Auckland Motor Vehicle Emissions Inventory

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Auckland Motor Vehicle Emissions Inventory

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Executive Summary

The Auckland air emissions inventory identifies key emission sources and how they change over space and time. It is a critical component of air quality management and plays a significant role in the development of air quality strategy, particularly for motor vehicles but also for air quality overall because it contributes to the overall emissions inventory. This report updates the motor vehicle emissions component of the Auckland air emissions inventory for 2011 and also estimates emissions for 2001 and 2006 to compare trends over this time. The results from this report will assist with assessing whether Auckland is on track to meet regional targets and national environmental standards by 2016.

Emissions from some vehicles have reduced significantly between 2001 and 2011 due to improvements in vehicle and fuel technology and increasingly stringent regulations for vehicles and fuels. At the same time, however, the number of vehicles, the amount they are driven and their average age (in Auckland) has increased (Auckland Council, 2012b).

This report details the methodology, assumptions, analysis and results of motor vehicle emissions estimates for 2001, 2006 and 2011. Calculations are based on total vehicle kilometres travelled for segments of road by vehicles (both heavy and light commercial vehicles, and cars) in the Auckland region, and emission factors by vehicle type based on various driving conditions related to speed.

Results

The 2011 motor vehicle inventory estimates the following:

- PM_{10} emissions from motor vehicles are 578 tonnes per year of which:
    - Diesel exhaust emissions account for 72 per cent;
    - Diesel cars account for 25 per cent of emissions despite representing only eight per cent of vehicle kilometres travelled;
    - Diesel light commercial vehicles account for 28 per cent of emissions despite representing only 11 per cent of vehicle kilometres travelled; and
    - Diesel heavy commercial vehicles account for 23 per cent of PM_{10} emissions, despite representing only five per cent of vehicle kilometres travelled.
- NO_x emissions from motor vehicles are 8,675 tonnes per year.
    - Diesel exhaust emissions account for 55 per cent of motor vehicle NOx emissions despite representing only 25 per cent of vehicle kilometres travelled;
    - Diesel heavy commercial vehicles account for 35 per cent of NOx emissions although they represent only six per cent of vehicle kilometres travelled.

Trends

Despite a 16 per cent increase in vehicle kilometres travelled between 2001 and 2011, emissions of total nitrogen oxides are estimated to have decreased by 30 per cent during this period. This reduction is also visible in measured levels of total nitrogen oxides at peak traffic monitoring sites (but not at other urban sites).

Diesel combustion remains the primary contributor to PM_{10} emissions from motor vehicles and this has stayed relatively constant between 2001 and 2011 (83 per cent in 2001, 81 per cent in 2006 and 78 per cent in 2011). Emissions control from diesel combustion has, however, improved significantly over this time period.

Petrol cars remain the primary contributor to emissions of total nitrogen oxides from motor vehicles although this is dropping due to improved emissions control, but is also due to an increase in light diesel vehicles in the fleet which is changing the contribution of emissions from light petrol vehicles. Petrol cars contributed 52 per cent of total nitrogen oxides emissions in 2001, 45 per cent in 2006 and 42 per cent in 2011.

Diesel cars and light commercial vehicles are increasing in importance with respect to total nitrogen oxides emissions from motor vehicles. The contribution of diesel cars and light commercial vehicles to total nitrogen oxides emissions grew from 13 per cent in 2001 to 18 per cent in 2006 and 20 per cent in 2011.

Uncertainty and sensitivity analysis

A comparison of inventory estimates with actual reported petrol consumption has yielded relatively good agreement. Similarly, emission inventory estimates are consistent with the trends in measured ambient levels of total nitrogen oxides peak traffic impacted air quality monitoring sites. These provide some confidence in estimates from this motor vehicle inventory.

A sensitivity analysis on key variables yielded the following insights:

- Emissions of PM_{10} and total nitrogen oxides are fairly sensitive to the assumed proportion of diesel vehicles. A relatively modest increase of two per cent in the assumed proportion of diesel vehicles results in an increase of seven per cent in estimated PM_{10} emissions and an increase of nine per cent in estimated total nitrogen oxides emissions.
- On a regional scale, emissions are not particularly sensitive to significant reductions in speed.
- Emissions estimates for PM_{10} and total nitrogen oxides are highly sensitive to small changes in road gradient. Given Auckland's undulating topography this could be significant.

Recommendations

- This analysis highlights the importance of on-going monitoring, investigation and validation to determine whether emission trends predicted by the inventory are realistic; and
- Emissions are highly sensitive to small changes in road gradient. Further work is required to develop a method for consideration of gradient in the Auckland inventory.

Conclusions

The motor vehicle emissions inventory estimates significant reductions in annual emissions for most pollutants since 2001. However, diesel vehicles remain disproportionate polluters for both PM_{10} and total nitrogen oxides.

The effect of the aging Auckland diesel car fleet and the effect of implementing light diesel vehicle standards in 2007 means that in 2011, a diesel car is estimated to produce almost half as much PM_{10} emissions as a diesel truck.

Measured levels of ambient total nitrogen oxides appear to reduce in line with estimated emissions from motor vehicles.

The spatial distribution of emissions indicates that the majority of daily emissions are generated by vehicles travelling along the state highway network and regional arterial routes. This could have significant health impacts for the population living and working near these routes.

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1.0 Introduction

The Auckland air emissions inventory identifies key emission sources and how they change over space and time. The emissions inventory was last updated in 2004 (Auckland Regional Council, 2006), and motor vehicle estimates were based on New Zealand transport emission rates (NZTER) emission factors which were developed in 1998. There have been considerable changes in the fleet composition, as well as fuel and emission regulation changes since this time. This report updates the motor vehicle emissions component of the Auckland air emissions inventory for 2011 using the most recent data available as well as updated emission factors. Emissions are also estimated for 2001 and 2006 to compare trends over this time. The results from this report can be used to assess whether Auckland is on track to meet regional targets and national environmental standards by 2016 and to support air quality strategies which work towards the Auckland Plan objective for Auckland to become the worlds' most liveable city.

1.1 Background

In the Auckland urban area, air quality has failed to meet the national standards and guidelines for particulate matter and nitrogen oxides on average 13 days per year from 2005 to 2012. The Auckland urban area also suffers from a visible 'smoggy' brown haze on average 30 days a year (Auckland Regional Council, 2010a). Other guidelines and targets are most likely being exceeded, such as the arsenic, benzene and benzo(a)pyrene guidelines. This means that the air in Auckland is impacting on the health of its residents.

The costs and magnitude of these health impacts are significant. Exposure to air pollution results in adverse health effects ranging from minor (coughing and discomfort), to moderate (restricted activity days, exacerbated respiratory disease) to severe (premature death). In 2012, the *Updated Health and Air Pollution in New Zealand Study* estimated health effects and social costs per year for a base year of 2006 for Auckland (Kuschel *et al.*, 2012), including:

- 291 premature deaths due to exposure to particulate matter which **126 premature deaths could be attributed to motor vehicles**;
- Almost half a million restricted activity days of which **215,000 restricted activity days could be attributed to motor vehicles**; and
- An overall estimated health cost of $1.07 billion from exposure to particulate matter. Of this, **$466 million could be attributed to motor vehicles**.

These figures depend on anthropogenic and natural background splits from the Auckland air emissions inventory and highlight the importance of this report.

1.2 Changes in vehicle emissions and air quality management

The Auckland air emissions inventory estimated that, in the Auckland region, motor vehicle emissions account for approximately 27 per cent of total particulate emissions and 48 per cent of total nitrogen oxide emissions for 2011 (Auckland Council, 2012a). Domestic fires and industry were also identified as the other major sources in the region, especially of particulate matter less than 10 micrometres in size (PM_{10}).

Over the last few decades both regional and central government have undertaken major initiatives to address air quality from transport. These include:

Cleaner fuels

- Banning lead in petrol (Ministry for Economic Development)
- Reducing sulphur in petrol and diesel (Ministry for Economic Development)
- Reducing benzene in petrol (Ministry for Economic Development)

Cleaner vehicles

- Placed requirements on the import of used vehicles to meet recent standards (Ministry of Transport, Land Transport New Zealand[1])
- Requiring all light and heavy commercial vehicles to meet emission standards (Ministry of Transport)
- 10 second on-road test for visible smoke (Ministry of Transport, Land Transport New Zealand)
- 5 second warrant of fitness (WOF) visible smoke check (Ministry of Transport, Land Transport New Zealand)
- Vehicle scrappage trial (Auckland Regional Council[2], Auckland Regional Transport Authority[3], Broken Car Collection Company, Ministry of Transport)
- Exhaust emissions rule (Ministry of Transport, Land Transport New Zealand)
- Requiring all new heavy duty diesel imports (including buses) to meet Euro V emissions standards (NZ Transport Agency)
- Requiring all urban bus fleets to have a fleet average age of no more than 12.5 years, with no individual vehicle older than 20 years (NZ Transport Agency)

[1] Land Transport New Zealand merged with Transit New Zealand on 1 August 2008 to form the New Zealand Transport Agency.

[2] Auckland Regional Council merged with four city councils (including North Shore City Council) and three district councils in the region to form the Auckland Council on 1 November 2010.

[3] The Auckland Regional Transport Authority became part of Auckland Transport on 1 November 2010.

Raising awareness

- 0800 Smokey campaign (Auckland Regional Council)
- Choke the Smoke campaign (Ministry of Transport)
- On road testing (New Zealand Transport Agency, Auckland Regional Council)

Demand management

- School and workplace sustainable travel initiatives (North Shore City Council[2], Auckland Regional Council, various schools)
- New Zealand Transport Strategy (Ministry of Transport)
- Regional Land Transport Strategy (Auckland Regional Council, other stakeholders)
- Regional Growth Strategy (Auckland Regional Council, other stakeholders)
- Public and sustainable transport investment (Auckland Council, Auckland Transport):
    - North Shore busway
    - Park and Ride
    - Britomart Transport Centre
    - Train network expansion and upgrades
    - High occupancy vehicle lanes
    - Cycle lanes

Other

- Ramp metering on motorway (New Zealand Transport Agency)

The above initiatives have gradually and significantly reduced the emissions per vehicle and in the network as a whole. However, these reductions are being offset by the growth in vehicle numbers, increased number of kilometres driven and the increasing age of the vehicle fleet (Auckland Council, 2012b). Auckland has one of the largest per capita ownership rates of private vehicles in the world with almost one million motor vehicles registered in the Auckland region in 2011 (Ministry of Transport, 2014). This includes light passenger vehicles, light commercial vehicles, motorcycles, heavy commercial vehicles and buses. As a result, Auckland's per capita emissions are also, very high.

The Auckland Plan sets a strategic direction to reduce air pollutant emissions of PM_{10} by 50 per cent (based on 2006 levels) by 2016 to meet national and international ambient air quality standards and guidelines, and achieve a further 20 per cent reduction by 2040. This strategic direction works towards the Auckland Plan objective for Auckland becoming the world's most liveable city.

It is clear then, why an update to the air emissions inventory is needed as it is a critical component of any strategy for air quality management in order to meet the directives and targets set in the Auckland Plan (Auckland Council, 2012c) and the Proposed Auckland Unitary Plan (Auckland Council, 2013).

1.3 Contents of this report

This report is structured as follows:

Section 2 of this report outlines the methods used to estimate Auckland regional motor vehicle emissions.

Section 3 presents the results for 2011, and trends between 2001, 2006 and 2011.

Section 4 details the analyses performed to give meaning to the inventory results. This includes:

- Trends; and
- Uncertainty and sensitivity analyses

Section 5 provides conclusions and recommendations for future work.

2.0 Method

The Auckland motor vehicle inventory uses emission factors from the vehicle emission prediction model version 5.1 (VEPM5.1) and traffic data from the Auckland regional transport model version 3 (ART3).

Emissions have been estimated for the following pollutants:

- carbon monoxide (CO)
- total nitrogen oxides (NO_x)
- sulphur dioxide (SO_2)
- volatile organic compounds (VOCs)
- particulate matter less than 10 micrometres in diameter (PM_{10})
- particulate matter less than 2.5 micrometres in diameter ($PM_{2.5}$)

Fuel consumption and carbon dioxide (CO_2) emissions are also included. Emissions are calculated for each vehicle type and each segment of road in grams per day as follows:

$$\boxed{emissions\ (g/day) = emission\ factor\ \ x\ \ vehicle\ kilometres\ travelled}$$

Emissions are calculated for each vehicle type and each road segment (referred to as road links) in the Auckland region. Road links are the spatial representation of actual road segments in the Auckland Regional Transport model, and have associated traffic and speed data. Speed based emission factors are calculated in VEPM by vehicle type, which are then applied to the traffic data for each road link to estimate emissions.

VEPM is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. VEPM is currently the best tool available in New Zealand to predict motor vehicle emissions in regional inventories, but, the model does not take into account the level of traffic (free flowing or congested) on a given road or include evaporative emissions.

2.1 Emission factors

The emission factors used are the default values provided in the vehicle emissions prediction model (VEPM5.1). Emission factors are defined for:

- all speeds between 10 and 99 kilometres per hour;
- every vehicle type; and
- every pollutant considered in the inventory (except as noted below).

