionment information available for high pollution days (ie, $PM_{2.5}$ above 25 µg/m^3) in Upper Hutt. However, an examination of the three highest $PM_{2.5}$ days showed that biomass burning was responsible for elevated PM coupled with stable atmospheric conditions at night (Davy 2007).



(Source: Adapted from Davy (2007) and Davy et al. (2009a))

Figure 5.6: Average estimated contribution from biomass burning, road dust, motor vehicles marine aerosol, soil and sulphate to PM_{10} on eight winter nights in Masterton (2003 to 2004) and on five winter nights in Wainuiomata (2006 to 2008) when $PM_{2.5}$ exceeded 25 µg/m^3

Figure 5.7: Air pollution from domestic fires shrouds Masterton on a winter's day in 2004

5.4 Particulate matter screening studies

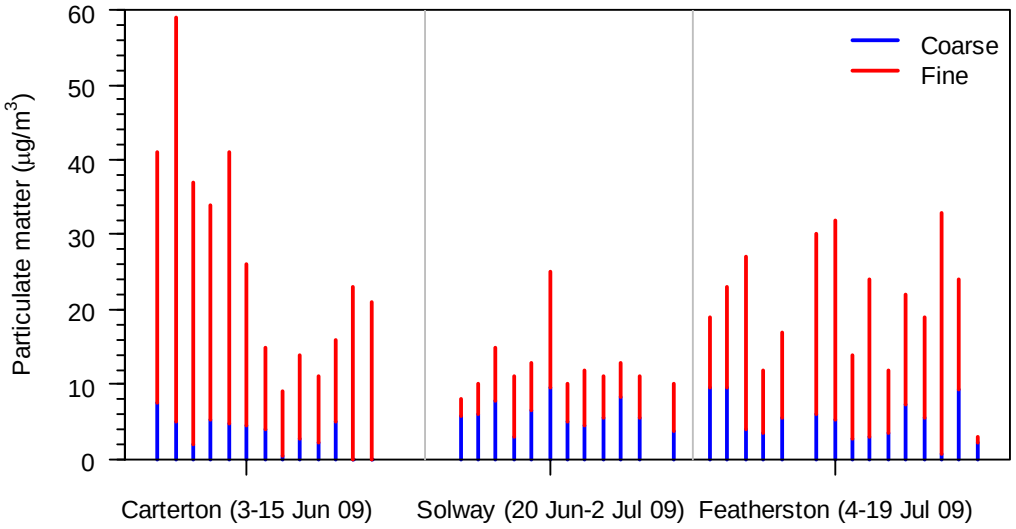
Using the techniques developed in the particulate matter research programme, two shorter studies were undertaken to identify whether air quality issues exist in some smaller urban areas across the region.

5.4.1 Wairarapa towns

A short screening study investigating air quality in Featherston, Carterton and on the outskirts of Masterton (Solway) was carried out in winter 2009. The gravimetric PM monitoring results are shown in Figure 5.8. A mass re-

construction technique was used to apportion the measured mass to likely sources (Davy et al. 2009b). In Carterton, it was found that fine PM dominated PM_{10} and that combustion sources, most likely emissions from domestic heating, were the primary contributors to fine PM. Although not directly comparable (because a non-standard monitoring method was used) there were five days when $PM_{2.5}$ was likely to have exceeded the WHO (2006) guideline of 25 µg/m^3.

PM_{10} concentrations were lower in Solway where the primary source of $PM_{2.5}$ was combustion emissions. Marine aerosol and crustal matter were the predominant contributors to coarse PM at Solway. At Featherston the primary source of $PM_{2.5}$ concentrations was attributed to domestic fires and there was one day when $PM_{2.5}$ was likely to have exceeded 25 µg/m^3.



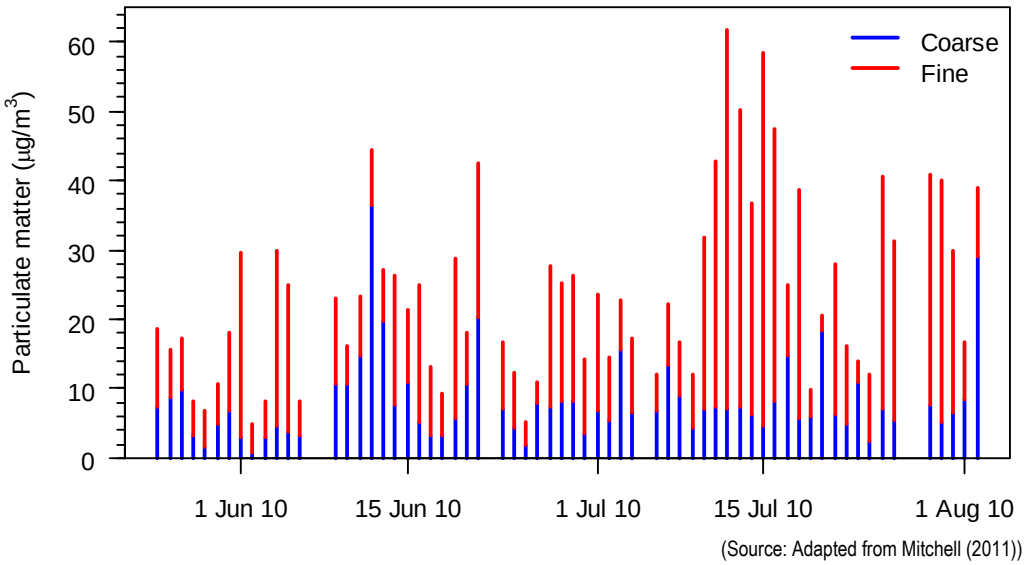
(Source: Adapted from Mitchell (2010))

Figure 5.8: Time series of fine and coarse particulate matter (24-hour average) measured at Carterton, Solway and Featherston by Partisol 2025D sampler during winter 2009

5.4.2 Raumati South

In response to local concerns about winter air quality in Raumati South, a small coastal settlement within the Kapiti Coast airshed, an intensive screening study was carried out in winter 2010 (Mitchell 2011). The PM monitoring results are shown in Figure 5.9. High pollution days with elevated $PM_{2.5}$ were recorded between 11 and 16 July. These days are notable because they represented a period of sustained calm weather coupled with very cold overnight temperatures.

The following sources of particulate matter were resolved using receptor modelling: biomass burning, marine aerosol, soil, motor vehicle emissions from local roads and secondary sulphate formed in the atmosphere from precursor sulphur dioxide (Davy et al. 2011a). Biomass burning was the principal source of PM on days where $PM_{2.5}$ concentrations were elevated. On average, biomass burning made up just over half of all PM_{10} measured during the winter period and marine aerosol accounted for just under a third. The elevated levels of $PM_{2.5}$ found on high PM_{10} days in Raumati South are also a



(Source: Adapted from Mitchell (2011))

Figure 5.9: Time series of fine and coarse PM (24-hour average) measured at Raumati South by Partisol 2025D sampler during winter 2010

feature of other locations in the Wellington region, such as Wainuiomata and Masterton, where emissions from wood burners are the principal source of particulate matter. Although not directly comparable (because a different monitoring method was used), the average winter PM_{10} concentration in Raumati South of 25 µg/m^3 was similar to that recorded for Masterton over the same winter period in 2010.

5.5 Summary

Source apportionment investigations undertaken in Upper Hutt, Masterton, Wainuiomata and Seaview identified soil, marine aerosol, road dust, biomass burning and secondary sulphate as the major contributing sources to PM measured in air.

$PM_{2.5}$ concentrations show distinct seasonality in Masterton, Upper Hutt and Wainuiomata. During the winter months more than half of ambient PM_{10} is composed of $PM_{2.5}$ which, as will be discussed in Section 7, has implications for assumptions made about the level of protection afforded by meeting the numerical guideline for PM_{10}. Domestic solid fuel fires are responsible for around 75% of PM_{10} and 90% of $PM_{2.5}$ measured during air pollution episodes occurring in the winter months in Masterton, Upper Hutt, Wainuiomata, Carterton, Featherston and Raumati South.

Of major importance is the ability to distinguish the contribution of anthropogenic sources that are controllable to that of natural sources. Natural sources (eg, marine aerosol and crustal matter) are a significant source of particulate matter in the region, particularly during the summer months. These natural sources occur mainly in the coarse fraction. Another important natural source that occurs in the fine fraction is secondary sulphate – which is thought to arise from atmospheric gas to particle conversion of dimethyl sulphate produced by marine organisms.

In addition to natural sources of PM, air quality at Seaview is highly influenced by local industrial sources of fine zinc particles and coarse sulphate particles. Some of the fine sulphate particles measured in Seaview may arise from ship movements in Wellington Harbour.

6. Spatial and temporal trends in air quality

Air quality is highly variable in both space and time. Spatial variability refers to differences in air quality at the same averaging time occurring in different locations. Temporal variability refers to variation in air quality over different timeframes (eg, over the course of a day, a week, a month or many years).

The main factors affecting spatial and temporal variation in air quality are sources and quantities of emissions and atmospheric stability (determined by meteorological factors). Meteorological impacts can be regional-scale weather patterns occurring over many days or finer-scale, such as localised temperature inversions, occurring over a few hours.

This section focuses on the spatial and temporal variation in air quality between monitoring sites – in particular daily, weekly and seasonal patterns. For sites where there are at least five years worth of continuous monitoring data, longer term trends are examined. Trends in Masterton, Wainuiomata and Wellington city are explored in more detail. Large-scale influences on air quality are also discussed. Details on the data analysis and presentation methods are outlined in Appendix 7.

6.1 Diurnal, weekly and seasonal variation across sites

6.1.1 Neighbourhood air quality monitoring sites

The daily, weekly and monthly variation in PM_{10} measured across the residential monitoring sites in Lower Hutt, Upper Hutt, Masterton, Tawa and Wainuiomata is shown in Figure 6.1. Masterton has the most pronounced diurnal variation, with the highest evening peak and the largest winter monthly means due to the influence of domestic fires. Wainuiomata shows a different pattern of diurnal variation, with a more sustained midday peak and lower evening peak. The reason for this pattern is not known. Lower Hutt shows the least seasonality and a diurnal pattern that is consistent with traffic emissions occurring at peak commuter times. Upper Hutt showed a similar diurnal pattern to Masterton, but with a much lower evening peak. Tawa was similar to Upper Hutt, but with higher PM_{10} concentrations recorded during the daytime.

Nitrogen dioxide concentrations at all residential sites show the influence of daily traffic morning and afternoon peaks (Figure 6.2). These peaks are most pronounced in Lower Hutt and least pronounced in Masterton. All sites show seasonality, with higher nitrogen dioxide concentrations recorded during the winter months as well as evidence of a mid-week peak on Wednesday and Thursday. The lowest concentrations occur during the weekend.

In terms of carbon monoxide, all sites show a double peak (Figure 6.3). The late afternoon peak in Lower Hutt coincides with peak nitrogen dioxide and is therefore traffic-related. In Masterton, Upper Hutt and in Tawa the peak carbon monoxide concentration occurs later in the evening and is therefore attributed to domestic fires. It is not clear whether the morning peak in carbon monoxide is principally related to morning traffic or domestic fires, or a combination of the two sources.

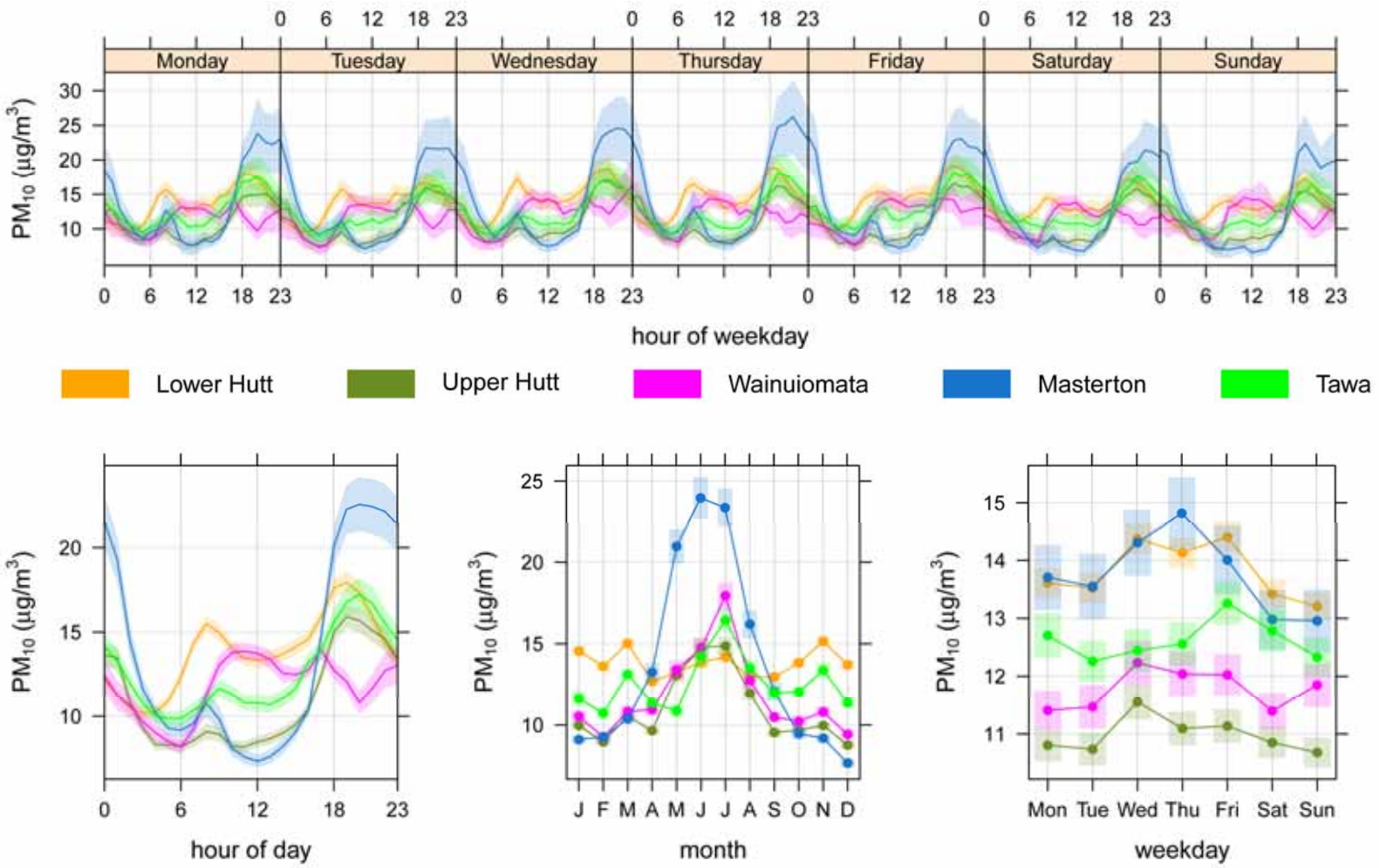


Figure 6.1: Temporal variation in PM_{10} concentrations at residential monitoring sites from 2006 to 2010. The four plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

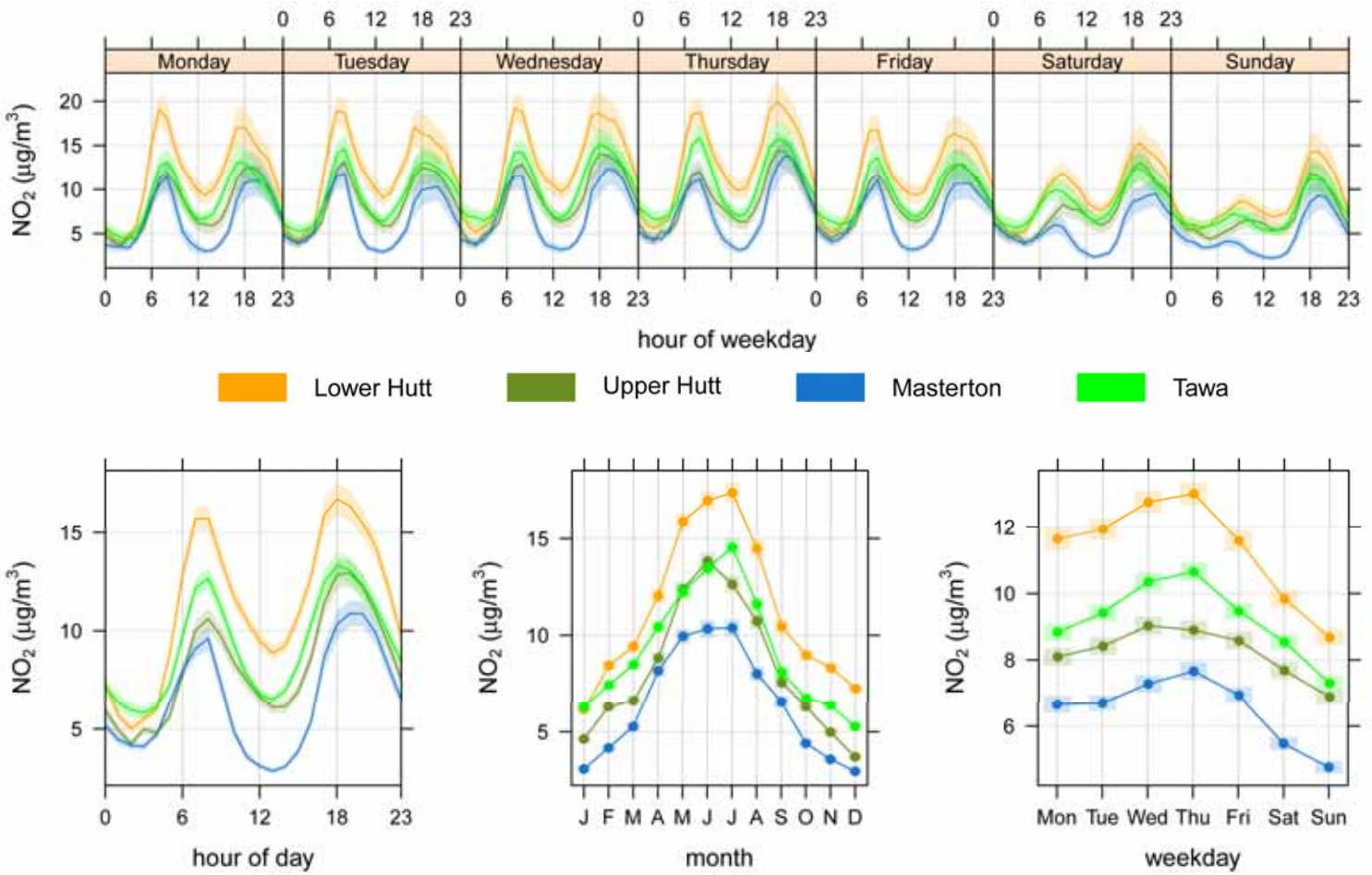


Figure 6.2: Temporal variation in nitrogen dioxide (NO_2) concentrations at residential monitoring sites from 2006 to 2010. The four plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

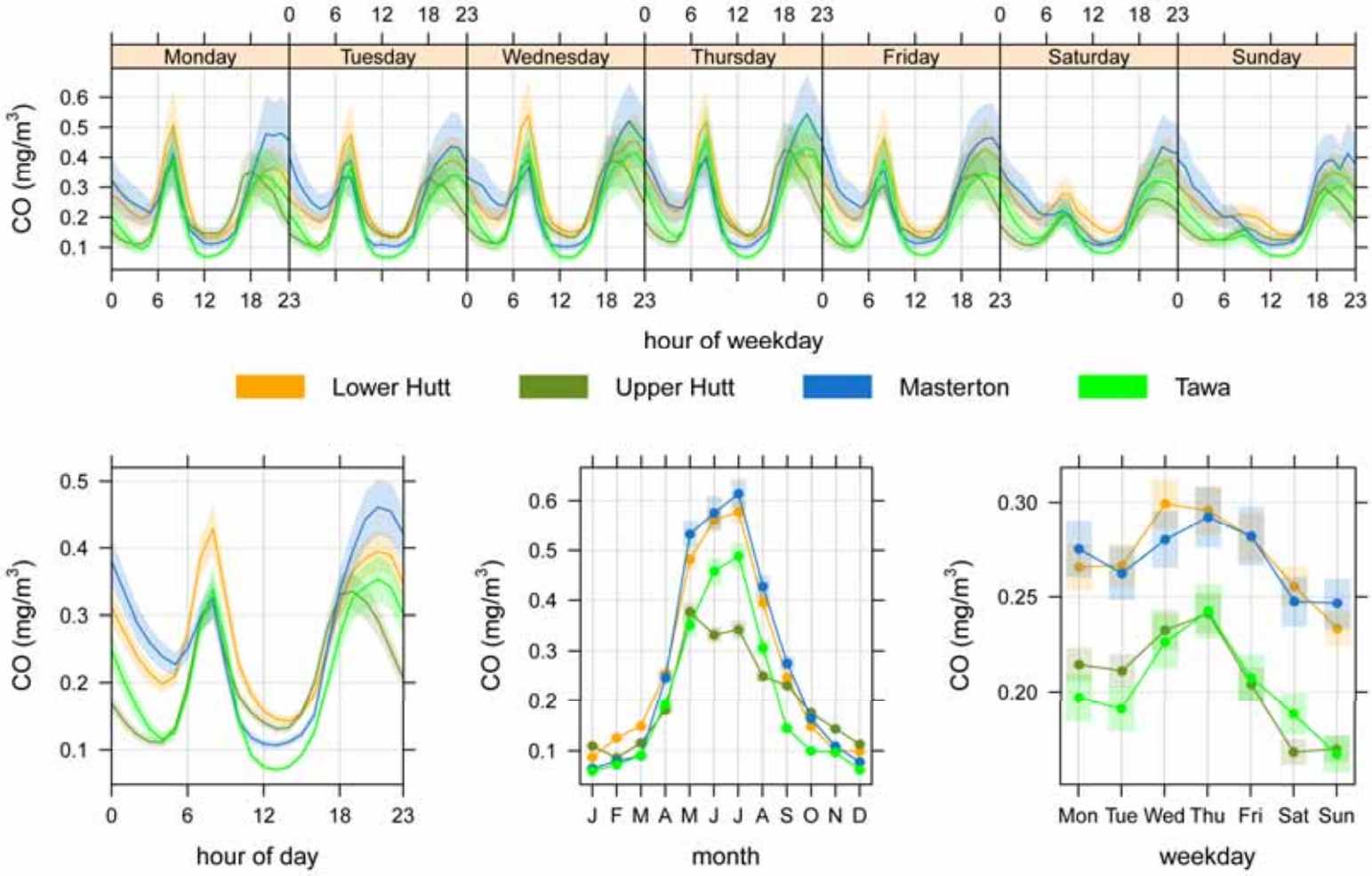
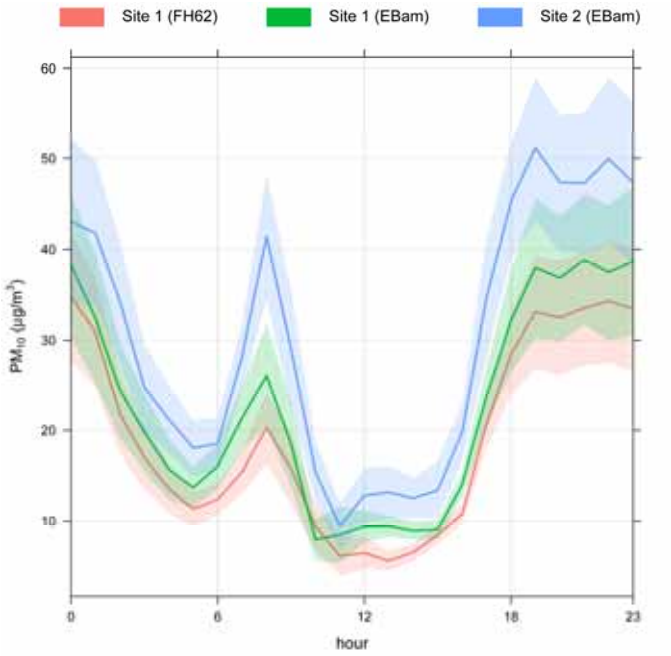


Figure 6.3: Temporal variation in carbon monoxide (CO) concentrations at residential monitoring sites from 2006 to 2010. The four plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

(a) Masterton urban area

In order to understand horizontal and vertical pollutant transport within the Masterton airshed, GNS Science collected PM at hourly resolution from three sites on a transect across Masterton in line with the general nocturnal drainage flows during winter 2010 (Ancelet et al. 2011). Hourly PM concentrations were also monitored using a non-standard continuous method (EBam). This method overestimates PM concentrations relative to the standard method (FH62) currently used at Wairarapa College (Figure A7.2D, Appendix 7). However, even when the over-estimation is taken into account, concentrations recorded approximately 1.2 km southwest of the Wairarapa College site were significantly higher during the evening (6 pm to midnight) and morning (9 am) peaks due to emissions from domestic solid fuel heating appliances (Figure 6.4).



