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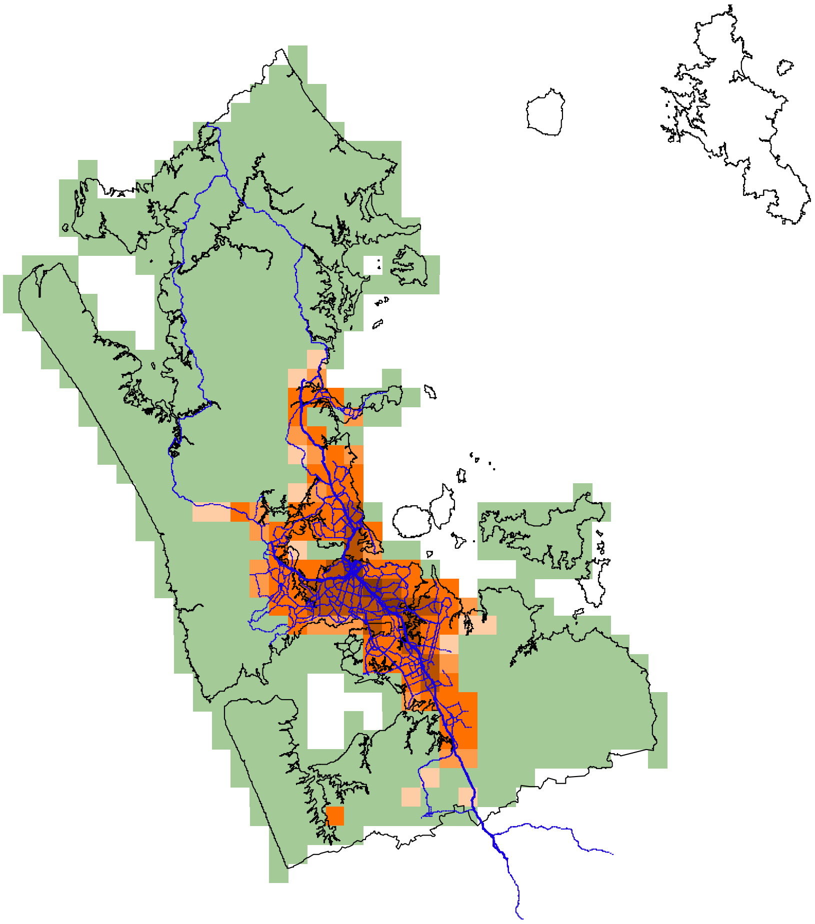
Auckland Air Emissions Inventory: 2004

February 2006 Technical Publication 292



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Auckland Air Emissions Inventory: 2004

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Executive Summary

This inventory estimates the emissions to air in the Auckland region from four major sectors (transport, domestic, industry and biogenic) with emphasis on emissions of four key ambient air pollutants (PM_{10}, NOx, CO, VOCs), assuming a base year of 2004. Emissions are broken down:

- ☐ sectorally (for the four major categories)
- ☐ spatially (for the entire region versus the urban area only), and
- ☐ seasonally (for a typical winter's day versus a typical summer's day).

An Auckland Air Emissions Inventory was first prepared in 1993. An upgrade of the emissions inventory commenced in 1998 undertaken by the Environment Protection Authority of Victoria. This report updates the 1998 inventory to produce air emissions estimates for 1993, 2004, 2011 and 2021.

Emissions are estimated for fine particles (PM_{10}), oxides of nitrogen (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), sulphur dioxide (SO_2) and carbon dioxide (CO_2). This report focuses primarily on PM_{10} because ambient concentrations measured in Auckland have exceeded the National Environmental Standard (NES) of 50μg m^{-3} at both peak traffic and urban monitoring sites. PM_{10} is considered a surrogate for health impacts from all air pollutants.

Breakdown of Emissions by Sector

The annual estimates of the total emissions across the entire Auckland region in 2004 of the six contaminants are approximately:

☐	5,900 t/yr PM_{10}	(47% transport, 39% domestic, 14% industry)
☐	35,000 t/yr NOx	(83% transport, 13% industry, 3% biogenic)
☐	171,200 t/yr CO	(85% transport, 13% domestic, 2% industry)
☐	64,200 t/yr VOC	(52% transport, 26% industry, 13% biogenic, 9% domestic)
☐	4,200 t/yr SO_2	(65% transport, 32% industry, 3% domestic)
☐	8,930,000 t/yr CO_2	(48% transport, 46% industry, 6% domestic)

Looking at the total annual emissions of all ambient air pollutants (excluding CO_2), the single largest individual sources in the sectors are:

- ☐ motor vehicles* at 70% and domestic heating⁺ at 10%

* motor vehicles are responsible for approximately 91% of the total transport sector emissions

⁺ domestic heating is responsible for approximately 85% of the total domestic sector emissions

Breakdown of Emissions by Location

The density of emissions varies across the region with the urban area, which represents less than 25% of the total regional landmass, contributing the majority of the total regional emissions for each pollutant as follows:

☐ 83% regional PM_{10}	(4,900 t/yr)
☐ 82% regional NOx	(28,600 t/yr)
☐ 91% regional CO	(155,600 t/yr)
☐ 82% regional VOC	(52,600 t/yr)
☐ 50% regional SO_2	(2,100 t/yr)
☐ 78% regional CO_2	(6,920,000 t/yr)

Breakdown of Emissions by Season

Seasonal variations in emissions are significant, both in terms of the amount as well as the relative contributions of sources, particularly for PM_{10} as follows:

- ☐ PM_{10} emissions on a typical winter weekday (29t/day) are nearly three times those of a typical summer weekday (10t/day).
- ☐ Domestic sources (principally domestic heating) account for 64% of PM_{10} on a typical winter weekday (June-August) but fall to 2% of PM_{10} on a summer weekday (December-February).
- ☐ Transport sources (principally motor vehicles) account for 27% of PM_{10} on a typical winter weekday (June-August) but rise to 74% of PM_{10} on a summer weekday (December-February).

Trends

Emissions have been estimated from 1993 out to 2021, based on the current inventory methodology, to indicate trends. In the period 1993 to 2004:

- ☐ CO emissions have fallen and are predicted to continue to fall in future, mainly due to increasing numbers of vehicles in the fleet with improved emissions control equipment.
- ☐ CO_2 emissions have risen and are predicted to continue to rise in future, mainly due to increased fuel consumption resulting from increased numbers of vehicles in the region and increased vehicle kilometres travelled.
- ☐ NOx emissions have risen slightly, mainly due to increased numbers of diesel vehicles in the fleet, but are predicted to fall slightly in future as diesel emissions control technology improves.

- SO_2 emissions have risen, mainly due to increased diesel fuel consumption resulting from increased numbers of diesel vehicles, but are predicted to fall in future as fuel sulphur levels continue to decrease.
- PM_{10} and VOC emissions have fallen slightly, mainly due to a shift away from coal and wood for both domestic heating and industrial use, and are predicted to fall in future with fuel trends and technology improvements.

Further Work

There are other potentially significant sources of PM_{10} that are not estimated by the current inventory, including secondary particulates, sea salt, and wind blown or re-suspended dust. Estimation of these sources is uncertain. However, preliminary investigations suggest that these sources could account for up to 20% of the total ambient PM_{10} on days of high air pollution (calm days, with 24-hour concentrations higher than 40μg m^{-3}). Further work is necessary to validate assumptions in the existing inventory and confirm key trends.

Key Conclusions

Ambient air concentrations of both PM_{10} and NOx in the Auckland region currently exceed accepted health guidelines and standards.

From the inventory, the largest single contributors to annual emissions of PM_{10} are motor vehicles (41%) and domestic heating (38%). For NOx emissions, the principal source is motor vehicles (71%). Consequently, emissions management strategies that target these sources will have the greatest impact on improving air quality in Auckland.

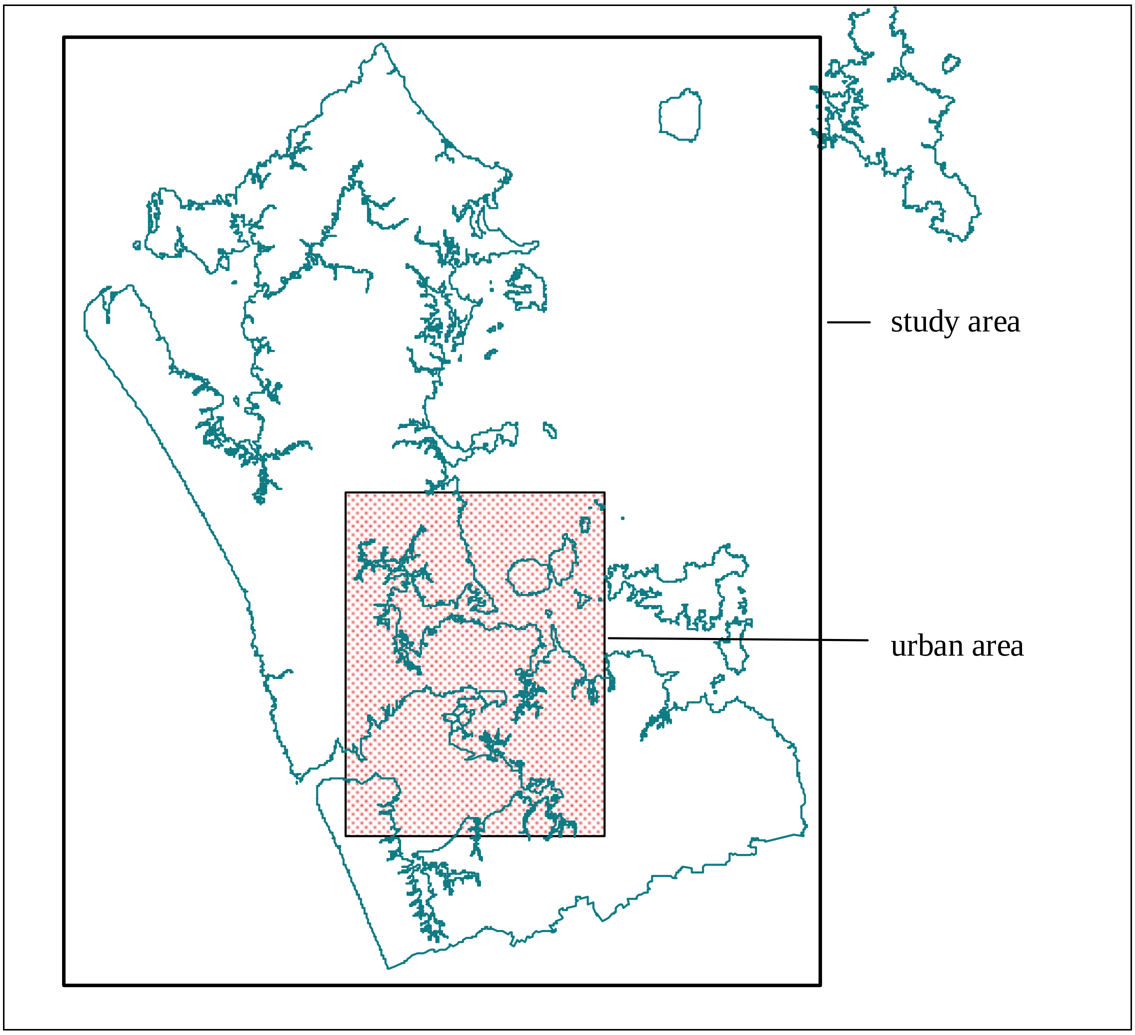
1 Introduction

This report summarises the results of the 2004 Auckland Air Emissions Inventory.

The inventory estimates emissions on a 3km x 3km grid basis for the entire study area shown in Figure 1.1, and on a more detailed 1km x 1km grid for the urban area highlighted. Emissions are estimated on an annual, daily (seasonal) and hourly basis. Seasonal emissions are estimated for typical Summer (December-February), Autumn (March-May), Winter (June-August) and Spring (September-November) days. Unless stated otherwise, all reported results are for the entire inventory area (3km x 3km grid).

Figure 1.1

Auckland air emissions inventory study area showing the boundaries of the urban area chosen for finer (1km x 1km) resolution of emissions



1.1 Background

An Auckland Air Emissions Inventory was first prepared in 1993 (ARC, 1997). An upgrade commenced in 1998, which produced emissions estimates for 1993, 1998, 2011 and 2021 (EPAV, 2005). The upgrade is referred to in this report as "the 1998 inventory". The 1998 inventory focused on improving estimates of the most significant pollution sources identified in the 1993 inventory. Detailed analysis undertaken for the 1993 inventory was not repeated for the 1998 inventory where the source contributions were small and/or the emissions would not have changed significantly. In such cases, emissions were scaled up on the basis of some relevant measure such as population.

This update (referred to as "the 2004 inventory") is based on the same methodology as the 1998 inventory, however a number of assumptions have changed as detailed in Table 1.1. 1998 and 2011 emissions estimates (calculated based on these new assumptions) were interpolated to provide 2004 estimates.

Emissions estimates are presented for 1993, 2004, 2011 and 2021 based on the methodology of the 1998 inventory and the new assumptions stated in Table 1.1.

Table 1.1
Comparison of assumptions made for the 2004 and 1998 emissions inventories

2004 Inventory	**1998 Inventory**	**Reason for Change**	**Effect of Change[1] (versus 1998)**
Total vehicle kilometres travelled (VKT) are based on Ministry of Transport estimates from the Vehicle Fleet Model (VFM)	VKT are based on outputs from the Auckland Regional Transport model (ART)	Regional fuel consumption estimated from the VFM derived VKT is closer to the actual fuel consumption recorded	Vehicle emissions increased by 30%
Diesel vehicle exhaust PM_{10} emissions factors have been adjusted (+15%) to attempt to account for the impact of gross emitters	All emissions factors are from the Ministry of Transport NZTER database (MoT, 2000)	Diesel vehicle exhaust is a significant contributor to PM_{10}, and it is likely that gross emitters are not accounted for by the NZTER emissions factors used in this inventory	Vehicle PM_{10} emissions increased by 10%
Re-suspended road dust is assumed to be zero. It is recommended that the road dust contribution to PM_{10} should be estimated based on monitoring and modelling.	Re-suspended road dust is calculated according to USEPA methodology	In a recent review, DEFRA concluded that re-suspended road dust an important source, however it is difficult to quantify with any accuracy, and can result in double-counting	Total PM_{10} emissions reduced. (Re-suspended road dust accounted for approximately 60% of all PM_{10} in the 1998 inventory)

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[1] Approximate change in mass emission based on 2004 emissions calculated with 1998 assumptions vs. 2004 emissions calculated with new assumptions. The change is reported as a % change in the current, actual 2004 emissions if they had been calculated with the 1998 methodology

Table 1.1 continued

2004 Inventory	**1998 Inventory**	**Reason for Change**	**Effect of Change[1] (versus 1998)**
It is assumed that 15% of TSP from vehicle tyre wear is PM_{10}	It is assumed that 40% of TSP from tyre wear is PM_{10}	A recent review (DEFRA, 2004) estimates that between 1-15% of tyre wear material is PM_{10}	Vehicle PM_{10} emissions decrease by 20%
Emissions from petrol storage at Wiri are estimated based on current and projected regional fuel consumption	Emissions from petrol storage are based on 1993 fuel consumption and located at Freemans Bay tank farm	Updated and corrected	VOC emissions from Wiri increased by 35% (approx 0.4% increase in total VOC)
The seasonal profile for domestic wood and coal is based on winter as June to August	The seasonal profile for domestic wood and coal is based on winter as July to September	The seasonal profile for domestic wood and coal usage was incorrect in the 1998 inventory	No effect on annual emissions. Winter emissions increased by about 20% and Autumn emissions decreased. (Summer and Spring unchanged)

1.2 Pollutants

This inventory estimates air emissions of particles (TSP, PM_{10} and $PM_{2.5}$), carbon monoxide, oxides of nitrogen, volatile organic compounds, sulphur dioxide, and carbon dioxide. The significance of these pollutants in the Auckland region is briefly described in Table 1.2. Further information on ambient air pollutants can be found in the State of the Auckland Region Report 2004 (ARC, 2004) and on the Ministry for the Environment website (www.mfe.govt.nz).

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[1] Approximate change in mass emission based on 2004 emissions calculated with 1998 assumptions vs. 2004 emissions calculated with new assumptions. The change is reported as a % change in the current, actual 2004 emissions if they had been calculated with the 1998 methodology.