The Auckland Council and the New Zealand Transport Agency (NZTA) developed the vehicle emissions prediction model (VEPM) to estimate emissions and analyse policy options. Version 5.1 of the model was updated in 2011 to incorporate the latest fleet data and projections from Ministry of Transport, as well as the latest international emission factors.

$PM_{2.5}$ and sulphur dioxide are not included in the vehicle emission prediction model. These pollutants have therefore been estimated as follows:

- Emissions of sulphur dioxide have been calculated using SO_2 emission factors (from in (Kar *et al*. 2008). These emission factors are based on the sulphur content in diesel and petrol for the inventory year (see Table 2-1) and are applied to the speed based fuel consumption data from VEPM to derive SO_2 speed based emission factors. Petrol is assumed to be of 80 per cent regular and 20 per cent premium petrol (Ministry of Economic Development, 2012). This method is in accordance with the methodology described in the VEPM 3.0 user notes (Kar *et al*. 2008); and
- $PM_{2.5}$ is assumed to be 100 per cent of PM_{10} for exhaust emissions, and 80 per cent of PM_{10} for brake and tyre wear in accordance with the recommendations by the Ministry for the Environment (Ministry for the Environment, 2008).

Table 2-1. Sulphur content in petrol and diesel in 2001, 2006 and 2011.

Year	Sulphur content (ppm)		
	Premium petrol	Regular petrol	Diesel
2001	500	500	3,000
2006	150	150	150
2011	50	50	10

2.2 Traffic data

The Auckland regional transport model version 3 (ART3, Auckland Regional Council, 2009) provides traffic data for almost 17,000 individual road links in the Auckland region. The Auckland regional transport model outputs are used to provide speed, proportion of vehicles and spatial allocation of vehicle kilometres travelled for three time periods of the day:

- AM: (7 am – 9 am)
- IP: (11 am – 1 pm) Inter peak
- PM: (4 pm – 6 pm) PM peak

And includes:

- vehicle kilometres travelled (VKT);
- speed; and
- proportion of cars and heavy commercial vehicles.

The inter peak period is extended from 9am to 3pm to cover the entire period between peak hours. The 9 to 11 and 1 to 3 periods within this are assumed to have the same vehicle kilometres travelled, speed and vehicle proportions as the inter peak 11am to 1pm period. School peak (3pm to 4pm) and off peak (6pm to 7am) numbers are not included in the Auckland regional transport model. Therefore, following assumptions were made to calculate emissions during these time periods:

- School peak (3pm to 4pm) vehicle kilometres travelled = 10 per cent of daily total
- Off peak vehicle (6pm to 7am) kilometres travelled = 16 per cent of daily total
- The speed and proportion of vehicles for both school peak and off peak are assumed to be the same as inter peak (11am to 1pm).

Traffic data for 2011 was obtained from Auckland Council and is based on a forecast for Auckland Council's Auckland Plan scenarios.[4]

2.2.1 2001 and 2006 traffic data

To provide for trend analysis, traffic data for 2006 was also obtained from the Auckland Regional Transport 3 model (Auckland Regional Council, 2009), however the model does not provide 2001 data. The Ministry of Transport's regional vehicle kilometres travelled data were used to back calculate traffic data for 2001.

Regional vehicle kilometres travelled for all years are reported by Ministry of Transport. These data are derived from territorial authorities and New Zealand Transport Agency road assessment and maintenance management (RAMM) systems. These figures provide a reasonable indication of regional trends and comparison with estimated vehicle kilometres travelled from the Auckland regional transport model.

Auckland regional vehicle kilometres travelled (as reported by Ministry of Transport) are shown in Table 2-2 and show that for the 2001/2002 annual year, Auckland's regional vehicle kilometres travelled was 87 per cent of vehicle kilometres travelled for 2006/2007.

As a result, traffic data for 2001 was back calculated using the following assumptions for each link (based on 2006 data):

- vehicle kilometres travelled are assumed to be 87 per cent of 2006 data; and

[4] Scenario H, Auckland Plan (1 March 2012 version)

- speed is assumed to be the same as 2006.

Total vehicle kilometres travelled for 2001, 2006 and 2011 used in this inventory are presented in Table 2-3.

Table 2-2 Ministry of Transport Auckland regional vehicle kilometres travelled (Ministry of Transport, 2014).

Year	Auckland Regional Road VKT (million)*	% Increase per annum	Percentage of 2006/07 VKT
2000/01	10,098		85%
2001/02	10,340	2%	87%
2002/03	10,797	4%	91%
2003/04	11,077	3%	93%
2004/05	11,401	3%	96%
2005/06	11,734	3%	99%
2006/07	11,853	1%	100%
2007/08	12,049	2%	102%
2008/09	12,088	0%	102%
2009/10	12,210	1%	103%
2010/11	12,348	1%	104%
2011/12	12,282	-1%	104%

* Ministry of Transport (2014)

Table 2-3 Total vehicle kilometres travelled used in this emissions inventory

Year	VKT (millions of km)	Basis
2001	10,046	87% of 2006 estimate based on trends measured by Ministry of Transport
2006	11,548	Calculated from Auckland regional transport model outputs based on the assumptions outlined in Section 2.1.1
2011	11,614	Calculated from Auckland regional transport model outputs based on the assumptions outlined in Section 2.2

2.3 Vehicle type

The Auckland regional transport model specifies vehicle kilometres travelled (VKT) for each link and the following vehicle types:

- heavy commercial vehicles (HCVs); and
- light commercial vehicles (LCVs) and cars (private passenger vehicles).

This fleet profile is further defined by the default fleet categories provided by the vehicle emissions prediction model (VEPM5.1) and shown in Table 2-4. The vehicle fleet in VEPM5.1 is based on the Ministry of Transport's Vehicle Fleet Emission Model (VFEM) estimates. The Vehicle Emission Fleet Model uses the current vehicle utilisation rates based on actual registration information with future rates based on projected regional growth (Jones *et al*. 2011). However, the fleet profile for Auckland differs from the national fleet profile as shown in Table 2-4.

Table 2-4 Vehicle fleet breakdown for the years 2001, 2006 and 2011.

Vehicle Type	Fuel	% of Total VKT		
		2001	2006	2011
Car	Petrol	72.9%	70.8%	70.3%
Light commercial	Petrol	5.9%	4.2%	3.6%
Hybrid and Electric	Petrol	0.0%	0.07%	0.3%
Car	Diesel	7.0%	8.1%	7.6%
Light commercial	Diesel	7.8%	9.7%	11.5%
Bus	Diesel	0.5%	0.6%	0.6%
Heavy	Diesel	5.9%	6.6%	6.1%
Total petrol (% of VKT)		79%	75%	74%
Total diesel (% of VKT)		21%	25%	26%

Table 2-5 National versus Auckland fleet profile for 2011.

Vehicle Type	% of Total VKT	
	Auckland	National
Cars	78%	81%
Light commercial	15%	12%
Heavy commercial*	7%	4%

* Heavy commercial vehicles includes buses

2.4 Estimation of motor vehicle emissions

Motor vehicle emissions are calculated separately for each pollutant, each vehicle type, each road link, and for each of the following time periods:

- AM: (7 am – 9 am).
- IP: (9 am – 3 pm) Inter peak.
- SP: (3 pm – 4 pm) School peak
- PM: (4 pm – 6 pm) PM peak.
- OP: (6 pm – 7 am) Off peak.

The detailed emission data by link have been developed to provide for spatial allocation and analysis of emissions in geographic information systems (GIS).

Compact spreadsheet versions of the emission calculations have also been developed to provide for sensitivity analyses.

3.0 Results

3.1 Results for 2011

3.1.1 PM_{10}

The Auckland motor vehicle inventory emissions estimates PM_{10} emissions from motor vehicles to be 578 tonnes per year in 2011. Diesel exhaust emissions account for 72 per cent of motor vehicle PM_{10} emissions, and petrol exhaust accounts for eight per cent as illustrated by Figure 3-1. The remaining 20 per cent of PM_{10} emissions is from brake and tyre wear. However, it is important to note that there is a high level of uncertainty associated with brake and tyre wear emissions factors (Ministry for Environment, 2008).

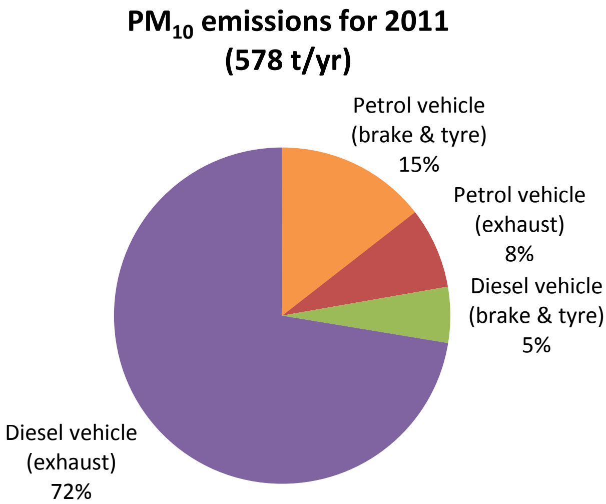

Figure 3-1 Motor vehicle PM_{10} emissions (2011)

The Auckland motor vehicle inventory estimates that in 2011 diesel cars account for 35 per cent of PM_{10} (Figure 3-2) although they represent only eight per cent of vehicle kilometres travelled as shown in Figure 3-3. Diesel light commercial vehicles (LCV) account for 23 per cent, and heavy commercial vehicles (HCV) account for 22 per cent of PM_{10} emissions despite representing only 10 per cent and five per cent of vehicle kilometres travelled respectively.

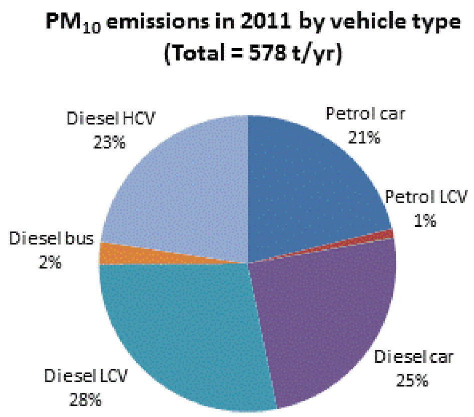

Figure 3-2 PM_{10} emissions (2011) by vehicle type

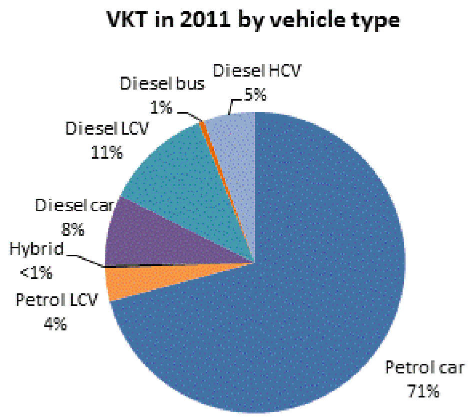

Figure 3-3 Vehicle kilometres travelled by vehicle type in 2011

This result is in contrast to the 2004 inventory, which estimated that heavy commercial vehicles accounted for 55 per cent of PM_{10} and eight per cent of vehicle kilometres travelled in 2004 (Auckland Regional Council, 2006).

Emission factors used in this inventory are from the vehicle emission prediction model (VEPM5.1). Fleet weighted, average emission factors for PM_{10} in 2011 are approximately 0.12 g/km for diesel cars, 0.09 g/km for diesel light commercial vehicles and 0.19 g/km for heavy commercial vehicles (Jones *et al.* 2011). Thus, in 2011, **the vehicle emission prediction model estimates that a diesel car produces almost half as much PM_{10} as a diesel truck**.

Vehicle emission standards were introduced in New Zealand as part of the Land Transport Rule: Vehicle Exhaust Emissions 2003 for new vehicles entering the fleet (Ministry of Transport, 2003). This rule required vehicles to meet progressively more stringent standards from 2005 for diesel heavy commercial vehicles and from 2007 for light diesel vehicles. Since diesel cars were required to meet these standards later than heavy commercial vehicles, it is one of the main reasons that diesel cars have disproportionately high PM_{10} emissions in 2006. This is illustrated in Figure 3-4 (Japanese diesel cars), Figure 3-5 (diesel light commercial vehicles) and Figure 3-6 (diesel heavy commercial vehicles). The x-axis shows the year of manufacture of vehicles which indicates the emission standard. Note: the age range on the graphs vary for each vehicle type as the standards came into effect over different years for diesel cars, diesel light commercial vehicles and diesel heavy commercial vehicles. The graphs show that diesel cars with newer emission standards (Figure 3-4) only account for a small proportion of total VKT travelled. In comparison, diesel light commercial vehicles (Figure 3-5) and heavy commercial vehicles (Figure 3-6) with newer emission standards account for more than half the proportion of total VKT travelled.