(Source: Adapted from Ancelet et al. (2011))

Figure 6.4: Temporal variation in PM_{10} concentrations at two sites in Masterton during winter 2010. Site 1 is the current Masterton monitoring site and site 2 is located approximately 1.2 km south west. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line.

During the monitoring period, average daily concentrations were about 5 to 6 ug/m^3 higher than those measured at Wairarapa College. Consequently, the number of potential high pollution days in the Masterton urban area was far greater than the number of exceedences recorded at Wairarapa College. The implications of this finding are discussed in Section 7.4.3.

6.1.2 Peak (road side) air quality monitoring sites

The daily, weekly and monthly variation in PM_{10} measured across the transport monitoring sites in Wellington central, Melling intersection and at Ngauranga is shown in Figure 6.5. Wellington central and Melling showed a similar diurnal pattern, with peak concentrations coinciding with weekday commuter rush hour. Ngauranga had significantly higher levels of PM_{10} throughout the

entire day. The reason for this is unclear and may be due to vehicle movements from trucks using a local road adjacent to the monitoring site to access the Kiwi Point industrial area. There is also likely to be a contribution from local industrial PM_{10} sources (eg, quarry, bitumen plant and aggregate stockpiles) to PM_{10} measured at Ngauranga. Little seasonality is evident in PM_{10} at the transport sites reflecting the absence of the contribution of domestic fires. The reason for the peak in monthly concentration in October is not known, but may in part be due to increased windiness during spring causing PM_{10} in the coarse fraction to be more widely dispersed.

All three roadside monitoring sites showed strong diurnal variation in nitrogen dioxide (Figure 6.6) and carbon monoxide concentrations (Figure 6.7) due to the influence of traffic flows. Wellington central recorded significantly higher concentrations of nitrogen dioxide compared to the other sites. Ngauranga had sustained inter-peak concentrations of both pollutants; carbon monoxide levels were similar to those measured at Wellington central but nitrogen dioxide concentrations were lower.

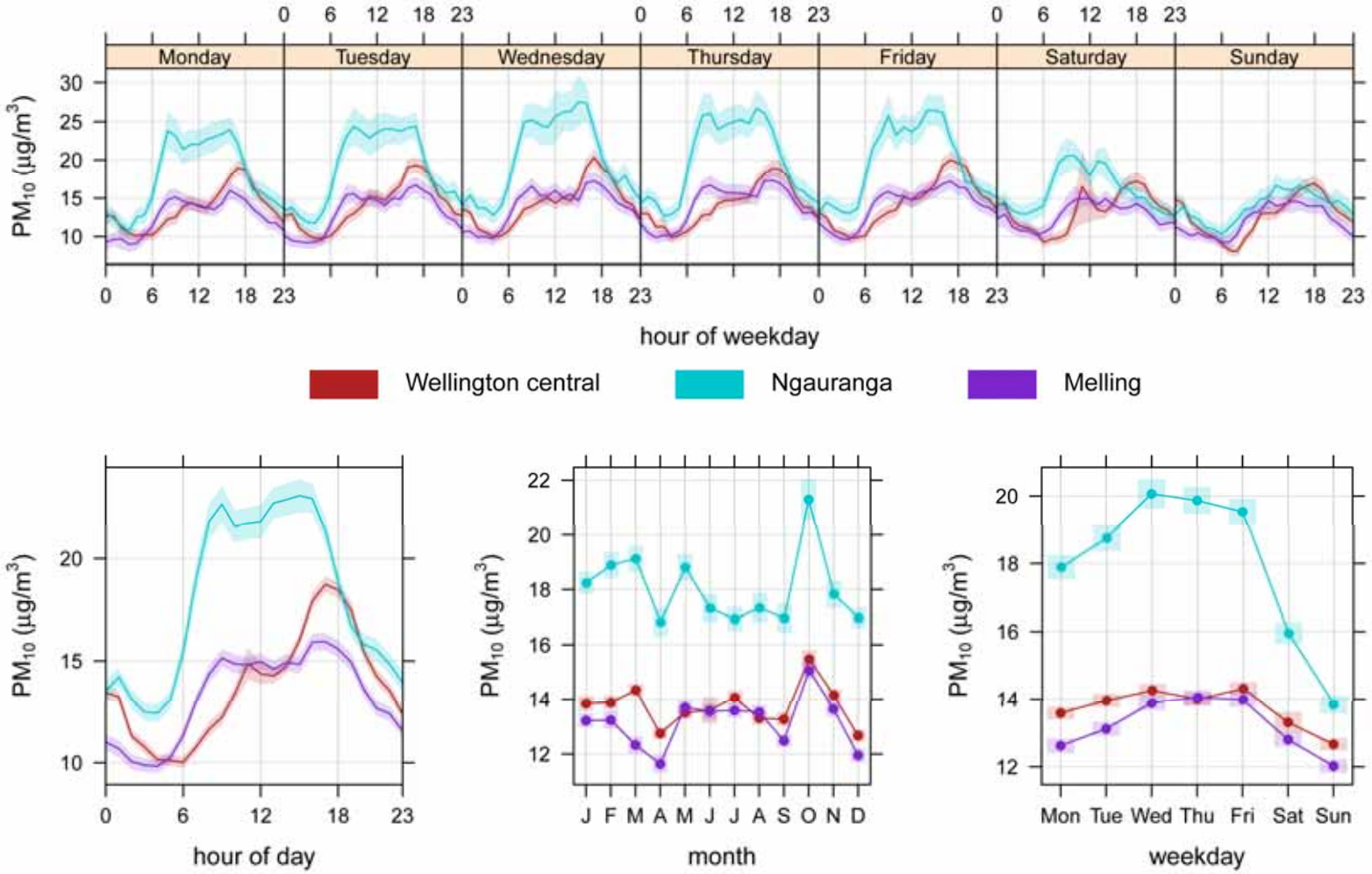


Figure 6.5: Temporal variation in PM_{10} concentrations at transport monitoring sites from late 2005 to 2010. The four plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

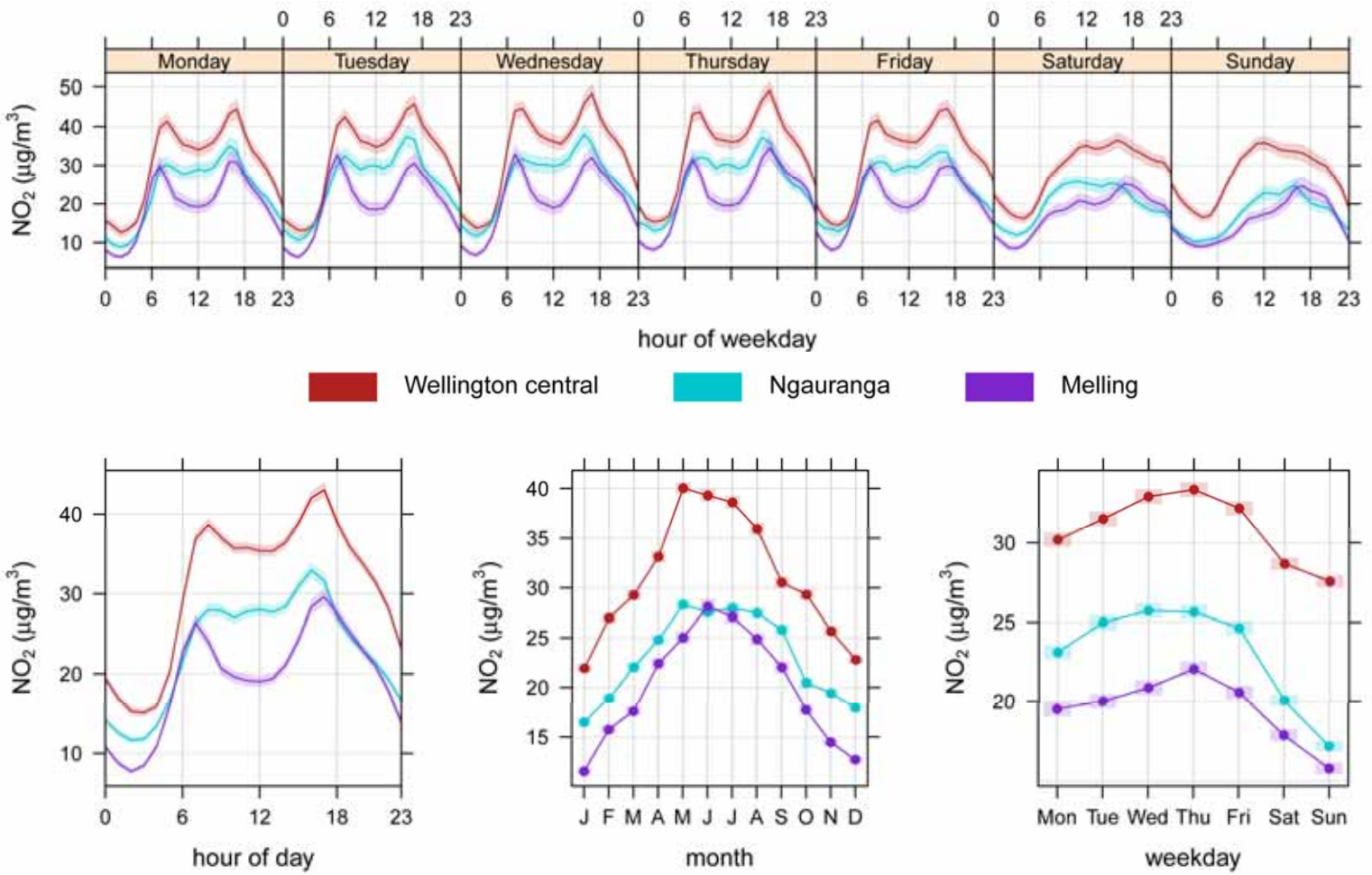


Figure 6.6: Temporal variation in nitrogen dioxide (NO_2) concentrations at transport monitoring sites from late 2005 to 2010. The plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

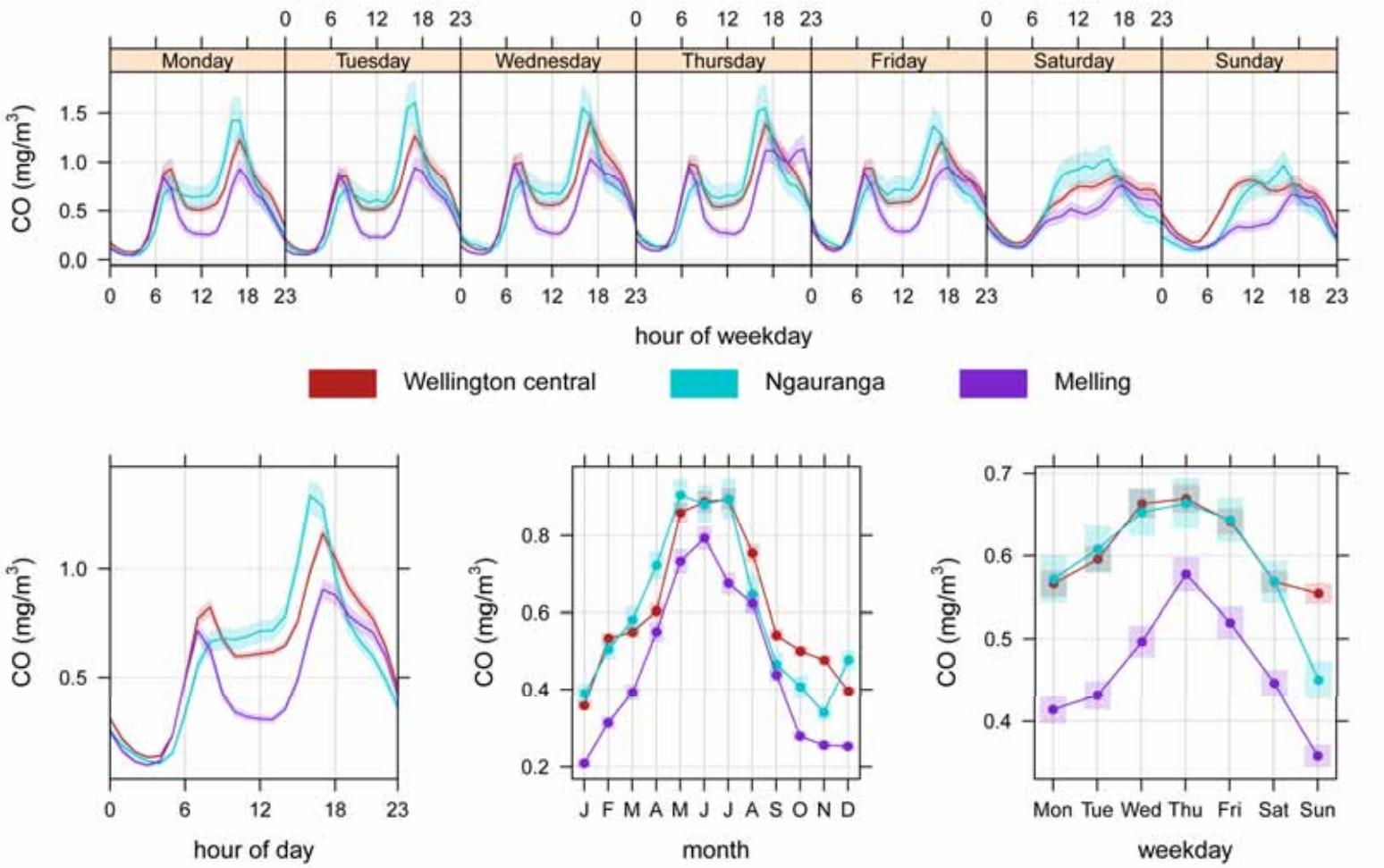


Figure 6.7: Temporal variation in carbon monoxide (CO) concentrations at transport monitoring sites from late 2005 to 2010. The plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

6.2 Long-term (temporal) trends

Trends over many years are most easily identified where there is a long record of measurements or where there has been a step change in emissions, for instance new regulations or removal of a particular emission source occurring at a known point in time.

Trends were examined at all sites with at least five years of continuous data using a simple non-parametric Theil-Sen approach implemented for analysing air quality data (Carslaw & Ropkins 2011). This trend analysis technique is performed on monthly means that have been de-seasonalised (where seasonality is present) using a LOESS procedure. Theil-Sen is best suited to describing monotonic trends (ie, where concentrations are either steadily increasing or decreasing over the monitoring period). The 95% confidence interval in the trend (slope) estimate was calculated using re-sampling methods (ie, bootstrap). Theil-Sen trend estimates are presented in Table 6.1.

A statistically significant downward trend in PM_{10} was observed at all sites, except Lower Hutt where no change was detected. The largest decrease in PM_{10} concentrations was seen at Wellington central with an average decrease of 0.75 $\mu g/m^3$ or 4.45%p per year since 2004. This equates to a substantial decrease of about 26% over the six-year monitoring period and reflects the highest annual mean recorded in 2004 and the lowest annual mean occurring in 2010. The reduction in PM_{10} at Wellington central was evident across all seasons, with the largest average decrease of 5.68% per annum occurring during the winter months (June, July and August).

PM_{10} concentrations also declined in Masterton on average 2% per year. Over the eight-year monitoring period this represents about a 21% decrease, although this is influenced by the maximum annual mean occurring in 2003 and the minimum annual mean occurring in 2010. When linear trends were examined by season, most of the decrease in PM_{10} could be attributed to reductions occurring during the summer months (-3.84% per year on average) with a lower reduction in the winter months (-1.22% per year on average). The evidence for a decreasing trend at Wainuiomata is weaker than for Wellington central and Masterton – although an average decrease of 1.96% per annum for the autumn period (March, April and May) is strongly supported. Upper Hutt experienced an average annual decrease in PM_{10} of 2.25% per year between 2006 and 2010; although there was no statistically significant decrease observed during the winter months.

Nitrogen dioxide concentrations decreased at all sites, apart from Lower Hutt where measurements were not suitable for performing trends analysis due to a step change in late 2007 attributed to improvements in data quality. Carbon monoxide concentrations decreased at Wellington central – with most of the decrease due to lower concentrations observed during autumn (decreasing 6.57% per year on average during autumn). No decrease in carbon monoxide levels were detected at Lower Hutt and measurements at Masterton and Upper Hutt were not suitable for performing trend analysis due to a step change in late 2007 (again attributed to improvements in data quality).

Table 6.1: Theil-Sen analysis of trends in annual mean of PM_{10} (µg/m³), nitrogen dioxide (µg/m³) and carbon monoxide (mg/m³) at five long-term air quality monitoring sites in the Wellington region. The 95% confidence interval in the trend is indicated in square brackets.

Site	Time period	Variable	Average change per year	Percentage change per year	Statistical significance
Masterton	2003–2010	PM_{10}	-0.32[-0.47,-0.19]	-2.00[-2.82, -1.21]	p <0.001
		NO_2	-0.56[-0.68,-0.46]	-5.89[-7.05,-4.8]	p <0.001
Wellington central	2004–2010	PM_{10}	-0.75[-0.91, -0.59]	-4.45[-5.21, -3.66]	p <0.001
	2005–2010	NO_2	-1.74[-2.35,-1.17]	-4.46[-5.93, -3.22]	p <0.001
	2004–2010	CO	-0.02[-0.04,-0.01]	-3.34[-5.44, -1.01]	0.001 < p < 0.01
Lower Hutt	2001–2010	PM_{10}			Not Significant
		CO			Not Significant
Upper Hutt	2006–2010	PM_{10}	-0.27[-0.42,-0.03]	-2.25[-3.40, -0.25]	0.01 < p < 0.05
		NO_2	-0.29[-0.75,0.05]	-3.24[-7.55, 0.58]	0.01 < p < 0.05
Wainuiomata	2001–2010	PM_{10}	-0.14[-0.26,-0.02]	-1.20[-2.14, -0.16]	0.01 < p < 0.05

In Section 6.2.1, trends are explored in more detail at Wellington central to establish the impact of major changes to traffic flows resulting from the installation of the inner City Bypass in 2007. Trends are also more fully examined in Masterton (Section 6.2.2) and Wainuiomata (Section 6.2.3) where concentrations of PM_{10} approach or exceed standards and guidelines for the protection of human health.

6.2.1 Wellington central

Nitrogen dioxide and carbon monoxide have been measured since 2004, and PM_{10} since 2005, at the Wellington central site (Figure 6.8). During the monitoring period there were major changes to road configuration and consequently traffic flows in the vicinity of the station due to the construction of an inner city bypass over a two-year period from 2004 to 2006. The re-configured traffic flows following the completion of the bypass in March 2007 are likely to have affected levels of pollutants measured at the Wellington central site.

A time series of monthly means (calculated from hourly data) for PM_{10}, nitrogen dioxide and carbon monoxide are shown in Figure 6.9.

There appears to have been a reduction in both peak and mean concentrations of all three pollutants over the monitoring period – with most of this reduction occurring between 2004 and 2007 (Figure 6.10). This reduction may be due to ongoing improvements in vehicle technology resulting in lower emissions per vehicle as seen in Auckland between 2003 and 2009 (Bluett et al. 2011).

(Source: Google Earth)

Figure 6.8: Aerial view of the location of Wellington central monitoring station

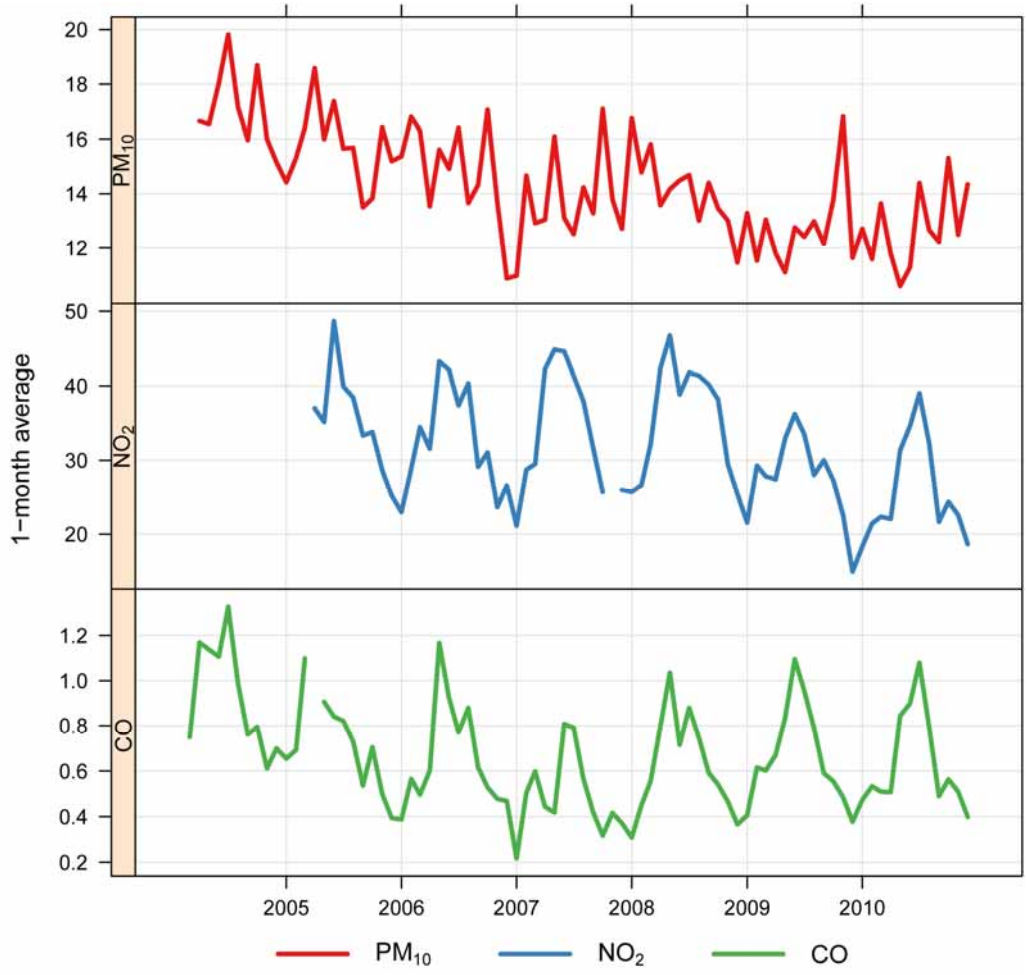


Figure 6.9: Monthly time series of PM_{10} (µg/m^3), nitrogen dioxide (NO_2, µg/m^3) and carbon monoxide (CO, mg/m^3) measured at Wellington central from 2004 to 2010

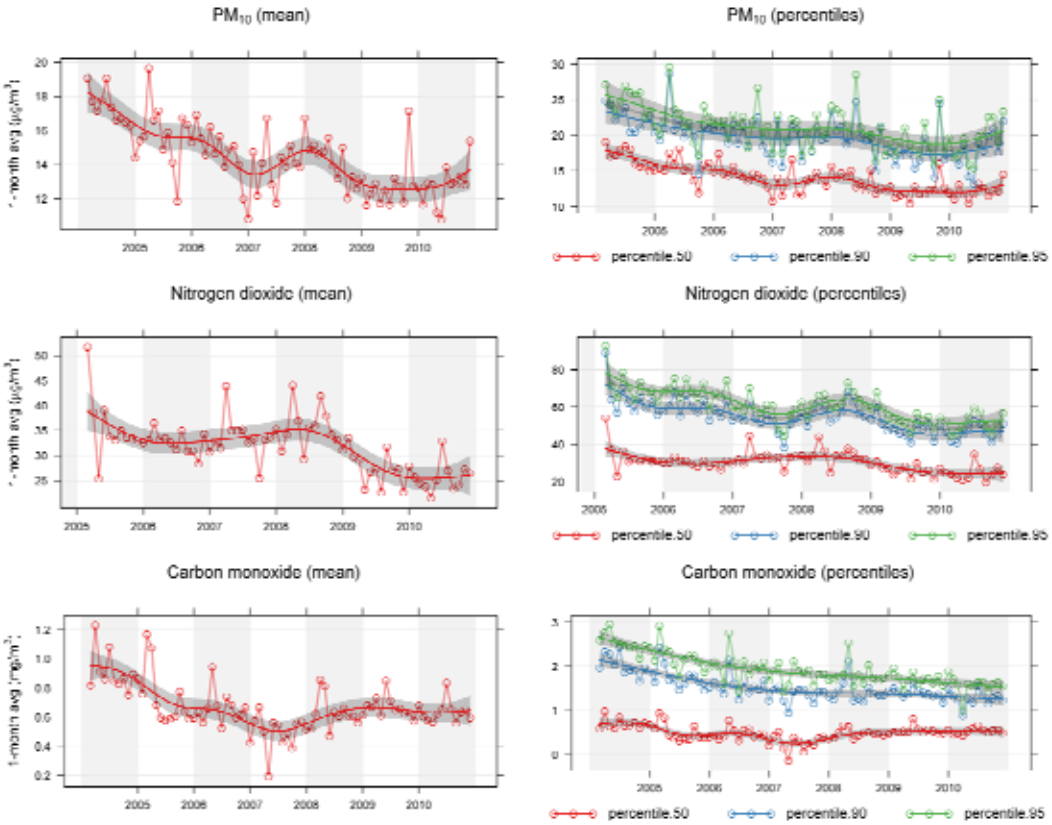


Figure 6.10: Smoothed time trend in de-seasonalised monthly average concentration and monthly percentile of PM_{10}, nitrogen dioxide and carbon monoxide at Wellington central (2004 to 2010) using a generalised additive model with 95% confidence intervals in the smoothed fit shown

Pollution roses (Figure 6.11) indicate that post-bypass (ie, 2007 onwards) there has been a shift in the direction of the predominant source of carbon monoxide and nitrogen dioxide measured at the monitoring site. About 30% of the overall mean concentration measured at the site occurred during light southwest winds (ie, less than 1 m/s) even though this wind direction occurs about 15% of the time. The other subtle change post-bypass is that although the peak commuter rush hour concentrations of nitrogen dioxide are lower, there appears to have been an increase in nitrogen dioxide concentrations between midnight and 6 am (Figure 6.12).