Table 1.2

Key air pollutants in Auckland

Pollutant	Significance for Auckland
Particles (TSP, PM_{10}, $PM_{2.5}$)	PM_{10} are tiny particles suspended in the air that are invisible to the human eye. PM_{10} are fine particles less than 10 microns in diameter, which are about 1/5th the size of a human hair. These particles can affect health, especially in asthmatics and people with heart and lung disease. Particles can carry carcinogenic (i.e. cancer producing) material into the lungs. Fine particles can increase hospital admissions and emergency department visits, school absences, lost work days and restricted activity days. Studies show a correlation between levels of fine particles and the number of people who die each year (the mortality rate). Particles larger than 10 microns in diameter are unlikely to result in health impacts but may cause nuisance effects. The finer ($PM_{2.5}$) size fraction is a subset of the PM_{10} size fraction and is particularly significant because of the ability of these particles to penetrate the lungs. Concentrations of PM_{10} measured in Auckland have exceeded both the NES of $50\mu g\ m^{-3}$ (24-hour average) and the ambient air quality guideline of $20\mu g\ m^{-3}$ (annual average) at urban monitoring sites. As PM_{10} is a “no safe threshold” contaminant, adverse health effects are likely to occur at concentrations lower than the standard and guideline levels.
CO	Carbon monoxide (CO) interferes with the blood's ability to absorb and circulate oxygen. This makes it relatively toxic. High levels of CO can affect people with heart conditions such as angina and can impair co-ordination and attention. Maximum CO concentrations are generally less than the NES at urban monitoring sites in the region. Levels at roadside sites have dropped significantly over recent years, but still may occasionally exceed ambient air quality guidelines.
VOCs	Volatile organic compounds (VOCs) are of concern because they contribute to the formation of ozone in the atmosphere. VOCs also include air toxics (such as formaldehyde and benzene), which can cause skin, throat and eye irritation, headaches, nerve and organ damage, and increased risk of cancers and premature death. Limited monitoring of benzene in the Auckland region has demonstrated that levels may exceed the ambient air quality guideline at roadside sites, but are within the guideline in other areas.
Ozone	Although ozone (O_3) is a vital component of the upper atmosphere, at ground level it is an unwanted toxic gas. Ozone causes runny eyes, nose and throat irritations and breathing difficulties, especially for asthmatics. It also affects the functioning of the heart. Like PM_{10}, no safe threshold has been identified below which effects of ozone do not occur. Ozone is referred to as a secondary pollutant because it is not emitted directly from typical pollution sources in the region. Ozone forms when NOx emissions react in the presence of sunlight and VOCs. Maximum ozone concentrations are close to the NES at ambient air quality monitoring sites within the region.
SO_2	Sulphur dioxide (SO_2) irritates the lungs, causing coughing, wheezing and breathlessness. Asthmatics may suffer from reduced airflow to the lungs when levels of SO_2 exceed guideline values. Concentrations of SO_2 measured in the region are typically less than 33% of the NES.

Table 1.2 continued

Pollutant	Significance for Auckland
NOx and NO_2	Nitrogen dioxide (NO_2) can irritate the lungs, increase the susceptibility and severity of asthma and lower resistance to infections such as the flu. It can also affect vegetation and can significantly degrade visibility because it contributes to the formation of brown hazes and smog. NO_2 concentrations are generally less than 66% of the NES at urban monitoring sites in the region but regularly exceed the standard at roadside monitoring sites. NO_2 concentrations in Auckland have generally increased over the past decade. NO_2 together with other oxides of nitrogen (NOx) are also important contributors to the formation of ozone.
CO_2	Estimates of emissions of CO_2 are included in the inventory to provide information for greenhouse gas emission inventories.

National Environmental Standards for air quality (NES) were introduced by the Ministry for the Environment in October 2004 (MfE, 2005a). These include ambient air quality standards for carbon monoxide (CO), fine particles (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3). In areas where the ambient air quality standards are not met, the NES requires Regional Councils to take action. In particular, for any airsheds that are likely to exceed the PM_{10} standard, and are gazetted, each Council is required to develop an action plan in the form of a “straight line path” (SLiP) or a “curved line path” (CLiP) to achieve compliance with the standard by September 2013 (MfE, 2005b).

Emissions estimates for all pollutants are presented in this report. However, the focus is on PM_{10}, because of the SLiP requirement. This report reviews and updates the Auckland Regional Emissions Inventory to provide a starting point for development of emissions projections to meet the SLiP. The information available to predict trends to 2013 is reviewed, and critical data gaps are identified.

1.3 Sources of Emissions

The inventory estimates emissions from significant sources, which are grouped into transport, industrial and commercial, domestic and biogenic categories as follows:

Transport

- Motor vehicles
- Off-road vehicles
- Trains
- Aircraft
- Ships and boats
- Bitumen (from road building)

Industrial and Commercial

- Industry
- Commercial and unallocated fuel combustion (e.g. boilers)
- Service stations
- Surface coatings (e.g. paints)
- Aerosols
- Dry cleaning
- Gas leakage

Domestic

- Domestic fuel combustion (including wood, coal, and gas for heating)
- Open burning of rubbish
- Lawn mowers

Biogenic (Natural)

- NOx and VOC emissions from vegetation and soils

This report summarises the emissions estimates, and briefly describes the methodology for estimating the emissions from all sources. However, the focus is primarily on motor vehicles and domestic heating because the 1993 and 1998 emissions inventories identified these as the main sources of PM_{10} in the region.

1.4 Results for Ambient Air Pollutants

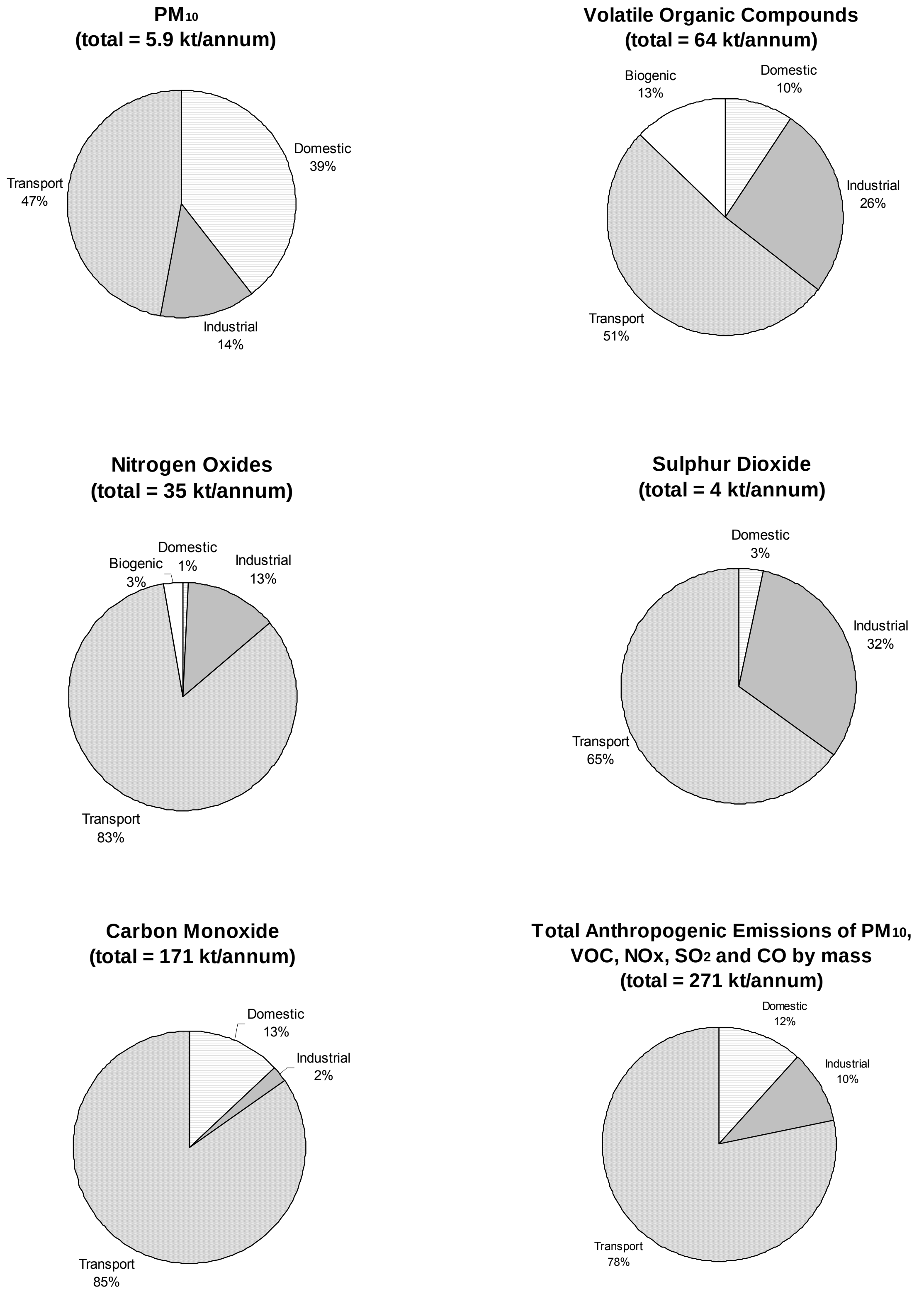
Figure 1.2 illustrates the contributions of various sources to total annual emissions of each ambient pollutant over the entire study area in 2004. A full summary of results is included in Appendix 1.

The emissions inventory estimates that transport emissions account for 78% of the total mass of all ambient pollutants (excluding CO_2) resulting from anthropogenic (man-made) sources.

For annual anthropogenic emissions of PM_{10}, the inventory estimates that 47% is from transport, 39% from domestic sources and 14% from industrial sources across the entire Auckland region.

Figure 1.2

Annual ambient air pollutant emissions for the Auckland region in 2004



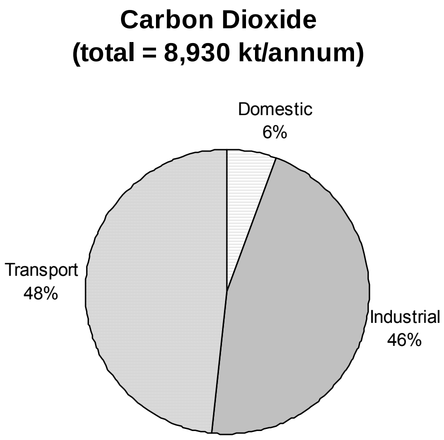
It should be noted that there are additional (and potentially significant) sources of PM_{10} emissions that have not been estimated by the inventory. These include:

- ☐ natural sources, such as sea salt, bush fires and wind blown dust;
- ☐ road dust generated by abrasion of the road surface and re-suspension;
- ☐ particles formed in the atmosphere when primary pollutants react producing secondary particulate

The likely contribution of these sources to ambient PM_{10} is discussed in the Unaccounted Emissions section of this report.

1.5 Results for CO_2

Figure 1.3
Annual CO_2 emissions for the Auckland region in 2004

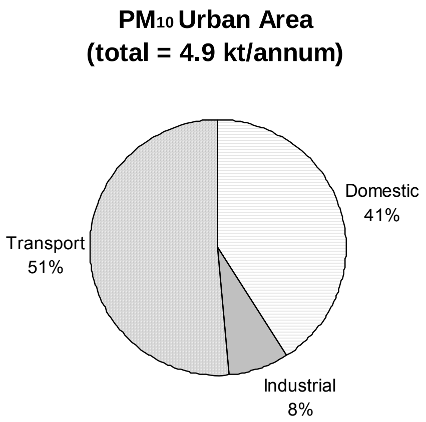


The emissions inventory estimates that 48% of CO_2 emissions are from transport, 46% from industry and 6% from domestic sources (see Figure 1.3). Other important greenhouse gases include methane and nitrous oxide, however these are not estimated in this inventory.

Greenhouse gas emissions are monitored and managed at a national level by the Ministry for the Environment.

1.6 Results for PM_{10} in the Urban Area

Figure 1.4
Annual PM_{10} emissions for the Auckland urban area only in 2004



Transport is estimated to contribute 51% of PM_{10} on an annual basis in the urban area (see Figure 1.4).

This proportion is higher than that estimated for transport across the entire emissions inventory study area (47%), because of large industrial sources located outside the urban area.

1.7 Results by Season

Annual emissions estimates indicate the likely contribution of sources to ambient air pollution over an entire year. The emissions inventory includes seasonal and hourly emissions data so that emissions can be predicted over shorter averaging periods, and compared with ambient air quality guidelines.

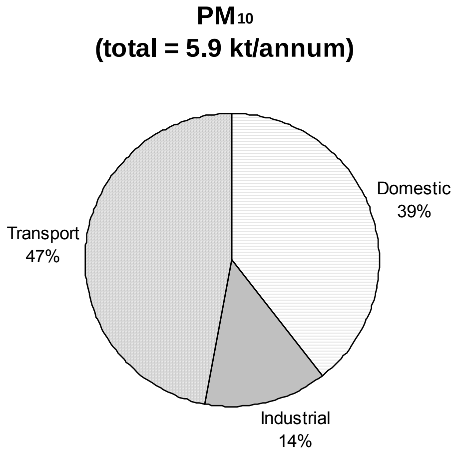
There is significant seasonal variation in PM_{10} emissions because of domestic heating in winter. This is discussed further in Section 2.

2 Domestic Emissions

2.1 Domestic Sources

Figure 2.1

Annual PM_{10} emissions for the Auckland region in 2004

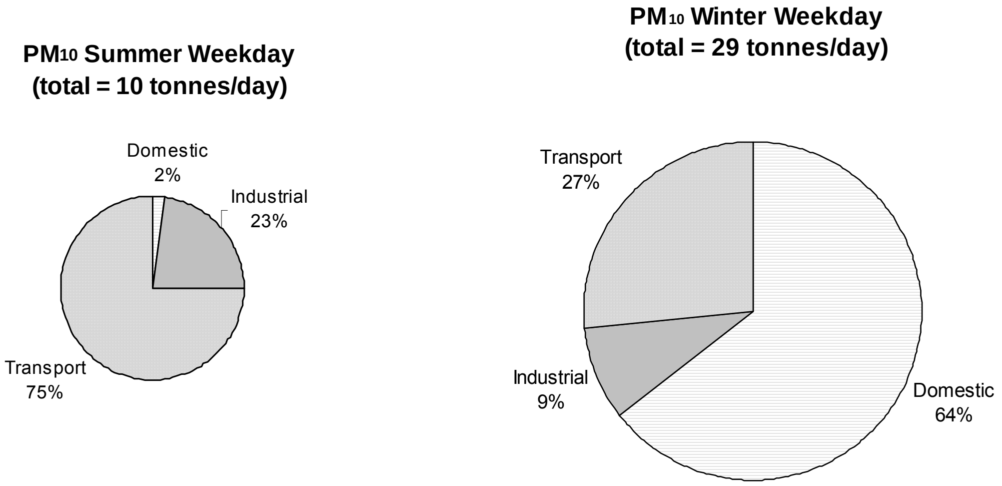


Domestic sources include fuel burning (primarily for heating), lawnmowing and open burning of rubbish. These sources combined are estimated to contribute 39% of PM_{10} on an annual basis (see Figure 2.1).

However, the relative contribution of domestic emissions to other sources varies significantly with season peaking at 64% in winter (June-August) but falling to only 2% in summer (December-February) as shown in Figure 2.2.

Figure 2.2

Seasonal variation in typical daily PM_{10} emissions in 2004. Note: winter weekday emissions are nearly three times those of summer



The majority of domestic PM_{10} comes from home heating with combustion of solid fuels – wood and coal – accounting for 95% of all annual emissions (see Figure 2.3). Across the whole of Auckland, around 28% of households use wood burners (109,000 households), 11% use open fires (42,000 households) and 3% use multifuel burners (11,000 households) for domestic heating[2]. Figure 2.4 illustrates the contribution of various heating methods to total domestic heating PM_{10} emissions.