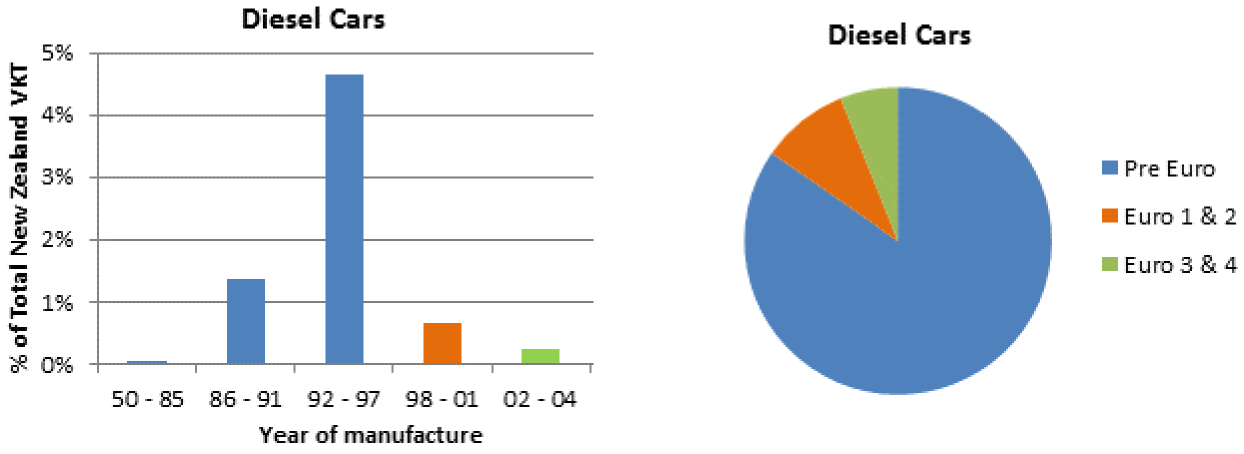

Figure 3-4 VEPM5.1 equivalent emission standard assumptions for Japanese diesel cars.

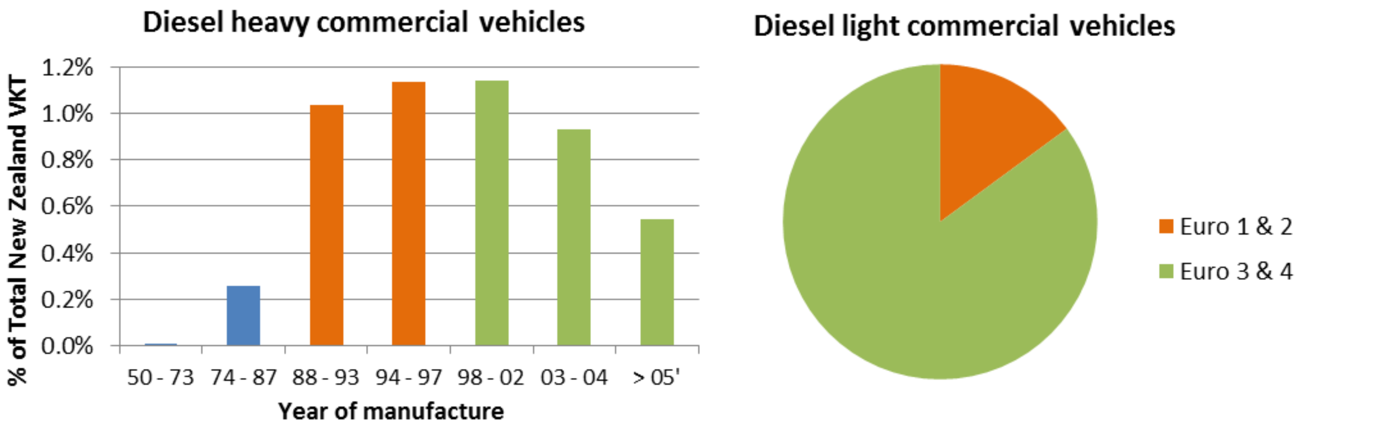

Figure 3-5 VEPM5.1 equivalent emission standard assumptions for Japanese diesel light commercial vehicles.

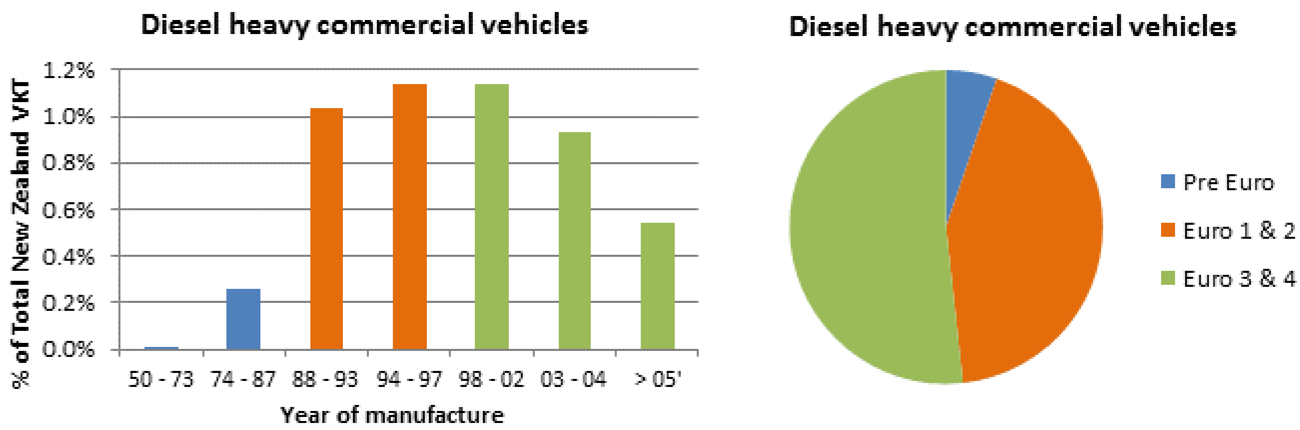

Figure 3-6 VEPM5.1 equivalent emission standard assumptions for Japanese heavy diesel vehicles.

Thus, the majority of Auckland's Japanese diesel cars are assumed to have emissions equivalent to pre-Euro emission standards, whereas the majority of diesel trucks are assumed to meet Euro III or IV emission standards. More detail on emission standards and the equivalency between Japanese and European vehicle emissions is provided in the vehicle emission prediction model technical reports (Kar *et al*. 2008; Jones *et al*. 2011).

3.1.2 Nitrogen oxides

The Auckland motor vehicle emissions inventory estimates total nitrogen oxides (NO_x) emissions from motor vehicles to be 8,675 tonnes per year for 2011. This accounts for approximately 48 per cent of emissions from all sources in the 2011 Auckland air emissions inventory (i.e. including domestic and industrial sources as well as transport). Figure 3-7 presents total nitrogen oxides emissions by fuel type.

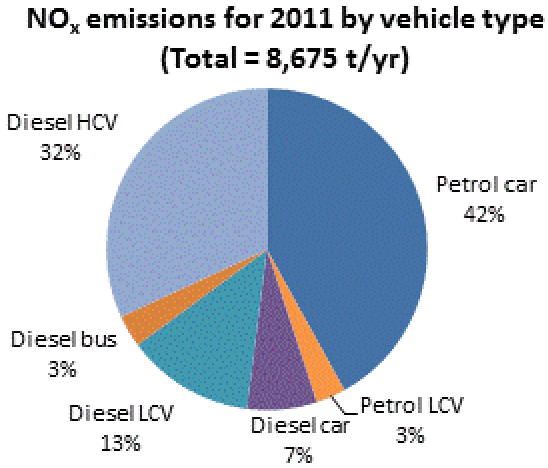

Figure 3-7 Motor vehicle total nitrogen oxides (NO_x) emissions (2011) by fuel type

The motor vehicle inventory for 2011 estimates that petrol cars emit only 42 per cent of NOx although they represent 71 per cent of vehicle kilometres travelled. Conversely, heavy diesel vehicles account for 32 per cent of NOx emissions although they represent only five per cent of vehicle kilometres travelled.

3.2 Results for 2001 and 2006

Motor vehicle PM_{10} emissions for 2001 and 2006 are presented in Figures 3-8 and 3-9 and then by vehicle kilometres travelled in Figure 3-10 and Figure 3-11. Figure 3-12 and 3-13 present motor vehicle total nitrogen oxides emissions for 2001 and 2006. Overall trends between 2001 and 2006 are discussed in Section 4.1.

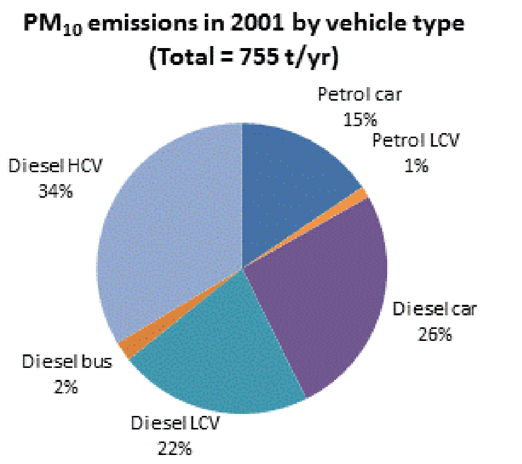

Figure 3-8 PM_{10} emissions (2001) by vehicle type

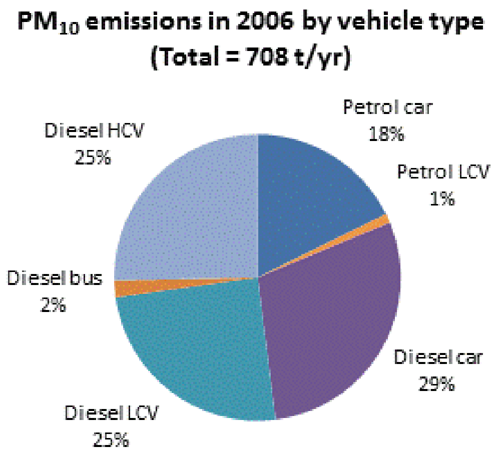

Figure 3-9 PM_{10} emissions (2006) by vehicle type

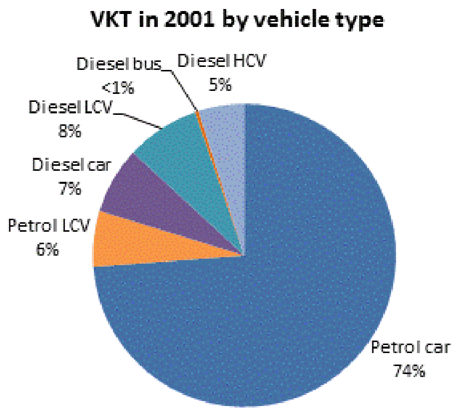

Figure 3-10 VKT (2001) by vehicle type

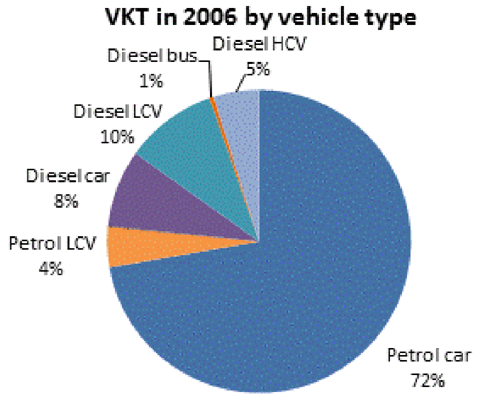

Figure 3-11 VKT (2006) by vehicle type

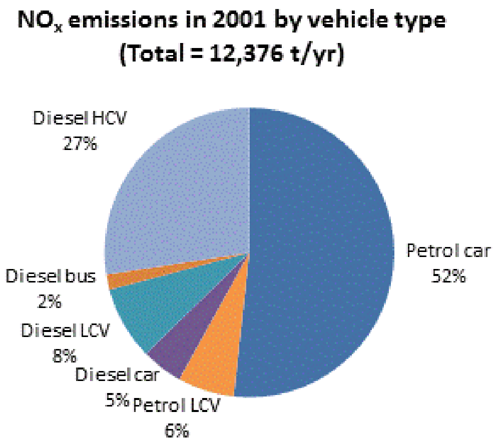

Figure 3-12 NOx emissions (2001) by vehicle type

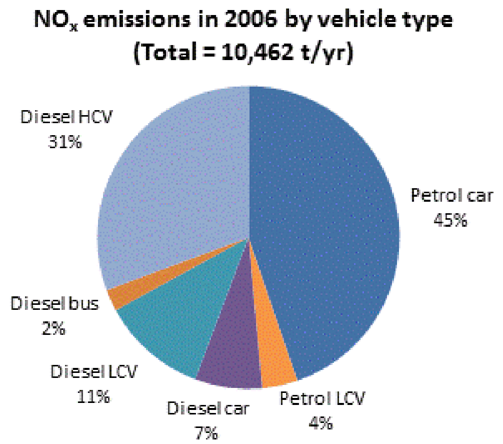

Figure 3-13 NOx emissions (2006) by vehicle type

3.3 Results for other pollutants

3.3.1 $PM_{2.5}$

Figure 3-14 shows estimated emissions of $PM_{2.5}$ from 2001 to 2011. In 2001, diesel vehicles (cars, light and heavy commercial vehicles) accounted for 87 per cent of $PM_{2.5}$ emissions, while petrol vehicles accounted for 13 per cent of estimated annual $PM_{2.5}$ emissions. Although the total overall $PM_{2.5}$ emissions have reduced since 2001 from approximately 700 tonnes per year to 525 tonnes per year in 2011, the contribution from some vehicle types have increased during this time.