The PM_{10} contribution is greatest under the prevailing northerly winds (at wind speeds greater than 2 m/s) indicating the likely impact of ubiquitous sources, such as crustal matter and marine aerosol on PM_{10} measured at Wellington central. This finding is consistent with the dispersal characteristics that differ by the PM size fraction; typically the coarse PM fraction ($PM_{2.5\text{-}10}$) is likely to become airborne in windy conditions, while the fine PM fraction $PM_{2.5}$ (which largely arises from vehicle exhausts) is more likely to remain airborne in low wind conditions. Without $PM_{2.5}$ measurements at the Wellington central site it is difficult to determine whether the reduction in PM_{10} is due to vehicle emissions or to other factors.

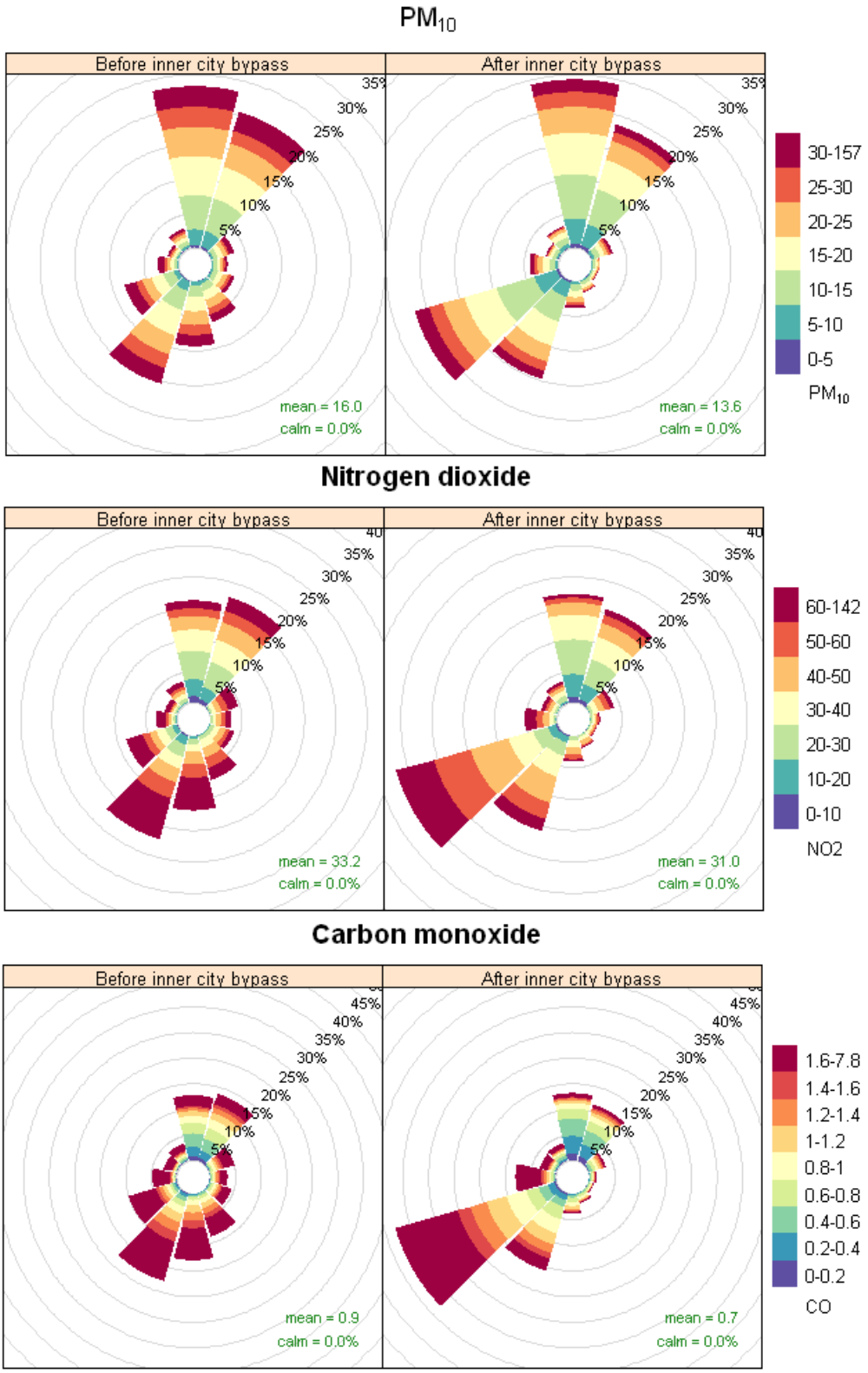


Figure 6.11: Pollution rose for 1-hour average of PM_{10} (µg/m³), nitrogen dioxide (µg/m³) and carbon monoxide (mg/m³) concentrations measured at Wellington central showing the contribution to annual mean concentration by wind direction before (pre-2007) and after completion of the inner city bypass (post-2007)

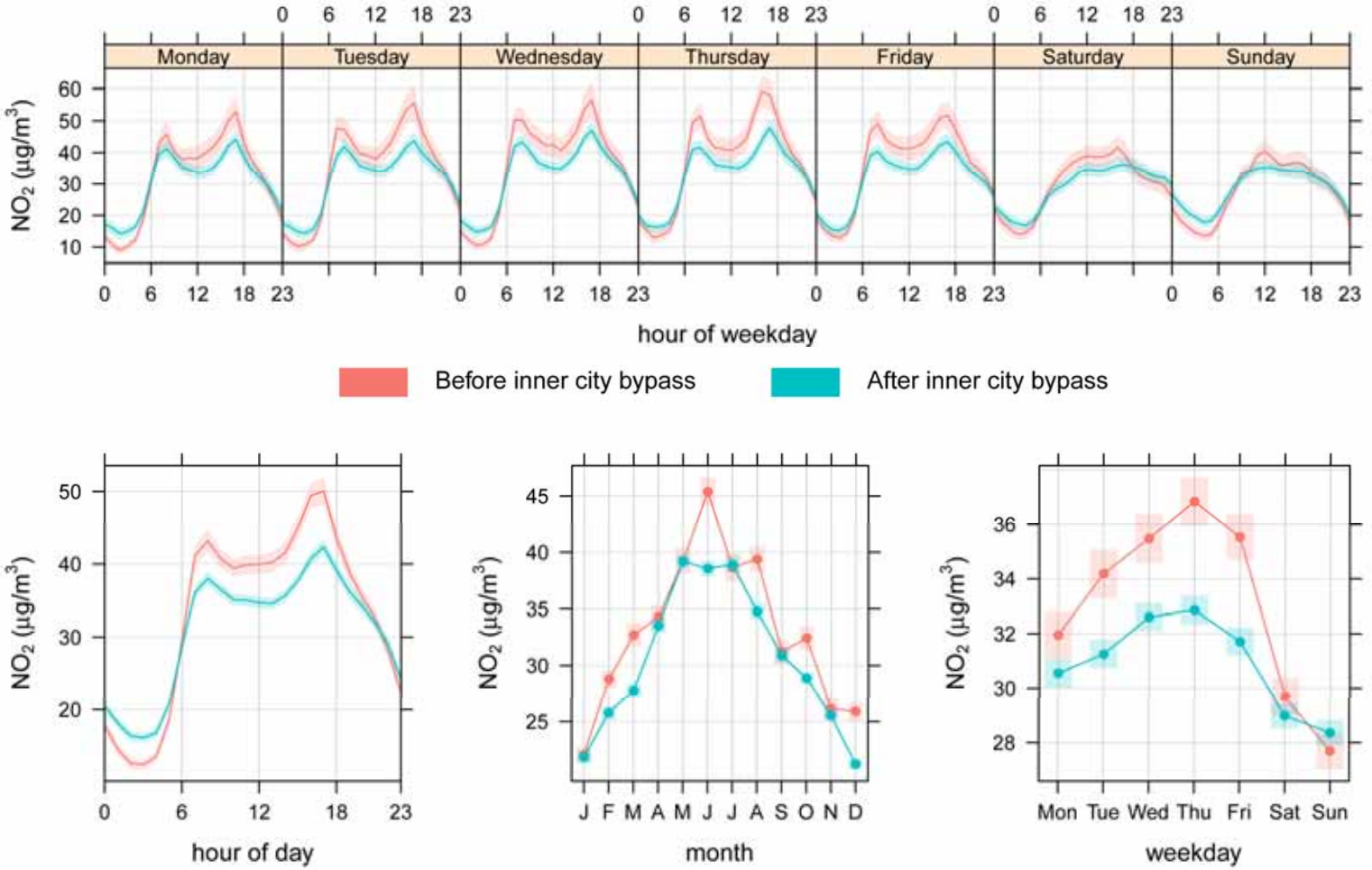


Figure 6.12: Temporal variation in nitrogen dioxide (NO_2) concentrations measured at Wellington central before (pre-2007) and after completion of the inner city bypass (post-2007). The four plots show variation in average concentration by: hour and day of the week; hour of all days; month; and day of the week. The 95% confidence interval in the mean is shown by the width of the coloured band around each solid line or point.

Overall, the changes in pollutant levels and direction of the most influential pollutant sources measured at Wellington central have been undoubtedly influenced by changes to traffic flows in the vicinity of the monitoring station due to the inner city bypass. For instance, the reversal in traffic direction on Vivian Street has meant since 2007 traffic travelled downhill rather than uphill past the monitoring station. Changes in levels of pollutants measured may also have been influenced by an increase in the height of trees immediately adjacent to the monitoring station.

6.2.2 Masterton

At Wairarapa College in Masterton, there appears to have been a reduction in the peak and mean concentrations of PM_{10} and nitrogen dioxide since monitoring began in 2003 (Figure 6.13). The carbon monoxide data for the period are not suitable for carrying out time trends analysis due to instrument changes and baseline shifts[17].

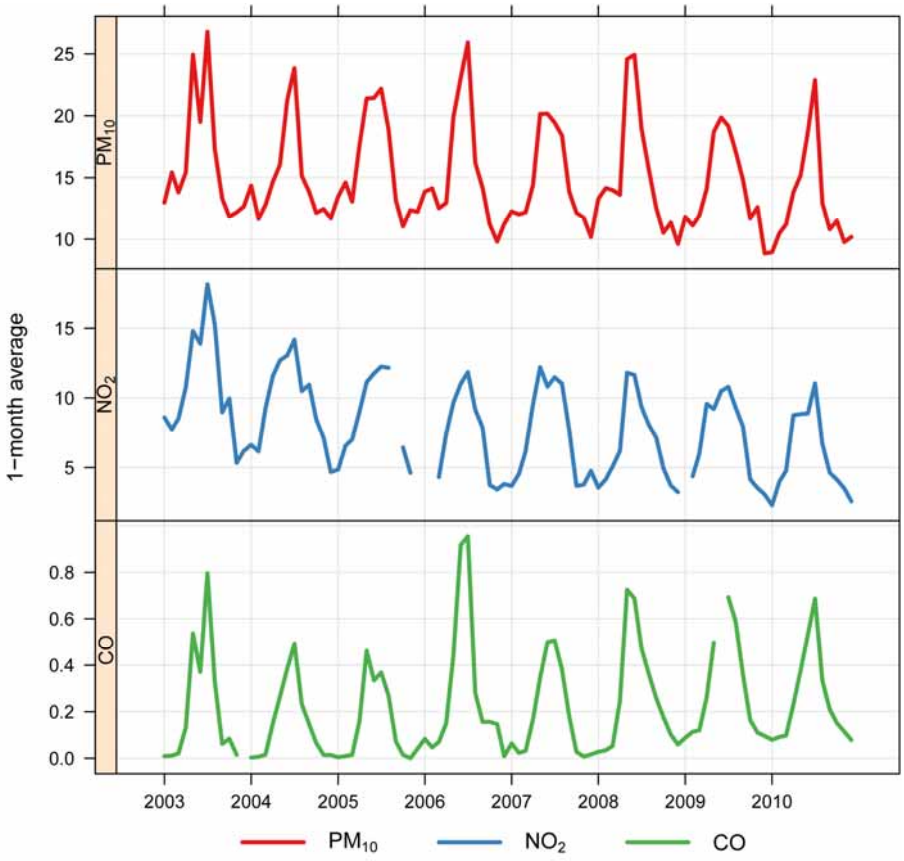


Figure 6.13: Monthly time series of PM_{10} (µg/m³), nitrogen dioxide (NO_2, µg/m³) and carbon monoxide (CO, mg/m³) measured at Masterton (2003 to 2010)

Mean PM_{10} concentrations (measured by TEOM) over the 2003 to 2010 reporting period declined, as did peak concentrations (90th and 95th percentiles) (Figure 6.14). Mean nitrogen dioxide concentration showed a marked reduction between 2003 and 2006. The trend in declining concentrations continued between 2006 and 2010, although at a slower rate (Figure 6.14).

[17] Carbon monoxide data from 2008 to 2010 are considered representative for assessing current air quality state only (refer Section 4).

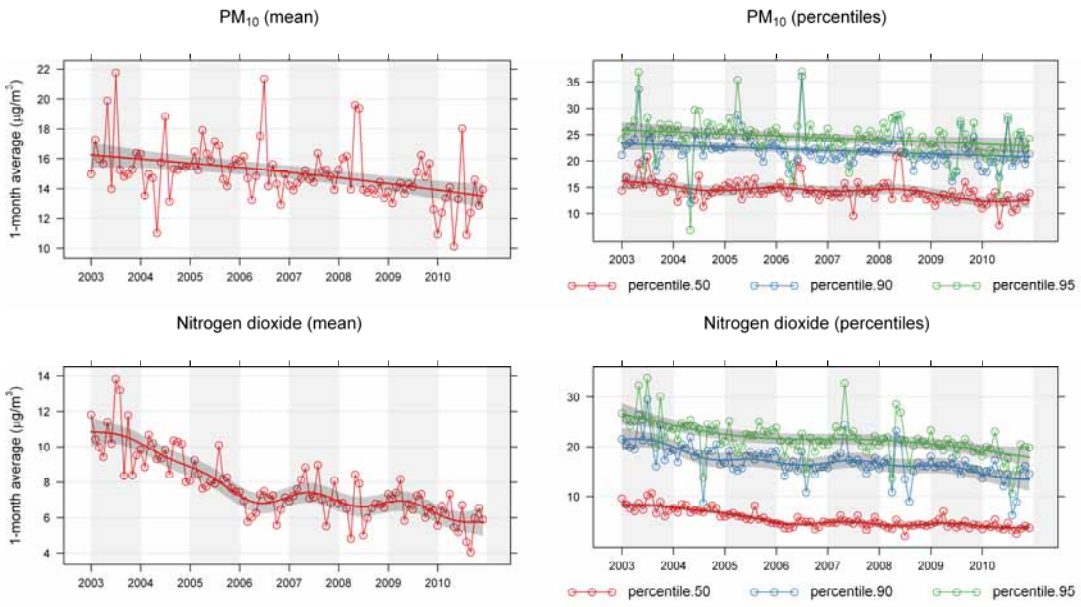


Figure 6.14: Smoothed time trend of de-seasonalised monthly average concentration and monthly percentile of PM_{10} (24-hour average) and nitrogen dioxide at Masterton (2003 to 2010) using a generalised additive model with 95% confidence intervals in the fit shown

At the Masterton station, exceedences of the NES-AQ threshold of 50 µg/m^3 have occurred infrequently (ie, between zero and five days per year between 2003 and 2010) (Table 6.2). Between 2003 and 2007 compliance with the NES-AQ was assessed using a TEOM instrument and between 2008 and 2010 an FH62 instrument. Measurements from these two instruments overlapped for 3.5 years beginning in June 2007. There was a strong linear relationship between daily averages obtained by the two monitoring methods (R^2=0.93), although the FH62 measured slightly higher values than the TEOM (Figure A7.2(B), Appendix 7). The FH62 instrument appears to be less susceptible than the TEOM to the loss of semi-volatiles and therefore measures high pollution events due to wood smoke more accurately than the TEOM instrument. Therefore, from 2008 onwards, the FH62 has been the monitoring method used to determine statutory compliance with the NES-AQ (when the annual data capture rate exceeded 75%).

Table 6.2: Number of NES-AQ PM_{10} exceedences per year recorded at Masterton between 2003 and 2010 (shaded areas denote monitoring instrument used for determining NES-AQ compliance)

Instrument	2003	2004	2005	2006	2007	2008	2009	2010
TEOM	2	3	1	3	0	3	1	1
FH62	–	–	–	–	2	5	1	4

There was little or no relationship between annual mean or any of the annual upper data percentiles and the number of exceedences in a given year for the TEOM measurements between 2003 and 2010. High pollution events (ie, daily PM_{10} mean above 50 µg/m^3) are restricted to the winter months. Between 2007 and 2010, high pollution events (12 in total) recorded by TEOM fluctuated from year to year independent of the downward trend in the mean. This is

illustrated by the weak linear relationship between the winter monthly mean and 99th percentile (TEOM: 2003 to 2010, R^2=0.56 and FH62: 2007 to 2010, R^2=0.43). The linear relationship between the winter mean and the 75th and 95th percentiles is stronger (R^2 >0.75) and therefore these two parameters are gradually declining along with the mean, whereas the 99th percentile is fluctuating.

A qualitative analysis of the differences between winter days on which elevated PM_{10} occurred and the remaining winter days was undertaken using the FH62 winter data collected between 2007 and 2010[18]. To increase the sample size this analysis defined an elevated PM_{10} day as the 95th percentile of winter daily concentrations (ie, 43 µg/m^3) rather than as the NES-AQ exceedence threshold (ie, 50 µg/m^3). There were 24 elevated pollution days defined using this criterion during the winter periods between 2007 and 2010. An examination of the hourly averages indicates a significant diurnal difference between elevated and non-elevated PM_{10} days, particularly between 7 pm and midnight and between 8 am and 10 am (Figure 6.15).

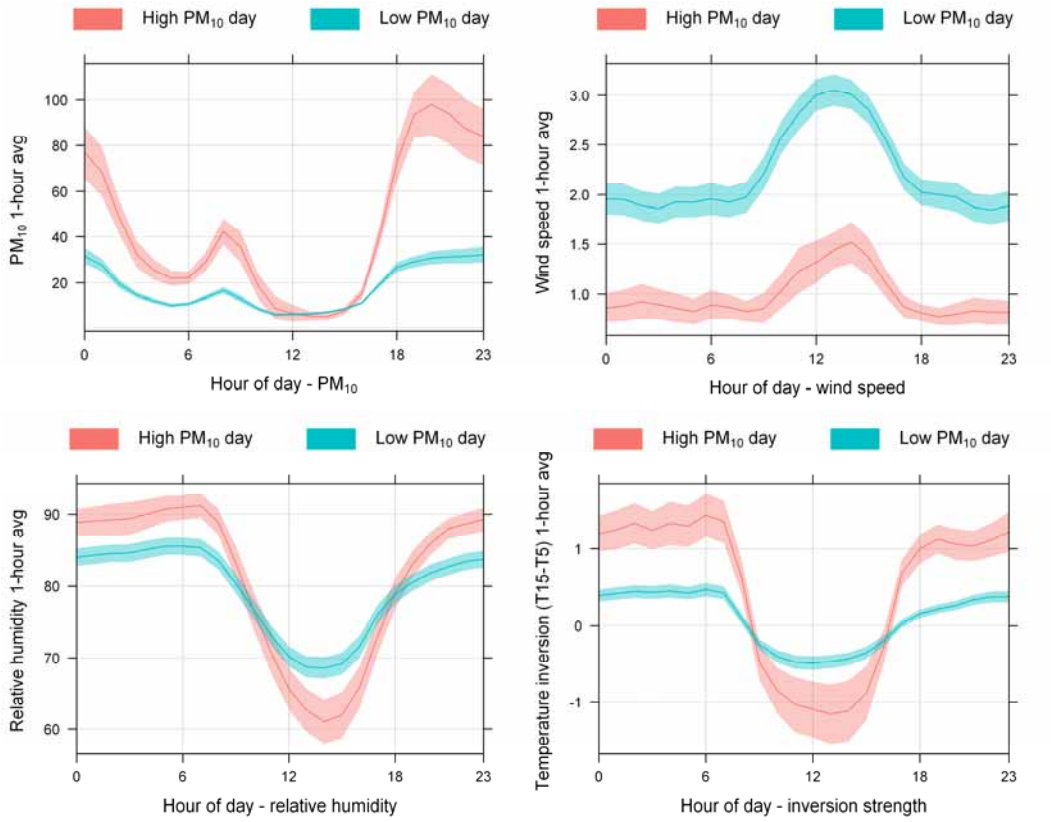


Figure 6.15: Diurnal variation in hourly average PM_{10} (top left), wind speed (top right), relative humidity (bottom left) and temperature inversion strength (bottom right) occurring on elevated (*n*=24) and non-elevated (*n*=416) pollution days during winter 2007 to 2010 at Masterton

Meteorological conditions during winter were substantially different on elevated and non-elevated pollution days. On elevated pollution days the early

[18] The FH62 data set was used instead of the full TEOM dataset because the FH62 more accurately measures pollution episodes due to wood smoke.

morning and late evening conditions were characterised by predominantly low wind speeds (ie, less than 1 m/s), and in the early morning by low temperatures (ie, less than 3°C) that are strongly inverted (Figure 6.15). These are all conditions which restrict the vertical and horizontal dispersion of PM_{10}.

6.2.3 Wainuiomata

PM_{10} was measured at Wainuiomata by high volume sampler (gravimetric standard method[19]) on a one-in-three day basis from 2001 to late 2007. Continuous monitoring using a standard method (FH62) commenced in July 2006. In order to examine trends between 2001 and 2010 these two monitoring records were merged – with the FH62 data corrected to the gravimetric method using an adjustment factor (described in Appendix 7) derived from the 18-month period when the two monitoring methods were co-located (Figure 6.16).

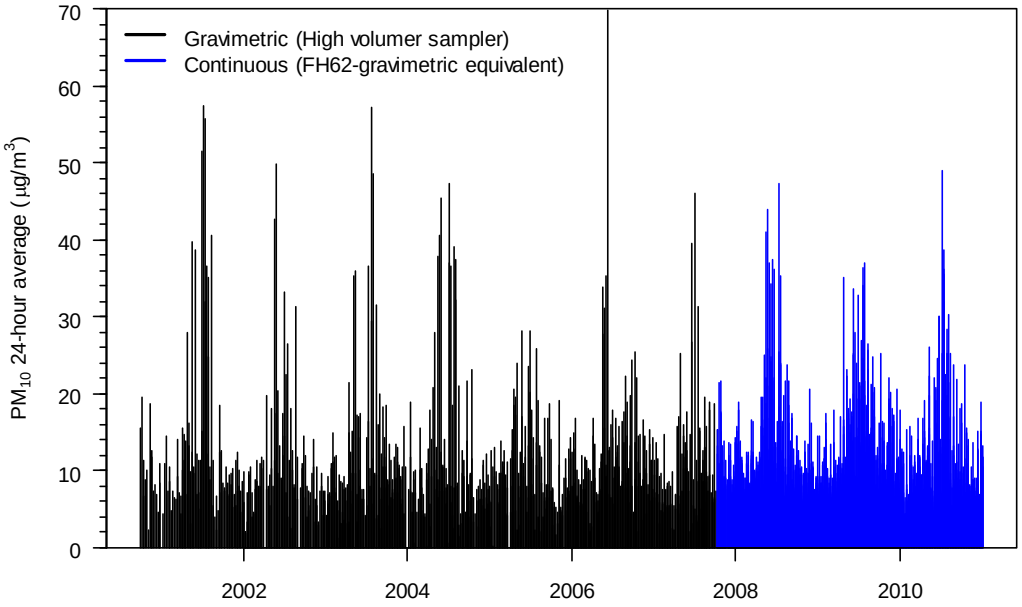


Figure 6.16: PM_{10} (24-hour average, midday to midday) at Wainuiomata measured by high volume sampler (black) and FH62 continuous method corrected for gravimetric equivalency (blue), 2001 to 2010

Using the Theil Sen method the average percentage change per year between 2001 and 2010 was estimated as -1.2% [-2.14, -0.16] which, although statistically significant (p<0.05), is only a very slight decrease from an environmental point of view. The long-term trend analysis is complicated in this case by the change in frequency of monitoring between the gravimetric and standard method. Data from the gravimetric method are more variable because of the lower monitoring frequency (ie, one-day-in-three) and the data capture rates are low meaning that monthly or seasonal averages may not be accurate.