Figure 2.3

Relative contribution of various sources to annual domestic PM_{10} emissions in 2004

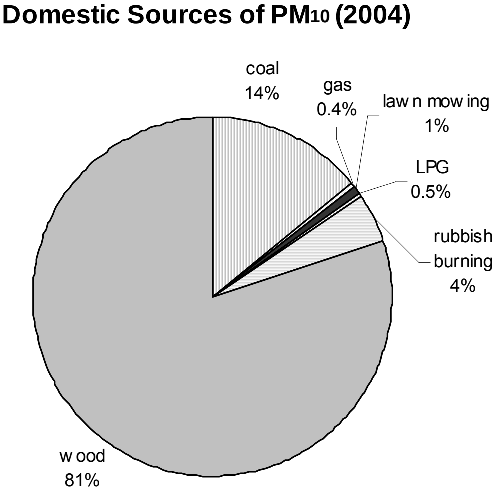


Figure 2.4

Relative contribution of various methods to annual home heating PM_{10} emissions in 2004

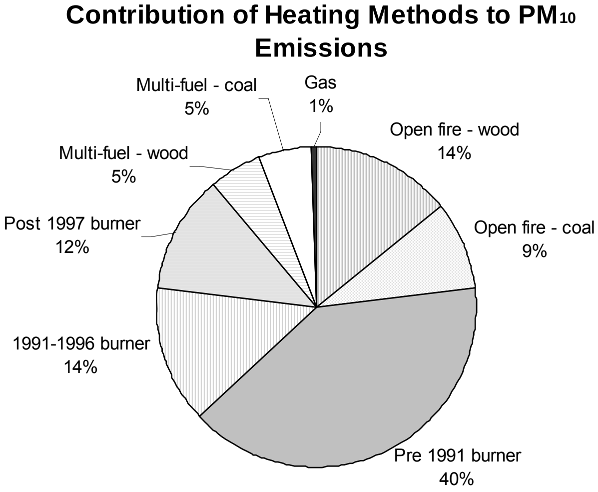
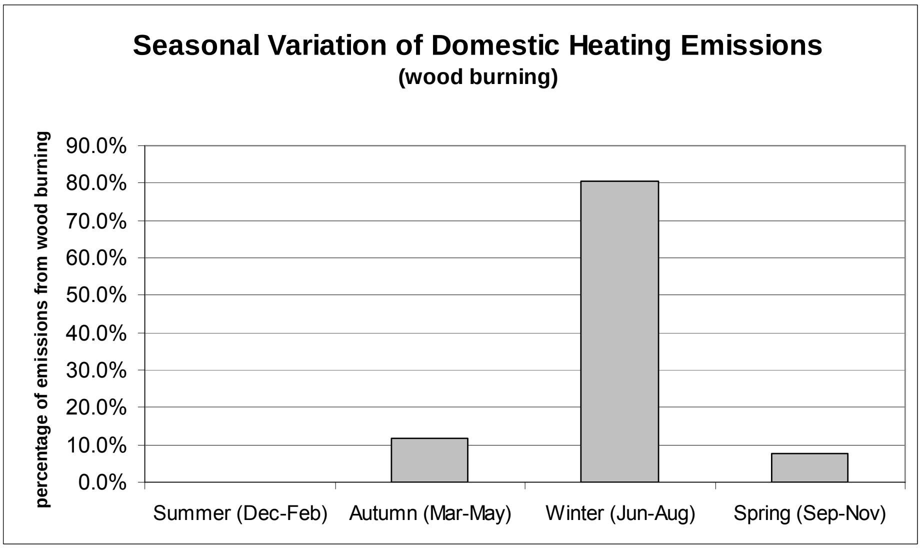


Figure 2.5 shows the seasonal variation in domestic heating emissions for wood burning, with greater than 80% of PM_{10} emissions occurring in the winter months of June through August.

Figure 2.5

Seasonal variation in domestic wood burning emissions



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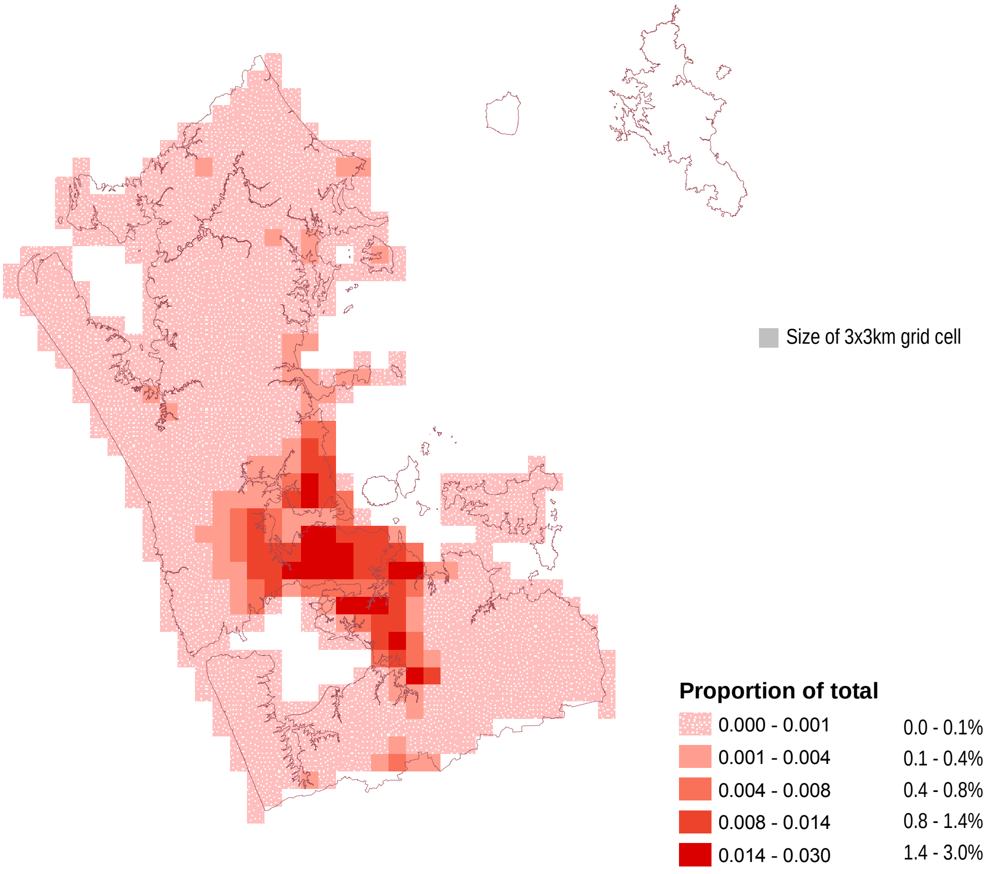
[2] Households using multiple methods are included more than once.

There is also significant geographical variation in domestic heating emissions (see Figure 2.6). The spatial distribution shown is based on the results of the domestic heating survey as well as census information.

Figure 2.6

Spatial distribution of domestic heating emissions.

* Note: The "proportion" refers to contribution of each 3km grid cell to the regional total.



2.2 Domestic Heating Emissions Estimation

Domestic heating emissions are calculated from emissions factors (g/kg of fuel burnt), and estimates of the amount of fuel burnt per household. The emissions factors used are shown in Table 2.1.

Table 2.1

Domestic heating emissions factors and average daily fuel use per appliance

Appliance Type	PM_{10}	CO	NOx	SO_2	VOC	CO_2	Average Daily Fuel Use (kg)
Open fire - wood (g/kg)	15	120	1.6	0.2	30	1,600	9
Open fire - coal (g/kg)	33	60	1.5	9.0	15	2,600	11
Pre 1991 woodburner (g/kg)	13	130	0.5	0.2	39	1,600	19
91-96 woodburner (g/kg)	7	70	0.5	0.2	21	1,800	17
Post 1997 woodburner (g/kg)	6	60	0.5	0.2	15	1,800	19
Multifuel – wood (g/kg)	13	130	0.5	0.2	39	1,600	11
Multifuel – coal[3] (g/kg)	28	120	1.2	9.0	15	2,600	8
Oil (g/kg)	0.9	0.6	2.2	3.8	0.25	3,200	8
LPG (g/kg)	0.6	0.18	1.3	0.00	0.2	2,500	1
Gas ($t/10^6m^3$ or g/m^3)	0.18	0.64	1.5	0.01	0.12	1,920	n/a[4]

Emissions factors for gas combustion are based on USEPA methodology as outlined in the 1993 inventory (ARC, 1997). Emissions factors for open fires are the same as those used in the 1996 Christchurch inventory (CRC, 1997). All other emissions factors are as recommended by Wilton (2002). These are based on emissions factors adopted in other North Island inventories, and are similar to those developed for the 1996 Christchurch inventory.

Updated emissions factors, based on testing undertaken in New Zealand, have been recommended by Wilton (2002) for open fires, and oil and gas burners. Emissions testing to determine real world emissions factors for other types of burners in New Zealand is currently being undertaken. When this information becomes available, all domestic heating emissions factors will be reviewed and updated.

Estimated wood, coal and LPG usage rates are based on the results of a domestic heating emissions inventory completed in 2001 (Wilton, 2002). Data on heating methods and fuels were obtained via a telephone survey conducted during winter 2002. The total sample size was 1,764 giving a statistical sampling uncertainty of 7.5%. The survey determined the fuel usage as well as the number of households using different heating methods at different times of year. To estimate fuel consumption, households were asked to estimate their daily fuel use in buckets of coal, or number of split logs put on the fire. These data were converted to weights based on the assumption that a split log weighs 1.4kg and a bucket of coal weighs 9kg. Gas consumption figures are based on sales data.

Estimated daily fuel consumption per appliance is included in Table 2.1. Annual fuel consumption figures are shown in Table 2.2. Projected fuel consumption rates are based on the results of a domestic heating emissions projection study (Wilton, 2004).

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[3] includes potbelly, incinerator, coal range and any enclosed burner that is used to burn coal.

[4] gas consumption was calculated based on measured sales figures. A daily consumption of 1kg/appliance was estimated based on survey results, however this figure was not used in the inventory.

Table 2.2
Annual domestic fuel consumption

Fuel	1998	2004	2011	2021
Wood (kt/year)	197	183	167	151
Coal (kt/year)	13.4	10.7	7.5	4.5
Natural Gas (10^6 m^3/year)	35.6	48.8	60.0	75.9
LPG (kt/year)	14.6	18.6	23.4	29.6

2.2.1 Baseline emission projections for domestic heating

The baseline projections for domestic heating emissions in 2011 and 2021 predict a modest reduction in domestic heating emissions overall, but solely due to a predicted decline in the use of wood and coal burners (as reported in Wilton, 2004). No allowance has been made for improvements in average domestic heating emissions factors over time. The promulgation of a National Environmental Standard for woodburners will result in improved average emissions factors over time. However the impact of the standard is highly dependent on the woodburner replacement rate, for which very little regional data exist, and so it is not incorporated into the baseline calculations. Further discussion is covered in Section 5 (Trends).

2.3 Emissions Estimation for Other Domestic Sources

Table 2.3 summarises the factors used to estimate emissions from other domestic sources.

Table 2.3
Emissions factors for open burning and lawn mowing

Pollutant	Open Burning (kg/t)	2-stroke Lawnmower (g/hr)	4-stroke Lawnmower (g/hr)
CO	42	731	489
CO_2	1,700	738	890
NO_x	3	1.45	4.85
SO_2	0.5	0.062	0.036
TSP	8	7.85	0.518
VOC	15	294	39.7

Emissions from open burning of rubbish were estimated in 1993 based on the results of a domestic survey. Rubbish burning was estimated as 15.4kg/year per person. Emissions factors for rubbish burning were based on USEPA emissions factors for open burning of municipal refuse, except for CO_2 which was based on the domestic wood combustion emissions factor. Most open burning has been banned in the Auckland Region through regulations in the Proposed Regional Plan: Air Land and Water, as well as the National Environmental Standard for air (MfE, 2005a). To reflect the likely effect of these regulations, it has been assumed that emissions from open burning reduce 66%

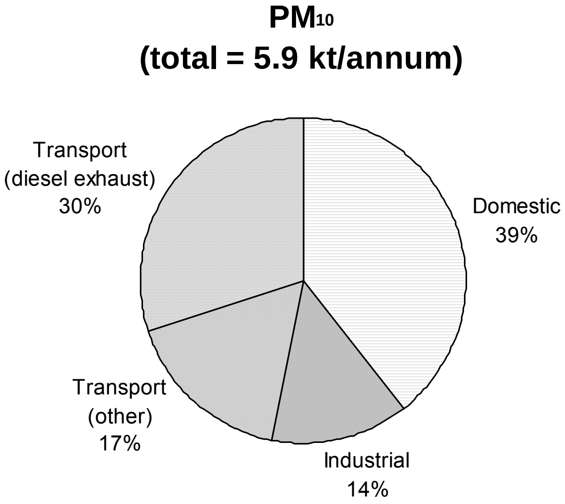
by 2011. This is based on the observed effectiveness of burning restrictions in Australian cities.

Lawn mowing emissions are also estimated based on the results of the 1993 domestic questionnaire. Per capita lawnmowing time was estimated as 4.23 hours per year per person. Emissions factors for lawnmowers are based on Australian data. Based on information from retailers, it was estimated that 40% of lawnmowers were 2-stroke in 1998, reducing to 10% by 2021. Lawnmower emissions have been scaled up according to population growth.

3 Transport Emissions

3.1 Transport Sources

Figure 3.1
Annual PM_{10} emissions across the Auckland region in 2004



Transport sources include motor vehicles, off-road vehicles, trains, aircraft, ships and boats, and emissions from bitumen used in road construction.

Figure 3.1 shows that transport sources are estimated to contribute 47% of PM_{10} emissions on an annual basis, with 88% of these emissions coming from motor vehicles, as shown by Figure 3.2.

Figure 3.2
Relative contribution of various sources to annual transport PM_{10} emissions

Figure 3.3
Sources of annual motor vehicle PM_{10} emissions

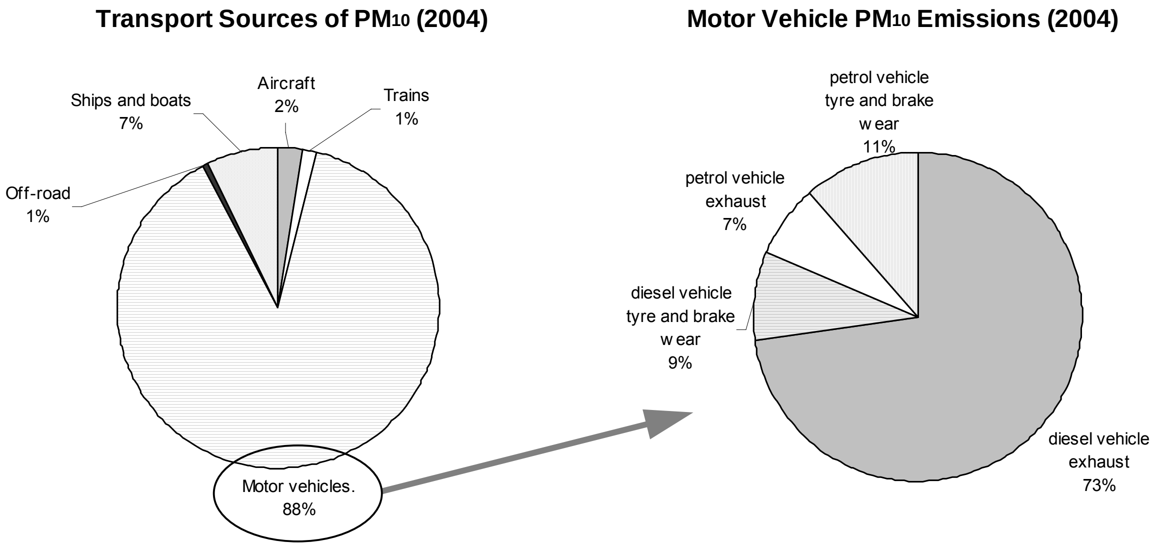
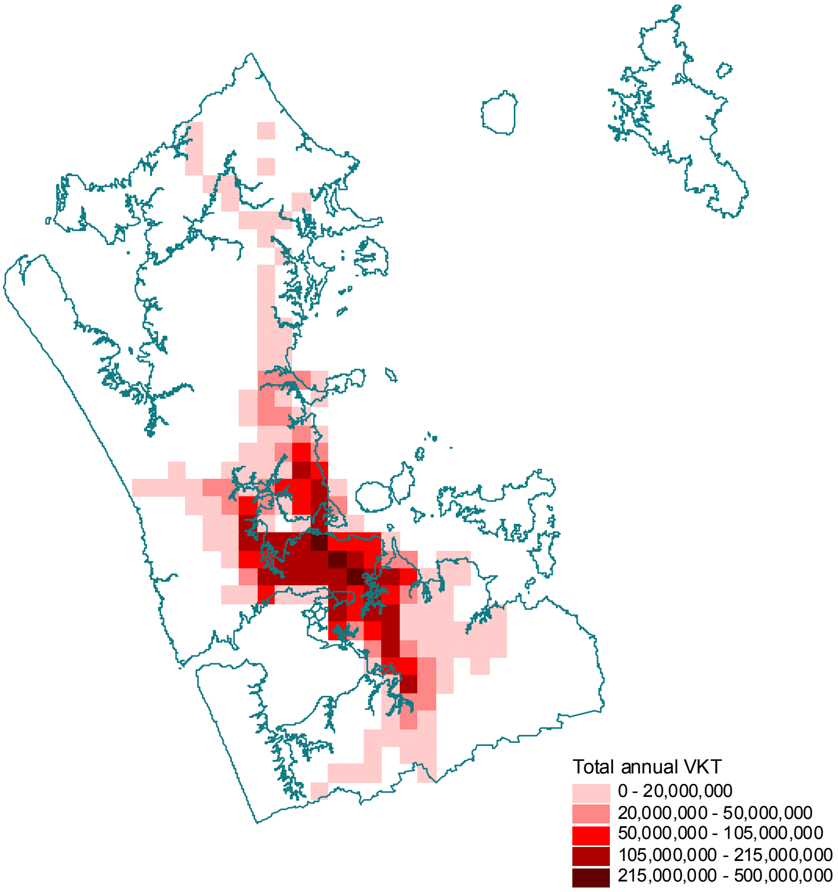


Figure 3.3 breaks down the motor vehicle emissions even further. The largest fraction (73% of motor vehicle PM_{10} emissions) comes from diesel exhaust, which contributes 30% of the total annual PM_{10} emissions across the region by itself.