Emissions from diesel heavy commercial vehicles (including buses) are estimated to have decreased since 2001 with a nine per cent reduction in emissions between 2001 and 2006. This reduction in emissions is due to the introduction of the Land Transport Rule: Vehicle Exhaust Emissions in 2003, and the use of cleaner fuels which allowed for newer vehicle technology to enter the fleet (such as Euro III vehicles). However, $PM_{2.5}$ emissions from diesel light commercial vehicles increased especially between 2001 and 2011, while $PM_{2.5}$ emissions from diesel cars increased between 2001 and 2006, but decreased again between 2006 and 2011. Meanwhile, emission contributions from petrol cars have slowly increased with petrol cars accounting for only 12 per cent in 2001 but increasing to 16 per cent in 2011.

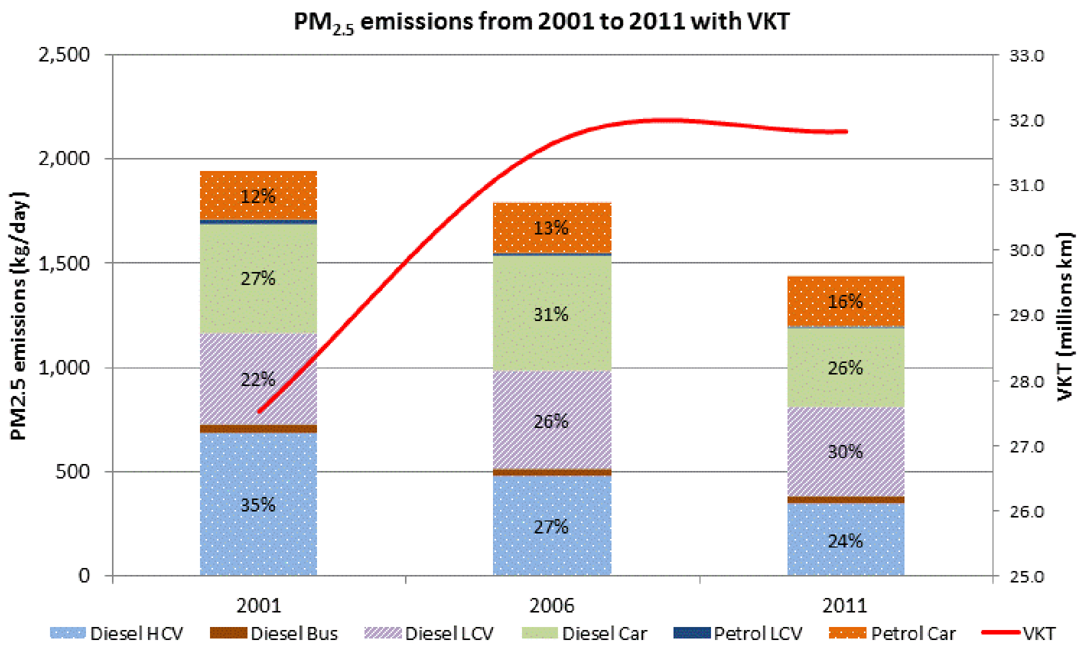

Figure 3-14 $PM_{2.5}$ emissions from 2001 to 2011 and vehicle kilometres travelled.

3.3.2 Carbon monoxide

Figure 3-15 shows emissions of carbon monoxide from 2001 to 2011. This shows that petrol vehicles account for the majority of carbon monoxide emissions with petrol cars consistently contributing approximately 88 to 89 per cent of annual carbon monoxide emissions. However, emissions have dropped 42 per cent from 2001 to 2011 with most of this reduction coming from petrol cars, primarily due to improvements in vehicle technology and fuel quality.

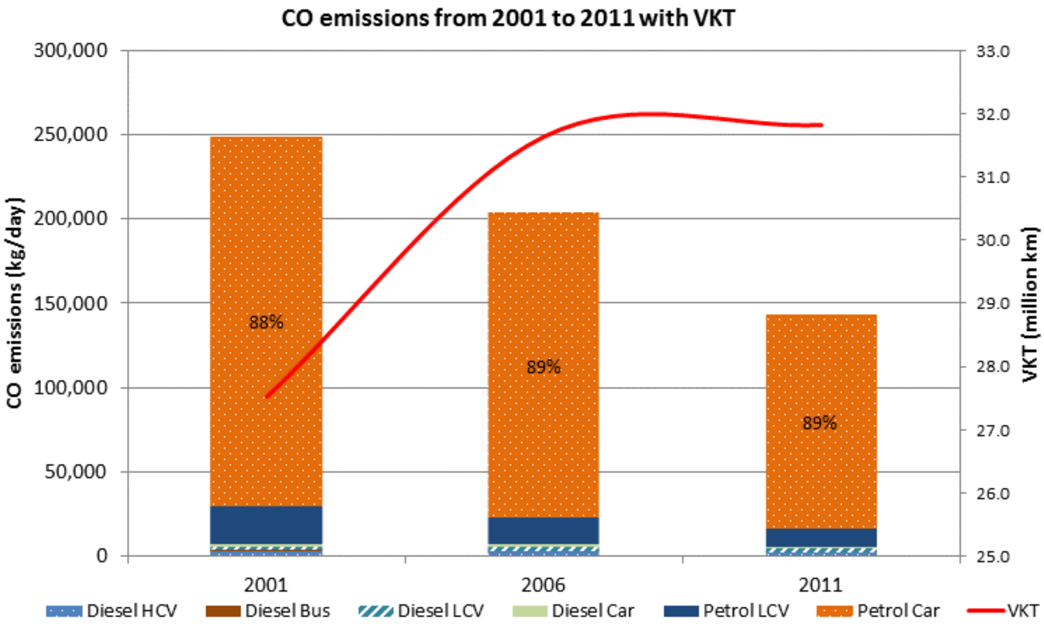

Figure 3-15 Carbon monoxide emissions from 2001 to 2011 and vehicle kilometres travelled.

3.3.3 Sulphur dioxide

Emissions of sulphur dioxide have reduced significantly since 2001 as shown in Figure 3-16 from almost 6,000 kg/day in 2001 to approximately 200 kg/day in 2011. Emissions dropped almost 89 per cent between 2001 and 2006 as a result of central government introducing regulations in 2002 reducing the sulphur content in petrol and diesel (see Table 2-1). The sulphur content in petrol and diesel was further reduced in 2006 which allowed for newer vehicle technology to enter the fleet (such as Euro 3 petrol and Euro IV diesel vehicle technology), which resulted in additional emissions reductions of sulphur dioxide between 2006 and 2011. The newer technology also reduces emissions of other contaminants.

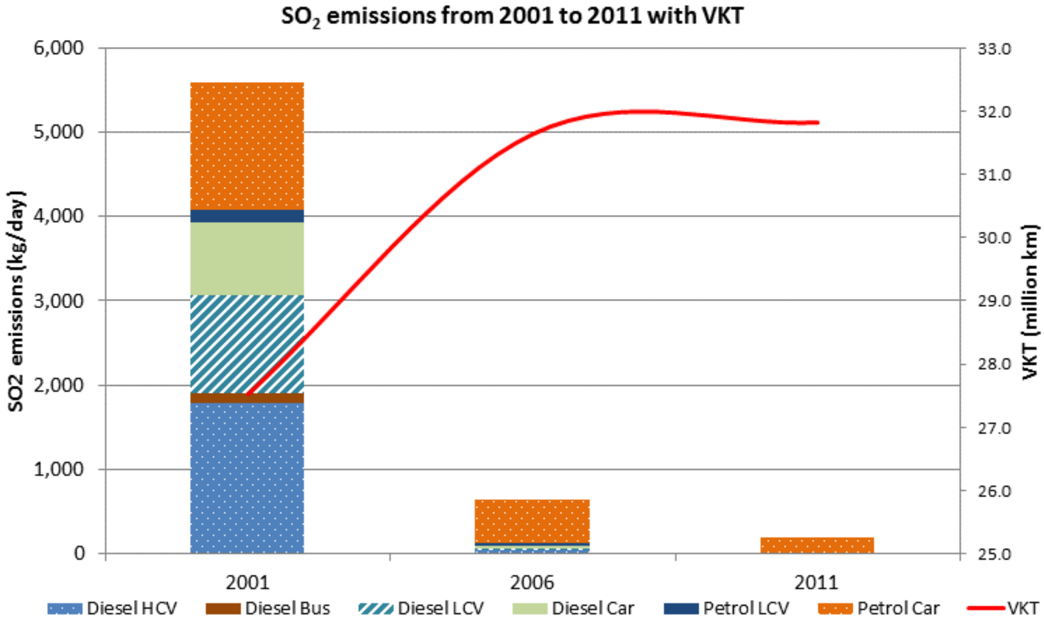

Figure 3-16 Sulphur dioxide emissions from 2001 to 2011 and vehicle kilometres travelled.

3.3.4 Volatile organic compounds

Figure 3-17 shows emissions of volatile organic compounds (VOCs) from 2001 to 2011. This shows that petrol vehicles again are the biggest contributor to VOC emissions with petrol cars accounting for an average of 79 per cent of emissions for each inventory year. VOC emissions have reduced 53 per cent between 2001 and 2011 since the introduction of fuel regulations in reducing the amount of benzene (a type of VOC) and other aromatic compounds in petrol. Additionally, more modern vehicles also have reduced emissions of VOCs due to improved emissions standards.

3.4 Spatial distribution of pollutants

The spatial distribution of emissions from both PM_{10} and NOx for 2011 is shown in Figure 3-18 and Figure 3-19 respectively. The maps clearly show that emissions are higher along state highways and regional arterial routes (Auckland Regional Transport Authority, 2009) with approximately 65 per cent of total daily PM_{10} and almost 66 percent of total daily NOx emissions from all vehicles travelling along these roads. Almost 16 per cent of total daily PM_{10} and 23 per cent of total daily NOx emissions along these routes are estimated to be specifically from diesel heavy commercial vehicles.

Spatial analysis of emissions estimates also indicates that approximately 71 per cent of total daily PM_{10} emissions and approximately 70 per cent of total daily NOx emissions are from vehicles travelling on roads within the urban airshed (which includes urban Auckland, North Shore and Whangaparaoa). This means that the impacts from exposure to these emissions could potentially be much higher, especially for sensitive populations living or working near the state highway/arterial routes or urban roads.

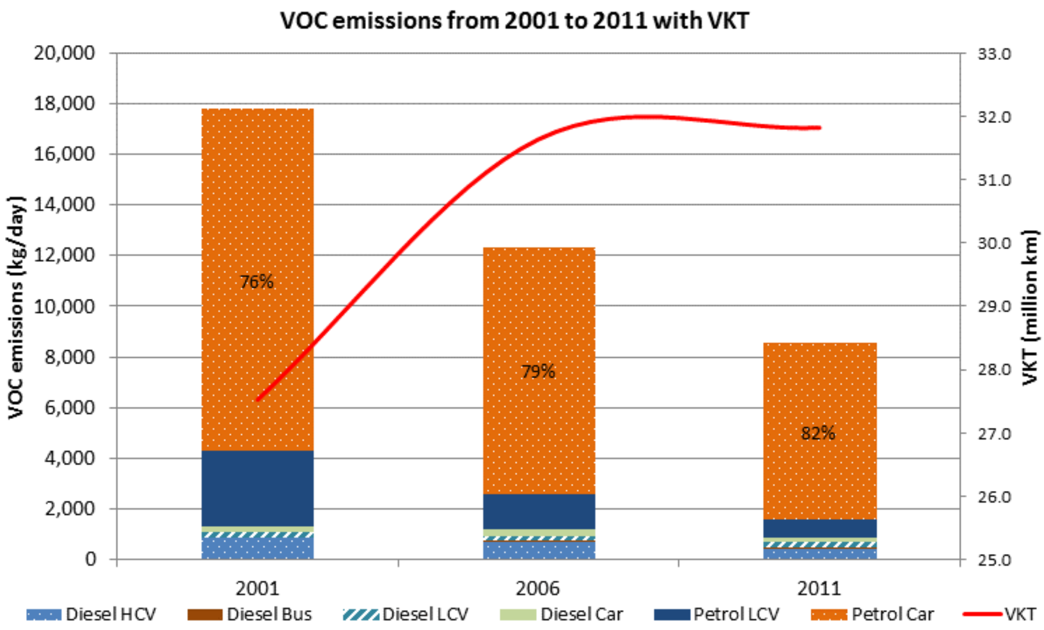

Figure 3-17 VOC emissions from 2001 to 2011 and vehicle kilometres travelled.