At the Wainuiomata station, exceedences of the NES-AQ threshold of 50 µg/m^3 were rare occurring on only five occasions between 2002 and 2010 (shown as annual maxima in Table 6.3). Since 2007 compliance with NES-AQ has been assessed using an FH62 instrument which measures the concentration of PM_{10} continuously.

[19] Operating midday to midday and therefore not compliant for NES-AQ reporting which stipulates midnight to midnight.

Table 6.3: Maximum annual daily PM_{10} concentration (µg/m^3) recorded at Wainuiomata between 2002 and 2010 (shaded areas denote monitoring instrument used for determining NES-AQ compliance)

Instrument	2002	2003	2004	2005	2006	2007	2008	2009	2010
HiVol	50	57	47	28	70	47	–	–	–
FH62		–	–	–	–	51	41	60	62

Wilton and Baynes (2008a) estimated that reductions in average daily winter PM_{10} emissions of 4.2% and 2.5% (between 2006 and 2010) could occur if households in Wainuiomata upgraded their woodburners to NES-AQ compliant models once they reached 15 and 20 years of age, respectively. Thiel-Sen trend analysis of air quality between July 2006 and 2010 finds some evidence ($0.01<p<0.05$) for an average annual percentage decrease in PM_{10} concentrations of 2.61 [-4.22, -0.46] (although no increase or decrease in the 95th and 99th percentiles were able to be detected over this period). There are insufficient data to carry out seasonal trends analysis to determine whether average winter concentrations are decreasing.

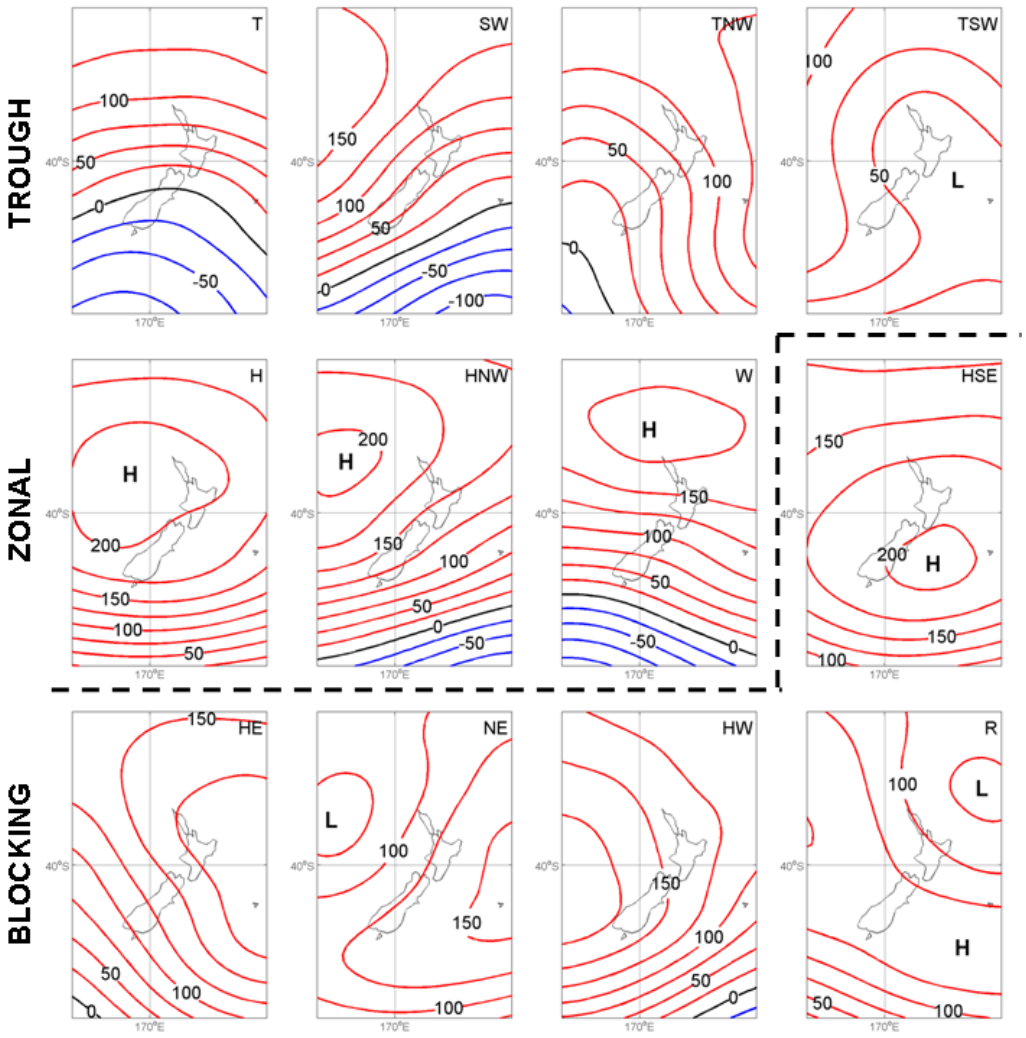
These trend results illustrate the difficulty in relating predicted changes in PM_{10} emissions to the occurrence of peak PM_{10} concentrations. This suggests that for air quality management purposes, emissions data may be able to be related to average PM_{10} concentrations but not to peak PM_{10} concentrations in airsheds with infrequent NES-AQ exceedences. Another emissions inventory would need to be undertaken to estimate any changes in emissions since 2006.

6.3 Large scale weather patterns affecting air quality

6.3.1 Approach to analysis

A relationship between weather types (and the antecedent sequences of these) and air quality can exist. To examine this relationship, the poorest winter air quality days at Wainuiomata (2001 to 2010), Masterton (2003 to 2010) and Upper Hutt (2000 to 2010) were identified as the five highest PM_{10} 24-hour averages in a given year at each site. Each high PM_{10} day was then ranked against all others to provide a regional ranking.

Mean sea level pressure charts (weather maps) typically show synoptic-scale features, such as lows, highs and frontal systems. New Zealand weather maps can be classified into 12 broadly similar weather types according to the Kidson (2000) classification scheme (Figure 6.17). These weather types are further grouped into three sub-groups: the predominantly unsettled ‘trough’ and ‘zonal’ regimes and the settled ‘blocking’ regime. Some weather types are quite common while others occur only infrequently. Seasonality is also present, with ‘blocking’ types occurring more often in summer and autumn and least often in spring – while the reverse is true for the ‘trough’ types.



(Source: NIWA (2011), adapted from Kidson (2000))

Figure 6.17: The twelve Kidson weather types with weather 'regime' grouping shown by the dashed black line

6.3.2 Key findings

Comparison of the region's ranked poor air quality days and Kidson (2010) weather types carried out by NIWA (Griffiths 2011) found several common themes, and some key differences between Wainuiomata, Masterton and Upper Hutt.

Three weather types, 'blocking' type HSE (high to southeast) and 'zonal' types H (high) and HNW (high to northwest) were most strongly linked to poor air quality events in Wainuiomata and Upper Hutt. However, in Upper Hutt the persistence of the HSE sequence for at least six days was required to produce the poorest air quality events. Only types H and HNW were influential in Masterton.

The anticyclonic weather types HSE and H typically produce fine weather, clear skies and light winds which in turn can lead to the development of night-time low-level temperature inversions that are conducive to air pollution events. The HNW weather type, although not a 'blocking' type, was also found to be associated with poor air quality events at Wainuiomata and Upper Hutt.

This weather type is associated with clear skies and relatively light winds over Wellington following the passage of a cold front across the North Island (ie, the 'turnaround' between southerly and imminent northerly flow around Cook Strait).

A different pattern emerges in Masterton; the HSE weather type – which was an important factor in determining poor air quality events in Wainuiomata and Upper Hutt – was not associated with poor air quality events. Due to Masterton's location east of the Tararua Range, under HSE conditions the light easterly wind would typically produce cloudy conditions in the Wairarapa, but clear skies in areas west of the ranges (such as Wainuiomata and Upper Hutt). Poor air quality events in Masterton were most strongly associated with the H anticyclonic weather type.

The Kidson weather typing analysis does not explain all the poor air quality events – as it did not sufficiently differentiate between days of one particular weather type which produced a poor air quality event and those which did not. These differences may be able to be explained by a finer-scale analysis of daily meteorological differences such as low-level temperature profile, temperature and wind characteristics.

6.4 Summary

Mean and median PM_{10} concentrations appear to have reduced at Masterton at an average rate of about 2% per year since 2003, although peak concentrations (95^{th} percentile and above) appear to fluctuate from year-to-year independent of mean concentrations. This poses difficulties for future certainty with respect to compliance with the NES-AQ. Pollution episodes only occur on winter days with low overnight wind speeds, and early morning temperature inversions.

There was also a statistically significant downward trend in mean PM_{10} concentrations at both Wainuiomata (1.2% between 2001 and 2010) and Upper Hutt (2.3% between 2006 and 2010). However, there was no statistically significant decline observed in peak concentrations at Wainuiomata. It is not known at this stage whether predicted decreases in emissions due to natural attrition of older wood burners are occurring.

Carbon monoxide concentrations declined sharply at Wellington central between 2004 and 2007, but mean and median concentrations have changed little since then. Carbon monoxide trends at the residential monitoring stations are less clear. No trend was evident at Lower Hutt and trends at Masterton and Upper Hutt were not able to be determined due to data quality issues prior to 2008.

Nitrogen dioxide levels declined at Wellington central at an average rate of 4.5% per year between 2005 and 2010, and by 3.2% at Upper Hutt between 2006 and 2010. Trends were not able to be determined at Lower Hutt due to improvements in data quality since 2008.

Altered traffic flows in the vicinity of the Wellington central monitoring station following the completion of the inner city bypass in early 2007 appear to have affected air quality monitoring results at the station. While overall average

pollutant concentrations have not increased, a greater contribution to observed levels is occurring under very light southwest conditions indicating that the intersection at Vivian and Victoria streets may now be more congested (there are now higher traffic flows along Victoria Street due to inner city vehicles accessing the north-bound route). The trend analysis in this case may be confounded to some extent by the underlying national trend in declining emissions per vehicle observed between 2003 and 2009 (Bluett et al. 2011) and the sharp increase in the price of petrol between 2007 and 2008. The reasons for the decline in PM_{10} are not clear and in order to relate these to traffic emissions information on $PM_{2.5}$ concentrations is required.

An analysis of the relationship between poorest air quality days in Masterton, Upper Hutt and Wainuiomata and large-scale weather patterns (Kidson types) shows that air quality in the western part of the Wellington region is influenced both by anticyclonic weather types (important in the formation of overnight temperature inversions which restrict the dispersion of pollutants) and the intervening period between southerly and northerly conditions which can also result in clear skies and light winds. More work is required to examine local meteorological influences at finer time scales to fully understand the role of meteorology in driving poor air quality events.

7. Discussion

This section revisits the main findings of the air quality monitoring and investigations presented in Sections 4 to 6. A regional overview of the state and trends is provided together with a discussion of the sources of particulate matter affecting air quality and the role of meteorology and climatic factors in determining air quality. The concentrations of the three air quality indicators in the region are then compared with those in other regions to provide a national context. The estimated impacts of exposure to particulate matter throughout the region on human health and associated social costs are provided. The national regulatory requirements for monitoring and managing PM_{10} concentrations are discussed, with particular emphasis on the implications for industry and air quality management in the Wairarapa airshed. Finally, the limitations of Greater Wellington's air quality monitoring programme and knowledge gaps are outlined.

7.1 Regional overview

7.1.1 State

Air quality monitoring at six core sites over 2008 to 2010 (five residential and one transport site) shows that, overall, the Wellington region has good air quality most of the time for three indicator pollutants: PM_{10}, carbon monoxide and nitrogen dioxide.

At neighbourhood (residential) sites in Lower Hutt, Upper Hutt, Wainuiomata, Masterton and Tawa, concentrations of carbon monoxide and nitrogen dioxide were relatively low and well within national standards and guidelines. PM_{10} concentrations at these sites were also low, apart from during the winter months in Masterton and Wainuiomata when the NES-AQ daily limit was approached or exceeded on some occasions. The Wairarapa airshed (Masterton monitoring site) was the only airshed in the region to breach the NES-AQ (ie, more than one exceedence per year in 2006, 2008 and in 2010).

Air quality at sites located next to heavily trafficked roads in central Wellington, and at short-term monitoring sites in Ngauranga and Melling, although poorer than that measured at the neighbourhood sites, met all national standards and guidelines for the three indicator pollutants measured. A national nitrogen dioxide screening programme carried out by NZTA (with support from Greater Wellington) showed that some local roads have poorer air quality than that measured at sites next to state highways and at the Wellington central monitoring site. As noted in Section 4.1.5, this finding may be due in part the monitoring method used by NZTA which allows closer siting to the roadside than allowed by standard monitoring methods utilised at the Wellington central monitoring site. In addition there is potential for more confinement of vehicle emissions due to surrounding buildings at some local road sites.

Toxic organic compounds such as benzo(a)pyrene have been detected in wood smoke arising from domestic home heating during the winter months in Wainuiomata and Masterton. Limited investigations show that arsenic levels in air are also elevated during the winter months in both areas due to the intermittent use of copper chrome arsenate treated timber as a fuel source for

domestic heating. There is the potential for annual guidelines for both arsenic and benzo(a)pyrene to be approached or exceeded in these areas and this is discussed further in Section 7.1.5.

One-off investigations carried out between 2000 to 2010 of local air quality influenced by industrial sources (ie, volatile organic compounds in Seaview, lead in Petone, and air toxics near a wood processing plant in Masterton) did not identify any significant issues.

7.1.2 Influence of meteorology and terrain on airshed air quality

The Wellington region has non-uniform terrain and diverse airshed climatology which means air quality is highly variable. Most parts of the region are relatively windy and this, coupled with generally low pollutant levels (by international levels), means air quality is good for most of the year. However, air quality can become degraded in low-lying areas when temperature inversions and low wind speeds enhance atmospheric stability (ie, low vertical and horizontal air movement). These conditions commonly occur during anticyclones and are characterised by low wind speeds, clear skies and ground frosts during winter. In valley areas, night-time cold air drainage from surrounding hills may increase the strength of the temperature inversion and hence the potential to trap emissions from domestic fires near ground level – such situations have been observed in the 'valley' airsheds of Masterton, Carterton, Upper Hutt and Wainuiomata. Although the Upper Hutt airshed has a large number of houses using solid fuel heating, winter air quality is not as poor as in Masterton or Wainuiomata – Davy (2007) suggested that overnight down-valley drainage in the Hutt Valley has a 'flushing' effect on PM_{10} concentrations which limits their accumulation.

Wellington city, Porirua and Kapiti airsheds are windy, coastal and rarely experience frosts – meaning air quality is typically good. However, there may be local 'pockets' of poor air quality in these airsheds during winter under light-wind, clear sky situations in low-lying areas – as found in Raumati South during winter 2010. Consequently, in these airsheds air quality can differ markedly from neighbourhood to neighbourhood.

7.1.3 Trends

There is strong evidence indicating that levels of PM_{10} decreased at Masterton between 2003 and 2010 at an average rate of about 2% per year – reductions were observed in all seasons and are considered environmentally significant. Similarly there was some evidence to suggest PM_{10} levels also decreased at Wainuiomata (2001 to 2010) by 1.2% per year and evidence to support an average annual decrease of 2.25% in Upper Hutt between 2006 and 2010. No change in PM_{10} concentrations was able to be detected at Lower Hutt.

Linking changes in air quality to changes in emissions is not possible with the data currently available. Winter PM_{10} emissions are predicted to decrease as older wood burners that have reached the end of their working life are being replaced with less polluting and more efficient models (mandatory since 1 August 2005 under the NES-AQ) or clean heat options (Wilton 2008). According to Statistics NZ census data, there has been a decline between 1996

and 2006 in the percentage of households that use coal (coal has higher emissions per kg fuel burnt than wood) as a fuel source in these airsheds. The percentage of households using wood for fuel has also decreased, but only in Wainuiomata and in Upper Hutt (Statistics NZ). Finer-scale emissions inventories would need to be repeated for these areas to confirm whether improvements in air quality can be linked to changes in wood burner types, numbers of wood burners and fuel types.

Despite the decline in average PM_{10} concentrations observed at Masterton there has not been a commensurate reduction in peak values (ie, 99th percentile) or obvious downward trend in the number of NES-AQ exceedences per year. Such high pollution days occur during specific overnight meteorological conditions that restrict the dispersion of PM_{10}; therefore peak concentrations are more influenced by variability in the extent to which meteorological conditions are conducive to restricted dispersion than the actual quantity of emissions on a particular night.

There was no evidence of any trends in carbon monoxide concentrations at the neighbourhood monitoring sites. In contrast, nitrogen dioxide concentrations decreased substantially at Masterton, with the annual average in 2010 almost half of that measured in 2003. Concentrations of nitrogen dioxide also decreased by about 20% at Upper Hutt between 2006 and 2010. These observed decreases in nitrogen dioxide concentrations are consistent with the underlying national trend for declining emissions per vehicle observed between 2003 and 2009 (Bluett et al. 2011).

Trends in pollutants measured at the long-term traffic monitoring site in Wellington central have been influenced by a major change to traffic flows due to the completion of the inner city bypass in early 2007 as well as improvements in data quality since 2008. PM_{10} concentrations decreased markedly (by 26% between 2004 and 2010), with most of this decrease observed between 2004 and 2007. This is an environmentally significant decrease, with annual levels falling from 17 ug/m^3 in 2004 to 13 ug/m^3 in 2010. Carbon monoxide levels also decreased substantially (33% reduction between 2004 and 2010), although the decrease is not environmentally significant; it represents a decrease of just 0.3 mg/m^3, for a pollutant which is found at very low levels. Most of the reduction in carbon monoxide that occurred between 2004 and 2007 is attributed to modernisation of the vehicle fleet and subsequent per vehicle reduction in emissions as seen in other areas of New Zealand (MfE 2010). Since 2008 carbon monoxide levels remained relatively unchanged. Annual average nitrogen dioxide levels have generally decreased (28% reduction between 2005 and 2010), with much of this decrease occurring between mid 2008 and mid 2009. This decrease is environmentally significant, representing a drop from 35.7 µg/m^3 in 2005 to 25.8 µg/m^3 in 2010 (which compares more favourably against the WHO (2006) annual average guideline of 40 µg/m^3).

7.1.4 Sources of particulate matter affecting air quality

Natural sources, namely crustal matter and marine aerosol, comprise most of the PM_{10} measured in air at neighbourhood (residential) monitoring sites in the

region. Most of the PM_{10} from natural sources is found in the coarse size range ($PM_{2.5-10}$). In residential areas where traffic density is higher, road dust arising from movement of vehicles along roadways is also a significant contributor to coarse particulate matter (Davy 2007).

During the winter months, in areas where solid fuel domestic heating is common, particulate matter from home heating can lead to degraded air quality under certain meteorological conditions. Most of the PM_{10} measured in air arising from domestic emissions comprises fine particulate matter ($PM_{2.5}$) and during pollution episodes up to 90% of $PM_{2.5}$ and about 75% of PM_{10} measured in air originates from domestic burners. Therefore, it is possible that the WHO (2006) $PM_{2.5}$ guideline and the MfE (2002) national reporting limit of 25 $\mu g/m^3$ will be breached on high pollution nights in Masterton, Wainuiomata, Upper Hutt, Carterton, Featherston and Raumati South despite the NES-AQ 50 $\mu g/m^3$ threshold for PM_{10} being met.

Motor vehicle exhaust emissions are another source of $PM_{2.5}$ affecting air quality in the region. However, the impact on air quality at the neighbourhood sites is relatively low compared to that of domestic heating emissions. Levels of $PM_{2.5}$ have not yet been measured at heavily trafficked sites in the region. Sulphate is also found in $PM_{2.5}$ throughout the region, with the largest contribution occurring during the summer months. While much of this sulphate is thought to originate from natural sources, in the Seaview industrial area Davy et al. (2008) suggest that ship movements in Wellington Harbour could be a contributing source under certain wind conditions. Industrial discharges containing fine zinc particles ($PM_{2.5}$) and coarse sulphate particles ($PM_{2.5-10}$) also affect air quality in Seaview.

7.1.5 Managing PM_{10} to reduce levels of other harmful air pollutants

Much of the focus of Greater Wellington's air quality monitoring centres on PM_{10} due to the regulatory imperative provided by the NES-AQ as well as the finding that a safe threshold for exposure to PM_{10} has not been identified (WHO 2006). As outlined in Section 2.6.2, it is now widely accepted that adverse human health effects associated with exposure to $PM_{2.5}$ (a subset of PM_{10}) are greater than those associated with PM_{10}. During the winter months when emissions from home heating are high, daily $PM_{2.5}$ concentrations can exceed WHO (2006) guidelines, but still meet the NES-AQ for PM_{10}. This apparent conflict between the New Zealand standards and WHO guidelines occurs because the ratio of PM_{10}:$PM_{2.5}$ exceeds 0.5 during pollution episodes. The implications are that maximum PM_{10} concentrations may need to be lower than that allowed by NES-AQ to accrue the full health benefits.

Other hazardous air pollutants of concern associated with emissions from domestic burners are PAHs and inorganic arsenic. PAHs, in particular benzo(a)pyrene, have been found to be associated with wood smoke in Christchurch (McCauley 2005) and were detected in Wainuiomata and Masterton during limited monitoring programmes. It is unclear whether meeting the NES-AQ for PM_{10} in these areas will be sufficient to ensure that PAH concentrations comply with national and international guidelines.

Receptor modelling studies have found elevated arsenic concentrations in air during winter associated with the burning in domestic dwellings of copper-chrome-arsenate (CCA) treated wood in suburban Auckland, Wainuiomata, Hastings and Nelson (Davy et al. 2011). Burning of CCA-treated timber is not permitted by Greater Wellington's Regional Air Quality Management Plan (RAQMP) as a waste management practice but this restriction is not explicitly applied to domestic heating. Preventing the use of CCA-treated timber as a domestic fuel source is most likely best achieved through education.

7.2 National context – indicator pollutants and public perceptions

There is no national assessment of air quality that aligns with the 10-year period examined in this report but national figures for PM_{10} compiled by MfE (2010) show that in the 2010 calendar year the Wellington region's airsheds were among the 83% of monitored airsheds in New Zealand that met the annual average guideline for PM_{10} of 20 µg/m^3. The seven airsheds that did not meet the guideline were all located in the South Island. The Wairarapa airshed recorded a maximum daily concentration of 67 ug/m^3 for this period (Figure 7.1) and was among the 50% of airsheds that had more than one exceedence in 2010 and therefore breached the NES-AQ.

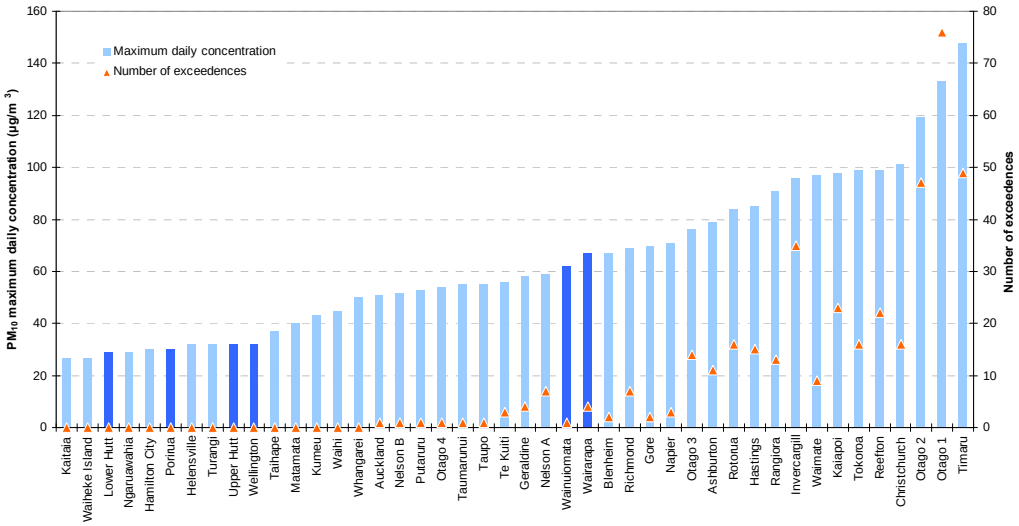


Figure 7.1: Maximum daily PM_{10} concentration and number of exceedences of the NES-AQ recorded in airsheds monitored across New Zealand during 2010[20] with Greater Wellington airsheds shown in dark blue

In 2008, all sites in New Zealand monitoring nitrogen dioxide met the NES-AQ (MfE 2010) and only one site (Queen Street, Auckland) failed to meet the annual WHO (2006) guideline. As at 2008, that there were no clear trends in nitrogen dioxide concentrations at any of the long-term monitoring sites (MfE 2010).