More than 90% of all motor vehicle travel in the Auckland Region takes place within the urban area as highlighted by the spatial distribution of VKT shown in Figure 3.4. In addition, motor vehicles are responsible for a higher proportion of transport emissions in the urban area (93% versus 88% across the region) due to the majority of shipping emissions occurring at sea.

Figure 3.4
Spatial allocation of VKT across the Auckland region in 2004



3.2 Motor Vehicle Emissions Estimation

Motor vehicle emissions are calculated from emissions factors (g of pollutant per km driven) developed for the regional vehicle fleet and estimates of vehicle travel (km per year).

3.2.1 Emissions factors

Single vehicle emissions factors in g/km for CO, NOx, TSP and VOC were obtained from the New Zealand Traffic Emissions Rates database (MoT, 2000). The database provides emissions factors for specified vehicle types[5], under different driving conditions and road types for a range of pollutants. The database provides a fleet average emission factor for any given year and any given combination of vehicle type/driving condition/road type. There are approximately 3000 combinations of pollutant/vehicle type/driving condition/road type for each year.

Diesel vehicle emissions factors

Diesel vehicle PM_{10} emissions have been adjusted to attempt to account for the impact of "gross emitters". Other pollutants and vehicle types were not considered at this stage, because of the current focus on PM_{10}. The impact of gross emitters has been estimated for diesel buses (EFRU, 2004). This study estimates a reduction in PM_{10} emissions of 12% in 2003, and 17% in 2011, for an inspection and maintenance programme that identifies and repairs the worst 20% of buses. The NZTER emissions factors do not account for the proportion of poorly tuned and marginally tuned vehicles in the fleet (SKM, 2003). In the absence of better information, diesel exhaust PM_{10} emissions factors have been increased by 15% for the 2004 inventory update.

CO_2 emissions factors

Emission factors for CO_2 were calculated from fuel consumption data. Fuel consumption data for most vehicle, road and driving types were based on data derived from the Ministry of Transport's Vehicle Fleet Model (VFM). Fuel consumption factors in later years were adjusted to account for the fleet becoming more efficient. Australian data (NGGI, 1998) were used to fill any gaps to produce fuel consumption figures for all years in L/km (MJ/km for CNG) by vehicle, fuel, road and congestion type.

SO_2 emissions factors

SO_2 emission factors were also based on the fuel consumption data. Fuel based emissions factors were derived based on New Zealand fuel sulphur contents using the methodology described in the EMEP/CONNAIR Emissions Inventory Guidebook (Campbell and Moncrieff, 2004) and are summarised in Table 3.1.

Table 3.1

SO_2 emissions factors for various motor vehicle fuels

Fuel	1993	1998	2011	2021
Petrol (kg SO_2/t fuel)[6]	0.7	0.3	0.08	0.01
Diesel (kg SO_2/t fuel)[6]	5.0	4.0	0.02	0.01
LPG (kg SO_2/t fuel)	0.026	0.026	0.026	0.026
CNG (mg SO_2/m^3 gas)	40	40	40	40

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[5] Emission factors for petrol HCVs and buses were not included in the MoT database. For these vehicles, emission factors for petrol LCVs were multiplied by the ratios of the corresponding Australian emission factors.

[6] Note SO_2 factors have been based upon a petrol sulphur content of 40ppm ('Euro 4'-like specification less manufacturing margin allowance) and 7ppm for diesel (possible 2011 diesel specification less manufacturing margin allowance) for 2011 and a maximum 5ppm sulphur specification for both petrol and diesel for 2021.

Calculated fleet weighted exhaust emissions factors

For the Auckland emissions inventory, vehicle kilometres travelled were estimated for each year, road type and congestion level as described in the following sections. The fleet weighted emissions factors calculated for 2004 are shown in Table 3.2.

Table 3.2

Fleet weighted exhaust emissions factors for various road types and driving conditions in 2004

Road Type	Congestion Level	2004 Fleet-Weighted Exhaust Emission Factors (g/km)					
		CO	CO_2	NOx	SO_2	PM_{10}[7]	VOC
Central Urban	Free	7.8	326	2.12	0.097	0.158	1.16
	Interrupted	12.8	492	2.74	0.132	0.213	1.61
	Congested	24.3	684	3.32	0.176	0.314	4.03
	Cold Start	43.7	693	2.83	0.169	0.332	4.96
Motorway	Free	3.82	261	2.54	0.080	0.182	0.53
	Interrupted	5.1	239	1.77	0.072	0.119	0.57
	Congested	7.9	287	1.82	0.083	0.148	0.99
	Cold Start	22.8	330	1.85	0.091	0.173	3.92
Suburban	Free	6.6	310	2.03	0.087	0.138	1.06
	Interrupted	10.2	355	2.20	0.097	0.163	1.24
	Congested	14.8	428	2.32	0.119	0.230	1.95
	Cold Start	33.3	498	2.47	0.124	0.261	5.40
Fleet Weighted Average		11.8	344	2.17	0.095	0.171	1.64

Non-exhaust emissions factors

Evaporative VOC, brake and tyre wear emissions factors were derived for New Zealand conditions using the VFM (see Tables 3.3 to 3.5). It was assumed that 40% of brake wear TSP is PM_{10} and 15% of tyre wear TSP is PM_{10}.

Table 3.3

Evaporative VOC emissions factors for different petrol vehicle types for various years (irrespective of road type)

Vehicle Type	Congestion Level	Evaporative VOC (g/km)			
		1993	1998	2011	2021
Petrol Car	Free	0.50	0.50	0.13	0.08
	Interrupted	2.80	2.60	0.30	0.10
	Congested	5.00	5.00	0.40	0.15
	Cold Start	0.30	0.20	0.10	0.04
Petrol LCV[8]	Free	0.80	0.80	0.20	0.10
	Interrupted	4.00	4.00	0.40	0.12
	Congested	6.00	6.00	0.50	0.20
	Cold Start	0.50	0.50	0.14	0.04

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[7] exhaust particulate emission factors are reported as TSP in NZTER. The emissions inventory assumes that 100% of TSP is PM_{10}.

[8] In the absence of other data, petrol HCVs and buses were assumed to have the same evaporative VOC emissions as petrol LCVs

Table 3.4

Tyre wear PM_{10} emissions factors for different vehicle types and various congestion levels (irrespective of year)

Vehicle Type	**Tyre Wear PM_{10} (g/km)**			
	Free	**Interrupted**	**Congested**	**Cold Start**
Car	0.009	0.018	0.036	0.018
LCV	0.011	0.023	0.045	0.023
HCV (small)	0.019	0.038	0.075	0.038
HCV (medium)	0.028	0.056	0.113	0.057
HCV (large)	0.126	0.252	0.504	0.254
Bus (medium)	0.027	0.054	0.108	0.054
Bus (large)	0.105	0.210	0.420	0.212
Motorcycle	0.005	0.009	0.018	0.009

Table 3.5

Brake wear PM_{10} emissions factors for different vehicle types and various congestion levels (irrespective of year)

Vehicle Type	**Brake Wear PM_{10} (g/km)**			
	Free	**Interrupted**	**Congested**	**Cold Start**
Car	0.004	0.013	0.017	0.010
LCV	0.006	0.018	0.024	0.014
HCV (small)	0.008	0.026	0.034	0.020
HCV (medium)	0.010	0.030	0.040	0.023
HCV (large)	0.016	0.048	0.064	0.037
Bus (medium)	0.010	0.028	0.038	0.022
Bus (large)	0.014	0.040	0.054	0.031
Motorcycle	0.002	0.004	0.008	0.004

3.2.2 Vehicle type

The fleet profile (vehicle type) is based on Ministry of Transport (MoT) estimates of nationwide vehicle kilometres travelled by each vehicle type generated from their Vehicle Fleet Model (VFM) (see Table 3.6).

VFM estimates current vehicle utilisation rates based on actual registration information, with future utilisation rates based on projected regional growth. Updated figures for vehicle utilisation rates from VFM were provided in 2004.

Table 3.6

Proportion of vehicle kilometres travelled by each vehicle type in Auckland

Vehicle Type	Fuel Type	Proportion of VKT			
		1993	2004	2011	2021
Car	petrol	72.77%	72.22%	71.87%	71.93%
Car	diesel	4.07%	4.71%	5.33%	5.14%
Car	CNG	0.01%	0.01%	0.01%	0.01%
Car	LPG	0.03%	0.03%	0.03%	0.03%
LCV[9]	petrol	8.75%	6.99%	5.37%	4.30%
LCV	diesel	5.31%	7.00%	8.59%	9.67%
LCV	CNG	0.00%	0.01%	0.01%	0.01%
LCV	LPG	0.01%	0.01%	0.01%	0.01%
HCV (small)[10]	petrol	0.28%	0.22%	0.16%	0.11%
HCV (medium)	petrol	0.14%	0.11%	0.08%	0.04%
HCV (large)	petrol	0.11%	0.08%	0.05%	0.03%
HCV (small)	diesel	3.10%	2.78%	2.49%	2.10%
HCV (medium)	diesel	1.04%	1.00%	0.96%	0.89%
HCV (large)	diesel	3.20%	3.51%	3.81%	4.55%
HCV (small)	CNG	0.02%	0.02%	0.02%	0.01%
HCV (medium)	CNG	0.01%	0.01%	0.01%	0.01%
HCV (large)	CNG	0.00%	0.00%	0.00%	0.00%
HCV (small)	LPG	0.02%	0.02%	0.01%	0.01%
HCV (medium)	LPG	0.01%	0.01%	0.01%	0.01%
HCV (large)	LPG	0.01%	0.01%	0.01%	0.01%
Bus (medium)[11]	petrol	0.05%	0.04%	0.03%	0.01%
Bus (large)	petrol	0.01%	0.01%	0.01%	0.01%
Bus (medium)	diesel	0.19%	0.20%	0.20%	0.24%
Bus (large)	diesel	0.46%	0.64%	0.59%	0.52%
Bus (medium)	CNG	0.00%	0.00%	0.00%	0.00%
Bus (large)	CNG	0.00%	0.00%	0.00%	0.00%
Bus (medium)	LPG	0.01%	0.01%	0.01%	0.01%
Bus (large)	LPG	0.00%	0.00%	0.00%	0.00%
Motorcycle	petrol	0.38%	0.35%	0.32%	0.31%
VKT Total (millions of km)		8,840	11,400	13,100	15,800

3.2.3 Vehicle kilometres travelled

Estimates of total vehicle kilometres travelled (VKT) in the region are also based on MoT's VFM (Campbell and Moncrieff, 2004)

Vehicle kilometres travelled (VKT) were estimated in the 1998 emissions inventory based on the Auckland Regional Transport model (ART). The peak flows predicted by the ART model were scaled up to provide daily and annual VKT estimates. The VFM estimates are significantly higher than the ART derived estimates. The VFM estimates are based on vehicle registration information, including odometer readings. The ART model is a strategic traffic demand model, which is calibrated to generate demands from the key drivers of travel, for example land use. The main aims of this model are to allow high level evaluation of policy alternatives and to produce travel demands for input into

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[9] Light commercial vehicle. Includes light bus and small bus categories from the Vehicle Fleet Model.

[10] Heavy commercial vehicle –small:3.5-7.5 t medium: 7.5-12.0 t large:>12.0 t

[11] Bus –medium:<12.0 t large:>12.0 t

more detailed models. The model provides traffic data for three separate 2-hour time periods: AM peak; midday; and PM peak. The emissions inventory requires daily and annual estimates of VKT, which were estimated for the 1998 inventory from the 7-9am peak results. There is a high level of uncertainty in scaling up to an annual estimate from one modelled 'typical' 2 hour peak result. It is considered likely that the VFM results will provide a better estimate of total annual VKT.

To check the likely accuracy of VKT from ART and VFM, the VKT have been used to calculate fuel consumption. The VKT totals derived from ART as well as the MoT's VFM-derived VKT have been extrapolated to estimate 2004 VKT. Regional fuel consumption was then estimated using VFM fuel consumption factors and the vehicle profile described above. The VFM-derived VKT result in a much better estimate of regional fuel consumption (see Table 3.7). Actual fuel consumption is a reliable measure of vehicle activity, therefore it is considered that the VFM-derived VKT are likely to be more realistic.

Table 3.7
Comparison of estimated annual fuel consumption based on ART and VFM derived VKT versus actual fuel consumption in Auckland

Fuel Type (ML/annum)	**Estimated Consumption**		**Actual Consumption (2002)**
	ART (2004)	**VFM (2004)**	
Petrol	816	1079	1050
Diesel	397	525	450

The 2004 emissions inventory uses VFM-derived VKT totals as shown in Table 3.8[12]. The ART model outputs are used to provide the gridded spatial distribution data for VKT. Different spatial distributions are used for each road/congestion/year combination. Traffic counts were used to estimate diurnal variation. Spatial and diurnal data were not updated for the 2004 emissions inventory.

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[12] VFM derived VKT were supplied for 2001, 2002, 2011, and 2021 (Campbell and Moncrieff, 2004). These VKT were back extrapolated to estimate 1993 VKT, and interpolated to estimate 2004 VKT.

Table 3.8

VFM derived annual VKT used in emissions inventory

	VKT (millions of km)				
	Free Flow	**Interrupted**	**Congested**	**Cold Start**	**Total**
1993					
Central Urban	44	206	31	63	344
Motorway	784	1,780	299	289	3,150
Suburban	874	3,050	515	910	5,350
					8,840
2004					
Central Urban	44	272	53	74	443
Motorway	1,000	2,150	398	388	3,940
Suburban	1,020	4,090	735	1,200	7,040
					11,400
2011					
Central Urban	46	320	63	88	517
Motorway	1,130	2,390	460	449	4,430
Suburban	1,090	4,800	901	1,390	8,180
					13,100
2021					
Central Urban	46	396	82	107	631
Motorway	1,260	2,790	567	549	5,170
Suburban	1,170	5,940	1,190	1,700	9,990
					15,800

3.3 Emissions Estimation for Other Transport Sources

Emissions from marine pleasure craft, commercial shipping, rail and off-road vehicles have been estimated.

Estimates of shipping activity were obtained from ports of Auckland, and rail activity from ARC. Marine pleasure craft activity estimates were based on registration data and the results of the 1993 domestic survey. Off-road vehicle usage was estimated on a per capita basis based on methodology recommended for Australian inventories. Aircraft emissions were based on aircraft movements in 1998 and projections supplied by Auckland International Airport Limited.

Emissions factors for rail, off-road vehicles and pleasure craft have been estimated on a per capita basis (see Table 3.9). Emissions from these sources are projected to increase in proportion to population growth.

Table 3.9

Population based emissions factors for pleasure craft, off-road vehicles and rail

Pollutant	Pleasure Craft (kg/yr per person)	Off-road Vehicles (kg/yr per person)	Rail (kg/yr per person)
CO	1.78	4.49	0.153
CO_2	20.4	35.1	24.6
NO_x	0.149	0.640	0.495
SO_2	0.013	0.0231	0.051
TSP	0.0086	0.0127	0.031
VOC	0.49	0.502	0.148

Emissions factors for shipping and aviation were derived from a variety of sources (see Table 3.10). Australian emissions factors are used for for commercial shipping. Emissions from aviation were estimated in 1993 based on USEPA methodologies. An emissions factor per aircraft movement is based on 1993 emissions.

Table 3.10

Emissions factors for shipping and aviation

Pollutant	Shipping Main Engine (kg/hr)	Shipping Auxiliary Engine (kg/hr)	Aviation All Types (kg/aircraft movement)
CO	13.5	1.19	9.68
CO_2	8040	430	1160
NO_x	167	6.66	5.36
SO_2	127	5.66	0.356
TSP	16.8	0.9	0.430
VOC	3.41	0.436	3.48

4 Industrial Emissions

4.1 Industrial Sources

This category includes the most significant industrial emitters in the region, with air emissions calculated for manufacturing processes as well as fuel combustion activities undertaken on site. Companies are listed according to industry type in Appendix 2,.

As well as significant industrial sources, this source category includes unallocated fuel combustion which refers to emissions resulting from small scale but widespread sources (such boilers used for heating schools and greenhouses) and commercial sources of VOC emissions (service stations, aerosol, dry cleaning, gas leakage, and surface coating). The commercial VOC sources account for 76% of the total industrial VOC emissions.