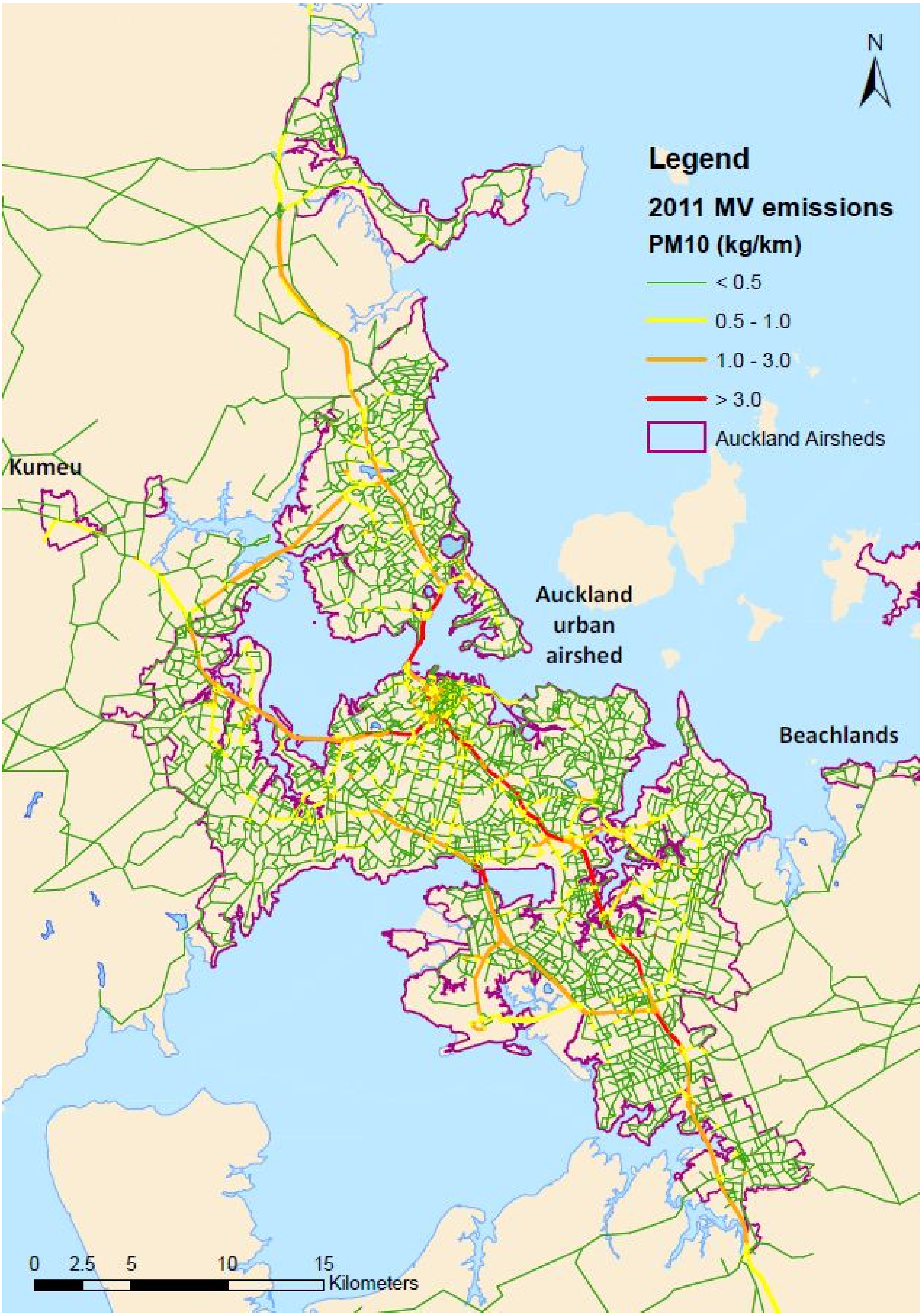

Figure 3-18 Spatial distribution of total daily PM_{10} emissions in 2011.

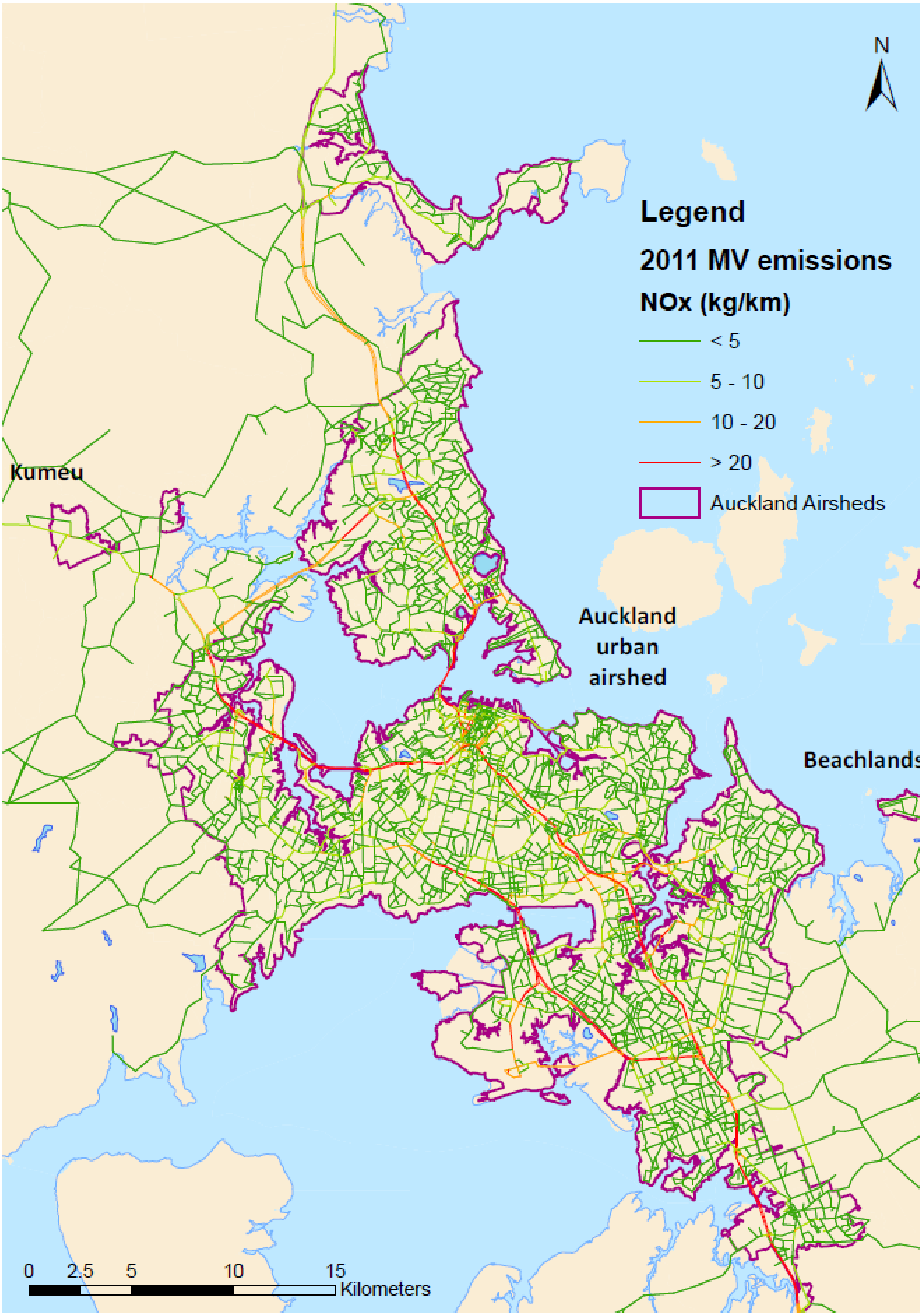

Figure 3-19 Spatial distribution of total daily NOx emissions in 2011.

4.0 Analyses of results

4.1 Comparisons with monitoring data

4.1.1 PM_{10}

This section compares ambient data from traffic monitoring sites (only) with the modelled vehicle emissions estimates. Other sites will be more heavily influenced by other sources of PM_{10}, particularly domestic sources and industry.

Table 4-1 compares modelled PM_{10} vehicle emissions for 2001, 2006 and 2011. This shows that despite a 16 per cent increase in vehicle kilometres travelled between 2001 and 2011, and an increase in the proportion of diesel vehicles, PM_{10} emissions have decreased by 23 per cent. The reason, also evident from Table 4-1, is a 29 per cent drop in PM_{10} vehicle exhaust emissions.

Table 4-1 Trends in PM_{10} emissions

Year	VKT (million km/yr)	% of VKT from diesel vehicles	PM_{10} (t/yr)		
			Exhaust	Brake and Tyre	Total
2001	10,046	20%	656	99	755
2006	11,548	23%	594	114	708
2011	11,614	25%	463	115	578

PM_{10} emissions from vehicles contribute approximately 20 per cent of the regional total of anthropogenic emissions.[5] Emissions from motor vehicles will have higher impacts at peak traffic monitoring sites, so the 23 per cent reduction in vehicle PM_{10} emissions from 2001 to 2011 estimated in this inventory could be reflected in ambient PM_{10} concentrations monitored at these sites. However, source apportionment undertaken by Auckland Council indicates that approximately only 30 per cent of PM_{10} is generated by motor vehicles at monitoring sites (GNS, 2011), and therefore the emissions reductions estimated here may not be seen in the ambient PM_{10} monitored levels.

Figure 4-1 plots annual average PM_{10} for Auckland traffic impacted air quality monitoring sites between 1998 and 2012 compared with modelled vehicle PM_{10} emissions estimates for 2001, 2006 and 2011. Figure 4-1 suggests a reduction in ambient PM_{10} measured at the Queen Street and Khyber Pass peak monitoring sites in Auckland, particularly between 2000 and 2003. There are several factors contributing to the reduction in PM_{10} concentrations at Khyber Pass and Queen Street. These include the emission reduction

[5] Natural sources (such as sea salt) also contribute to regional PM_{10} concentrations.

from the vehicle fleet, particularly due to changes in emission standards which introduced progressive reductions in the sulphur content of diesel fuel in the early 2000s. Sulphate particulate matter is produced during the combustion of fuels (such as petrol and diesel), so any reduction in fuel sulphur immediately reduces the amount of sulphates produced (Walsh, 2014). Significant local changes in the transport network both at Khyber Pass and Queen Street (such as the Grafton Gully Project motorway improvements and local improvements at Queen Street) also contributed to the reduction in ambient PM_{10} concentrations. However, the long-term, overall trend in ambient concentrations between 2001 and 2011 is less pronounced.

Figure 4-2 presents estimated (modelled) vehicle PM_{10} emissions against Auckland Council's Auckland Plan emissions target of reducing PM_{10} emissions in the Auckland region by 50 per cent (based on 2006 levels) by 2016. As shown in Figure 4-2, PM_{10} emissions from motor vehicles need to further reduce by almost 40 per cent (compared to 2011 levels, or 32% from 2006 levels) in order to achieve the targets set in the Auckland Plan.

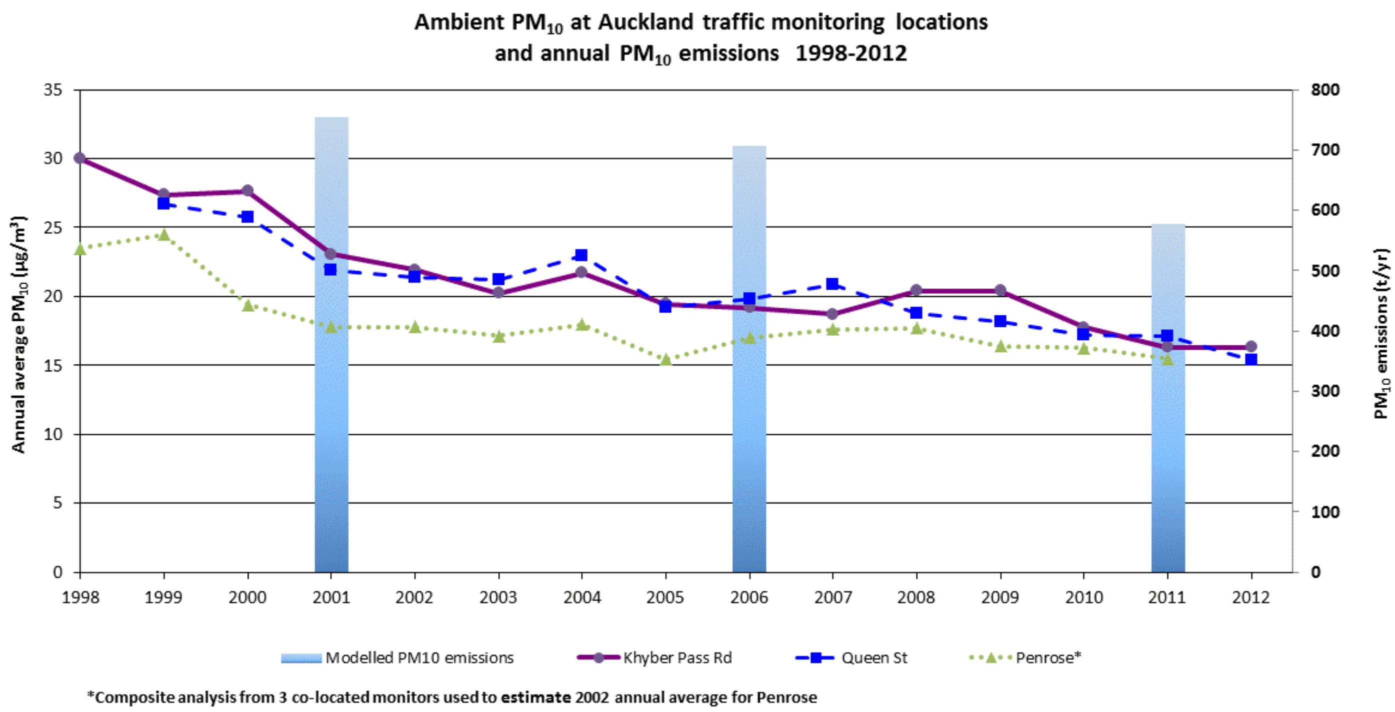

Figure 4-1 Measured PM_{10} concentrations compared with modelled vehicle PM_{10} emission estimates at Auckland traffic sites 1998 to 2012 (there were some changes of the locations of the Penrose site).