[20] Source: http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/

A nation-wide nitrogen dioxide screening programme at 128 sites in 2010 found annual average concentrations ranging from 8.3 µg/m^3 to 43.3 µg/m^3 (NZTA unpublished data). Nitrogen dioxide levels at background monitoring sites throughout the country were consistently low, while concentrations measured at both local roads and on state highways were quite variable (Figure 7.2). Median concentrations measured in the Wellington region were slightly lower than national medians for each monitoring site category (Table 7.1).

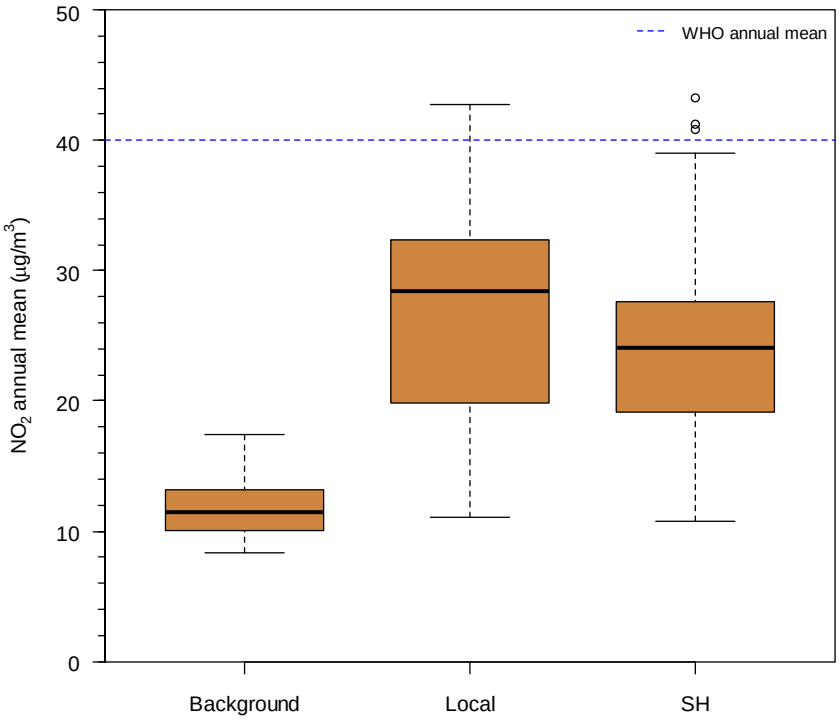


Figure 7.2: Distribution of annual mean nitrogen dioxide concentrations measured at 119 sites across New Zealand in 2010 (by passive diffusion method), based on unpublished data provided by NZTA)

Table 7.1: National comparison of annual average nitrogen dioxide concentrations measured at 119 sites across New Zealand in 2010 (by passive diffusion method), based on unpublished data provided by NZTA)

Site type	Background	Local roads	State highways
Nation-wide			
Maximum	17.4 (Auckland)	42.8 (Christchurch)	43.3 (Auckland)
Minimum	8.3 (Dunedin)	11.1 (Dunedin)	10.8 (Auckland)
Median	11.5 (*n*=22)	28.4 (*n*=33)	24.1 (*n*=73)
Wellington			
Maximum	13.0	40.3	35.3
Minimum	10.1	12.8	14.1
Median	10.5 (*n*=5)	23 (*n*=4)	21.4 (*n*=17)

In 2008, carbon monoxide concentrations at all air quality monitoring sites in New Zealand met the NES-AQ (MfE 2010). The maximum concentration recorded at Wellington central was less than maximum values measured at Auckland and Christchurch transport sites, although the annual mean was

higher than that recorded in Christchurch and on Auckland's North Shore (Takapuna site) but considerably lower than that recorded in inner Auckland (Kyber Pass, Newmarket). The decreasing trend in carbon monoxide concentrations evident at long-term monitoring sites in Christchurch (since 1989) and Auckland (Kyber Pass, since 1997) is largely attributable due to improvements in New Zealand's vehicle fleet resulting in lower per vehicle emissions (MfE 2010).

A national public perceptions survey conducted in 2010 (Quality of Life Survey 2010 eight cities report[21]) found that most respondents believed New Zealand had good air quality. Just over one in five (23%) of residents in the eight cities surveyed agreed that air pollution was a problem in their area. People living in Christchurch (31%) and Auckland (28%) were more likely to agree that air pollution was an issue. In contrast, only a small percentage of those living in Wellington (7%), Lower Hutt (9%) and Porirua (10%) thought that air pollution was a problem.

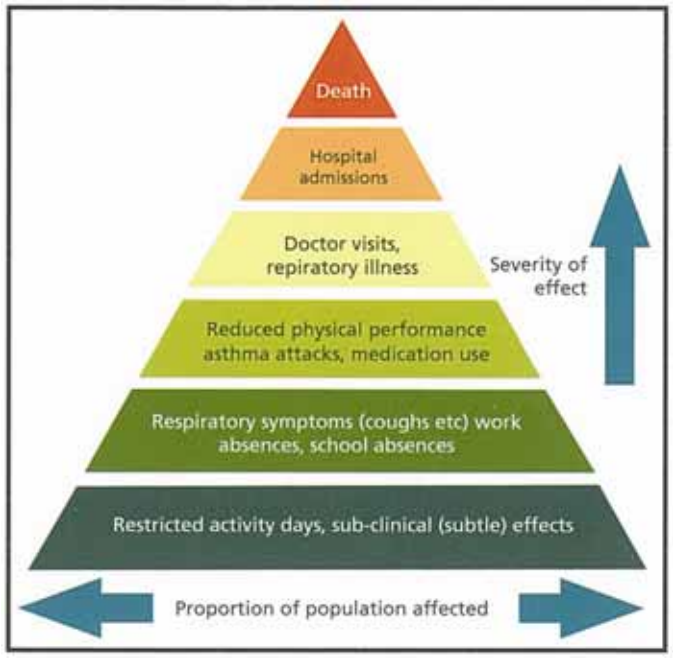
7.3 Estimated health effects due to PM_{10} exposure

The adverse health effects associated with exposure to PM_{10} are predominantly respiratory and cardiovascular. The total impacts on human health and well-being range from symptoms to functional changes (eg, reduced lung function), restricted activities (eg, school or work absenteeism), doctors or emergency department visits through to hospital admissions, reduced life expectancy and premature death for those with pre-existing conditions (Figure 7.3). Premature death means that people may die from an existing condition earlier than they would have if they had not been exposed to air pollution (ie, air pollution is one of many contributing factors). This hastening of death may be a matter of days, weeks, months or even years in some cases.

Linking air quality directly to health effects in exposed populations is complex because the effects that air pollution can have on health may also be caused by a number of other environmental factors, such as extremes of temperature, smoking, allergies, occupational exposure and indoor air quality (Coulson & Bluett 2006). Certain groups within the population are more severely affected by air pollution than others. Susceptibility depends on factors that are unique to each individual (eg, age, heath status, genetic makeup) as well as exposure (eg, time spent outside or proximity to major roads). Susceptible groups include children, the elderly, people with pre-existing heart or lung conditions, asthmatics, diabetics, pregnant women and Maori (Emission Impossible 2011).

Health effects attributed to exposure to air pollution in urban areas throughout New Zealand were first estimated in the Health and Air Pollution in New Zealand (HAPINZ) study (Fisher et al. 2007) using 2001 population census figures and modelled pollutant concentrations. Another study in 2007 was commissioned by the Health Research Council of New Zealand, the Ministry of Health and the Ministry of Transport (with support from regional councils) to predict health risks arising from exposure to the major sources of air pollution (ie, domestic fires, natural, industry and vehicles).

[21] www.bigcities.govt.nz/pdfs/Quality_of-_ife_2010.pdf



(Source: Greater Wellington GW/RP-G-04/81 2004)

Figure 7.3: Pyramid of health effects due to air pollution

An update of the HAPINZ health impact assessment for the Wellington region airsheds, focussing on the primary health effects due to exposure to PM_{10}, was carried out by Emission Impossible (2011) using 2006 population census data, actual ambient monitoring data and receptor modelling results to distinguish between anthropogenic and natural sources of PM_{10}. The numerical relationship between health outcomes and ambient PM concentrations used to estimate the updated Wellington figures is based on epidemiological studies carried out overseas and in Christchurch which have found a statistically significant association between air quality and hospital records (ie, an exposure-response function).

The updated HAPINZ predicts that on average each year, exposure to PM_{10} in the Wellington region's airsheds, from anthropogenic sources (ie, excludes the contribution of natural sources) is estimated to contribute to:

- 95 premature deaths (people aged over 30 years only)
- 26 cases of acute respiratory hospital admissions
- 13 cases of acute cardiovascular hospital admissions
- 88,000 restricted activity days.

It should be noted that the figures above are based on a modelled risk assessment rather than location-specific epidemiological studies, and are therefore indicative only because they are based on long-term statistical associations, rather than a specific predictor for a given year.

The overall estimated social cost of these health effects for the Wellington region is $322 million per year. The cost calculations applied to health effects

uses the cost-benefit analysis framework used by Ministry for the Environment for the review of the NES-AQ (Clough & Guria 2009).

7.4 Regulatory requirements for PM_{10}

PM_{10} is the only air pollutant in the Wellington region that fails to meet the daily average threshold stipulated by the NES-AQ; this occurs on occasion in the Wairarapa and Wainuiomata airsheds. Analysis of these 'high pollution' days shows that the PM_{10} source is largely domestic fires, with the pollution occurring under meteorological conditions unfavourable for the dispersion of pollutants (low overnight wind speeds, low temperatures and inversion conditions). The frequency of these winter-time meteorological conditions varies from year to year and cannot be precisely inferred from large-scale weather patterns. This poses a problem for predicting compliance with the NES-AQ based on emissions reduction scenarios.

7.4.1 Airshed compliance with NES-AQ

The 2011 amendments to the NES-AQ provide for 'split-target' airsheds, such as the Wairarapa, with on average more than one but fewer than 10 exceedences in a 12-month period (based on five years of monitoring data prior to September 2011), to have unlimited permitted exceedences until 31 August 2016. In the five years prior to 1 September 2011, the Wairarapa airshed had an average of two exceedences per year. Therefore regardless of the number of exceedences per year the Wairarapa airshed will not breach the standard, although Greater Wellington is still required to give public notice within 30 days of a second exceedence in a 12-month period. From 1 September 2016, the number of permitted exceedences per year in the Wairarapa airshed reverts to one.

The 2011 amendments include provisions relating to new open fires in domestic dwellings. If the Wairarapa airshed experiences more than one exceedence in winter 2012 or any winter thereafter, Greater Wellington must give public notice that the discharge from domestic solid fuel **open** fires is prohibited from open fires installed on or after 12 months after the date of the second exceedence. In other words, no **new** open fire installations would be allowed after a specified date no sooner than 2013.

7.4.2 Implications for industrial discharges

The 2011 NES-AQ amendments also have implications for resource consent applications to discharge PM_{10} post 1 September 2012 in 'polluted' airsheds. The Wairarapa airshed is deemed to be a 'polluted' airshed because the average number of exceedences per year exceeds one (based on the five-year period between 2007 and 2012 and even allowing for a best-case scenario of no exceedences to be recorded in 2011 or 2012).

Under a status-quo scenario we can expect a decline in PM_{10} as older, more polluting woodburners are replaced by either clean heat or less-polluting NES-AQ compliant woodburners. However, this reduction will take time before it significantly impacts on the frequency of high pollution nights and therefore new industrial activities that discharge PM_{10} may face constraints.

The NES-AQ stipulates that in 'polluted' airsheds, Greater Wellington must decline resource consent applications for new industry where the proposed discharge would be likely, at any time, to increase the 24-hour concentration of PM_{10} by more than 2.5 $\mu g/m^3$. Alternatively, Greater Wellington could require the applicant to 'offset' their proposed discharge by reducing PM_{10} from another source in the airshed. Recent dispersion modelling undertaken by Beca (2011) predicts that discharges from combustion appliances that currently meet the permitted activity status (ie, combined generation capacity of 2 MW) under Greater Wellington's RAQMP could at times result in offsite PM_{10} 24-hour concentrations greater than 2.5 $\mu g/m^3$ (particularly for appliances using wood or coal).

7.4.3 Implications for air quality monitoring

The NES-AQ stipulates that in airsheds where it is likely that the PM_{10} standard will be breached, monitoring must be conducted in that part of the airshed where air quality is poorest. MfE (2011) recommend all councils document their rationale for choice of monitoring sites that represent 'worst' air quality in the airshed. Siting of Greater Wellington's stations was based largely on results of emission inventories and/or screening assessments (Davy 2005), surrounding topography and practical considerations, such as access to power and site security.

An investigation by GNS Science (supported by Greater Wellington) of PM_{10} concentrations in urban Masterton during winter 2010 indicates that the current monitoring site at Wairarapa College may substantially underestimate the number of high pollution nights occurring each year in the Wairarapa airshed. Observations show that night time air pollution from domestic fires drifts across the Masterton urban area in a southwest direction due to the influence of cold air drainage (Trompeter et al. 2011). As outlined in Section 6.1.1, monitoring undertaken during winter 2010 has indicated that higher PM_{10} concentrations are likely to be found 1.24 km southwest of the Wairarapa College site (Ancelett et al. 2011). There are also other locations outside of the Masterton urban area in the Wairarapa airshed that are currently not monitored and where exceedences are likely, for instance Carterton.

In other airsheds in the region with complex terrain variability of PM_{10} is likely to be high, both spatially and temporally (ie, the 'worst' place in the airshed can vary from night to night depending on meteorological conditions). For instance, within airsheds such as Kapiti, where in general air quality is likely to be good, there may be localised areas in winter where air quality is degraded due to domestic emissions, such as found in Raumati South. This observation is consistent with a study by Trompetter et al. (2010) which found that winter PM_{10} concentrations in many areas throughout New Zealand depend on environmental confinement due to meteorology and are not well correlated with the number of wood burners or population size.

Identifying and monitoring (with standard methods) potentially numerous localised areas of poor winter air quality in the region would be cost-prohibitive in Greater Wellington's current air quality monitoring programme. Further screening is needed though to increase our understanding of the spatial

variability of PM_{10} in certain locations within the following airsheds: Wairarapa (Masterton, Greytown, Carterton and Featherston), Karori, Porirua (Tawa) and Kapiti (Raumati South). This would allow us to determine whether existing stations are sited so as to monitor 'worst-case' air quality and may also provide data suitable for making an informed decision on whether the boundaries of any airsheds should be re-defined for air quality management purposes.

7.4.4 Implications for air quality management

Of the airsheds in the region which have has five years worth of 'meaningful' data required by the NES-AQ – only the Wairarapa airshed is failing to meet the NES-AQ. Greater Wellington is therefore required to manage air quality in this airshed to ensure compliance by 2016. As domestic heating is the principal source of PM_{10} emissions in the Wairarapa airshed, the only way to improve air quality is to reduce these emissions. The current RAQMP effectively permits discharges to air from domestic fires – as the plan only regulates industrial and trade premises, and there are no rules relating to domestic emissions. To date Greater Wellington's air quality management efforts surrounding domestic emissions, as directed by the RAQMP, have been limited to education and advocacy, principally through the *Be the Difference* programme[22]. Other measures such as *Warm Greater Wellington*[23] while not directly aimed at air quality, may have co-benefits for air quality by improving energy efficiency and facilitating households to switch to clean heat. To date[24] 18,875 households in the region have participated in the Energy Efficiency and Conservation Authority (EECA) scheme – 2,870 of these households used Greater Wellington's voluntary targeted rates scheme. Overall, 87% of the households across the region had insulation retrofitted and 20% of retrofits were for heating (H. Livesey (EECA), pers comm. November 2011).

Emissions projections scenarios predict that under the status quo (ie, no intervention) the rate of wood burner retirement (wood burners replaced after 20 years of service) may be sufficient to ensure that the NES-AQ is met in 2016 (Wilton & Baynes 2008b). However, air quality between 2008 and 2010 has not improved commensurate with the emissions reductions expected under this scenario. While average air quality may have improved, there has been no change in the annual number and magnitude of peak concentrations – the metric for assessing NES-AQ compliance. The reasons for this finding are unknown, but may relate to uncertainties in the emissions inventory, economic factors affecting rates of wood burner upgrades, and the inherent difficulties in relating estimated emissions to air quality under worst case meteorological conditions in airsheds which are borderline compliant with NES-AQ (ie, dip in and out of compliance from year-to-year).

Wilton and Baynes (2008b) recommended various intervention measures for Masterton, such as prohibiting outdoor burning, open fires and new installations of multi-fuel burners, and also recommended incentivising

[22] *Be the Difference* is Greater Wellington's programme for engaging people and their communities to make a positive difference to the environment (http://www.gw.govt.nz/about-the-programme).

[23] Warm Greater Wellington is a targeted rates scheme offering financial assistance to rate payers for the remaining cost of home insulation and clean heating over and above the grant provided by Energy Efficiency Conservation Authority (EECA).

[24] 1 July 2009 to 30 September 2011.

households to replace older solid fuel heating appliances with clean heat options that would result in a greater decline in emissions over a shorter timeframe and hence more surety of NES-AQ compliance. Consequently, an airshed action plan as promoted by MfE (2011) may need to be developed in consultation with Wairarapa residents and the local territorial authorities to ensure that the Wairarapa airshed complies with the NES-AQ by 2016.

While none of the Wellington region's other airsheds currently breach the NES-AQ, it is suspected that there may be 'pockets' of poor winter air quality from time-to-time within some of these airsheds (for example, Raumati South in the Kapiti airshed) which may mean that the NES-AQ is breached on a neighbourhood by neighbourhood basis. This situation may be problematic for airshed management, as intervention provisions may only need to apply to a small part of an airshed.

The benefits of any reductions in ambient PM are expected to result in health improvements – as there is little evidence to suggest a threshold below which no adverse health effects from exposure to PM would be anticipated (WHO 2006). Consequently MfE (2011) recommend that councils should continue to work towards minimising long-term health effects beyond the minimum required to meet current regulations.

7.5 Monitoring programme limitations and knowledge gaps

Greater Wellington's air quality monitoring programme provides important information on the levels of key indicator pollutants at a range of residential sites and one transport monitoring site. However:

- There is not currently enough information available on the spatial representativeness of current monitoring sites and whether these represent the worst air quality in an airshed as required by the NES-AQ as discussed in section 7.4.3. In order to investigate spatial variability of PM_{10}, resources may need to be re-diverted from routine monitoring of key indicator pollutants (such as carbon monoxide and nitrogen dioxide) which are found at low concentrations at some sites.

- More information is required on $PM_{2.5}$ levels (measured with standard methods) at traffic sites and residential sites affected by domestic heating. At residential sites which are impacted by domestic emissions, it is likely that compliance with the PM_{10} standard is not always sufficient to ensure compliance with international guidelines for $PM_{2.5}$. Likewise concentrations of hazardous air pollutants, such as arsenic and benzo(a)pyrene, should be assessed in targeted campaigns in airsheds with significant impacts from domestic emissions. Monitoring $PM_{2.5}$ at the heavily trafficked site in Wellington central would allow the impact of vehicle emissions on PM levels to be differentiated from other sources, such as soils and marine aerosol.

- Consideration needs to be given to assessing levels of sulphur dioxide around the Port of Wellington that may be affected by emissions from vessels using marine-grade diesel.

In terms of knowledge gaps, a major gap is how to link domestic emissions to resultant air quality and how peak concentrations are affected by fine-scale meteorological parameters. In order to fill this gap – more detailed and updated emissions data are required on the types of woodburners, emissions factors, type of fuel used and burning patterns. Another important knowledge gap is quantifying health effects as a result of population. More information is required on the impact of air pollution on sensitive sub-groups in the population, for instance children who may be exposed to traffic emissions at schools or daycares located close to busy roads. This particulate knowledge gaps needs to be addressed at a national level by research organisations (eg, NIWA is involved in an international study on effects of ultrafine particles from traffic on children's health[25]).

[25] http://www.niwa.co.nz/our-science/ei/research-projects/uptech-nz

8. Conclusions

Air quality monitoring undertaken over the last ten years shows that the Wellington region experiences good air quality most of the time. The only indicator pollutant of concern is PM_{10} which is found at elevated concentrations in the Wairarapa and Wainuiomata airsheds – and most likely in small 'pockets' elsewhere in the region – during winter on cold, calm and clear nights.

Emissions from domestic fires used for home heating are the major source of PM_{10} contributing to poor winter air quality in Masterton, Upper Hutt, Wainuiomata, Carterton, Featherston and Raumati South. Most of this PM_{10} is emitted in the form of $PM_{2.5}$ – a finer fraction (and a component of PM_{10}) which is more strongly associated with adverse health effects than PM_{10}. In areas of the region where emissions from home heating occur during meteorological conditions that restrict the dispersal of particulate matter it is likely that both the WHO (2006) $PM_{2.5}$ guideline and the MfE (2002) $PM_{2.5}$ reporting limit will not be met despite the PM_{10} standard being met. Furthermore, $PM_{2.5}$ may contain other hazardous air pollutants such as PAHs and, in areas such as Wainuiomata where CCA-treated timber is used as an intermittent fuel source, arsenic.

Average concentrations of PM_{10} declined in Masterton, Wainuiomata and in Upper Hutt during the past 10 years – but there was no apparent trend in the number of high pollution nights experienced each year. A closer examination of the relationship between meteorology and high pollution episodes is needed in order to understand the impact of inter-annual variation in meteorology on air quality trends.

The Wairarapa airshed was the only airshed that breached the NES-AQ (in 2006, 2008 and 2010) and, based on the number of high PM_{10} nights over 2008 to 2010 alone, on 1 September 2012 the airshed will be deemed as 'polluted' under the NES-AQ. This means that Greater Wellington is required to implement air quality management strategies in the airshed to reduce PM_{10} emissions so that the number of high pollution nights per year drops to one by 2016. While natural attrition of the older and more polluting wood burners may assist with reducing PM_{10} emissions, it is unclear from the 2008 Masterton emission inventory whether this alone will be sufficient to ensure compliance with the NES-AQ by 2016. A further complicating factor is that screening studies undertaken at other locations in urban Masterton during winter 2010 suggest that the existing monitoring site at Wairarapa College may not represent the worst air quality in the Wairarapa airshed (as required by the NES-AQ).

Emissions from transport, although significant in the Wellington region – do not translate into poor air quality as measured by the three indicator pollutants: PM_{10}, carbon monoxide and nitrogen dioxide. Daily traffic counts are low by international levels and the times of peak traffic flows do not coincide with meteorological conditions that restrict the dispersal of pollutants. Pollutant concentrations measured at the long-term traffic monitoring site in central

Wellington city declined over 2004[26] to 2010, although the trends were in part influenced by a major change in traffic flows due to the completion of the inner city bypass in early 2007 as well as improvements in data quality since 2008. Despite full compliance with air quality guidelines at transport monitoring sites, NZTA data indicate that there is the potential for elevated nitrogen dioxide levels on some roads which are heavily trafficked and surrounded by buildings that interfere with the dispersal of pollutants. There may also be potential for some impact on air quality in areas adjacent to the Port of Wellington as a result of sulphur dioxide emissions from shipping activities in Wellington Harbour.

8.1 Recommendations

1. Review each monitoring site to determine exposure characteristics and spatial variability of PM_{10} in each airshed as recommended by MfE (2011). This will require screening studies and possibly dispersion modelling.

2. Obtain more up-to-date information on domestic emissions in Masterton and other urban areas in the Wairarapa airshed. In particular more detailed information on heating patterns and sources of fuel and a greater understanding of the factors that would motivate/allow people to switch to clean heat options.