The contribution of industry to total emissions is very dependent on the spatial boundaries considered. For the entire region, the inventory estimates that 14% of annual PM_{10} emissions come from industrial sources (see Figure 4.1). However, this fraction reduces to 8% for annual emissions in the urban area (see Figure 4.2) due to a number of significant industrial sources being located outside the 1km x 1km grid limits.

Figure 4.1

Annual PM_{10} emissions for the Auckland region in 2004

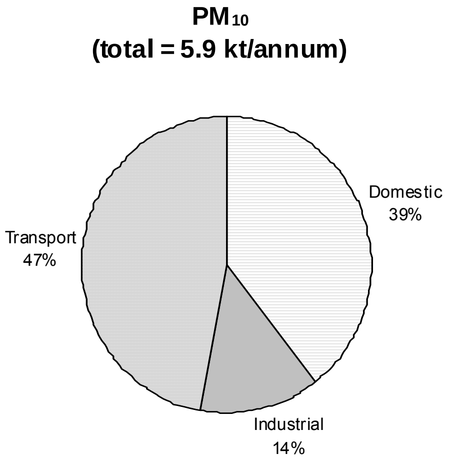
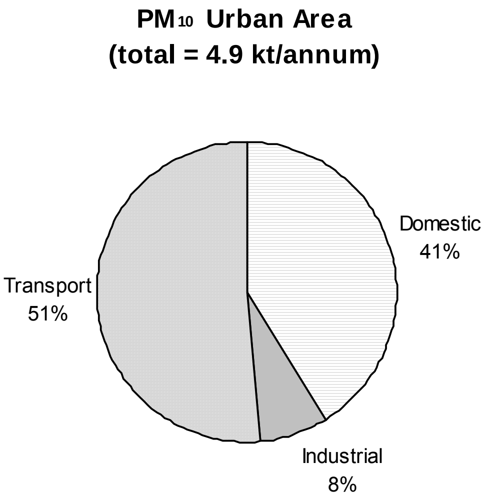


Figure 4.2

Annual PM_{10} emissions for the Auckland urban area only in 2004



Figures 4.3 and 4.4 show the breakdown of industry types for region-wide and urban area only emissions respectively. Facilities involved in metal products and non-metallic products are responsible for the majority of industrial PM_{10} emissions regardless of the area under consideration.

Figure 4.3

Industrial sources of PM_{10}

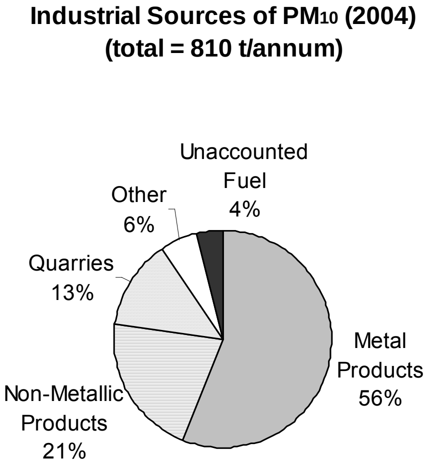
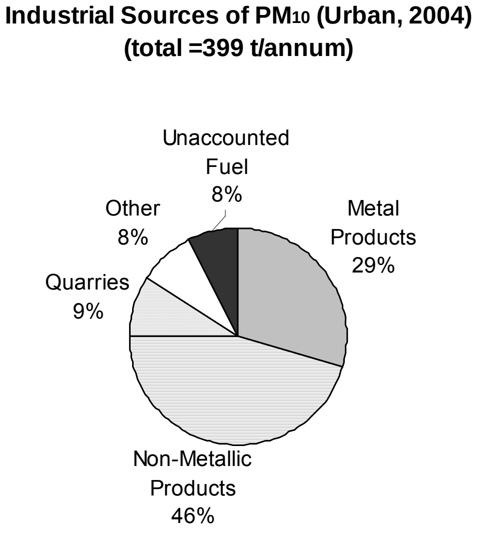


Figure 4.4

Industrial sources of PM_{10} in the urban area



Combustion emissions from industry were estimated to provide information for source apportionment studies. In the urban area it is estimated that 33% of industrial PM_{10} emissions are from combustion sources.

4.2 Industrial Emissions Estimation

Industrial emissions estimates are based on questionnaires completed by industry, as well as ARC resource consent information and USEPA emissions factors. Where stack test data were available, these were used in preference to literature emission rates. Emissions information for some sources has not been updated since 1993, however, most of the significant sources were updated in 2001.

Unaccounted fuel includes emissions from coal combustion by schools and by horticulture (for greenhouse heating). Coal consumption figures were based on estimates provided by all coal suppliers in the region. Consumption was estimated as 6,000 tonnes/annum for horticulture and 1,800 tonnes/annum for schools This category also includes commercial gas combustion. Regional gas consumption figures were based on accurate regional sales information.

For future years it is assumed that industrial emissions do not change, unless the industry predicted a change of emissions in the industrial questionnaire.

5 Trends

The emissions inventory includes emissions projections to 2011 and 2021. Annual emissions estimates for all years are summarised in Appendix 1.3. The predicted trends are illustrated in Figures 5.1 and 5.2. The emissions factors and assumptions adopted for these 'baseline predictions' are discussed briefly in previous sections. Key assumptions for the baseline projections are:

- ☐ Motor vehicle emissions are based on VKT and fleet projections from the Ministry of Transport vehicle fleet model (VFM), and NZTER emissions factors.
- ☐ Domestic heating emissions projections assume that there is no improvement in average emissions factors, but that use of coal and wood declines as open fires and fireplaces are replaced.

These projections need to be updated to reflect a number of changes that have occurred including:

- ☐ Changes to national fuel specifications and vehicle emissions regulations that have occurred since the NZTER emissions factors were published in 2000.
- ☐ Promulgation of a National Environmental Standard for woodburners, which should ensure that average emissions factors from domestic heating improve over time.

Domestic heating and vehicle emissions projections are discussed further in the following sections.

Figure 5.1
Predicted baseline trends for PM_{10}

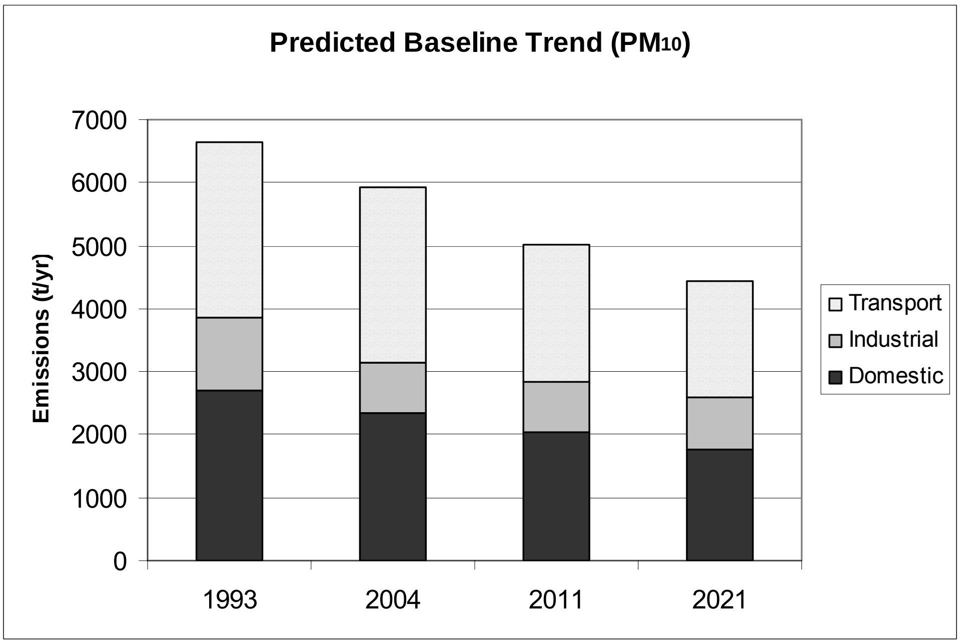
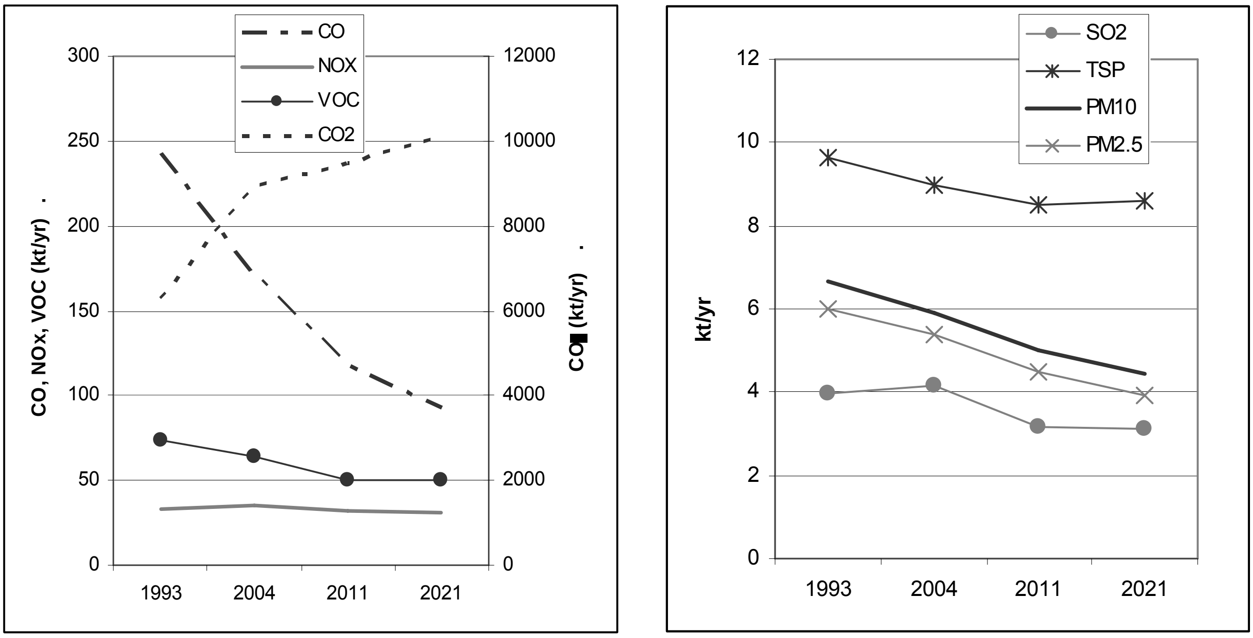


Figure 5.2
Predicted baseline trends for all pollutants



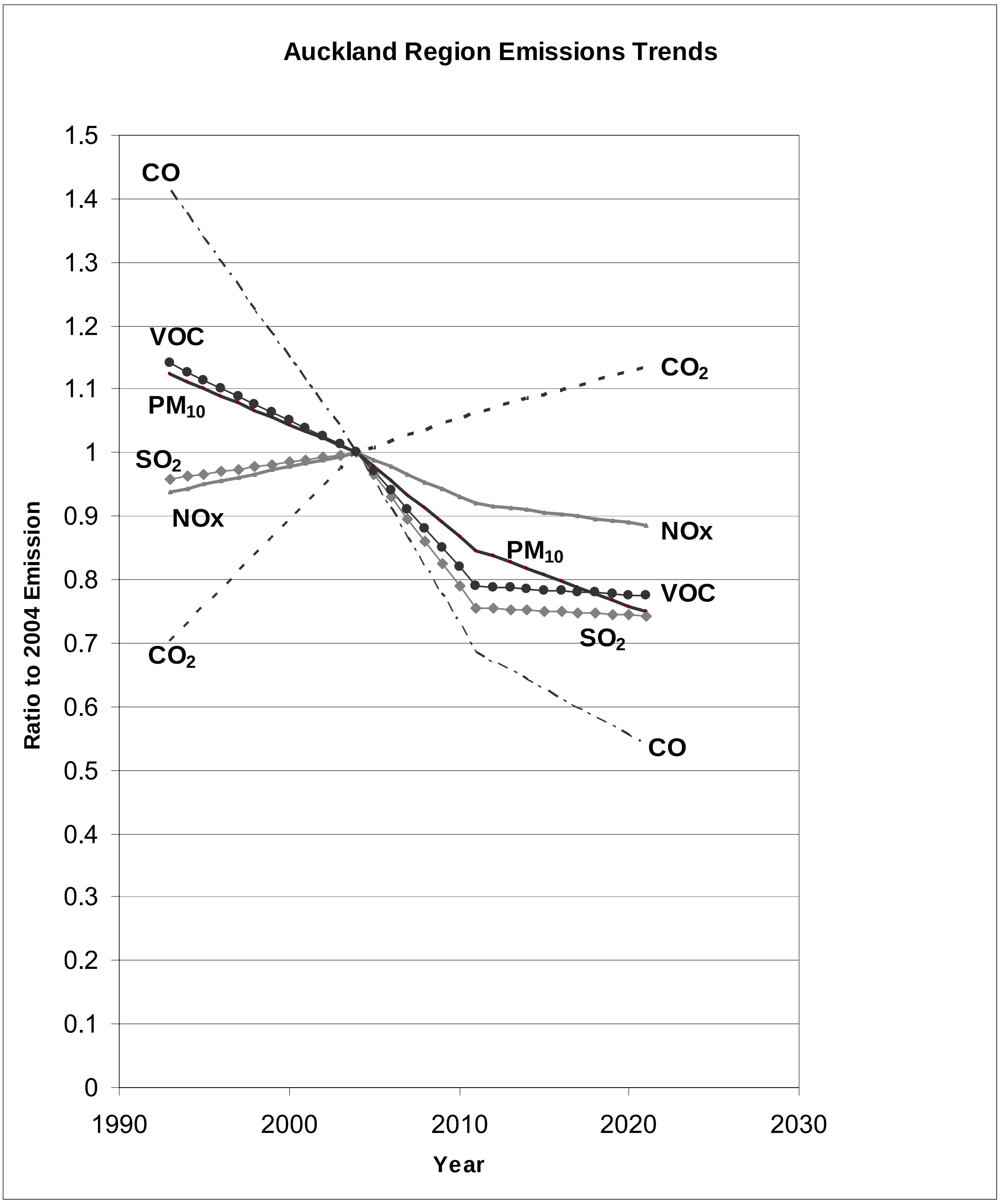
5.1 Overall Trends

The overall trends, using the corrected emissions for 1993 (based on the 2004 methodology) and extrapolated to 2021, are shown in Figure 5.3. These data are normalised to the 2004 emissions to highlight the relative trends. In the period 1993 to 2004:

- CO emissions have fallen and are predicted to continue to fall in future, mainly due to increasing numbers of vehicles in the fleet with improved emissions control equipment.
- CO$_2$ emissions have risen and are predicted to continue to rise in future, mainly due to increased fuel consumption resulting from increased numbers of vehicles in the region and increased vehicle kilometres travelled.
- NOx emissions have risen slightly, mainly due to increased numbers of diesel vehicles in the fleet, but are predicted to fall slightly in future as diesel emissions control technology improves.
- SO$_2$ emissions have risen, mainly due to increased diesel fuel consumption resulting from increased numbers of diesel vehicles, but are predicted to fall in future as fuel sulphur levels continue to decrease.
- PM$_{10}$ and VOC emissions have fallen slightly, mainly due to a shift away from coal and wood for both domestic heating and industrial use, and are predicted to fall in future with fuel trends and technology improvements.

Figure 5.3

Overall emissions trends (normalised to 2004 emissions)



5.2 Trends in Domestic Heating Emissions

The baseline projections for domestic heating emissions assume no improvement in domestic heating emissions factors over time. A modest reduction in domestic heating emissions is predicted, due to a predicted decline in the use of wood and coal burners.

A range of possible scenarios for reduction of domestic heating emissions have been evaluated. These are reported in full by Wilton (2004) who adopted 10 study areas for the Auckland region. Different assumptions have been made for the different areas on the basis of survey and census results. The key assumptions, and the range of values adopted for the 10 study areas are:

- ☐ 2% - 15% of new dwellings install new burners
- ☐ 5% - 50% decrease in the number of open fires from 2001 to 2021
- ☐ 50% - 90% of households replacing burners will choose new burners, with the remainder choosing electricity or gas.