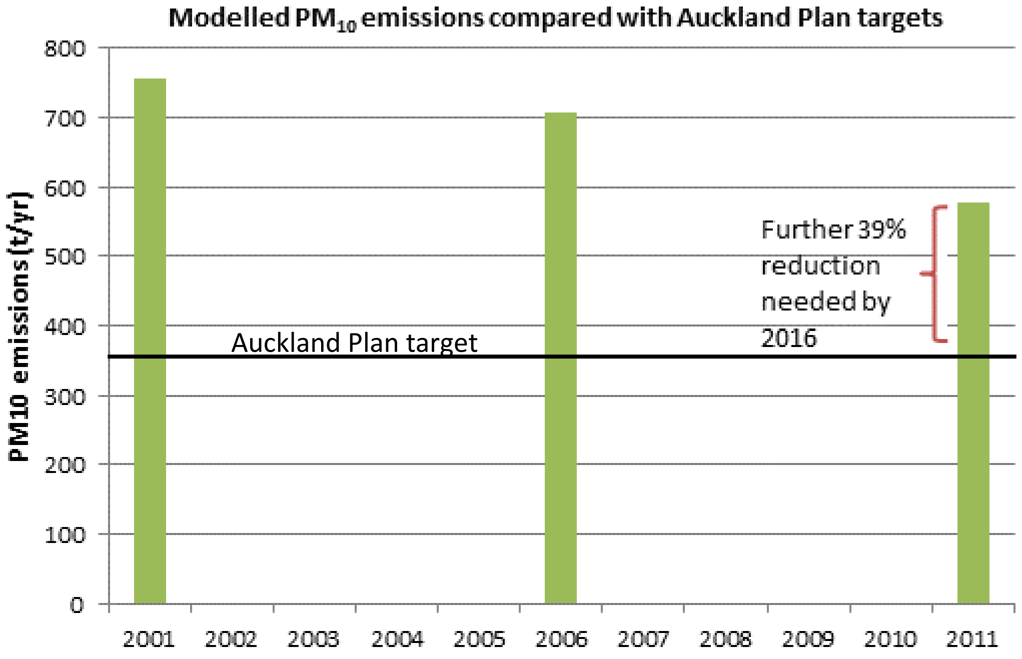

Figure 4-2 Modelled vehicle PM_{10} emission estimates (2001, 2006, 2011) compared with Auckland Plan targets.

4.1.2 Nitrogen oxides

Table 4-2 provides total nitrogen oxides (NO_x) emissions for 2001, 2006 and 2011. This shows that despite a 16 per cent increase in vehicle kilometres travelled between 2001 and 2011, estimated total nitrogen oxides emissions have decreased by 30 per cent.

Table 4-2 Trends in total nitrogen oxides (NO_x) emissions

Year	VKT (million kms)	NO_x (kg/day)
2001	10,046	12,376
2006	11,548	10,462
2011	11,614	8,675

It is estimated that total nitrogen oxides emissions from motor vehicles contribute approximately 45 per cent to regional total nitrogen oxides so a reduction of this magnitude should be seen in ambient total nitrogen oxides levels.

Figure 4-3 compares annual average, total nitrogen oxides for Auckland traffic impacted air quality monitoring sites between 1998 and 2012 with the modelled total nitrogen oxides emission estimates during this period. Figure 4-3 shows a drop in ambient total nitrogen oxides concentrations at the Khyber Pass and Queen Street monitoring sites that is similar in magnitude to the estimated drop in total nitrogen oxides emissions from vehicles.

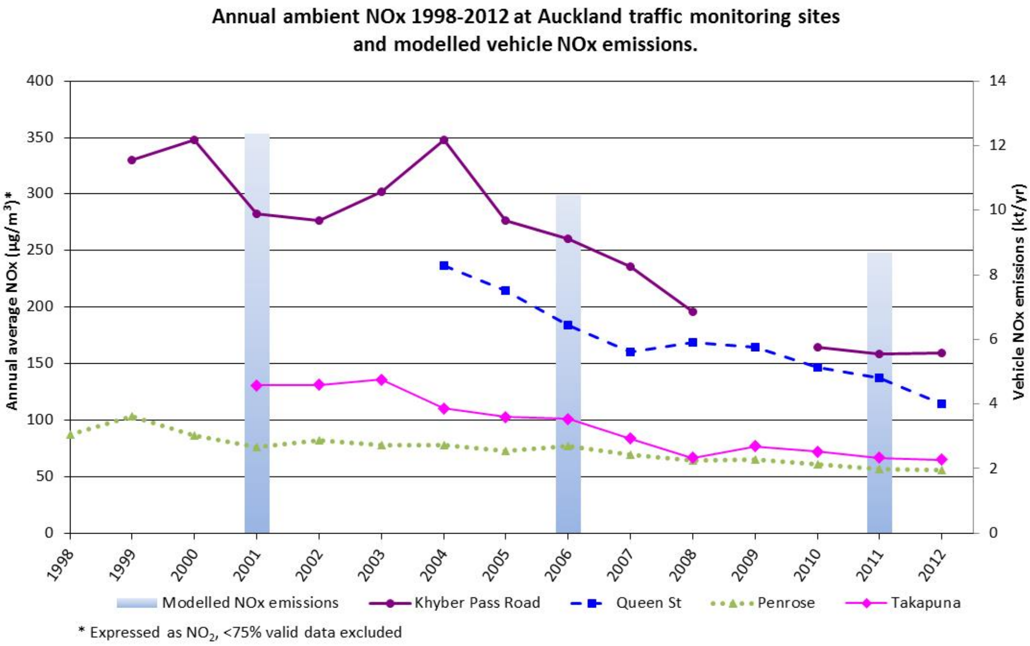

Figure 4-3 Measured ambient (NO_X) concentrations 1998 – 2012 at Auckland traffic sites compared with modelled vehicle emissions of total nitrogen oxides. Note: Penrose is located in an industrial area and is also impacted by industrial emissions.

In Auckland, the results of remote sensing also suggest that emissions of nitrogen oxide are not reducing in accordance with the emission inventory estimates. A report by the Auckland Council concluded that (Auckland Council, 2012b):

- Nitric oxide (NO) emissions improvements may have plateaued (especially from diesel vehicles) which is of concern with many urban environments showing steady or even increasing levels of ambient nitrogen dioxide (NO_2).
- The aging vehicle fleet is also a concern because much of the improvement observed in the fleet emissions is due to new lower emitting vehicles entering the fleet.
- While per vehicle average emissions are reducing, the number of vehicles in New Zealand and the distance they are being driven is increasing and driving conditions are becoming more congested, especially in the urban areas.

Therefore it is likely that at least some of the individual vehicle emissions improvements are being eroded by the other factors that influence the total amount of emissions being discharged by New Zealand's light duty vehicle fleet.

It is noted that similar trends (i.e. large estimated reductions in vehicle emissions of total nitrogen oxides but no corresponding reduction in ambient nitrogen dioxide levels) have been observed overseas. A recent review in the UK found that ambient concentrations of total nitrogen oxides and nitrogen dioxide have not decreased by as much as suggested by current emission factors (Carslaw *et al*. 2011). This review also found that total nitrogen oxides emission estimates based on remote sensing are higher than suggested by the emission factors that are used in this emissions inventory.

Trends in the fraction of nitrogen dioxide in vehicle exhaust total nitrogen oxides are also important. In the UK, the fraction of nitrogen dioxide in total nitrogen oxides exhaust has increased from around five per cent to seven per cent in 1996 to 15 per cent to 16 per cent in 2009 (Carslaw et al. 2011).

Figure 4-7 shows annual total nitrogen oxides and nitrogen dioxide at five Paris traffic sites between 1998 and 2008. Despite obvious and significant reductions in total nitrogen oxides emissions (which is assumed to be primarily due to regulatory induced reductions in vehicle emissions), there is no change in ambient nitrogen dioxide at all.

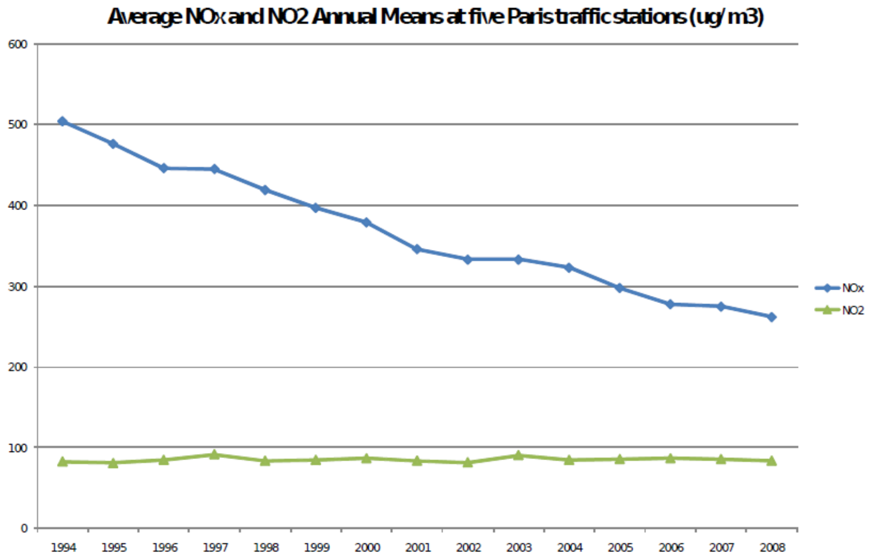

Figure 4-4 Measured ambient total nitrogen oxides (NO_x) and nitrogen dioxide (NO_2) concentrations at five Paris traffic sites 1998 – 2008.

There is some doubt over whether total nitrogen oxides emissions will continue to reduce in accordance with emission inventory predictions and there is also considerable uncertainty about the effect any measures to reduce total nitrogen oxides will have on ambient nitrogen dioxide concentrations.

Further investigation is required to estimate and understand likely nitrogen dioxide emission trends, but this analysis highlights the importance of on-going monitoring, investigation and validation to determine whether emission trends predicted by the inventory are realistic.

4.2 Uncertainty

Estimation of motor vehicle emissions for the emissions inventory relies on several models, each with its own limitations. Errors associated with the estimation of vehicle emissions are not easily quantified, however the following section provides some indication of the overall accuracy of the inventory by comparing estimated fuel consumption from the inventory with actual fuel sales.

4.2.1 Comparison with fuel sales figures

To provide a “reality check” of the emissions inventory, predicted fuel consumption can be compared with actual regional fuel sales. Table 4-3 shows that estimated petrol consumption is approximately 14 per cent less than reported petrol sales figures. Perfect agreement is not expected because of the uncertainties in the inventory. However, the relatively good agreement between the inventory estimates and the actual reported **petrol** consumption provides some confidence in the motor vehicle inventory estimates.

Table 4-3 also presents estimated diesel consumption against actual regional sales. Overall, the estimated consumption of diesel by motor vehicles is approximately 20 to 30 per cent less than total regional fuel sales.

Table 4-3 Actual regional fuel sales compared with fuel consumption estimated using the emissions inventory.

Year	Estimated fuel use			Actual fuel sales*			Difference		
	Petrol (ML/yr)	Diesel (ML/yr)	Total (ML/yr)	Petrol (ML/yr)	Diesel (ML/yr)	Total (ML/yr)	Petrol	Diesel	Total
2001	822	285	1,107	987	417	1,405	17%	32%	21%
2006	905	362	1,268	1,072	520	1,592	16%	30%	20%
2011	859	384	1,245	1,040	476	1,516	17%	19%	18%

* Auckland Council (2011)

This difference may be due to the off-road use of diesel. At a national level, the Ministry of Economic Development estimates that only 64 per cent of diesel is used for road transport with the remaining 36 per cent being used by other sectors including agriculture, industry, commercial and construction (OMS, 2008). Taking into account that off-road transport emissions are not calculated in this emissions inventory, the comparison of estimated diesel use with actual sales figures is, therefore, in very good agreement. However, this does highlight that the regional inventory for all sources may be underestimating emission estimates given the uncertainties around off-road diesel usage.