3. Monitor arsenic in air in Wainuiomata for a period of up to two years using a standard methodology to enable comparison with the national air quality guideline and to determine whether a targeted education programme is needed discouraging the burning of CCA-treated timber.

4. Monitor benzo(a)pyrene for a period of one year in either Wainuiomata or Masterton to enable comparison with the national air quality guideline and to examine the relationship between PM_{10} concentrations and benzo(a)pyrene levels.

5. Investigate possible re-configuration of pollutants measured at monitoring sites in order to reduce carbon monoxide and nitrogen dioxide monitoring as levels of both these pollutants are low.

6. Intensify monitoring of PM_{10} to enable a better representation of spatial variability of PM_{10} across the region, particularly in the Wairarapa airshed.

7. Complement PM_{10} monitoring with $PM_{2.5}$ monitoring at existing residential sites where winter air quality is poor, and at the Wellington central traffic monitoring site.

8. Investigate concentrations of nitrogen dioxide on local roads where screening studies suggest these may be elevated, focussing in particular on sensitive receptors, such as childcare centres located next to busy roads.

[26] 2005 to 2010 for nitrogen dioxide.

9. Consider carrying out a screening study to investigate levels of sulphur dioxide around the Port of Wellington that may be impacted by emissions from vessels using marine-grade diesel.

10. Take into account the findings of this report in the review of Greater Wellington's existing Regional Air Quality Management Plan, in particular:

    - address air quality issues arising from $PM_{2.5}$ and hazardous air pollutants associated with PM_{10}; and

    - consider reducing discharges from domestic fires using methods which are acceptable to affected communities.

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- Juliet Milne (Greater Wellington) provided guidance on the preparation of this report and reviewed draft versions. Paul Denton and Ted Taylor (Greater Wellington) also provided comments on the document.

Appendix 1: Airshed terrain maps

Figure A1.1: Kapiti Coast

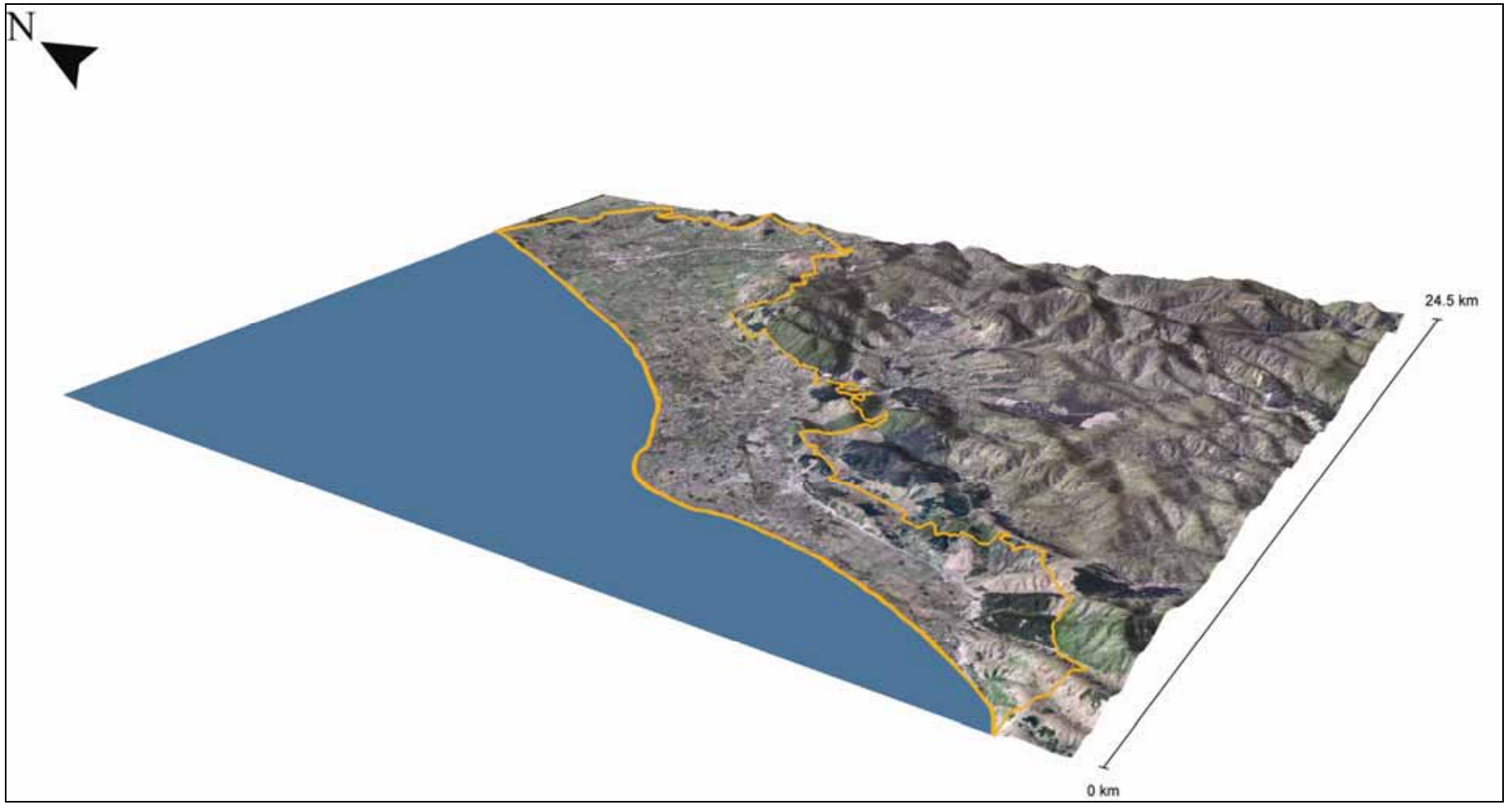


Figure A1.2: Porirua basin

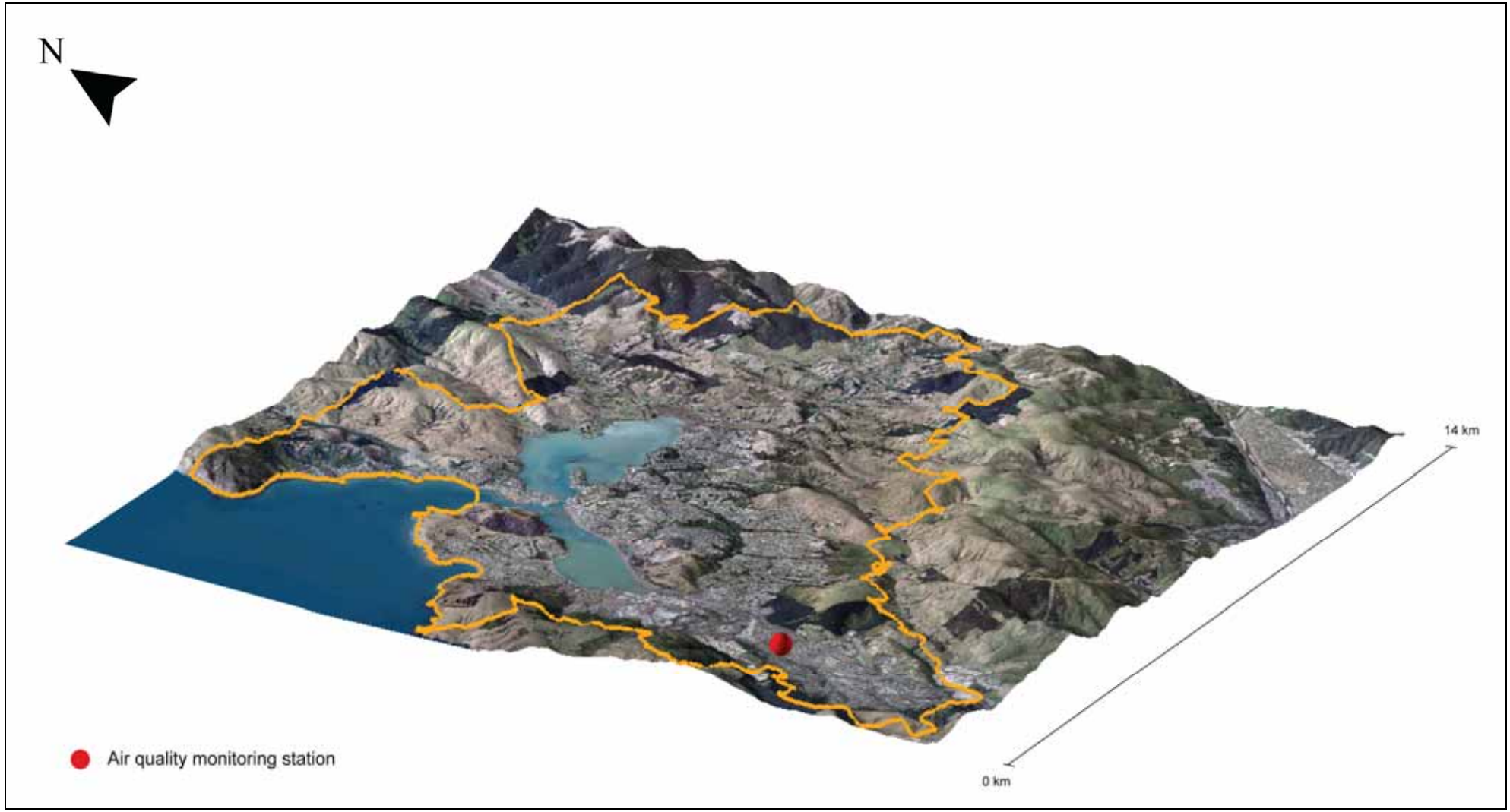


Figure A1.3: Karori

Figure A1.4: Wellington city

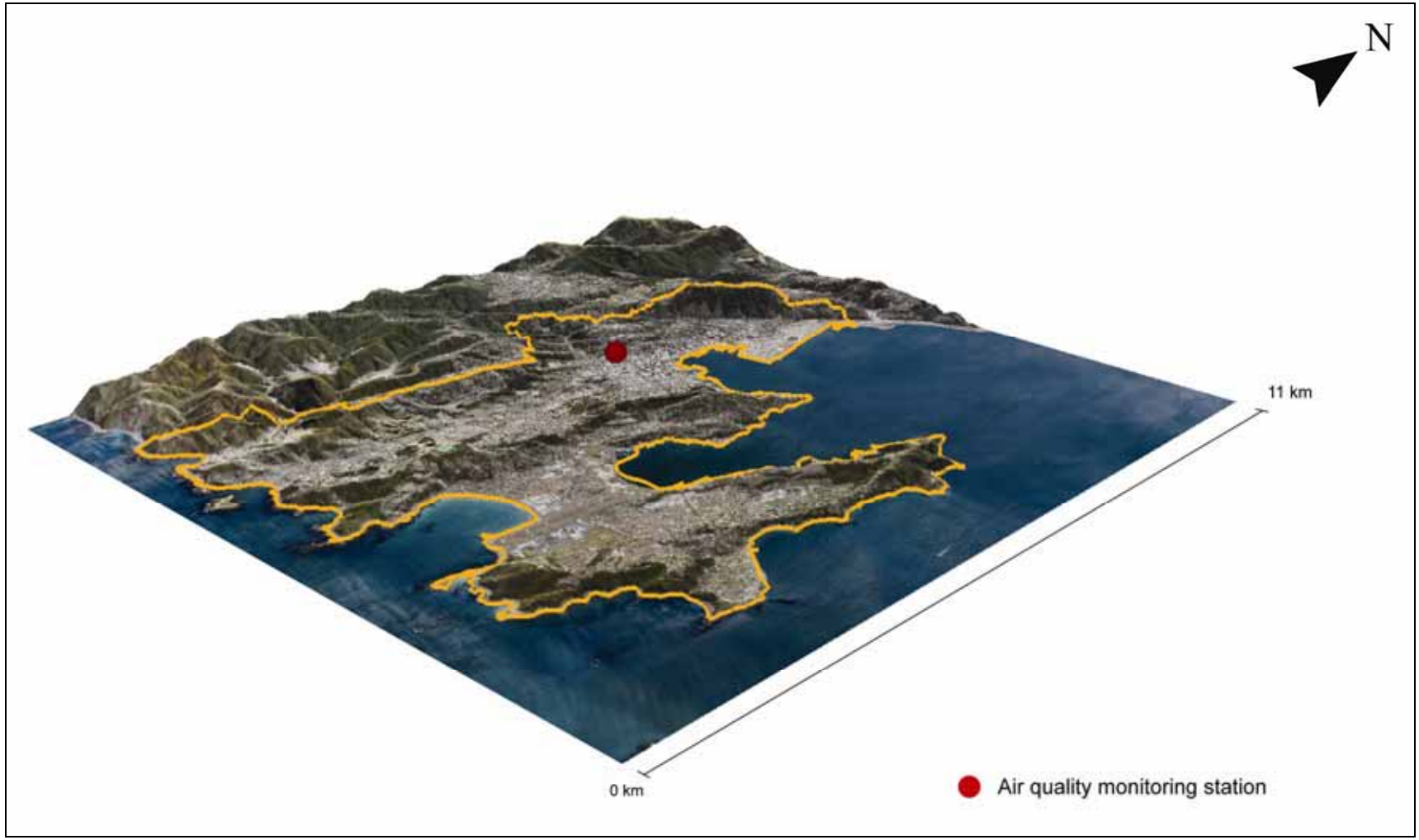


Figure A1.5: Wainuiomata

Figure A1.6: Lower Hutt Valley

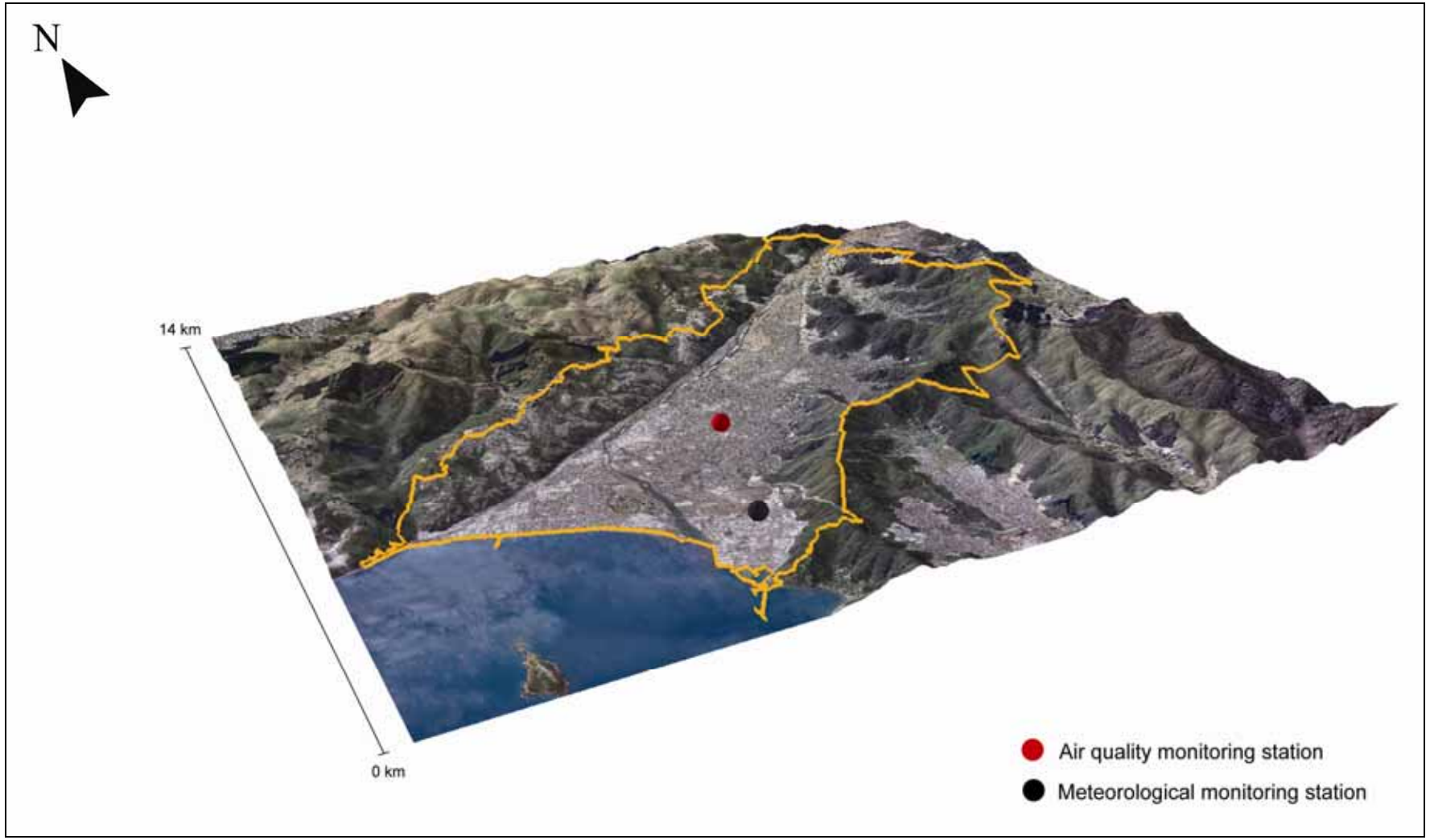
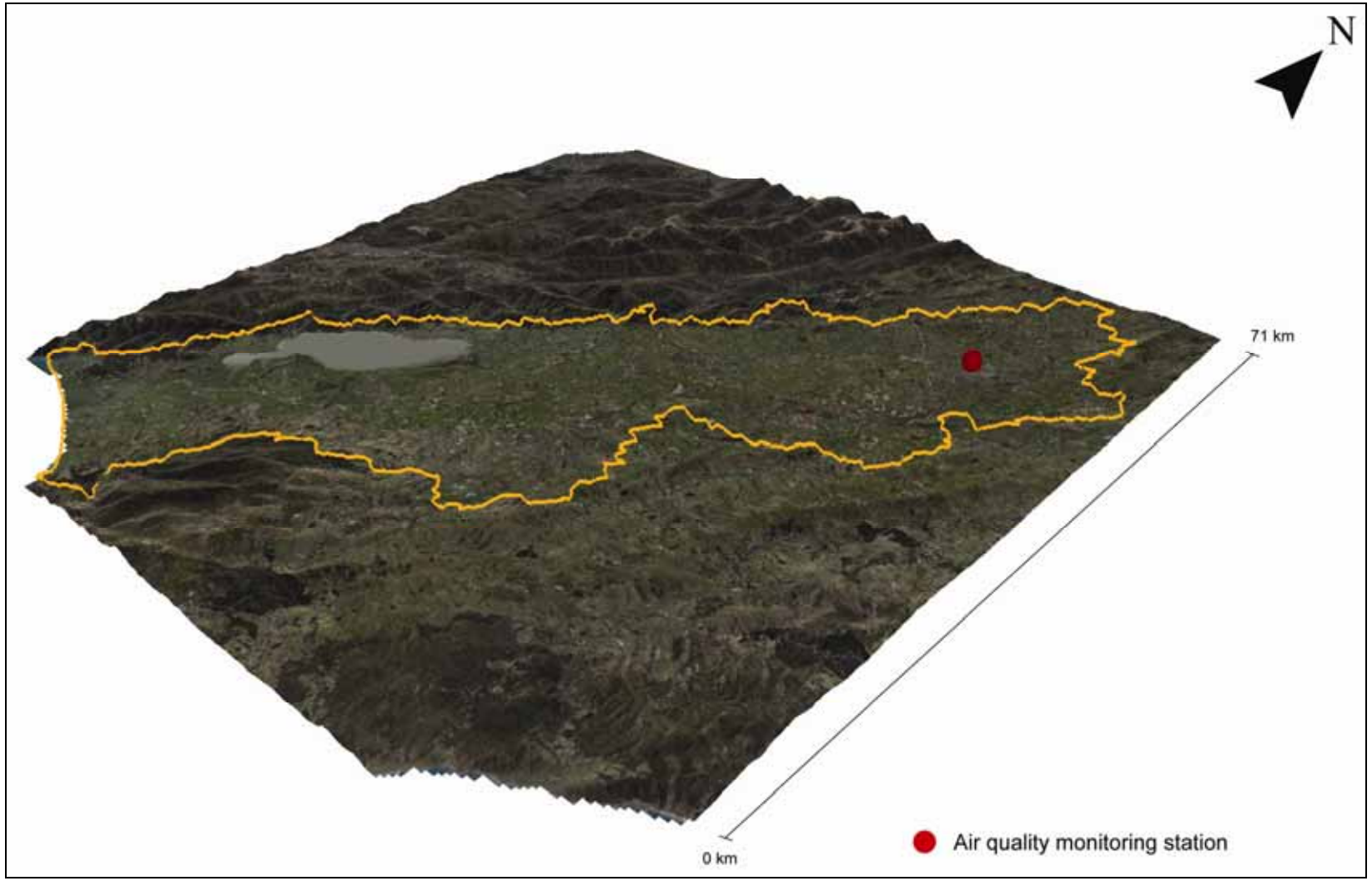


Figure A1.7: Upper Hutt Valley

Figure A1.8: Wairarapa Valley



Appendix 2: Monitoring sites

Table A2.1: Greater Wellington monitoring sites, including short-term investigation sites

Site	Station	Easting (NZTM)	Northing (NZTM)	Purpose	Contaminant	Method	Frequency	Duration
Wellington central	Corner V, corner Victoria & Vivian Street, Te Aro	1748457	5427080	SOE NES-AQ	PM_{10}	BAM (FH62)	Continuous	23/03/2004 to present
					CO	GFC (API)	Continuous	12/03/2004 to present
					NO_2	Chemiluminescence (API)	Continuous	29/03/2005 to present
Lower Hutt	Birch Lane, Phil Evans Reserve	1761032	5435863	SOE NES-AQ	PM_{10}	TEOM	Continuous	05/04/2001 to present
					CO	GFC (API)	Continuous	25/10/2001 to present
					NO_2	Chemiluminescence (API)	Continuous	13/08/2001 to present
Wainuiomata	Wainuiomata Bowling Club, Moohan Street	1763651	5429683	Survey	PM_{10}	High volume sampler	1-day-in-3	30/09/2000 to 06/10/2007
				SOE NES-AQ	PM_{10}	BAM (FH62)	Continuous	30/06/2006 to present
Upper Hutt	Savage Park, Savage Crescent	1773805	5445685	SOE NES-AQ	PM_{10}	BAM (FH62)	Continuous	07/11/2005 to present
					CO	GFC (API)	Continuous	30/09/2005 to present
					NO_2	Chemiluminescence (API)	Continuous	19/09/2005 to present
Masterton	Wairarapa College, Cornwell Street	1822756	5463164	SOE NES-AQ	PM_{10}	BAM (FH62)	Continuous	18/06/2007 to present
					PM_{10}	TEOM	Continuous	08/10/2002 to 01/01/2011
					PM_{10}	High volume sampler	1-day-in-3	17/04/2003 to 30/03/2005
					CO	GFC (API)	Continuous	8/10/2002 to present
					NO_2	Chemiluminescence (API)	Continuous	1/1/2003 to present
Tawa	Duncan Park, Linden	1753584	5442138	SOE NES-AQ	PM_{10}	TEOM	Continuous	09/05/2007 to 06/01/2009
					PM_{10}	BAM (FH62)	Continuous	28/01/2009 to present
					CO	GFC (API)	Continuous	14/02/2007 to present
					NO_2	Chemiluminescence (API)	Continuous	22/02/2007 to present
Carterton	Swimming pool	1811937	5455680	NES-AQ	PM_{10}	BAM (FH62)	Continuous	28/04/2010 to 09/09/2010
				Survey	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	Partisol (Dichotomous)	24-hour	03/06/2009 to 15/06/2009
Karori	Terawhiti Bowling Club, Karori Park	1744252	5427887	Survey NES-AQ	PM_{10}	BAM (FH62)	Continuous	16/07/2007 to 14/01/2010
					CO	GFC (API)	Continuous	11/06/2007 to 14/01/2010
					NO_2	Chemiluminescence (API)	Continuous	11/06/2007 to 14/01/2010
Melling	SH2, Block Road	1759880	5436969	Survey NES-AQ	PM_{10}	BAM (FH62)	Continuous	12/05/2006 to 20/01/2010
					CO	GFC (API)	Continuous	11/05/2006 to 19/01/2010
					NO_2	Chemiluminescence (API)	Continuous	02/05/2006 to 19/01/2010