This report is based on the same methodology however it is assumed that solid fuel burners are replaced after an average life of 20 years (as opposed to 15 years in the original report). The results of projections (percentage reduction compared with 2004 emissions) are summarised in Table 5.1. The projection scenarios are:

1. **Baseline scenario from the 1998 and 2004 inventories**. This scenario assumes no improvement in average domestic fire emissions factors (so does not take account of newer burners having better emissions performance). A gradual reduction in use of domestic wood and coal burners is assumed.
2. **All new burners installed from 2001 meet a 4g/kg emissions limit** as specified in the Proposed Regional Plan: Air Land and Water. This emissions limit applies under test conditions. “Real world” emissions are generally higher than in controlled test conditions, so an emissions factor of 6g/kg is assumed for these burners (reported as baseline scenario in Wilton (2004)).
3. **All new burners installed from 2006 meet a 1.5g/kg emissions limit.** A “real world” emissions factor of 3g/kg is assumed for these burners.
4. **80% of new burners installed from 2006 meet a 1.5g/kg emissions limit**. The remaining 20% are unregulated domestic fires. An emissions factor of 10g/kg is assumed because unregulated domestic fires (e.g. open fires) can have high emissions. Unregulated burners also tend to have low efficiency, so will burn more wood to deliver the same amount of heat. A wood consumption rate of 30kg/night is assumed for unregulated domestic fires (compared to an average fuel consumption rate of 19kg/night for woodburners).

The baseline scenario assumes no improvement in emissions factors over time. This is unrealistic because new burners are expected to have lower emissions. The baseline scenario provides an indication of the expected reduction in emissions due to predicted reduction in the use of wood and coal for domestic heating.

Ministry for the Environment has recently promulgated a National Environmental Standard for wood burners. The standard requires new wood burners in urban areas to meet an emissions standard of 1.5g/kg from September 2005. The 1.5g/kg scenario described above applies to all new burners (including any coal, multifuel and open fires) in all areas from 2006, so the predicted rate of reduction could be affected if significant numbers of coal, multifuel or open fires are installed (as suggested by scenario 4).

Table 5.1
Comparison of domestic heating emissions scenarios

Scenario	2004 PM_{10} (t/yr)	2011 PM_{10} Emissions (as % of 2004)	2021 PM_{10} Emissions (as % of 2004)
1. Baseline (no change in emissions factors)	2,220	88%	77%
2. All new burners from 2001 meet 4.0g/kg		66%	51%
3. All new burners from 2006 meet 1.5g/kg		59%	35%
4. 80% new burners from 2006 meet 1.5g/kg.		67%	55%

The rate of reduction in emissions is sensitive to the assumptions made. This analysis makes a number of assumptions about the effects of the standards, the uptake of new burners, the way they are operated and the actual emissions (which may not be the same as the anticipated emissions). Further work is needed to validate these key assumptions.

5.3 Trends in Motor Vehicle Emissions

The predicted baseline trend for motor vehicle emissions is based on Ministry of Transport predictions for VKT and vehicle fleet profile, and NZTER emissions factors.

To predict motor vehicle emissions to assess the likelihood of meeting the straight line path required by the National Environmental Standards, it will be necessary to evaluate:

- ☐ The likely impact of national fuel specification regulations.
- ☐ The likely impact of any national vehicle emissions control regulations.
- ☐ The likely impact of any regional policy options, such as retrofitting diesel oxidising catalysts to the heavy duty fleet.
- ☐ The sensitivity of VKT and congestion predictions to regional and national policy initiatives and factors such as petrol prices.
- ☐ The sensitivity of vehicle emissions factors to variables such as average vehicle age, and proportion of vehicles with malfunctioning emissions control equipment.

NZTER provides one default emissions value for each vehicle class, so does not allow the user to evaluate these types of policies. Alternative emissions estimation techniques, or emissions factors will be needed for development of predictions to meet the straight line path.

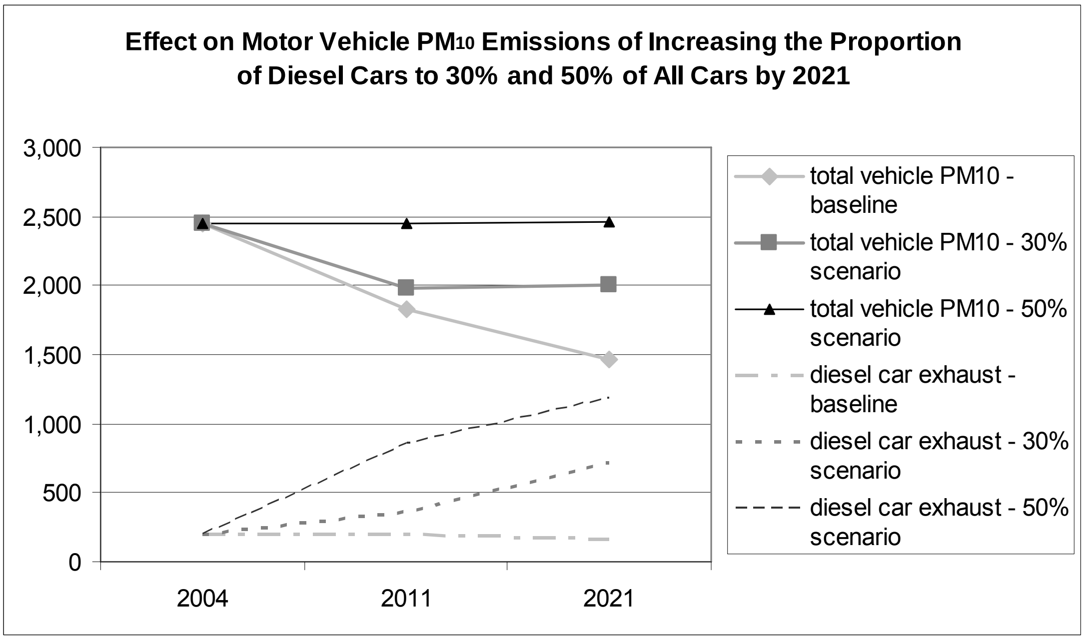
5.3.1 Impact of increasing prevalence of diesel cars.

There has been a rapid increase in the sales of diesel cars in Europe in recent years. It is estimated that diesel cars will account for 42% of all new car sales by 2010 in the UK.

To investigate the sensitivity of future vehicle emissions to the predicted fleet profile, the effect of increasing the proportion of diesel cars on PM_{10} emissions has been estimated. Figure 5.5 shows how increasing the proportion of diesel vehicles affects the predicted decline in PM_{10} from motor vehicles. Two scenarios are shown:

1. **30% Scenario:** Increasing the proportion of diesel cars to 12% of all cars by 2011 and 30% of all cars by 2021 (compared to 6% in 2004). These proportions are based on the assumption that diesel cars reach 30% of all car sales by 2011. This would effectively halve the predicted baseline reduction in PM_{10} from motor vehicles.
2. **50% Scenario:** Increasing the proportion of diesel cars to 30% of all cars by 2011 and 50% of all cars by 2021, would completely offset the expected reduction in exhaust emissions. This more extreme scenario illustrates that trends such as the increasing prevalence of diesel cars could significantly affect predicted trends.

Figure 5.5
Effect of increasing proportion of diesel cars on PM_{10} projections



6 Unaccounted Emissions

This inventory does not include PM_{10} emissions resulting from secondary particulate formation, natural sources nor road dust. The potential likely contribution of these sources to ambient PM_{10} concentrations is discussed in the following sections.

6.1 Secondary Particulate

Secondary particulate is created when precursor gases react to form particles. In Auckland, it is likely that secondary particulate will be dominated by nitrates (from the reaction of nitrogen oxides) and sulphates (from the reaction of sulphur dioxide).

Secondary particulate can be estimated through advanced airshed modelling studies or can be measured directly. Modelling or measurement of secondary particulate is not straightforward and reliable estimates are not yet available for Auckland. Estimates of secondary particulate are also difficult to build into grid based inventories, as the production of secondary particulates can occur at locations up to 20km distant from the precursor sources.

Preliminary estimates in Auckland suggest that up to 5-10% of ambient PM_{10} may be due to secondary particulate on a calm day. For windy (lower pollution) days, the contribution of secondary particulate to PM_{10} is likely to be close to zero because precursor gases are dispersed. These estimates are based on very limited data and have not been validated.

Secondary particulate in Auckland is expected to be primarily nitrates resulting from the emissions of NOx from motor vehicles. There may also be a contribution from rural sources (eg. nitrogen fertilisers) however this has not been quantified.

6.2 Sea Salt and Wind Blown Dust

Natural sources of PM_{10} can include volcanoes, sea salt, pollens, fungal spores and wind blown dust. Natural sources are difficult to quantify both in terms of their magnitude, emission rate and temporal emission characteristics. Many sources of natural particles are produced by complex processes and are best described through atmospheric measurements and source apportionment studies (DEFRA 2004).

In Auckland, limited source apportionment work has been undertaken. The most recent study was carried out using TSP, PM_{10} and $PM_{2.5}$ collected on 127 filters at several sites (Wilton, 2002). This work showed that vehicle emissions are the predominant source of PM_{10} in Auckland. The analysis also indicated that wood burning can be a significant source of PM_{10} on some days. This is variable and is likely to be influenced primarily by weather. The other significant source of PM_{10} measured at all sites was sea salt, which was highly variable, occasionally dominating PM_{10}. It is expected that the proportion of sea salt in PM_{10} will be highest on windy (lower pollution) days, and will be very low, say less than 2μg m^{-3}, on calm (higher pollution) days.

6.3 Unaccounted Transport Sources

Particles can be generated by vehicle movements through:

- ☐ exhaust emissions;
- ☐ tyre wear;
- ☐ brake wear;
- ☐ clutch wear;
- ☐ road surface wear;
- ☐ re-suspended PM_{10};
- ☐ corrosion of vehicle components street furniture and crash barriers.

These processes can lead to the deposition of particles on the road surface. The material that collects on the road surface (road dust) can also include deposited particles from non-transport sources. Road dust may be subsequently suspended or re-suspended in the atmosphere as a result of tyre shear, vehicle-generated turbulence, and wind.

The emissions inventory estimates emissions from exhaust, brake wear and tyre wear as described in Section 3. There is still a degree of uncertainty on these amounts, and their fractional contribution to ambient PM_{10} concentrations. The emitted amounts depend on road surface types, driving conditions, driving behaviour, vehicle fleet profiles, etc. These factors can vary significantly between countries and even between cities in New Zealand. Other sources of PM_{10} from transport are not estimated in this emissions inventory.

A recent review of PM_{10} sources in the UK concluded that the re-suspended component of PM_{10} can be as large, and in some cases much larger than exhaust emissions (DEFRA, 2004). However, because the significance of re-suspension is governed by many factors (e.g. vehicle type, road surface condition, meteorological conditions), resuspended material is highly variable in terms of its source emission rate and is difficult to quantify with any certainty. There is also a potential difficulty with double counting in inventories since a proportion of PM_{10} assumed to be re-suspended in origin might have already been accounted for elsewhere (for instance, PM_{10} from domestic heating deposited on the road).

Re-suspended road dust has been estimated for Auckland in the 1998 emissions inventory using USEPA emissions factors. This resulted in an estimated annual emission of PM_{10} of over 5,000 tonnes per annum in 1998, which would amount to approximately 50% of annual total PM_{10} emissions in the region. Given the extremely high level of uncertainty in estimating re-suspended road dust with emissions inventory techniques, it is considered more appropriate to estimate the unaccounted portion of road dust based on source apportionment, examination of ambient monitoring results and receptor modelling techniques. Preliminary analysis of ambient monitoring results suggests that the 1998 estimate of re-suspended road dust may be 2 to 3 times too high (NIWA, 2004). On this basis, a more realistic, but still uncertain, estimate of road dust would be 1,600 tonnes per annum. The NIWA analysis attempted to quantify the unaccounted portion of PM_{10} from roads, so this figure includes any re-suspended dust, as well as any dust from corrosion or road surface wear.

It seems likely that this will still over-estimate the unaccounted portion of road dust, because the limited source apportionment work that has been undertaken in Auckland (Wilton, 2002) did not indicate any significant contribution from road surface wear or corrosion (for example silicon might be expected if there was significant dust generated from road abrasion). Although source apportionment would not identify whether PM_{10} was directly emitted or re-suspended, it seems that any attempt to account for resuspended exhaust, brake and tyre wear PM_{10} may lead to double counting.

6.4 Likely Contribution of Unaccounted Emissions to Ambient PM_{10}

Unaccounted emissions contribute to ambient levels of PM_{10}. These sources are not expected to reduce over time, so it is important to understand their likely contribution to ambient air pollution levels, especially on high pollution days. This understanding is necessary in order to predict the reduction required in PM_{10} emissions (from transport/domestic/industry sources) to meet the required targets.

Meterorological conditions significantly influence ambient air quality, and are expected to affect the magnitude of unaccounted sources.

It is expected that ambient levels of sea salt and re-suspended dust will be significantly higher on windy days because these sources are generated by wind, and these particles tend to be coarser size fraction, which settle out more quickly in calm conditions (compared to combustion particles). Secondary particulate levels will be low on windy days when precursor gases are likely to disperse.

High pollution days tend to occur on calm days because of reduced dispersion. Pollution levels are also influenced by the amount of pollution produced, so the highest pollution days are likely to occur on calm days with high emissions (eg. a cold still day in winter when more domestic fires are in use).

Estimation of unaccounted emissions is still uncertain and requires significant further work. There is insufficient information available to estimate the contribution of unaccounted emissions to ambient air pollution on any given day. However on the basis of work undertaken to date the likely contributions to overall PM_{10} are estimated for a calm day and a windy day in Table 6.1.

Table 6.1

Estimated likely contribution of unaccounted sources to ambient PM_{10} concentrations in Auckland (2004)

Source Type	**Estimated Contribution to Ambient PM_{10}**	
	Calm Day	**Windy Day**
Accounted transport/domestic/industrial sources	78%	20%
Secondary particulate	7%	0%
Sea salt	5%	50%
Unaccounted transport sources*	10%	30%
Total	**100%**	**100%**

* including any PM_{10} from re-suspended road dust, road wear, corrosion, or clutch wear

The PM_{10} concentrations on a 'calm' day will tend to be higher, and may be 40-50µg m^{-3} or more. Concentrations on a 'windy' day will tend to be lower, and may be 10µg m^{-3} or less.

7 Conclusions and Recommendations

7.1 Conclusions

7.1.1 Key results

This inventory estimates the emissions to air in the Auckland region from four major sectors (industry, transport, domestic and biogenic) for key air contaminants including fine particles (PM_{10}), oxides of nitrogen (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), sulphur dioxide (SO_2) and carbon dioxide (CO_2). This report focuses primarily on PM_{10} because ambient concentrations measured in Auckland have exceeded the National Environmental Standard (NES) of 50µg m^{-3} at peak traffic and urban monitoring sites.

Emissions are broken down sectorally (for the four major sources), spatially (for the entire region and the urban area only), and seasonally (for a typical winter's day versus a typical summer's day) assuming a base year of 2004. This report updates the 1998 inventory to produce air emissions estimates for 1993, 2004, 2011 and 2021.

The annual estimates of the total emissions across the Auckland region in 2004 of the six contaminants are as follows:

- 5,900 t/yr PM_{10} (47% transport, 39% domestic, 14% industry)
- 35,000 t/yr NOx (83% transport, 13% industry, 3% biogenic)
- 171,200 t/yr CO (85% transport, 13% domestic, 2% industry)
- 64,200 t/yr VOC (52% transport, 26% industry, 13% biogenic, 9% domestic)
- 4,200 t/yr SO_2 (65% transport, 32% industry, 3% domestic)
- 8,930,000 t/yr CO_2 (48% transport, 46% industry, 6% domestic)

Typically in excess of 80% of the emissions occur in the urban area alone.

Emissions vary significantly with season both in terms of the amount as well as the relative contributions of sources. PM_{10} emissions on a typical winter weekday (29t/day) are nearly three times those of a typical summer weekday (10t/day). Domestic sources (principally domestic heating) account for 64% of PM_{10} on a typical winter weekday (June-August) but fall to 2% of PM_{10} on a summer weekday (December-February).

7.1.2 Key trends

Emissions have been estimated from 1993 out to 2021, based on the current inventory methodology, to indicate trends. In the period 1993 to 2004:

- CO emissions have fallen and are predicted to continue to fall in future, mainly due to increasing numbers of vehicles in the fleet with improved emissions control equipment.
- CO_2 emissions have risen and are predicted to continue to rise in future, mainly due to increased fuel consumption resulting from increased numbers of vehicles in the region and increased vehicle kilometres travelled.
- NOx emissions have risen slightly, mainly due to increased numbers of diesel vehicles in the fleet, but are predicted to fall slightly in future as diesel emissions control technology improves.
- SO_2 emissions have risen, mainly due to increased diesel fuel consumption resulting from increased numbers of diesel vehicles, but are predicted to fall in future as fuel sulphur levels continue to decrease.
- PM_{10} and VOC emissions have fallen slightly, mainly due to a shift away from coal and wood for both domestic heating and industrial use, and are predicted to fall in future with fuel trends and technology improvements.