Figure 4-8 plots actual fuel sales against vehicle kilometres travelled. This shows that, in recent years, diesel consumption has dropped slightly whereas vehicle kilometres travelled has steadily increased. This is most likely due to a combination of factors such as the global recession of 2008/09 depressing construction and other off-road diesel use (EEA, 2014) as well as vehicles becoming more fuel efficient due to improved vehicle technology.

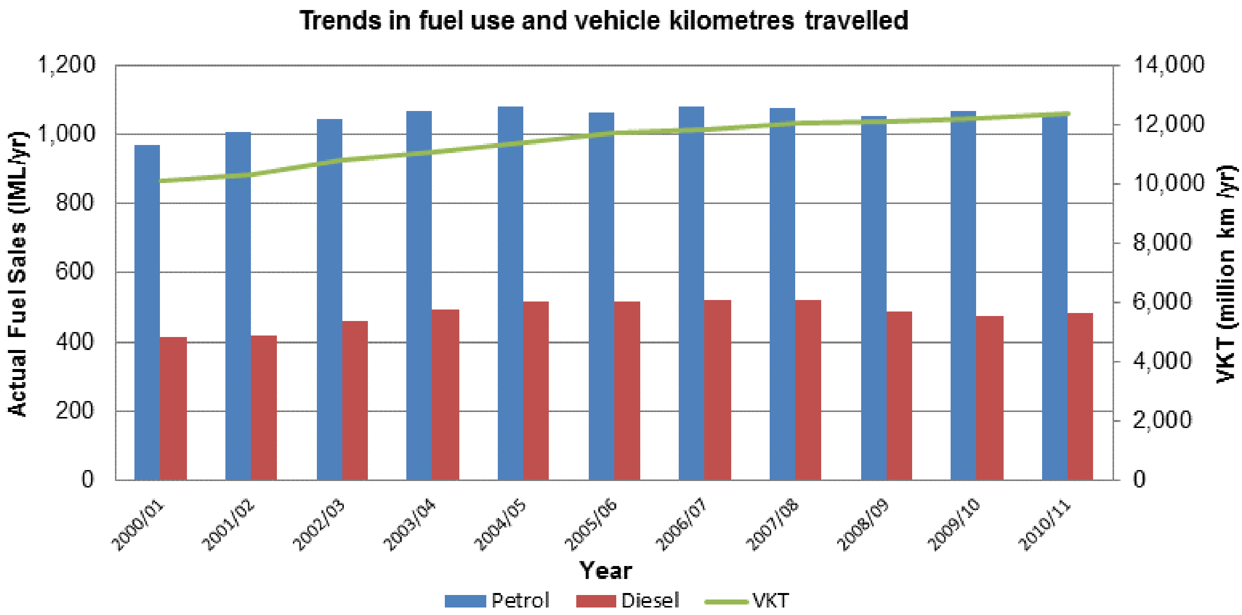

Figure 4-5 Trends in fuel consumption and Ministry of Transport estimates of vehicle kilometres travelled.

4.2.2 Uncertainty in trends

The significant reductions in vehicle emissions over the last 10 to 20 years has been driven by continual improvements in both vehicle technology and cleaner fuels. Newer vehicles discharge less air pollution per kilometre travelled than older vehicles. Auckland Council (2012b) noted that as fuel quality improves and as old vehicles are replaced by new in the New Zealand fleet, the amount of pollutants discharges on a **per vehicle** basis should (on average) also be reducing. However, it is unknown how much influence (if any) new technology and improved fuel is actually having on the 'real-world' emissions from light duty **vehicle fleet as a whole**.

This is because fleet emissions are also directly influenced by other factors such as fleet composition, the rate of turnover and the total vehicle kilometres travelled. Between 2003 and 2009 (NZTA 2011):

- the average age of vehicles increased;
- vehicle kilometres travelled increased; and
- the proportion of diesel vehicles increased.

These factors are likely to offset, to some extent, anticipated fleet emissions reductions. Trend analysis can, therefore, provide a reality check on the estimated vehicle emissions inventory.

In this case, trends in measured ambient levels of PM_{10} and nitrogen dioxide at some sites do not necessarily reflect predicted emissions. In the case of PM_{10}, this may simply be due to the influence of other (non-traffic) sources on ambient PM_{10} levels. With respect to nitrogen dioxide, data from the remote sensing campaign carried out by New Zealand Transport Agency suggest a levelling off in nitric oxide emissions. Similar trends have been reported overseas with monitored ambient concentrations of nitric oxide and nitrogen dioxide plateauing showing no further reductions despite there being significant reductions in overall total nitrogen oxide emissions.

4.3 Sensitivity analyses

The sensitivity of the motor vehicle emissions inventory to key input factors was analysed, the results of which are discussed in the following sections.

4.3.1 Effect of diesel vehicle proportion

Diesel vehicles emit disproportionately higher PM_{10} emissions per kilometre compared with petrol vehicles. Regional emissions are, therefore, sensitive to the proportion of diesel vehicles in the total vehicle kilometres travelled.

The estimated proportion of vehicle kilometres travelled from heavy commercial vehicles and buses in 2011 is 6.1 per cent. This is calculated based on Auckland regional transport model outputs.

The estimated proportion of vehicle kilometres travelled in the 2004 inventory by heavy commercial vehicles and buses was 8.1 per cent (Auckland Regional Council, 2006). This was calculated based on national fleet statistics. The national fleet statistics have been updated since the 2004 inventory was published. The national average proportion of heavy commercial vehicles in 2011 is now estimated as 6.8 per cent.

The sensitivity of the proportion of vehicle kilometres travelled from heavy commercial vehicles on emission predictions has been tested. Table 4-4 summarises 2011 emissions estimates based on the assumption that the proportion of vehicle kilometres travelled from heavy commercial vehicles is 8.1 per cent (equal to the proportion assumed in the 2004 inventory) and 6.8 per cent (equal to the national average for 2011).

Table 4-4 Sensitivity of estimated total emissions to proportion of heavy commercial vehicles

Scenario	Difference with respect to base case		
Per cent heavy commercial vehicles (base case = 6.1%)	PM_{10}	NO_x	Fuel consumption
8.1% heavy commercial vehicles	10%	14%	4%
6.8% heavy commercial vehicles	7%	9%	3%

The results show that, if the national average of 6.8 per cent heavy commercial vehicles is assumed, estimated PM_{10} emissions would be seven per cent higher, total nitrogen oxides emissions would be nine per cent higher and fuel consumption three per cent higher than the base case.

The 6.1 per cent proportion of heavy commercial diesel vehicles for 2011 from this inventory uses the Auckland regional transport model which is based on traffic count data and should be more realistic than the national fleet statistics (which were used in the 2004 inventory).

The proportion of vehicle kilometres travelled from light commercial diesel vehicles is assumed to be approximately 18 per cent in this motor vehicle inventory. The proportion of diesel vehicles measured on Auckland roads during remote sensing campaigns (NZTA, 2011) have shown good agreement with the Ministry of Transport figures, so the data used to estimate emissions in this inventory is considered realistic.

4.3.2 Effect of speed

The vehicle emission prediction model is a speed dependent model. This means that the emission factor is defined by the average speed of vehicles for the link under consideration. Figure 4-9 illustrates the variation of 2011 fleet weighted PM_{10} and total nitrogen oxides (NO_x) emissions with speed. This shows that emissions are sensitive to average speed.

The average speed along a link is defined by traffic model outputs. An emission factor for a defined average speed from VEPM is not representative of a vehicle travelling at steady speed (rather they are a composite of different driving conditions). The emissions factors used in VEPM have been obtained from international emission tests on a large number of vehicles of different types, sizes and technologies. The test cycles used were, on the whole, representative of real on-road driving conditions. Test cycles comprise periods of idle, acceleration, cruise and deceleration, as well as simulating down hills and up hills. The emissions factors therefore cover a wide range of road speeds around the average and should be reasonably representative of 'typical' emissions for an average speed.

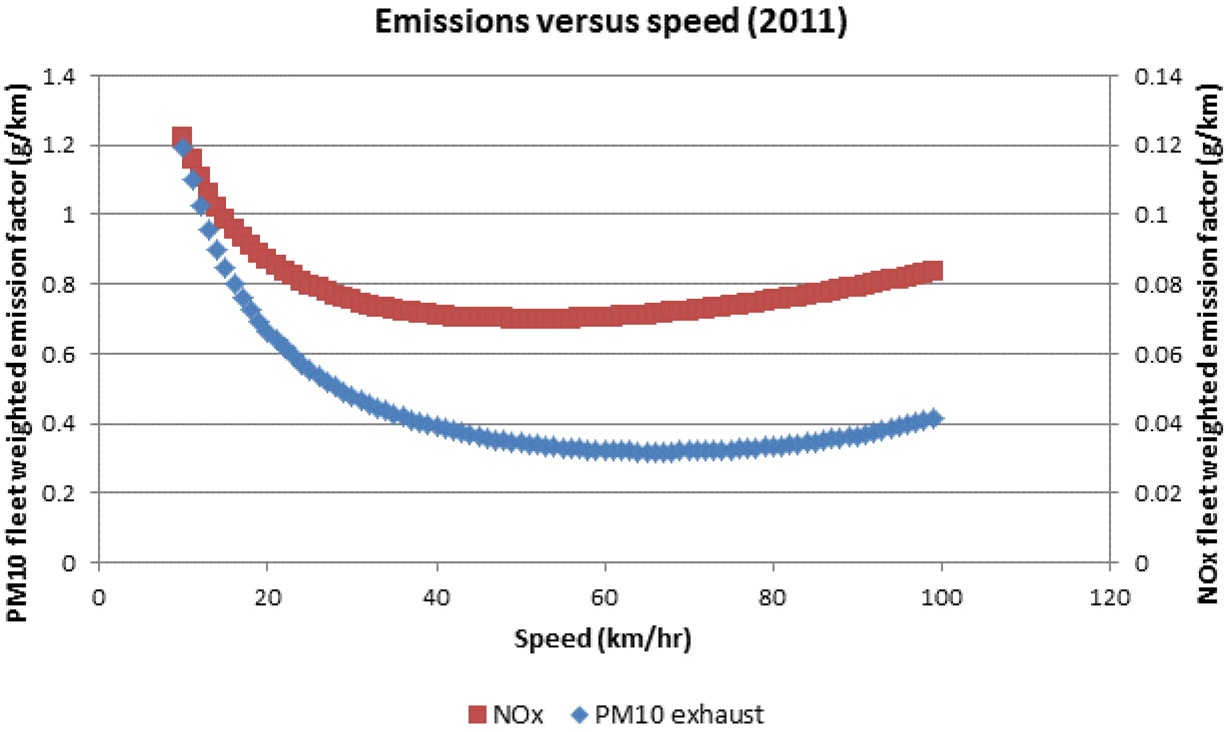

Figure 4-6 Variation of vehicle emissions with speed.

Average speed is defined in the emissions inventory by the Auckland regional transport model. This model is a regional scale model, which may not accurately reflect speeds on each link. The average speeds on each link could actually be lower than those defined by the Auckland regional transport model. It is therefore appropriate to test the sensitivity of the emissions inventory to changes in actual speeds of each link.

Table 4-5 summarises the results of sensitivity analysis for speeds that are significantly lower than the speeds defined by the Auckland regional transport model. In the first scenario the speed during morning and afternoon peaks was reduced by 30 per cent and speeds outside peak times were reduced by 10 per cent; as compared with the base case (as defined by the Auckland regional transport model). In the second scenario the speed during morning and afternoon peaks was reduced by 50 per cent and speeds outside peak times were reduced by 10 per cent.

Table 4-5 Sensitivity of estimated emissions to speed

Scenario	Difference with respect to Base Case		
Speed	PM_{10}	NO_x	Fuel Consumption
Peak 30% slower, off peak 10% slower	4%	-1%	3%
Peak 50% slower, off peak 10% slower	13%	0%	9%

This analysis suggests that, on a regional scale, emissions are not particularly sensitive to significant reductions in speed. This is because there is only a small amount of difference between emission factors for speeds ranging from approximately 30km/hour to 100 km/hour as seen in Figure 4-9. For example, the average morning speed for 2011 is 46 km/hour. If this speed is 50 per cent slower (i.e. at 23 km/hour), there is approximately 0.01 g/km difference in the emission factor for nitrogen oxides and approximately 1.2 g/km difference in PM_{10} emission factor.

4.3.3 Effect of gradient

The developers of the vehicle emissions prediction model (Jones *et al*. 2011) have undertaken analysis that shows that emissions from heavy commercial vehicles are sensitive to changes in road gradient. VEPM tests uphill and downhill cycles, however these are based on average vehicle speeds. Given that Auckland is relatively undulating, the gradient of a road can heavily influence vehicle speed and the speed based emission factor, which could have a significant effect on regional emissions and fuel consumption estimates.