Site	Station	Easting (NZTM)	Northing (NZTM)	Purpose	Contaminant	Method	Frequency	Duration
Ngauranga	Centennial Highway	1751351	5433128	Survey NES-AQ	PM_{10}	BAM (FH62)	Continuous	09/11/2005 to 04/08/2008
					CO	GFC (API)	Continuous	07/11/2005 to 04/08/2008
					NO_2	Chemiluminescence (API)	Continuous	04/11/2005 to 04/08/2008
Upper Hutt	Trentham Fire station	1771466	5444704	Survey	PM_{10}	TEOM	Continuous	22/5/2000 to 06/09/2006
					CO		Continuous	19/05/2000 to 06/09/2006
					NO_2	Chemiluminescence (API)	Continuous	19/05/2000 to 06/06/2006
				Investigation	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	GENT	1-day-in-3	12/05/2000 to 15/02/2002
Mabey Road	Lower Hutt	1762787	5438453	Survey	PM_{10}	TEOM	Continuous	04/12/1997 to 05/03/1998
Raumati South	Kapiti coast	1766687	5466883	Investigation	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	Partisol (Dichotomous)	12-hour	25/5/2010 to 02/08/2010
Solway	Solway School	1819816	5462397	Investigation	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	Partisol (Dichotomous)	24-hour	20/6/2009 to 02/07/2009
Featherston	Featherston School	1795453	5445321	Investigation	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	Partisol (Dichotomous)	24-hour	04/07/2009 to 19/07/2009
Seaview	Hutt Park Road	1760400	5432820	Investigation	VOCs	USEPA TO-17	1-day-in-3	01/03/2003 to 01/11/2004
				Investigation	$PM_{2.5}$/$PM_{2.5\text{-}10}$	GENT	1-day-in-3	23/04/2002 to 13/09/2002
Petone	Waione Street & Kirkcaldy Street	1758698	5466884	Investigation	Pb and As in TSP	High volume sampler	1-day-in-2	01/03/2009 to 05/07/2009
				Investigation	Pb and As in TSP	High volume sampler	1-day-in-2	01/02/2008 to 31/05/2008
				Investigation	Pb and As in TSP	High volume sampler	1-day-in-2	11/02/1999 to 12/02/1999
San Marino	Te Aro, Wellington	1748244	5427101	Survey	CO	TEI 48C	Continuous	30/01/2002 to 26/01/2009
Masterton	Railway Crescent	1823888	5464375	Investigation	VOC	USEPA TO-11A	1-day-in-3	26/05/2004 to 30/09/2004
					TSP, Cu, Cr, As	High volume sampler	1-day-in-3	26/05/2004 to 30/09/2004
Huia Pool	Petone	1759670	5435718	Survey	PM_{10}	TEOM	Continuous	08/05/1998 to 01/06/1999
				Investigation	$PM_{2.5}$ & $PM_{2.5\text{-}10}$	GENT		08/06/1998 to 01/06/1999
Masterton	Memorial Park	1823392	5462721	Survey	PM_{10}	TEOM	Continuous	05/06/1999 to 17/05/2000
Rural Otaki	GW Otaki Depot	1780982	5484663	Survey	PM_{10}	High volume sampler	1-day-in-3	11/06/1998 to 01/09/2000
Basin Reserve	Dufferin Street	1749156	5426302	Survey	CO	TEI 48C	Continuous	23/09/1998 to 10/05/1999
Civic Square	Wellington	1748872	5427698	Survey	PM_{10}	TEOM	Continuous	05/03/1998 to 05/05/1998
					CO	TEI 48C	Continuous	05/03/1998 to 05/05/1998
					NO_2	ML9841	Continuous	05/03/1998 to 05/05/1998
Newtown	Government House	1748984	5425808	Survey	PM_{10}	High volume sampler	1-day-in-3	09/03/1998 to 05/12/1998
Queens Wharf	Wellington	1748877	5428117	Survey	CO	TEI 48C	Continuous	03/01/1998 to 26/05/1998
Victoria & Vivian Street		1748419	5427076	Survey	CO	TEI 48C	Continuous	26/05/1998 to 18/09/1998

Appendix 3: Monitoring methods – key contaminants

Table A3.1: Monitoring methods at air quality monitoring sites

Variable	Site	Method
PM_{10}	Tawa, Lower Hutt, Masterton	TEOM series 1400AB (Rupprech & Patashnick) designated as automated method (EQPM-1090-079) equivalent to the United States Code of Federal Regulations[27]
	Wellington central, Masterton, Upper Hutt, Karori, Tawa	FH62 C14 beta attenuation (ThermoElectron Corp) designated as automated method (EQPM-1102-150) equivalent to the United States Code of Federal Regulations
	Wainuiomata, Masterton	High volume sampler in accordance with AS/NZS 3580.96:2003
CO	Wellington central, Masterton, Upper Hutt, Lower Hutt, Karori	API 300 series Gas Filter Correlation Infrared Analysers in accordance with AS3580.7.1:1992.
NO_2, NO, NOx	Wellington central, Masterton, Upper Hutt, Lower Hutt, Karori	API 200 series Chemiluminscence Analysers in accordance with AS3580.5.1:1993.
	Tawa	Ecotech ML 9841B designated as reference method (PFNA-1292-090) equivalent to the United States Code of Federal Regulations (40 CFR Part 53)
Site installation		Australian Standard AS/NZS 3580.1.1:2007 Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment

[27] Title 40 – Protection of the Environment, Volume 2, Part 50, Appendix J: Reference Method for the Determination of Particulate Matter as PM_{10} in the Atmosphere.

Appendix 4: Monitoring methods – meteorological variables

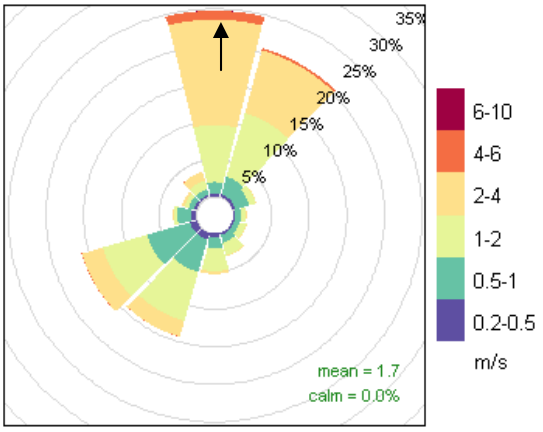
Table A4.1: Meteorological variables measured at air quality monitoring sites

Site	Variables measured	Instrument	Mast height
Wellington central	Temperature and Relative humidity	Vaisala 50Y	4m
	Wind speed and direction	Vaisala WS425	4m
Lower Hutt	Temperature	Campbell CS107	1.5m
	Temperature	Vaisala 50Y	10m
	Wind speed	A101	10m
	Wind direction	W200P	10m
	Relative humidity	Vaisala 50Y	10m
	Solar radiation	Licor LI-200SZ	10m
	Rainfall	0.5 mm Ota	
Wainuiomata	Temperature	Campbell CS107	3m
	Temperature and Relative humidity	Vaisala 50Y	10m
	Wind speed and direction	Vaisala WS425	10m
	Solar radiation	Licor LI-200SZ	10m
Upper Hutt	Temperature	Campbell CS107	4m
	Temperature and Relative humidity	Vaisala 50Y	10m
	Wind speed and direction	Vaisala WS425	10m
	Barometric pressure	PTB 100A	10m
	Soil temperature	Campbell CS107	
	Soil moisture	Campbell CS615	
	Rainfall	0.5 mm Ota	
Masterton	Temperature	Vector T302	5m, 15m
	Temperature	Vaisala 50Y	10m
	Wind speed	A101	10m
	Wind direction	W200P	10m
	Wind speed and direction	Vaisala WS425	15m
	Relative humidity	Vaisala 50Y	10m
	Barometric pressure	PTB 100A	10m
	Net solar radiation	NR Lite	10m
	Soil temperature	Campbell CS107	
	Soil moisture	Campbell CS615	
	Rainfall	0.5 mm Ota	
Tawa	Temperature	Campbell CS107	3m
	Temperature	Vaisala 50Y	6m
	Wind speed	A101	6m
	Wind direction	W200P	6m
	Relative humidity	Vaisala 50Y	6m
	Barometric pressure	PTB 100A	6m
Shandon	Temperature	Vector T302	5m
	Temperature	Vaisala 50Y	10m
	Temperature	Vector T302	15m
	Wind speed	A101	10m
	Wind direction	W200P	10m
	Wind speed and direction	Vaisala WS425	15m
	Relative humidity	Vaisala 50Y	10m
	Barometric pressure	PTB 100A	10m
	Net solar radiation	NR Lite	10m
	Soil temperature	Campbell CS107	
	Soil moisture	Campbell CS615	
	Rainfall	0.5 mm Ota	

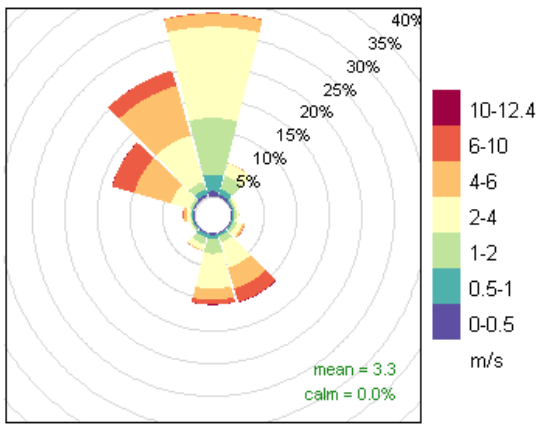
Appendix 5: Wind roses by monitoring site

A5.1: Wind roses of speed and direction recorded at air quality monitoring stations between 2005 and 2010 with mast height in brackets

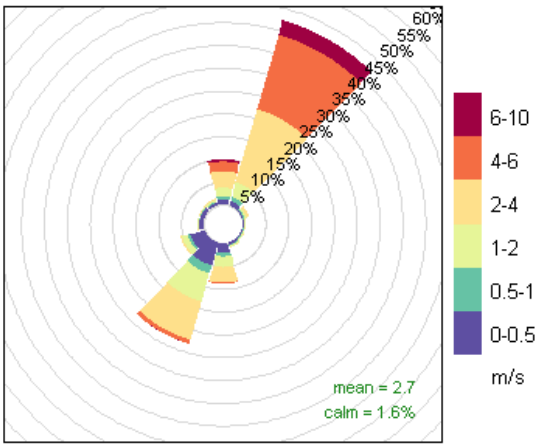
Wellington central (4m)



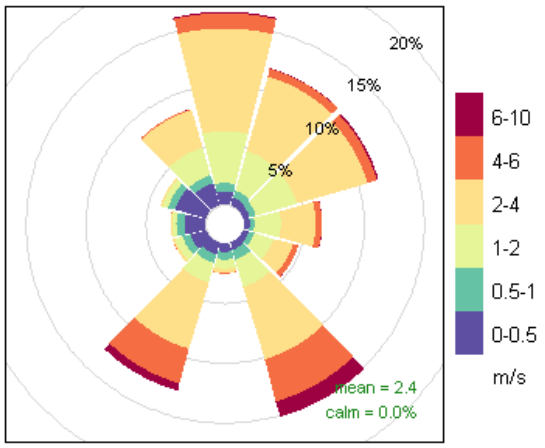
Lower Hutt (10m)



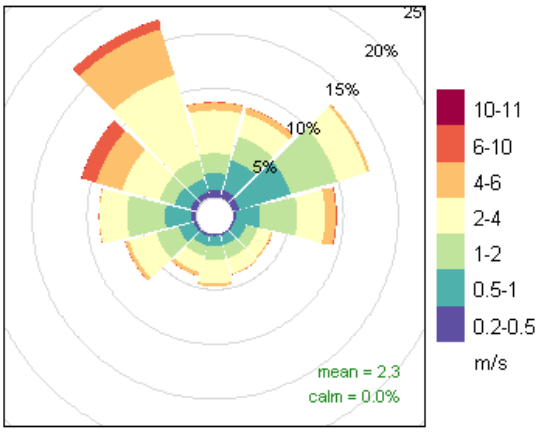
Tawa (6m)



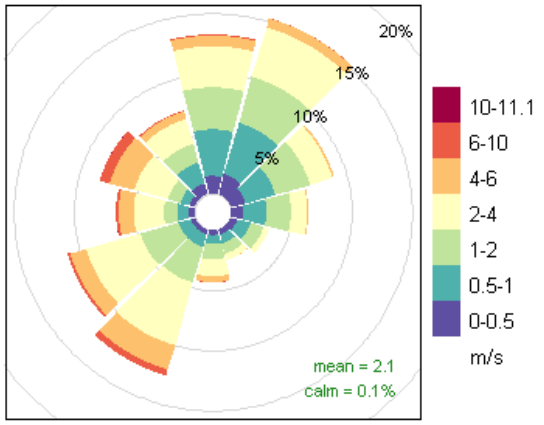
Karori (10m)

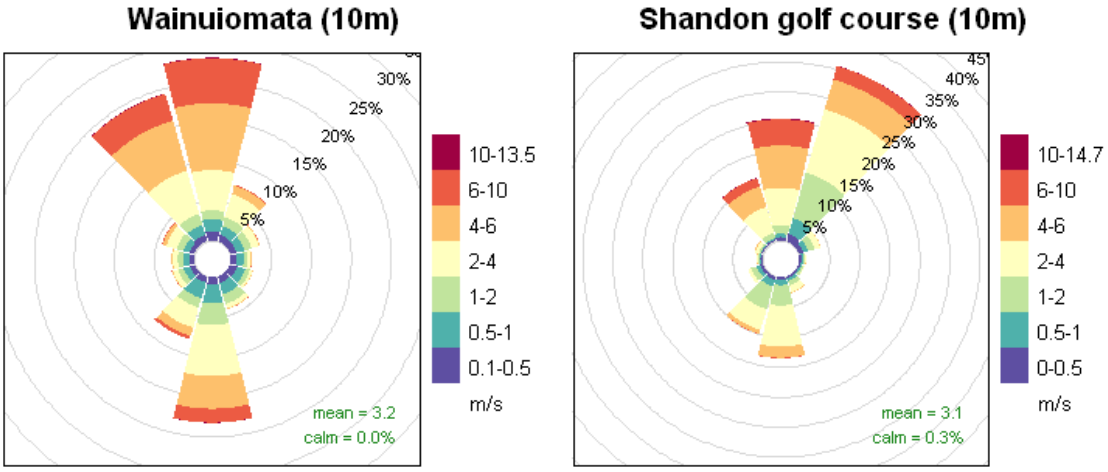


Upper Hutt (10m)



Masterton (10m)




Wainuiomata (10m)
30%
25%
20%
15%
10%
5%
mean = 3.2
calm = 0.0%
10-13.5
6-10
4-6
2-4
1-2
0.5-1
0.1-0.5
m/s
Shandon golf course (10m)
45
40%
35%
30%
25%
20%
15%
10%
5%
mean = 3.1
calm = 0.3%
10-14.7
6-10
4-6
2-4
1-2
0.5-1
0-0.5
m/s

Appendix 6: Airshed climatology

The information in this section was provided by Griffiths (2011).

Kapiti airshed

The Kapiti airshed is the most western of all the airsheds, and its climate is described as 'western-coastal' in nature. The airshed is very exposed to westerly or northwesterly airstreams (common over the lower North Island), and subsequently the airshed is relatively windy (Paraparaumu mean wind speed was 4.3 m/s over 2005 to 2010) and has a moderated temperature range due to its proximity to the sea and its windiness. Extremes in temperature are fairly unusual, although air frosts can occur on the inland plain and closer to the foothills. The relatively windy nature of this airshed would often inhibit low-level inversions, but they would occur from time to time over the plains given the extremely low minimum temperatures that exist in the observational record.

Porirua airshed

The Porirua airshed is described as 'western-coastal' in nature and is likely to be the second-windiest of the eight airsheds (although there was insufficient on-shore wind data to quantify this). It has a reduced temperature range due both to its windiness and proximity to the sea. Extremes in temperature are fairly unusual and air frosts would be rare in this airshed. The windiness of the airshed and the lack of extremely low, persistent minimum temperatures would most likely inhibit inversion formation.

Karori airshed

This airshed has a climate that could be described as 'inland Wellington' in nature. While there is virtually no climate data available for Karori, this area is likely to be relatively windy. Karori lies in a bowl surrounded by hills. On occasion, during light-wind, clear-sky winter situations, cold air drainage into the Karori bowl would probably occur leading to temperature inversions also.

Wellington airshed

This airshed has a climate that is 'coastal' in nature and it is the windiest of the eight airsheds (Wellington airport mean wind speed was 6.8 m/s between 2005 and 2010) with a reduced temperature range due to its windiness and proximity to the sea. Temperature extremes and air frosts are very rare. This windiness combined with lack of extremely low persistent minimum temperatures would usually inhibit the formation of temperature inversion.

Wainuiomata airshed

Like the Lower and Upper Hutt airsheds, the climate of the Wainiomata airshed is described as 'valley' in nature and average wind speeds are much lower than those observed in the Wellington, Kapiti, or Porirua airsheds (the Wainuiomata mean wind speed over 2005-2010 was 3.2 m/s). Since Wainuiomata is effectively an enclosed valley system, the observed temperature range is much larger than the western and coastal airsheds (the extreme maximum temperature over 2005-2010 was 27.6°C, extreme minimum -3.5°C). During light-wind, clear sky winter situations, cold air drainage/ponding into the valley would occur, leading to the formation of low-level temperature inversions.

Lower Hutt airshed

The climate of the Lower Hutt airshed is termed 'valley' in nature, albeit the lower end of the Hutt Valley is still influenced to some degree by the proximity of the sea (meaning temperatures would be somewhat moderated immediately adjacent to the sea). The Lower Hutt mean air wind speed over 2005 to 2010 was 3.0 m/s at Shandon and 3.3 m/s at the Lower Hutt air quality monitoring station, implying a much lower average wind speed than that observed in Wellington, Kapiti or Porirua airsheds. This is consistent with the Hutt Valley's topography, being a valley somewhat sheltered by surrounding hills and ranges on either side. The observed temperature range over the period 2005 to 2010 was lower than in Wainuiomata and Upper Hutt. During light-wind, clear sky winter situations, cold air drainage into the valley would occur leading to the formation of low-level temperature inversions.

Upper Hutt airshed

The climate of the Upper Hutt airshed is also described as 'valley' in nature. The mean wind speed measured at the Upper Hutt air quality monitoring station over 2005 to 2010 was 2.3 m/s, implying a much lower average wind speed than observed in the Wellington, Kapiti or Porirua airsheds, and also a lower average wind speed than recorded in the Lower Hutt and Wainuiomata airsheds. This is consistent with the Upper Hutt Valley's topography, being the head on an island valley sheltered by surrounding hills and ranges either side. The observed temperature range over the period 2005 to 2010 was more than that observed in Lower Hutt, similar to that observed at Wainuiomata, but less than that observed in the Wairarapa airshed. During light-wind, clear sky winter situations, cold air drainage into the valley would occur leading to the formation of low-level temperature inversions. Over the period 2005 to 2010 there was a fairly similar distribution of hourly temperatures to that observed in Masterton and Wainuiomata.

Wairarapa airshed

The climate of the Wairarapa airshed is another airshed that can be described as 'valley' in nature – this inland plain is bounded by the Rimutaka Range to the west, the Aorangi Range to the southeast and the coastal hills of the Wairarapa Coast to the east. The Masterton mean wind speed over 2005-2010 was 2.1 m/s, meaning this airshed is the least windy of all eight airsheds on average – although Masterton's eastern location would imply very gusty conditions are likely during strong northwest or westerly flows. The observed temperature range over the period 2005-2010 at Masterton and Martinborough was the greatest of all eight airsheds. During light-wind, clear-sky winter situations, cold air drainage/ponding into the valley is known to occur, leading to the formation of low-level temperature inversions.

Appendix 7: Data analysis and presentation methods

Reporting units (Section 2.6 Air quality assessment criteria)

All pollutants at SoE monitoring sites are monitored continuously with instruments that are connected by digital interface to data loggers. Ambient air is sampled at 10 to 20 second intervals (depending on the number of instruments at a site) and these measurements are averaged and reported as 10-minute averages at New Zealand Standard Time (NZST). These 10-minute values are then aggregated to hourly averages where there is at least 75% data capture (ie, at least five 10-minute means must be present for a 1-hour average to be considered valid and included in the data set). The hourly averages apply to the preceding hour (eg, a 1-hour average at 17:00 refers to data collected between 16:00 and 16:59).

Carbon monoxide is measured in ppm and is converted to mg/m^3 by multiplying by 1.25 (0^oC). For comparison with the NES-AQ, 8-hour moving means are calculated on the hour for the preceding 8-hour period using 1-hour averages. At least 6 hours (ie, 75% or greater data capture) must be present for an 8-hour mean to be considered valid and included in the data set. Carbon monoxide values are rounded to one significant figure for reporting purposes in accordance with MfE (2009) recommendations.

Nitrogen dioxide is measured in ppb and is converted to $\mu g/m^3$ by multiplying by 2.05 (0^oC) NES-AQ. Nitrogen dioxide 1-hour averages are rounded to one significant figure for reporting purposes in accordance with MfE (2009) recommendations.

PM_{10} is measured as $\mu g/m^3$ which is the same unit as the NES-AQ limit. 24-hour averages are calculated from 1-hour averages between midnight to midnight (00:00 to 23:59) and require at least 18 hours of data for each 24-hour period to be included in the data set. PM_{10} values are rounded up to the nearest whole number for reporting purposes in accordance with MfE (2009) recommendations. An exceedence of the NES-AQ is therefore 51 $\mu g/m^3$ or higher.

Box plots (Section 4.1 Key indicator pollutants)

The box plots in this report were produced using R Statistical Software version 2.13.0 (R Development Core Team. 2011) with details of the construction of box plots presented in Figure A7.1.

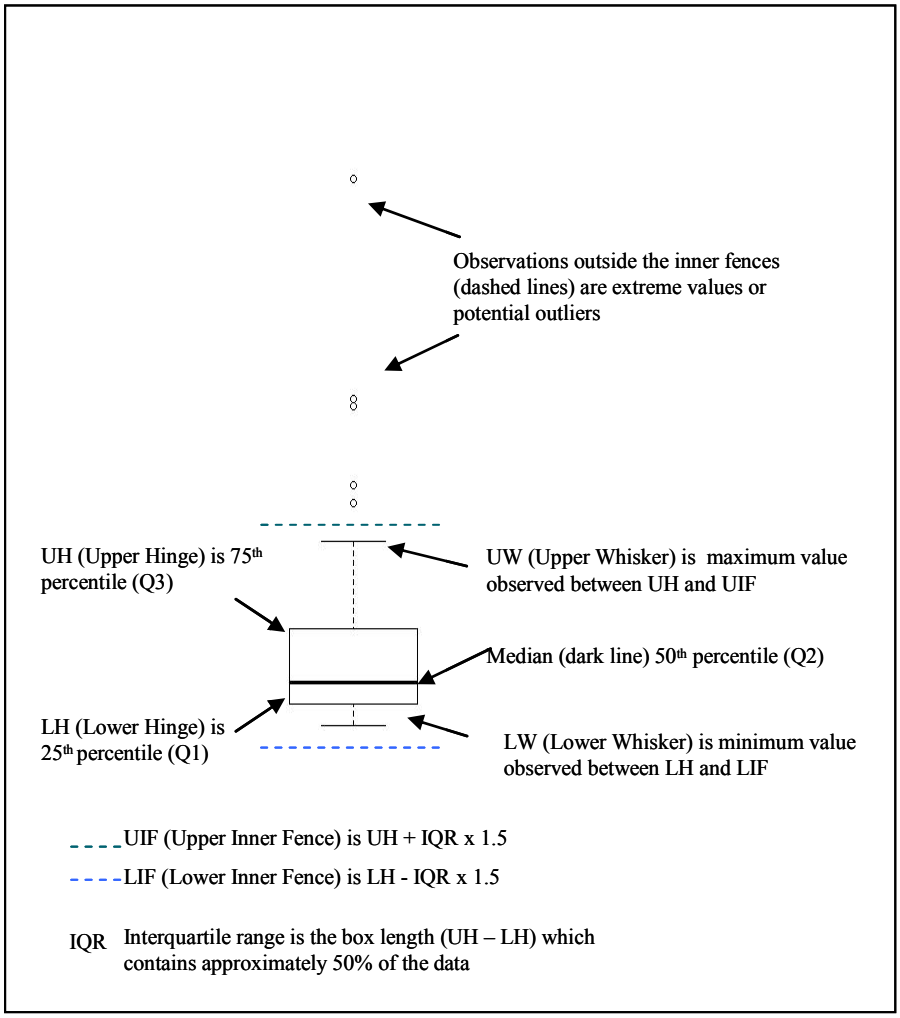


Figure A7.1: Interpretation of Tukey box plot as implemented in R

Correlation coefficients (Section 4.2 Hazardous air pollutants)

In this report unless otherwise specified, Pearson's correlation coefficients are used and denoted *r*. 95% confidence intervals for the true correlation coefficient are provided (where available) instead of the *p*-value where the correlation coefficient is significantly different from zero.