7.1.3 Uncertainties

There are other potentially significant sources of PM_{10} that are not estimated by the current inventory, including secondary particulates, sea salt, and wind blown or re-suspended dust. Estimation of these sources is uncertain. However, preliminary investigations suggest that these sources could account for up to 20% of the total ambient PM_{10} on days of high air pollution (calm days, with 24-hour concentrations higher than $40 \mu g\ m^{-3}$). Further work is necessary to validate assumptions in the existing inventory and confirm key trends.

Uncertainties have not been quantified for this emissions inventory because in most cases quantitative information is not available. To provide an indication of uncertainty, the sensitivity of motor vehicle and domestic heating emissions to possible variations in emissions factors and activity data has been considered.

The emissions inventory (and previous inventories) indicates that motor vehicles are the predominant source of PM_{10} on an annual basis, and that domestic fires are important in winter. As the emissions inventory is improved and refined, the proportions attributable to these sources may change, however the overall conclusion will probably not change. The limited source apportionment work that has been undertaken in Auckland shows that PM_{10} is dominated by combustion particles. The emissions inventory provides enough certainty to know that these combustion particles are principally from motor vehicles and domestic heating.

7.2 Recommendations for future work

7.2.1 Unaccounted emissions

Unaccounted emissions cannot be quantified with any certainty based on current information. However, for the purposes of air quality management it is necessary to estimate the proportion of PM_{10} which will not be affected by reductions and mitigation policies. It is estimated that up to 23% of PM_{10} could be from unaccounted sources on a calm (higher pollution) day, and that up to 80% of PM_{10} could be from unaccounted sources on a windy (lower pollution) day. These estimates are uncertain. In order to improve these estimates studies on source apportionment, detailed analysis of ambient monitoring, meterological monitoring and atmospheric modelling studies are being undertaken.

7.2.2 Source apportionment

Source apportionment analysis, conducted appropriately, can provide further information on the causes of high pollution events. Measurement of PM_{10} composition is one way to validate the results of the emissions inventory and trends in individual sources. Significant geographical variation in home heating trends can occur in the Auckland Region, and separate analysis will be required in several locations.

7.2.3 Vehicle emissions estimation

NZTER Emissions factors for motor vehicles were developed in 1998. These emissions factors need to be updated and validated.

In order to assess the ability of policy options to meet the straight line path for 2013 emissions projections need to be improved. In particular, it will be necessary to further evaluate:

☐ The likely impact of national fuel specification regulations.

☐ The likely impact of any national vehicle emissions control regulations on new and used imported vehicles, and in service vehicles.

☐ The likely impact of any regional policy options such as retrofit of diesel oxidising catalysts to the heavy duty fleet.

☐ The sensitivity of vehicle emissions factors to variables such as average vehicle age, and proportion of vehicles with malfunctioning emissions control equipment.

NZTER provides one default emissions value for each vehicle class, so does not allow for the evaluation of these types of policies. Alternative emissions estimation techniques, or emissions factors will be needed for development of the emissions projections to meet the required targets.

An update of the emissions inventory should be considered when the Auckland Regional Transport model is upgraded. This may provide improved accuracy and resolution for estimation of VKT and congestion.

7.2.4 Domestic heating emissions estimation

There is considerable uncertainty in estimating the amount of wood burnt in the region, and further work is needed to improve this estimate.

Further work is also needed to improve domestic heating emissions factors (MfE, 2002).

In order to assess the ability of policy options to meet the straight line path for 2013, the baseline projection needs to be updated to reflect the likely impact of the National Environmental Standard for woodburners. Key assumptions for projections should also be validated, in particular, the average age of burners when they are replaced, the amounts of fuel actually used, the time of usage, the operating behaviour of the householder, the demographic changes in solid fuel heating, and the correlation between emission standards and real-world emissions.

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Appendix 1: Summary Tables

Appendix 1.1 Summary of annual emissions 2004 (entire study area)

Category/ Source	CO (kt/yr)	CO_2 (kt/yr)	NOx (kt/yr)	SO_2 (kt/yr)	TSP (kt/yr)	PM_{10} (kt/yr)	$PM_{2.5}$ (kt/yr)	VOC (kt/yr)
Domestic								
Coal	0.91	27.8	0.01	0.10	0.35	0.33	0.32	0.16
Mowing	3.05	4.6	0.02	0.00	0.01	0.01	0.01	0.63
LPG	0.00	46.7	0.02	0.00	0.01	0.01	0.01	0.00
Gas	0.03	90.1	0.07	0.00	0.01	0.01	0.01	0.01
Waste	0.55	22.2	0.04	0.01	0.10	0.10	0.10	0.20
Wood	18.02	310.9	0.11	0.04	1.99	1.86	1.79	5.15
Total	22.56	502.3	0.28	0.14	2.48	2.33	2.24	6.15
Industry								
Aerosol	0.00	0.0	0.00	0.00	0.00	0.00	0.00	4.40
Dry clean	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.16
Gas Leak	0.00	0.2	0.00	0.00	0.00	0.00	0.00	0.69
Industrial	3.44	3959.2	4.51	1.25	1.50	0.78	0.41	3.94
Service stn	0.00	0.0	0.00	0.00	0.00	0.00	0.00	2.68
Surf. coats	0.00	0.0	0.00	0.00	0.00	0.00	0.00	4.84
Unallocated	0.04	146.9	0.10	0.07	0.08	0.03	0.01	0.00
Total	3.48	4106.3	4.61	1.32	1.57	0.81	0.42	16.71
Transport*								
Aviation	2.52	191.5	0.87	0.06	0.07	0.07	0.07	0.61
Bitumen	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.13
Locomotive	0.20	31.6	0.64	0.07	0.04	0.04	0.04	0.19
Motor veh.	134.22	3929.8	24.72	1.09	4.59	2.45	2.42	30.78
Off-road	5.77	45.1	0.82	0.03	0.02	0.02	0.01	0.65
Pleas. craft	2.28	26.2	0.19	0.02	0.01	0.01	0.01	0.63
Ships - berth	0.04	15.4	0.24	0.20	0.03	0.03	0.03	0.02
Ships - sea	0.14	79.5	1.63	1.25	0.17	0.16	0.16	0.04
Total	145.17	4319.1	29.12	2.71	4.92	2.78	2.74	33.03
Biogenic*			0.95					8.28
All Sources	**171**	**8,928**	**35.0**	**4.16**	**8.98**	**5.92**	**5.40**	**64.2**

* these estimates do not include secondary particulate, natural sources of particles or road dust. The likely contribution of these sources to PM_{10} is discussed in the Unaccounted Sources section of this report.

Annual emissions as % of total emissions (entire study area)

	CO	CO_2	NOx	SO_2	TSP	PM_{10}	$PM_{2.5}$	VOC
Domestic	13.2%	5.6%	0.8%	3.4%	27.7%	39.4%	41.5%	9.6%
Industry	2.0%	46.0%	13.2%	31.6%	17.5%	13.7%	7.8%	26.0%
Transport	84.8%	48.4%	83.3%	65.0%	54.8%	46.9%	50.7%	51.5%
Biogenic			2.7%					12.9%

Appendix 1.2 Summary of annual emissions 2004 (urban area only)

Category/ Source	CO (kt/yr)	CO_2 (kt/yr)	NOx (kt/yr)	SO_2 (kt/yr)	TSP (kt/yr)	PM_{10} (kt/yr)	$PM_{2.5}$ (kt/yr)	VOC (kt/yr)
Domestic								
Coal	0.79	24.0	0.01	0.08	0.31	0.29	0.27	0.14
Mowing	2.69	4.1	0.02	0.00	0.01	0.01	0.01	0.55
LPG	0.00	40.3	0.02	0.00	0.01	0.01	0.01	0.00
Gas	0.03	77.7	0.06	0.00	0.01	0.01	0.01	0.00
Waste	0.49	19.7	0.03	0.01	0.09	0.09	0.09	0.17
Wood	15.54	268.1	0.10	0.03	1.72	1.61	1.55	4.45
Total	19.53	433.9	0.25	0.12	2.15	2.01	1.94	5.32
Industry								
Aerosol	0.00	0.0	0.00	0.00	0.00	0.00	0.00	3.91
Dry clean	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.15
Gas Leak	0.00	0.2	0.00	0.00	0.00	0.00	0.00	0.61
Industrial	2.47	2320.2	2.41	0.29	0.45	0.34	0.25	3.76
Service stn	0.00	0.0	0.00	0.00	0.00	0.00	0.00	2.48
Surf. coats	0.00	0.0	0.00	0.00	0.00	0.00	0.00	4.27
Unallocated	0.04	130.6	0.09	0.06	0.07	0.03	0.01	0.00
Total	2.51	2450.9	2.50	0.35	0.52	0.37	0.26	15.18
Transport*								
Aviation	2.52	191.5	0.87	0.06	0.07	0.07	0.07	0.61
Bitumen	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.12
Locomotive	0.14	21.8	0.44	0.05	0.03	0.03	0.03	0.13
Motor veh.	128.71	3767.7	23.67	1.04	4.42	2.35	2.32	29.64
Off-road	0.27	2.1	0.04	0.00	0.00	0.00	0.00	0.03
Pleas. craft	1.88	21.6	0.16	0.01	0.01	0.01	0.01	0.52
Ships - berth	0.04	15.4	0.24	0.20	0.03	0.03	0.03	0.02
Ships - sea	0.03	15.7	0.32	0.25	0.03	0.03	0.03	0.01
Total	133.58	4035.8	25.74	1.61	4.59	2.52	2.49	31.07
Biogenic*			0.14					1.04
All Sources	**156**	**6,921**	**28.6**	**2.08**	**7.26**	**4.90**	**4.69**	**52.6**

* these estimates do not include secondary particulate, natural sources of particles or road dust. The likely contribution of these sources to PM_{10} is discussed in the Unaccounted Sources section of this report.

Annual emissions as % of total emissions (urban area only)

	CO	CO_2	NOx	SO_2	TSP	PM_{10}	$PM_{2.5}$	VOC
Domestic	12.6%	6.3%	0.9%	5.8%	29.6%	41.0%	41.4%	10.1%
Industry	1.6%	35.4%	8.7%	16.8%	7.2%	7.6%	5.5%	28.8%
Transport	85.8%	58.3%	89.9%	77.4%	63.2%	51.4%	53.1%	59.1%
Biogenic			0.5%					2.0%

Appendix 1.3 Summary of summer and winter weekday emissions (entire study area)

Summer weekday emissions in the Auckland region for 2004

Source	**CO (t/d)**	**CO_2 (t/d)**	**NO_X (t/d)**	**SO_2 (t/d)**	**TSP (t/d)**	**PM_{10} (t/d)**	**$PM_{2.5}$ (t/d)**	**VOC (t/d)**
Domestic	6.3	212	0.2	0.0	0.2	0.2	0.2	1.4
Industry	10.1	9,869	11.7	3.8	4.6	2.4	1.3	51.3
Transport	377.0	12,178	82.2	7.5	13.9	7.8	7.7	99.3
Biogenic			4.0					34.1
Total	**393.5**	**22,259**	**98.1**	**11.4**	**18.8**	**10.5**	**9.2**	**186.1**
% Anthropogenic	*100%*	*100%*	*95.9%*	*100%*	*100%*	*100%*	*100%*	*81.7%*
% Biogenic			*4.1%*					*18.3%*

Winter weekday emissions in the Auckland region for 2004

Source	**CO (t/d)**	**CO_2 (t/d)**	**NO_X (t/d)**	**SO_2 (t/d)**	**TSP (t/d)**	**PM_{10} (t/d)**	**$PM_{2.5}$ (t/d)**	**VOC (t/d)**
Domestic	166.5	3,613	1.6	1.1	20.3	19.0	18.3	46.7
Industry	10.6	13,112	14.3	3.8	4.8	2.6	1.5	50.7
Transport	434.4	12,145	82.0	7.5	13.9	7.8	7.7	85.2
Biogenic			1.5					13.8
Total	**611.5**	**28,871**	**99.4**	**12.4**	**39.0**	**29.4**	**27.4**	**196.5**
% Anthropogenic	*100%*	*100%*	*98.5%*	*100%*	*100%*	*100%*	*100%*	*93.0%*
% Biogenic			*1.5%*					*7.0%*

Appendix 1.4 Motor vehicle emissions in the Auckland region for 2004 (tonnes/year)

Vehicle Type	**Fuel**	**% Total VKT**	**CO**	**CO_2**	**NOx**	**SO_2**	**VOC**	**PM_{10}**	**PM_{10} tyre + brake**	**PM_{10} exhaust**
Heavy Duty	diesel	7.3%	2,003	925,096	10,940	608	908	1177	147	1,030
Light Commercial	diesel	7.0%	1,178	259,681	559	173	293	440	30.8	409
Car	diesel	4.7%	597	139,650	318	93.1	175	215	15.8	199
Bus	diesel	0.8%	272	77,870	1,539	52.3	125	162	19.6	143
Heavy Duty	petrol	0.4%	3,075	25,626	168	1.6	306	17	5.2	11.4
Light Commercial	petrol	7.0%	17,032	256,889	1,253	17.2	3,499	50	30.8	19.3
Car	petrol	72.2%	108,924	2,232,138	9,850	143	25,267	377	242	135
Bus	petrol	0.1%	269	2,575	20.5	0.2	36.4	9.3	0.8	8.5
Motorcycle	petrol	0.4%	812	5,306	5.3	0.3	133	2.4	0.5	1.9
Heavy Duty	CNG/LPG	0.1%	13.1	3,086	50.7	0.0	4.0	1.1	0.9	0.2
Light Commercial	CNG/LPG	0.0%	24.7	495	2.7	0.0	3.2	0.1	0.1	0.0
Car	CNG/LPG	0.0%	39.5	1,217	5.2	0.0	6.1	0.2	0.1	0.1
Bus	CNG/LPG	0.0%	3.5	671	13.4	0.0	0.9	0.3	0.2	0.1
Total (t/yr)		**100%**	**134,243**	**3,930,300**	**24,726**	**1,088**	**30,757**	**2,451**	**493**	**1,958**
Total diesel (t/yr)		19.8%	4,050	1,402,298	13,356	926	1,501	1,994	213	1,781
Total petrol (t/yr)		80.1%	130,112	2,522,533	11,298	163	29,241	455	279	177
% motor vehicle emissions from diesel			*3.0%*	*35.7%*	*54.0%*	*85.0%*	*4.9%*	*81.4%*	*43.2%*	*91.0%*
% motor vehicle emissions from petrol			*96.9%*	*64.2%*	*45.7%*	*15.0%*	*95.1%*	*18.6%*	*56.6%*	*9.0%*

Appendix 1.5 Summary of total annual emissions in the Auckland region for all years

1993[13]

Source	CO (t/yr)	CO$_2$ (kt/yr)	NO$_X$ (t/yr)	SO$_2$ (t/yr)	TSP (t/yr)	PM$_{10}$ (t/yr)	PM$_{2.5}$ (t/yr)	VOC (t/yr)
Domestic	24,873	494	258	181	2,895	2,714	2,612	6,983
Industry	3,558	2,497	3,404	1,651	2,314	1,147	617	13,162
Transport	213,408	3,282	28,204	2,159	4,428	2,780	2,752	44,738
Biogenic	0	0	952	0	0			8,283
Total	**241,838**	**6,274**	**32,818**	**3,992**	**9,636**	**6,641**	**5,981**	**73,166**
%Anthropogenic	*100%*	*100%*	*97.1%*	*100%*	*100%*	*100%*	*100%*	*88.7%*

2004

Source	CO (t/yr)	CO$_2$ (kt/yr)	NO$_X$ (t/yr)	SO$_2$ (t/yr)	TSP (t/yr)	PM$_{10}$ (t/yr)	PM$_{2.5}$ (t/yr)	VOC (t/yr)
Domestic	22,561	502	284	140	2,484	2,330	2,243	6,148
Industry	3,479	4,106	4,611	1,316	1,574	810	422	16,712
Transport	145,171	4,319	29,118	2,707	4,925	2,776	2,737	33,026
Biogenic	0	0	952	0	0	0	0	8,283
Total	**171,210**	**8,928**	**34,964**	**4,163**	**8,983**	**5,916**	**5,401**	**64,168**
% Anthropogenic	*100%*	*100%*	*97.3%*	*100%*	*100%*	*100%*	*100%*	*87.1%*

2011

Source	CO (t/yr)	CO$_2$ (kt/yr)	NO$_X$ (t/yr)	SO$_2$ (t/yr)	TSP (t/yr)	PM$_{10}$ (t/yr)	PM$_{2.5}$ (t/yr)	VOC (t/yr)
Domestic	20,639	495	282	106	2,161	2,026	1,951	5,478
Industry	3,327	4,077	4,623	1,324	1,583	813	423	18,403
Transport	93,338	4,927	26,304	1,719	4,743	2,169	2,123	18,510
Biogenic	0	0	952	0	0	0	0	8,283
Total	**117,304**	**9,498**	**32,160**	**3,148**	**8,487**	**5,008**	**4,497**	**50,673**
% Anthropogenic	*100%*	*100%*	*97.0%*	*100%*	*100%*	*100%*	*100%*	*83.7%*

2021

Source	CO (t/yr)	CO$_2$ (kt/yr)	NO$_X$ (t/yr)	SO$_2$ (t/yr)	TSP (t/yr)	PM$_{10}$ (t/yr)	PM$_{2.5}$ (t/yr)	VOC (t/yr)
Domestic	19,037	507	307	76	1,893	1,775	1,710	4,886
Industry	2,784	3,937	4,640	1,335	1,596	818	425	19,763
Transport	70,597	5,686	25,085	1,684	5,124	1,837	1,782	16,787
Biogenic	0	0	952	0	0	0	0	8,283
Total	**92,419**	**10,130**	**30,983**	**3,094**	**8,613**	**4,431**	**3,916**	**49,718**
% Anthropogenic	*100%*	*100%*	*96.9%*	*100%*	*100%*	*100%*	*100%*	*83.3%*

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[13] Re-calculated using the 2004 methodology. Note these figures are not the same as those published in the original Technical Publication, for the reasons outlined in this report.