Table 4-6 presents the results of changes in the assumed gradient for heavy commercial vehicles (only). This shows that emissions are highly sensitive to small changes in gradient. Further work is required to develop a method for consideration of gradient in the Auckland inventory.

Table 4-6 Sensitivity of estimated emissions to gradient

Scenario	Difference with respect to base case		
Gradient heavy commercial vehicles (Base case = 0%)	PM_{10}	NO_x	Fuel consumption
Average +2% and – 2%	0%	+6%	+5%
Average +4% and – 4%	+18%	+32%	+36%

5.0 Conclusions and recommendations

The Auckland air emissions inventory identifies key emission sources and how they change over space and time. Over the last few decades both regional and central government have undertaken major initiatives to address air quality from transport which has resulted in a gradual reduction of emissions per vehicle. This Auckland motor vehicle emissions inventory updates emissions estimates for 2011 using the most recent data available along with updated emission factors.

The Auckland motor vehicle emissions inventory estimates the following:

PM_{10}

- PM_{10} emissions from motor vehicles are 578 tonnes per year of which:
  - Diesel exhaust emissions account for 72 per cent;
  - Diesel cars account for 25 per cent of PM_{10} emissions despite representing only eight per cent of vehicle kilometres travelled;
  - Diesel light commercial vehicles account for 28 per cent PM_{10} emissions despite representing only 10 per cent vehicle kilometres travelled; and
  - Diesel heavy commercial vehicles account for 23 per cent of PM_{10} emissions, despite representing only five per cent of vehicle kilometres travelled.
- The primary contributor to PM_{10} emissions from motor vehicles is diesel combustion and this remains relatively constant over the period under investigation. It was 83 per cent in 2001, 81 per cent in 2006 and 78 per cent in 2011.
- Improvements in diesel vehicle technology have improved significantly over this period. Estimated PM_{10} emissions from heavy commercial vehicles in 2011 are approximately 145 tonnes per annum which is 45 per cent of 2001 PM_{10} emissions.

Total nitrogen oxides

- NO_x emissions from motor vehicles are 8,675 tonnes per year.
  - Diesel exhaust emissions account for 55 per cent of motor vehicle NO_x emissions despite representing only 25 per cent of vehicle kilometres travelled.
  - Diesel heavy commercial vehicles account for 35 per cent of NO_x emissions although they represent only six per cent of vehicle kilometres travelled.
- Petrol cars are the primary contributor to total nitrogen oxides emissions from motor vehicles although this is dropping due to improved emissions control.

Petrol cars contributed 52 per cent of total nitrogen oxides emissions in 2001, 45 per cent in 2006 and 42 per cent in 2011.

- Diesel cars and diesel light commercial vehicles are increasing in importance with respect to total nitrogen oxides emissions from motor vehicles. The contribution of diesel cars and light commercial vehicles to total nitrogen oxides emissions grew from 13 per cent in 2001 to 18 per cent in 2006 and 20 per cent in 2011.
- Despite a 16 per cent increase in vehicle kilometres travelled between 2001 and 2011, total nitrogen oxides emissions are estimated to have decreased by 30 per cent during this period. Vehicle emissions are estimated to contribute approximately 45 per cent to regional total nitrogen oxides. Total nitrogen oxides measured at traffic monitoring sites in Auckland show a visible reduction that is consistent with the estimated reduction in total nitrogen oxides emissions from vehicles during this period.

Uncertainty and sensitivity analysis

- A comparison of inventory estimates with actual reported **petrol** consumption has yielded a relatively good agreement. This provides some confidence in the 2011 motor vehicle inventory.
- Whilst the trends in measured ambient levels of some pollutants do not necessarily reflect predicted emissions, possible explanations are available. These give confidence that emissions inventory is within reasonable bounds.
  - In the case of PM_{10}, this may simply be due to the influence of other (non-traffic) sources on ambient PM_{10} levels.
  - Data from the remote sensing campaign carried out by the Auckland Council and the New Zealand Transport Agency suggests a levelling off in nitric oxide emissions. Similar trends have been reported overseas with plateaued nitric oxide and nitrogen dioxide levels despite significant reductions in total nitrogen oxides emissions.
- A sensitivity analysis on key variables yielded the following insights:
  - Emissions of PM_{10} and total nitrogen oxides are fairly sensitive to the assumed proportion of diesel vehicles. A relatively modest increase of the assumed proportion of diesel vehicles results in an increase of seven per cent in estimated PM_{10} emissions and an increase of nine per cent in estimated total nitrogen oxides emissions.
  - On a regional scale, emissions are not particularly sensitive to significant reductions in speed.
  - Emissions estimates for PM_{10} and total nitrogen oxides are highly sensitive to small changes in gradient. Given Auckland’s undulating topography, this could be significant.

Recommendations

- This analysis highlights the importance of on-going monitoring, investigation and validation to determine whether emission trends predicted by the inventory are realistic; and
- Emissions are highly sensitive to small changes in gradient. Further work is required to develop a method for consideration of gradient in the Auckland inventory.

Overall Conclusions

- Diesel vehicles remain disproportionate polluters for both PM_{10} and NO_x.
- Overall $PM_{2.5}$ emissions have reduced but emissions from petrol cars and diesel LCVs have increased.
- The effect of the aging Auckland diesel car fleet and the effect of implementing light diesel vehicle standards in 2007 means that in 2011, a diesel car is estimated to produce almost half as much PM_{10} emissions as a diesel truck.
- Measured levels of ambient total nitrogen oxides show a visible reduction in line with estimated emissions reductions from motor vehicles.
- The spatial distribution of emissions indicates that the majority of daily emissions are generated by vehicles travelling along the state highway network and regional arterial routes.

6.0 Acknowledgements

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8.0 Glossary

Term	Definition
AC	Auckland Council formed on 1 November 2010
ARC	Auckland Regional Council which merged with four city councils and three district councils in the Auckland region to form the Auckland Council on 1 November 2010.
ART	Auckland Regional Transport model
CO	Carbon monoxide
CO_2	Carbon dioxide
COPERT	COmputer Programme to calculate Emissions from Road Transport, the technical development of which is managed by the European Environment Agency
Euro	European vehicle emission standards, the stages of which are referred to with Roman numerals (e.g. Euro V, Euro VI) for heavy duty vehicle standards, and Arabic numerals (e.g. Euro 5, Euro 6) for light duty vehicle standards.
HCV	Heavy commercial vehicles
LCV	Light commercial vehicles
Link	Spatial representation of actual road segments in the Auckland Regional Transport model
MED	Ministry for Economic Development, which merged with three other ministries to form the Ministry of Business, Innovation and Employment on 1 July 2012.
MfE	Ministry for the Environment
MoT	Ministry of Transport
NESAQ	National environmental standards for air quality developed in 2004.
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NZTA	New Zealand Transport Agency formed on 1 August 2008 from merging Transit New Zealand and Land Transport New Zealand.
PM_{10}	Particulate matter measuring less than 10 micrometres in size.
$PM_{2.5}$	Particulate matter measuring less than 2.5 micrometres in size.
SO_2	Sulphur dioxide
VEPM	Vehicle Emissions Prediction Model
VFEM	Vehicle Fleet Emissions Model
VKT	Vehicle kilometres travelled
VOCs	Volatile organic compounds

Appendix A: Tabulated results 2001 - 2011

Auckland region

Motor vehicle inventory results for the Auckland region are shown in Table A-1 (2001), Table A-2 (2006) and Table A-3 (2011).

Table A-1 Motor vehicle emissions estimates for 2001 in the Auckland region

2001															
Vehicle type	Fuel type	VKT	% Total VKT	CO	CO_2	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	PM_{10} Exhaust	PM_{10} Brake and Tyre	$PM_{2.5}$ Exhaust	$PM_{2.5}$ Brake and Tyre	Fuel Consumption
		Million kms/day		kg/day	t/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day
Car	Petrol	20.3	73.8%	218,862	4,433	17,542	1,523	13,499	322	232	126	196	126	106	2,051,018
Light commercial	Petrol	1.6	6.0%	23,033	427	2,137	149	2,988	26	19	10	16	10	9	200,181
Hybrid and Electric*	Petrol	0.0	0.0%	0	0	0	0	0	0	0	0	0	0	0	0
Car	Diesel	2.0	7.1%	1,135	451	1,571	862	220	535	526	516	19	516	10	171,822
Light commercial	Diesel	2.2	7.9%	2,286	608	2,779	1,161	185	446	436	425	21	425	11	231,536
Bus	Diesel	0.1	0.4%	224	57	577	109	43	45	45	44	1	44	1	21,772
Heavy	Diesel	1.3	4.9%	2,961	937	9,300	1,786	825	694	686	676	18	676	10	356,000
Total		27.5	100%	248,501	6,913	33,907	5,590	17,761	2,067	1,944	1,796	271	1,796	147	3,032,330
Annual															
		VKT (Million kms/yr)		t/yr	kt/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr
Total		10,046		90,703	2,523	12,376	2,040	6,483	755	709	656	99	656	54	1,107
Total petrol		8,012	79.8%	88,291	1,774	7,183	610	6,018	127	92	50	77	50	42	822
Total diesel		2,034	20.2%	2,411	749	5,193	1,430	465	628	618	606	22	606	12	285

* There were no hybrids or electrics cars in the fleet in 2001

Table A-2 Motor vehicle emissions estimates for 2006 in the Auckland region

2006															
Vehicle type	Fuel type	VKT	% Total VKT	CO	CO_2	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	PM_{10} Exhaust	PM_{10} Brake and Tyre	$PM_{2.5}$ Exhaust	$PM_{2.5}$ Brake and Tyre	Fuel Consumption
		Million kms/day		kg/day	t/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day
Car	Petrol	22.9	72.3%	180,676	5,071	12,831	516	9,737	343	242	123	220	123	120	2,316,023
Light commercial	Petrol	1.4	4.3%	16,079	355	1,080	37	1,424	20	14	7	13	7	7	164,336
Hybrid and Electric	Petrol	0.0	0.1%	0.9	2.2	0.3	0.1	0.0	0.2	0.1	0.0	0.2	0.0	0.1	974
Car	Diesel	2.6	8.2%	1,180	619	2,057	20	240	568	556	543	25	543	14	235,594
Light commercial	Diesel	3.1	9.9%	2,584	872	3,245	28	190	481	467	451	30	451	16	331,500
Bus	Diesel	0.1	0.4%	256	74	662	2	46	36	36	35	2	35	1	28,255
Heavy	Diesel	1.5	4.8%	2,715	1,047	8,789	33	683	491	482	470	21	470	11	397,074
Total		31.6	100%	203,491	8,041	28,664	636	12,320	1,939	1,797	1,627	312	1,627	169	3,473,757
Annual															
		VKT (Million kms/yr)		t/yr	kt/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr
Total		11,548		74,274	2,935	10,462	232	4,497	708	656	594	114	594	62	1,268
Total petrol		8,849	76.6%	71,816	1,981	5,078	202	4,074	133	94	47	85	47	46	906
Total diesel		2,699	23.4%	2,458	954	5,385	30	423	575	562	547	28	547	15	362

Table A-3 Motor vehicle emissions estimates for 2011 in the Auckland region

2011															
Vehicle type	Fuel type	VKT	% Total VKT	CO	CO_2	NO_x	SO_2	VOC	PM_{10}	$PM_{2.5}$	PM_{10} Exhaust	PM_{10} Brake and Tyre	$PM_{2.5}$ Exhaust	$PM_{2.5}$ Brake and Tyre	Fuel Consumption
		Million kms/day		kg/day	t/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	kg/day	Litres/day
Car	Petrol	22.5	70.8%	127,119	4,902	9,975	165	6,952	336	237	118	217	118	118	2,217,510
Light commercial	Petrol	1.1	3.6%	11,113	298	714	10	733	15	10	4	11	4	6	137,095
Hybrid and Electric	Petrol	0.1	0.3%	3.3	8.9	1.1	0.1	0.1	0.8	0.5	0.0	0.8	0.0	0.5	3,869
Car	Diesel	2.4	7.6%	854	539	1,670	3	181	389	378	366	23	366	13	204,896
Light commercial	Diesel	3.7	11.6%	2,194	1,000	3,065	6	202	445	429	410	35	410	19	379,871
Bus	Diesel	0.2	0.6%	267	101	770	1	45	39	37	36	2	36	1	37,819
Heavy	Diesel	1.8	5.5%	1,835	1,151	7,573	7	417	358	347	334	24	334	13	430,419
Total		31.8	100%	143,385	8,000	23,768	193	8,530	1,583	1,440	1,269	314	1,269	171	3,411,478
Annual															
		VKT (Million kms/yr)		t/yr	kt/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	t/yr	ML/yr
Total		11,614		52,335	2,920	8,675	70	3,114	578	525	463	115	463	62	1,245
Total petrol		8,678	74.4%	50,456	1,902	3,902	64	2,805	129	90	45	84	45	45	859
Total diesel		2,936	25.3%	1,879	1,019	4,774	6	308	449	435	418	31	418	17	384