Temporal variation (Section 6.1)

Time variation plots were produced in R statistical software (R Development Core Team. 2011) using the 'openair' package (Carslaw & Ropkins 2011). Four plots: day of the week variation, mean hour of day variation and a combined hour of day – day of week plot and a monthly plot were produced using hourly averages with a least 75% data capture. The 95% confidence interval in the mean is shown by the width of a shaded band around the line or point estimate.

Long-term trends (Section 6.2)

Theil-Sen approach

Theil-Sen is a non-parametric linear regression approach undertaken using R statistical software (R Development Core Team. 2011) with the 'openair' package (Carslaw & Ropkins 2011). Hourly data were averaged into monthly data and the monthly means

de-seasonalised using the R `stl` function based on seasonal trend decomposition using LOESS (Cleveland et al. 1990). The estimated regression slope for the de-seasonalised mean pollutant concentration (y) and time (x) is the median of all the slopes calculated for each x, y pair. The 95% confidence interval in the slope and the associated *p*-value are estimated through bootstrap re-sampling. The slope estimates are also expressed as a percentage change per year. The percentage change uses the concentration at the beginning and end months to express the mean slope (trend) as follows:

$$T\ [\%Year\text{-}1] = 100*(C_{End} / C_{Start} - 1) / N_{Years}$$

T = Trend
C_{Start} = mean concentration at start date
C_{End} = mean concentration at end date
N_{Years} = number of years (or fractions of) the time series spans

Smoothed trends approach

Long-term smoothed time trends as shown in Figures 6.10, 6.14 and 6.17 were produced using the default settings in the R Openair package (Carslaw & Ropkins 2011) which fit a smooth line to a plot of monthly concentrations based on hourly averages. The smooth line is determined using Generalized Additive Modelling using the R `mgcv` package. Before fitting the smooth line, the monthly data are de-seasonalised using the R `stl` function

Pollution roses (Section 6.2) and wind roses (Appendix 5)

The wind roses in Appendix 5 were created using R statistical software (R Development Core Team. 2011) using the 'openair' package (Carslaw & Ropkins 2011). The wind roses show the proportion of time (represented as a percentage on the grey circles) that the wind is from a particular angle (30^o increments) and wind speed range (shown on the righthand scale in metres per second). The wedge points towards the direction the wind is blowing from.

Pollution roses are a variant on wind roses in which wind speed is replaced by a specified pollutant concentration. The pollution roses show which wind directions dominate overall mean pollutant concentrations.

PM_{10} methods inter-comparison (Sections 6.2.2 and 6.2.3)

From time to time PM_{10} instruments are co-located in order to assess their equivalency. MfE (2009) recommends that TEOMs are co-located with a standard gravimetric measurement instrument (high volume sampler) to determine whether measurements made by TEOMs need to be adjusted for gravimetric equivalency using a site-specific adjustment factor. The results of inter-comparisons at Masterton (Wairarapa College) and at Wainuiomata are shown in Figure A7.2.

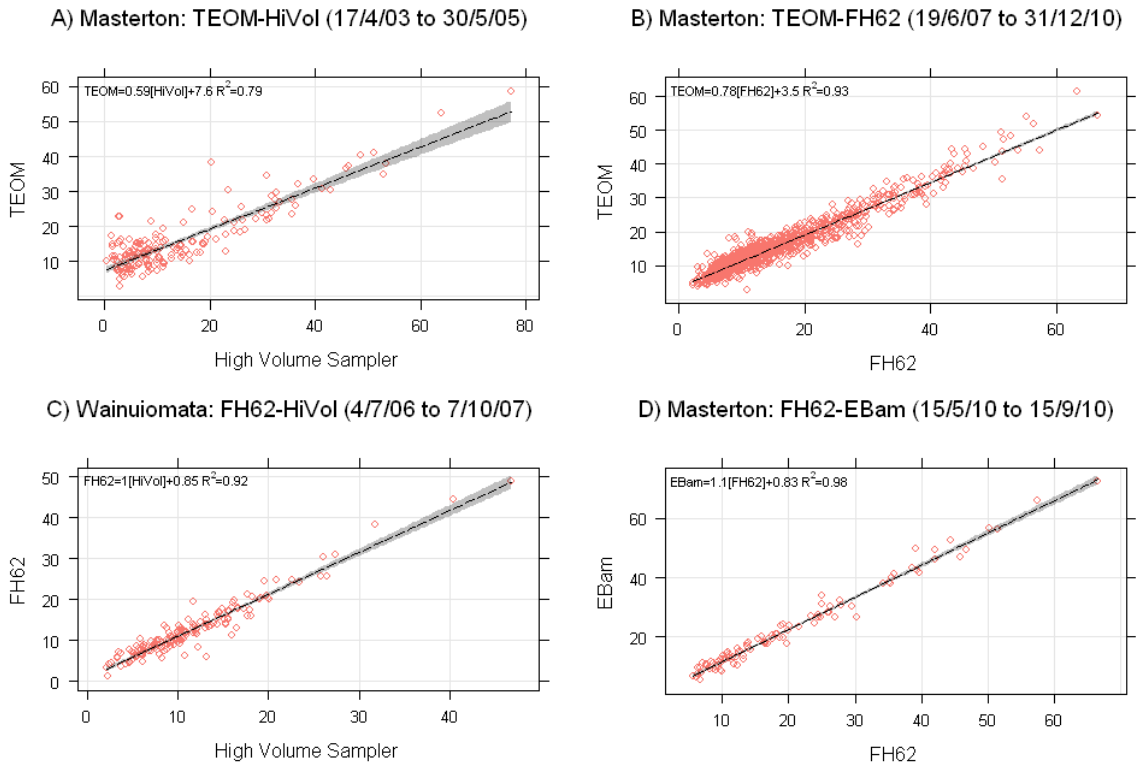


Figure A7.2: Linear relationship between co-located instruments for 24-hour average PM_{10} measurements

At Masterton, the TEOM instrument (set to report positive values only) tended to underestimate compared to the high volume sampler (Figure A7.2(A)) whereas the FH62 measured higher than the TEOM (Figure A7.2(B)). The EBam overestimated relative to the FH62 (Figure A7.2(D)). At Wainuiomata, the FH62 tended to measure slightly higher than the high volume sampler (Figure A7.2(C)).

Further analysis was done using the Wainuiomata co-location data to determine a suitable adjustment factor to enable trend analysis to be carried out using the long-term monitoring record. The best linear model for this relationship was found using a reduced major axis using high volume measurements uncorrected for standard temperature and pressure HiVol = 0.915[FH62]-0.568.

Summary statistics (Appendix 8)

All summary statistics were calculated in R from hourly averages (eg, the annual mean is the arithmetic mean of hourly means during a calendar year). From time to time negative 10-minute averages are produced by monitoring instruments and these were retained in the data set as they are within the expected error margin of the monitoring method. However, following aggregation any negative hourly averages (NO_2) and negative 8-hour means (CO) were substituted with zero values before summary statistics were calculated.

The reported percentiles for each pollutant were interpolated from the data and therefore do not necessarily represent actual values. Percentiles were calculated in R statistical software (R Development Core Team. 2011) where the i^{th} ranking observation is the (i-1)/(n-1) quantile and intermediate quantiles are obtained by linear interpolation.

Valid data (%) means the percentage of reporting units in a year that contained at least 75% valid data. For example, a valid data rate of 83% for nitrogen dioxide means that out of a possible 8,760 hours in a year there were 7,270 hours that contained at least 75% of useable data.

Appendix 8: Air quality summary statistics by monitoring site

Table A8.1: Wellington central

	2004	2005	2006	2007	2008	2009	2010
PM_{10} (µg/m³) 24-hour mean	FH62	FH62	FH62	FH62	FH62	FH62	FH62
Mean	17	16	15	14	14	13	13
Maximum	49	30	37	27	60	31	32
Median	17	15	14	13	14	12	12
Standard deviation	4.98	4.27	4.89	4.34	5.02	4.14	4.15
Interquartile range	6	6	6	5	6	5	6
25th percentile	14	13	12	11	11	10	10
75th percentile	20	18	17	16	16	15	15
95th percentile	24	23	22	22	23	20	21
99th percentile	31	28	30	26	27	24	24
Valid data (%)	76.7	98.9	99.5	99.5	98.9	100.0	97.5
Carbon monoxide (mg/m³) 8-hour moving mean							
Mean	0.9	0.7	0.7	0.5	0.6	0.7	0.6
Maximum	4.5	3.3	3.7	3.6	3.1	2.9	3.2
Median	0.8	0.6	0.5	0.3	0.5	0.5	0.5
Standard deviation	0.72	0.60	0.57	0.54	0.50	0.46	0.43
Interquartile range	0.9	0.8	0.8	0.7	0.6	0.6	0.5
25th percentile	0.4	0.3	0.2	0.0	0.3	0.3	0.3
75th percentile	1.3	1.1	1.0	0.7	0.9	0.9	0.8
95th percentile	2.4	1.9	1.7	1.6	1.6	1.6	1.5
99th percentile	3.3	2.6	2.5	2.4	2.3	2.2	2.1
Valid data (%)	79.0	95.6	98.9	97.1	99.7	93.3	97.4
Nitrogen dioxide (µg/m³) 1-hour mean							
Mean		35.7	32.7	33.6	35.7	27.5	25.8
Maximum		138.4	141.9	102.7	100.7	100.1	105.4
Median		32.6	28.7	31.5	33.2	25.1	23.2
Standard deviation		22.24	21.04	16.34	17.43	16.5	16.99
Interquartile range		31.5	29.6	22.8	24.7	25.0	24.0
25th percentile		18.6	16.6	21.6	22.6	14.5	12.5
75th percentile		50.1	46.2	44.4	47.3	39.5	36.5
95th percentile		75.9	71.7	62.8	67.6	57.2	57.3
99th percentile		95.6	88.7	76.3	78.7	68.8	72.0
Valid data (%)		75.0	98.6	94.2	96.6	96.9	97.6

Table A8.2: Masterton

	2003	2004	2005	2006	2007	2008	2009	2010
PM_{10} (µg/m³) 24-hour mean	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM	FH62	FH62
Mean	16	15	16	15	14	15	14	13
Maximum	62	54	62	53	43	59	55	67
Median	14	13	14	13	13	12	11	10
Standard deviation	8	7	8	8	7	9	8	10
Interquartile range	7	7	7	6	7	7	8	8
25th percentile	11	10	11	11	10	10	8	7
75th percentile	19	17	18	17	17	17	16	15
95th percentile	34	28	33	31	29	33	30	35
99th percentile	43	43	43	48	39	47	41	51
Valid data (%)	98.4	99.7	100.0	98.9	98.4	100	100	100
Carbon monoxide (mg/m³) 8-hour moving mean								
Mean	0.22	0.15	0.15	0.29	0.18	0.27	0.29	0.25
Maximum	4.04	3.55	3.37	4.26	2.54	3.7	2.66	3.19
Median	0.02	0.02	0.01	0.11	0.02	0.12	0.15	0.13
Standard deviation	0.45	0.34	0.36	0.48	0.34	0.42	0.37	0.33
Interquartile range	0.14	0.08	0.09	0.3	0.2	0.22	0.24	0.17
25th percentile	0.01	0.01	0	0.01	0	0.05	0.09	0.08
75th percentile	0.15	0.09	0.09	0.31	0.2	0.26	0.33	0.25
95th percentile	1.24	0.89	0.89	1.28	0.94	1.21	1.15	0.94
99th percentile	2.1	1.67	1.82	2.42	1.6	2	1.84	1.73
Valid data (%)	90.5	98.8	98.4	97.0	98.4	99.6	96.5	99.1
Nitrogen dioxide (µg/m³) 1-hour mean								
Mean	10.8	9.6	8.5	7.2	7.4	6.6	7.1	5.9
Maximum	67.3	60.5	60.9	57.6	58.2	57.7	55.3	59.7
Median	7.7	7.0	6.0	4.2	4.3	3.7	4.5	3.3
Standard deviation	9.07	7.32	7.75	7.94	8.3	7.77	7.64	6.81
Interquartile range	7.9	6.1	6.6	7.2	7.1	6.0	6.7	5.7
25th percentile	5.1	5.1	3.6	2.1	2.2	2.0	2.1	1.6
75th percentile	13	11.2	10.3	9.3	9.3	8.0	8.8	7.3
95th percentile	31	25.2	25.2	24.5	25.4	23.1	23.5	20.5
99th percentile	46.3	38.8	39.4	37.8	40.5	39.1	38.2	33.1
Valid data (%)	96.3	98.5	89.5	81.9	97.2	96.6	92.1	98.0

Table A8.3: Lower Hutt

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
PM_{10} (µg/m³) 24-hour mean	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM
Mean	13	15	14	15	14	15	14	14	14	14
Maximum	30	41	34	45	39	34	33	31	31	29
Median	13	14	13	14	13	14	13	13	13	13
Standard deviation	5	5	4	5	4	5	4	4	5	4
Interquartile range	6	6	5	6	5	6	5	5	6	6
25th percentile	10	11	11	12	11	11	11	11	11	10
75th percentile	16	18	16	18	16	17	16	16	17	16
95th percentile	22	23	22	24	22	24	22	22	23	22
99th percentile	25	27	28	30	25	28	26	24	29	26
Valid data (%)	73.0	99.0	95.0	99.0	99.0	99.0	98.0	98.0	98.0	98.0
Carbon monoxide (mg/m³) 8-hour moving mean										
Mean		0.09	0.3	0.37	0.34	0.21	0.27	0.22	0.2	0.19
Maximum		2.6	3.11	2.98	2.52	2.17	2.56	1.84	1.92	2.48
Median		0.01	0.24	0.33	0.31	0.14	0.22	0.15	0.14	0.13
Standard deviation		0.23	0.31	0.35	0.3	0.26	0.3	0.26	0.21	0.2
Interquartile range		0.06	0.39	0.43	0.4	0.23	0.3	0.31	0.15	0.11
25th percentile		0	0.05	0.08	0.09	0.03	0.06	0.0	0.09	0.09
75th percentile		0.06	0.45	0.51	0.5	0.27	0.36	0.31	0.24	0.21
95th percentile		0.51	0.85	1.03	0.9	0.7	0.78	0.73	0.63	0.58
99th percentile		1.23	1.41	1.7	1.38	1.33	1.46	1.25	1.06	1.07
Valid data (%)		100.0	100.0	98.3	95.7	80.0	86.7	97.7	99.3	98.6
Nitrogen dioxide (µg/m³) 1-hour mean										
Mean		9.1	12.1	10.4	9.5	10.1	11.1	11.7	11.1	11.3
Maximum		83.3	75.5	81.4	60.8	58.5	69.1	58.5	69.7	63.8
Median		6.0	8.2	7.0	6.2	7.2	7.7	8.4	7.9	8.0
Standard deviation		9.78	11.65	10.1	9.82	9.17	9.92	9.85	9.53	9.92
Interquartile range		9.5	12.3	9.8	10.0	9.5	10.2	10.8	10.9	10.4
25th percentile		2.7	3.9	3.8	2.8	3.8	4.4	4.8	4.2	4.5
75th percentile		12.1	16.2	13.6	12.8	13.3	14.6	15.6	15.1	14.9
95th percentile		30.1	37.3	32	31	30.1	32.4	32.9	31.2	33.3
99th percentile		45.2	52.3	47	43.7	42.0	45.5	44.7	43.0	45.7
Valid data (%)		84.1	96.4	90.7	94.0	97.2	97.0	97.0	97.4	98.2

Table A8.4: Upper Hutt (Trentham)

	2000	2001	2002	2003	2004	2005	2006
PM_{10} (µg/m³) 24-hour mean	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM	TEOM
Mean	14	14	14	15	12	9	9
Maximum	44	50	49	34	49	23	33
Median	12	12	13	14	11	7	8
Standard deviation	6	8	6	5	7	4	6
Interquartile range	7	6	6	6	10	4	5
25th percentile	10	9	11	11	6	6	6
75th percentile	17	16	17	17	16	10	11
95th percentile	26	32	26	26	24	17	23
99th percentile	34	49	34	31	31	22	28
Valid data (%)	94.6	56.2	98.6	99.7	97.0	87.9	99.2
Carbon monoxide (mg/m³) 8-hour moving mean							
Mean	0.67	0.36	0.32	0.29	0.25	0.22	0.16
Maximum	4.81	3.93	4.11	2.64	3.36	3.11	2.39
Median	0.39	0.20	0.17	0.12	0.07	0.10	0.05
Standard deviation	0.67	0.51	0.47	0.42	0.42	0.37	0.32
Interquartile range	0.59	0.40	0.32	0.36	0.23	0.25	0.16
25th percentile	0.26	0.04	0.06	0.01	0.01	0.00	0.00
75th percentile	0.85	0.43	0.38	0.37	0.24	0.25	0.16
95th percentile	2.11	1.41	1.31	1.22	1.22	1.02	0.67
99th percentile	3.16	2.51	2.35	1.87	1.94	1.8	1.78
Valid data (%)	87.4	86.0	98.5	99.0	82.7	97.0	62.6%
Nitrogen dioxide (µg/m³) 1-hour mean							
Mean	9.3	11.3	8.7	8.7	8.8	9.9	8.9
Maximum	46.1	105.3	58.5	60.5	102.7	215.5	49.3
Median	6.4	6.9	5.0	4.8	5.8	5.8	6.9
Standard deviation	9.13	12.20	9.70	9.90	8.56	13.22	7.75
Interquartile range	11.1	12.8	10.6	11.2	9.6	9.2	10.8
25th percentile	2.2	2.7	1.7	1.4	2.7	2.8	2.6
75th percentile	13.4	15.5	12.3	12.6	12.3	12.0	13.4
95th percentile	29.2	37.3	30.3	30.5	26.8	29.8	23.7
99th percentile	38.6	54.4	41.0	41.9	36.4	67.1	34.8
Valid data (%)	98.2	95.5	77.4	59.8	98.9	96.1	90.2

Table A8.5: Upper Hutt (Savage Park)

	2006	2007	2008	2009	2010
PM_{10} (µg/m³) 24-hour mean	FH62	FH62	FH62	FH62	FH62
Mean	12	12	11	11	11
Maximum	38	45	31	25	32
Median	11	11	10	10	10
Standard deviation	6	5	5	5	5
Interquartile range	7	6	6	6	6
25th percentile	8	8	8	7	7
75th percentile	15	14	14	14	13
95th percentile	23	21	21	20	21
99th percentile	30	30	27	23	27
Valid data (%)	98.4	98.9	98.6	95.9	99.5
Carbon monoxide (mg/m³) 8-hour moving mean					
Mean	0.23	0.21	0.28	0.27	0.26
Maximum	2.84	2.72	1.92	2.18	2.43
Median	0.10	0.11	0.17	0.15	0.16
Standard deviation	0.36	0.30	0.32	0.30	0.30
Interquartile range	0.24	0.19	0.27	0.20	0.19
25th percentile	0.02	0.05	0.08	0.10	0.10
75th percentile	0.26	0.24	0.35	0.29	0.29
95th percentile	0.99	0.84	1.01	0.94	0.91
99th percentile	1.77	1.45	1.49	1.46	1.52
Valid data (%)	97.7	99.1	98.0	99.7	98.4
Nitrogen dioxide (µg/m³) 1-hour mean					
Mean	8.9	8.7	9.3	8.2	7.2
Maximum	58.3	49.9	53.5	52.0	51.0
Median	5.9	5.6	6.1	5.5	4.3
Standard deviation	8.81	8.30	8.35	7.87	8.03
Interquartile range	9.9	8.6	9.2	8.5	8.0
25th percentile	2.5	3.0	3.4	2.6	1.7
75th percentile	12.4	11.5	12.6	11.2	9.7
95th percentile	28.2	27.3	27.8	25.2	25.0
99th percentile	39.7	37.3	37.2	36.5	35.8
Valid data (%)	86.7	97.0	96.8	97.5	97.9

Table A8.6: Tawa

	2007	2008	2009	2010
PM_{10} (µg/m³) 24-hour mean	TEOM	TEOM	FH62	FH62
Mean	18	16	13	12
Maximum	54	32	30	30
Median	17	15	12	11
Standard deviation	7	5	5	5
Interquartile range	8	7	7	7
25th percentile	14	12	9	8
75th percentile	22	19	17	15
95th percentile	31	25	23	22
99th percentile	37	28	28	26
Valid data (%)	64.7	100.0	99.4	95.9
Carbon monoxide (mg/m³) 8-hour moving mean				
Mean	0.15	0.16	0.23	0.21
Maximum	4.33	2.18	2.81	2.36
Median	0.02	0.04	0.11	0.11
Standard deviation	0.34	0.31	0.34	0.29
Interquartile range	0.12	0.17	0.16	0.12
25th percentile	0.00	0.00	0.06	0.06
75th percentile	0.12	0.17	0.23	0.19
95th percentile	0.79	0.88	0.98	0.85
99th percentile	1.82	1.47	1.73	1.52
Valid data (%)	98.6	99.9	99.6	99.4
Nitrogen dioxide (µg/m³) 1-hour mean				
Mean	14.4	9.9	9.7	8.1
Maximum	52.0	52.5	48.5	47.3
Median	11.9	7.0	7.1	5.1
Standard deviation	9.58	8.15	7.81	8.26
Interquartile range	14.5	9.0	8.9	8.8
25th percentile	6.5	4.2	4.2	2.4
75th percentile	21.0	13.2	13.1	11.2
95th percentile	32.7	27.6	26.6	26.3
99th percentile	40.2	36.9	34.9	36.6
Valid data (%)	95.2	97.5	97.1	96.9

Table A8.7: Karori

	2007	2008	2009
PM_{10} (µg/m³) 24-hour mean	FH62	FH62	FH62
Mean	12	12	11
Maximum	29	28	30
Median	11	11	10
Standard deviation	5	5	5
Interquartile range	6	6	5
25th percentile	9	9	8
75th percentile	15	14	13
95th percentile	22	20	20
99th percentile	27	24	24
Valid data (%)	45.5	98.1	99.7
Carbon monoxide (mg/m³) 8-hour moving mean			
Mean	0.07	0.09	0.09
Maximum	1.06	1.59	1.32
Median	0.02	0.01	0.04
Standard deviation	0.14	0.19	0.16
Interquartile range	0.07	0.07	0.06
25th percentile	0.00	0.00	0.01
75th percentile	0.07	0.07	0.07
95th percentile	0.34	0.53	0.43
99th percentile	0.71	0.99	0.78
Valid data (%)	45.7	99.6	99.9
Nitrogen dioxide (µg/m³) 1-hour mean			
Mean	3.1	3.7	3.1
Maximum	35.1	45.7	47.1
Median	1.2	1.7	1.5
Standard deviation	4.99	5.52	4.59
Interquartile range	2.3	3.2	2.7
25th percentile	0.6	0.7	0.6
75th percentile	2.9	3.9	3.3
95th percentile	14.4	16.0	13.1
99th percentile	25.6	26.6	23.0
Valid data (%)	45.2	97.3	98.1

Table A8.8: Wainuiomata

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
PM_{10} (µg/m^3) 24-hour mean	HiVol	HiVol	HiVol	HiVol	HiVol	HiVol	FH62	FH62	FH62	FH62	FH62
Mean	10	13	11	11	11	10	12	12	11	12	11
Maximum	19	57	50	57	47	28	29	51	41	41	62
Median	9	10	9	9	8	9	11	10	10	11	10
Standard deviation	5	12	8	9	10	6	5	6	6	6	7
Interquartile range	5	6	5	6	5	7	7	6	6	7	6
25th percentile	7	7	7	6	6	6	8	8	8	8	7
75th percentile	12	13	11	12	12	13	15	15	14	15	13
95th percentile	19	40	26	31	37	20	22	25	25	24	23
99th percentile	19	56	44	48	45	28	27	32	35	34	32
Valid data (%)	13.2	67.8	70.2	90.9	90.1	94.2	50.7	97.3	99.7	98.6	99.5

Appendix 9: NES-AQ PM_{10} exceedence dates and concentrations

PM_{10} concentrations are listed in brackets in $\mu g/m^3$. The monitoring instrumentation (TEOM or FH62) is also listed.

Airshed	2006	2007	2008	2009	2010
Wairarapa	08/06/2006 (52) 02/07/2006 (52) 29/07/2006 (53) TEOM		13/06/2008 (59) 14/07/2008 (52) 06/08/2008 (51) TEOM	25/06/2009 (55) FH62	22/06/2010 (67) 23/06/2010 (51) 04/07/2010 (57) 26/07/2010 (51) 21/07/2010 (53)* FH62
Wainuiomata		28/06/2007 (51) FH62			02/07/2010 (62) FH62
Wellington central			28/06/2008 (60) FH62		
Ngauranga		24/10/2007 (53) FH62			
Tawa		28/06/2007 (54) TEOM			

* Carterton short-term monitoring site.

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