Appendix 2: Industrial Sources

Electricity and Gas Supply
Contact Energy, Otahuhu B
Otahuhu A Power Station
Southdown Cogeneration Ltd
Watercare Services Ltd (Mangere)

Food Manufacturing
Auckland Abattoir Ltd

Government Administration
Paremoremo Prison

Health Services
Auckland Hospital
Greenlane Hospital

Machinery and Equipment Manufacturing
Air New Zealand Ltd
Ford Motor Co.

Metal Product Manufacturing
Ajax Building & Industrial Fasteners
AMCOR
BHP NZ Steel Ltd
Capral Aluminium
Consolidated Alloys
CSP Galvanising
East Tamaki Galvanising Ltd
Fletcher Aluminium
Fletcher Challenge
Franklin Machinery Ltd
Galvanising Services Ltd
Glucina Smelters Ltd
Hayes Metal Refineries Ltd
Masport Ltd
Morris and Watson Ltd
National Can
NZ Nail
Pacific Steel Ltd
Pacific Wire
Southcorp Packaging (Can)
Southcorp NZ (Drum)
Steel Masters
Yuasa Batteries New Zealand Ltd

Non-Metallic Products
ACI Glass Penrose
Industrial Processes
Monier Brickmakers Ltd
Tasman Insulation
Winstone Wallboard Ltd

Quarries
Beachlands Quarry
Excell Corporation Ltd
Redvale Lime Co Ltd
W. Stevensons
Winstone Aggregates Ltd (3 Kings)
Winstone Aggregates Ltd (Flat Top)
Winstone Aggregates Ltd (Hunua)
Winstone Aggregates Ltd (Roscommon & Wiri)
Winstone Aggregates Ltd (Whangaripo)
Winstone Aggregates Ltd (Lunn Avenue Quarry) - closed
Winstone Aggregates Ltd (Puketutu Island Quarry)
Works Infrastructure Ltd

Waste Services
Medical Waste Group
NDS Greenmount
NDS Rosedale
Waste Disposal Limited (Whitford)
Waste Management NZ Ltd (Redvale) (1993)
Waste Resources (Airport)
WCC Kay Road Balefill

Chemical Products
3M New Zealand Ltd
Bitumix Ltd
Blacktop (Asphalt)
Dunlop Flexible Foams Ltd
Edson Chemicals
Fernz Timber Protection
Flint Inks
Formica (NZ) Ltd
Fulton Hogan Contracting Ltd
Hatrick A.C. Ltd
Huhtamaki van-Leer
Nuplex Industries Ltd (Onehunga)
Nuplex Industries Ltd (Penrose)
Rohm & Haas NZ Ltd
Sealed Air
SICPA NZ
Vita New Zealand Ltd

Printing and Publishing
Bascands Ltd
Comprint Ltd
Flaxall Pacific Limited (Manukau)
Times Colourprint
Webprint Colour Ltd

Wood Products
Fletcher Wood Panels (Kumeu)
Fletcher Wood Panels (Penrose)

Storage
Wiri Oil Services Limited

Water Supply, Sewerage and Drainage
Army Bay Wastewater Treatment Plant
North Shore Waste Water Treatment Plant
Watercare Services Ltd (Mangere)

Appendix 3: Sensitivity Analysis

Sensitivity Analysis for Domestic Heating Emissions

Domestic heating emissions estimates are directly proportional to the estimated weight of fuel burnt. There is no way to directly measure overall wood usage rates in the region, so the inventory relies on the results of a survey. Although an adequate sample size was surveyed, the estimated amount of wood or coal burnt still depends on individual estimates of daily usage (number of logs or buckets), and the estimated weight of each log of wood or bucket of coal. Average log weights for inventories around New Zealand have included 1.4, 1.6 and 1.9kg. The latter value was based on a survey undertaken in Christchurch in 2002.

Wood sales data, combined with estimates of self collected wood, could be used to validate wood usage rates. However, an informal telephone survey found that wood merchants were reluctant or unable to provide sales information. The seasonal nature of the business also means that it can be difficult to locate all wood merchants in the region.

Domestic fire emissions vary considerably depending on the rate of burn, fuel type, fuel condition and fuel loading. Emissions factors are based on limited test results, which may not represent real life conditions well. Testing in the United States for example, has indicated that actual emissions are likely to be 0.8 to 15 times the laboratory test values. Some effort has gone into real life testing of wood burners in New Zealand, however a high degree of uncertainty remains (MfE, 2002).

For comparison, PM_{10} emissions factors from the 1998 Port Philip emissions inventory (EPAV, 1998) are shown in Table A3.1.

Table A3.1

Comparison of Australian and NZ domestic heating emissions factors

Appliance Type	**PM_{10} Emission Factor (g/kg fuel)**		
	Port Philip (EPAV, 1998)	**Auckland (Base Case, 2004)**	**Updated NZ (Wilton, 2001)**
Open Fire	17.3		
Open Fire (wood)		15	10
Open Fire (coal)		33	21
Wood Burner	12		
Wood Burner (pre 1991)		13	
Wood Burner (emission control)	5.5		
Wood Burner (post 1997)		6	

These emissions factors were based on Australian and US test results and expert advice. These emissions factors are very similar to the emissions factors used in this inventory (base case). Table A3.1 also includes the updated emissions factors for open fires as recommended by Wilton (2001), based on a review undertaken for the 1999 Christchurch emissions inventory.

The effect of the updated emissions factors on open fire and overall domestic heating emissions is shown in Table A3.2. The effect of assuming 1.9kg logs as opposed to 1.4kg logs is also shown (assuming base case emissions factors) for 2001. (Results are reported for 2001 because the domestic heating inventory was undertaken in 2001.)

Table A3.2

Comparison of 2001 PM_{10} emissions for open fires derived from base case Auckland and updated NZ emissions factors

Appliance Type	**PM_{10} Emissions (tonnes/annum, 2001)**		
	Base Case Auckland	**Updated NZ**	**1.9kg log weight**
Open Fire (wood)	310	207	
Open Fire (coal)	186	118	
Total Domestic Heating	**2,275**	**2,104**	**3,087**

The updated NZ emissions factors do not significantly change the total emissions from domestic fires, because these apply only to open fires.

The overall emissions from domestic fires are approximately 35% higher when a 1.9kg log weight is assumed. There has been no work in Auckland to estimate the weight of logs. Current estimates of log weights are all based on Christchurch studies. It is likely that wood sources are significantly different in Auckland and Christchurch, so this is an area where work should be undertaken. In the interim, it seems likely that Auckland will have lower average log weights than Christchurch, because of a higher prevelance of packaged wood.

There is significant uncertainty in the estimation of fuel usage, and in the emissions factors for domestic heating emissions. Ambient monitoring and dispersion modelling results for the Auckland Region suggest that emissions from home heating may be overestimated by the inventory (NIWA, 2004). It is important that further work is undertaken to improve the certainty of these estimates.

Sensitivity Analysis for Motor Vehicle Emissions

To investigate the sensitivity to emissions factors in the 1998 inventory, motor vehicle emissions were calculated using the nearest corresponding emissions factors used by the Environment Protection Authority of Victoria (EPAV). The ratios of EPAV-based emissions estimates to NZTER-based estimates are shown in Table A3.3.

Table A3.3

Ratios of vehicle emissions estimated using EPAV factors versus NZTER factors

	Ratios of Total Vehicle Emissions Based on Different Emissions Factors (EPAV/NZTER)		
Pollutant	**1998**	**2011**	**2021**
CO	1.11	0.91	0.43
CO_2	0.99	0.99	0.99
NOx	0.86	0.74	0.67
SO_2	0.69	0.52	6.44
TSP	0.90	0.66	0.62
VOC	0.66	0.57	0.45

This analysis shows that Australian emissions factors result in significantly lower emissions estimates, particularly for future years. This is not unexpected because Australia has regulated vehicle emissions in advance of New Zealand.

The emissions factors are based on different fleets and emissions requirements, so are not necessarily expected to provide good agreement. However, it is clear that emissions estimates are sensitive to the emissions factors adopted, so it is important that further work is undertaken to improve our understanding and confidence in vehicle emissions factors.

Appendix 4: Comparison of BEPM with NZTER

The Auckland Regional Council has developed a model for prediction of bus emissions[14]. This model allows the user to define:

- average speed,
- fleet profile (% of each vehicle type by country of origin/technology),
- fuel (sulphur content, biodiesel, water blend fuel),
- % retrofit of diesel oxidising catalysts or particle traps.

To investigate how BEPM compares with NZTER emissions factors, BEPM has been used to predict emissions factors for an estimated New Zealand heavy commercial vehicle (HCV) fleet for 2004 and 2013. The New Zealand fleet profile was estimated using Vehicle Fleet Model (VFM) results provided by MoT. VFM estimates the number of vehicles in the New Zealand fleet by country of origin and year of manufacture for any given year. To derive the fleet information required by BEPM (see Table A4.1) it was assumed that all New Zealand-new vehicles were equivalent to pre-Euro and Australian vehicles were assumed to be equivalent to the European standard in force at the time of manufacture. The resulting fleet profiles are shown below.

Table A4.1
Estimated NZ HCV fleet profile for input to BEPM

Estimated NZ HCV Fleet Profile for Input to BEPM		**Number in Fleet**	
Emissions Technology Level	**Model Year**	**2004**	**2013**
1.1 European			
Pre-Euro	< '88	50,707	30,196
Euro 0	88-91	375	241
Euro I	92-95	1,440	1,162
Euro II	96-99	2,713	3,323
Euro III	00-04	3,545	6,137
Euro IV	05-07		3,425
Euro V	>'08		4,326
1.2 Japanese			
Pre-J94	< '94	9,801	5,250
J94	94 - 97	6,757	6,391
J98	98 - 02	9,758	17,742
J03	03 - 04	3,203	7,093
J05	> 05		20,820

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[14] The Bus Emissions Prediction Model was developed on behalf of ARC by the Energy and Fuels Research Unit at Auckland University. A CD entitled "Bus Emissions Prediction Model", 31 May 2005, is available from ARC (ARC, 2005).

BEPM is designed to predict emissions factors for buses, which are typically around 12 tonnes. NZTER provides emissions factors for Small (<7.5 t), Medium (7.5 – 12 t) and Large (>12t) HCVs. Large and medium bus emissions factors are the same as large and medium HCV emissions factors in NZTER.

Emissions factors predicted by BEPM at 30km/hour are compared to NZTER emissions factors for medium and large HCVs in the suburban interrupted driving condition in Table A4.2.

Table A4.2
Comparison of BEPM and NZTER emissions factors

Emissions Factors				**CO**	**NOx**	**PM_{10}**
2004	BEPM	30km/hour		5.94	11.98	0.94
	NZTER	suburban interrupted	medium HCV	2.68	9.93	1.06
			large HCV	5.37	24.28	2.07
2013	BEPM	30km/hour		4.46	9.39	0.66
	NZTER	suburban interrupted	medium HCV	1.42	7.92	0.48
			large HCV	2.54	18.92	0.76

There is reasonable agreement for NOx and PM_{10} between the BEPM and the NZTER (medium HCV) emissions factors. NZTER predicts significantly lower CO emissions compared to BEPM.

The reduction in PM_{10} emissions factors between 2004 and 2013 is predicted to be 25% by BEPM and 54% by NZTER. The rate of reduction in emissions is heavily dependent on the rate of turnover of vehicles in the fleet (because newer vehicles have better emissions standards). The fleet profile for prediction of emissions from BEPM was estimated from VFM, which is the basis of NZTER. Therefore, a reasonable agreement in the rate of emissions reduction between NZTER and BEPM was expected.

As stated above, the fleet derived for BEPM is based on the assumption that all New Zealand-new vehicles were equivalent to pre-Euro vehicles. To evaluate sensitivity to this assumption, an alternative assumption that New Zealand-new vehicles met the Euro emissions standards with a 2 year delay has been modelled. The reduction in PM_{10} emissions factors between 2004 and 2013 is predicted to be 40% by BEPM for this assumption. In reality however, it is unlikely that all New Zealand-new vehicles would have met Euro standards because there were no emissions requirements in force in New Zealand at the time of manufacture.

The reduction in PM_{10} emissions factors predicted by BEPM is between 25% and 40% compared to 54% predicted by NZTER. The reason for the significantly higher rate of reduction in PM_{10} emissions predicted by NZTER is not known. However, this does indicate that the rate of reduction in PM_{10} emissions from motor vehicles may be lower than the current baseline estimate. This highlights the need for a better understanding of vehicle emissions factors.

Appendix 5: Comparison with Previous Inventories

An emissions inventory backcast to 1993 has been undertaken using the 1998 and 2004 emissions inventory methodology and assumptions to provide for comparison of the three Auckland inventories.

There were significant improvements in the 1998 emissions inventory upgrade, which are described in detail in the 1998 emissions inventory report (EPAV, 2005). The most significant upgrades were:

- ☐ Incorporation of New Zealand specific emissions factors for motor vehicles (NZTER) (MoT, 2000).
- ☐ VKT based on the results of regional models (significantly lower than 1993 VKT estimates).
- ☐ Updated domestic heating inventory with updated methodology and emissions factors (Wilton, 2001).
- ☐ Incorporation of re-suspended road dust.

The further changes made for the 2004 inventory are summarised in Table 1.1 in the Introduction section. The most significant changes between 1998 and 2004 methodologies are:

- ☐ VKT based on MoT models (VKT are significantly higher than estimates for the 1998 inventory, but still lower than 1993 estimates).
- ☐ Diesel PM_{10} emissions factors increased by 15% to account for "gross emitters".
- ☐ Removal of re-suspended road dust source.

Emissions estimates for 1993 from the three different inventories are summarised in the table overleaf. Compared to the 2004 methodology:

- ☐ The 1993 methodology over-estimated the emissions of NOx, and CO, but under-estimated TSP.
- ☐ The 1998 upgrade methodology under-estimated the emissions of VOC, NOx, and CO, but over-estimated TSP.

Table A5.1

Comparison of 1993 emissions estimated using the methodologies from the 1993, 1998 and 2004 emissions inventories.

	1993 Emissions Based on 1993 Methodology (ARC, 1997)				**1993 Emissions Based on 1998 Methodology (EPAV, 2004)**				**1993 Emissions Based on 2004 Methodology (This report)**			
	VOC	**NOx**	**CO**	**TSP***	**VOC**	**NOx**	**CO**	**TSP***	**VOC**	**NOx**	**CO**	**TSP***
Total	71,700	37,000	340,600	6,290	58,700	28,000	195,000	32,300^{+}	73,200	32,800	242,000	9,400
% change from 1993					*-18%*	*-24%*	*-43%*	*414%*	*2%*	*-11%*	*-29%*	*50%*
Domestic Heating	8,570	350	19,830	2,670	6,085	221	21,480	2,525	6,085	221	21,480	2,525
Major Industry	3,410	2,810	1,990	2,020	3,470	3,230	1,460	1,950	3,470	3,230	1,460	1,950
Motor Vehicles	40,850	30,655	306,205	865	28,600	21,100	159,000	2,880	42,900	26,000	205,000	4,280
VKT	10.04 x 10^9 km/year				6.9 x 10^9 km/year				8.84 x 10^9 km/year			

* PM$_{10}$ is not included as it was not reported in the 1993 inventory. The comparison here is done with TSP emissions instead.

$^{+}$ The 1998 methodology includes a significant contribution from road dust which is EXCLUDED from the estimates using the 1993 and 2004 methodologies due to the large uncertainties