Separation Distances for Roads

A discussion document

Prepared for Auckland Council

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Executive Summary

This report investigates the use of air quality separation distances (buffer zones), for roads and motorways in the Auckland Unitary Plan (currently under preparation).

It reviews and updates information on the adverse effects caused by air pollution and associated with vehicle emissions. This provides sobering and compelling data:

- There is a widespread consensus that air pollution causes adverse health effects. These effects range from increased prevalence of asthma and wheeze to adverse pregnancy outcomes (such as child mortality and low birth weight) and premature mortality.
- There is also a strong body of evidence that residential proximity to traffic is associated with adverse health effects. Whilst the studies stop short of determining causality (between the proximity to roads and adverse health effects), we consider it to be a reasonable hypothesis.
- Notably, where investigated, a recurring feature of the studies was the disproportionate exposure of disadvantaged sectors of the population to traffic pollution with associated disproportionate adverse health effects. In other words, poorer people tend to live closer to roads and suffer more adverse health effects.
- We conclude that residential proximity to traffic is associated with adverse health effects and poses a public health threat in Auckland.

This report reviews the existing regulatory framework for roads and air quality in Auckland and looks at other approaches adopted in the US, Canada and Australia with a view to recommending separation distances (ie, buffers). In doing so we are mindful of the fact that the majority of roads in Auckland are already built.

We also note the following Auckland context:

- air quality consistently approaches, and sometimes exceeds, regional targets and national standards for air quality. This means that whilst exceedances are not regular, background levels are regularly elevated (i.e. annual public exposure may be significant);

- asthma rates are high by international standards. The most recent health survey by the Ministry of Health indicates that one in seven children aged 2-14 years (15%) and one in nine adults (11%) had been diagnosed with asthma and were taking medication for this condition (Ministry of Health, 2008). This means a significant percentage of the Auckland population may be classified as vulnerable to air pollution.

- road freight is anticipated to dominate for the foreseeable future and is forecast to grow by over 65% by 2031 compared with 2006;

- even with significant increases in public transport patronage, the majority of trips will be made by private transport in the foreseeable future;

- there are 162 early childhood centres within either 70 m of a regional arterial route or 150 m of a strategic route in Auckland. For an average 25 children in each centre, this equates to around 4,000 babies, infants and children exposed to elevated levels of air pollution from traffic for just under 20 hours per week.

- there are 52 schools that are within 70 m of a regional arterial route or 150 m of a strategic route in Auckland. This is around 35,000 children exposed to elevated levels of air pollution from traffic for at least 30 hours per week.

- nearly 50,000 people, around 4%, of the Auckland population, live 70 m of a regional arterial route or 150 m of a strategic route in Auckland. These figures are based on 2006 census data and will have increased since that time.

- the EPA recently approved a new motorway extension to pass within 20 m of a house.

We note the difficulties in selecting separation distances that are protective of human health yet do not ‘sterilise’ land required to meet the mixed use, higher density development targets specified in the Auckland Growth Concept. Separation distances, by their very nature, conflict directly with a compact urban form and the need to avoid community severance.

We conclude that separation distances should be a ‘secondary’ strategy for air quality management. Separation distances can only limit or minimise, as far as reasonably practicable, the impact of vehicle emissions on human health whereas primary strategies (e.g. vehicle emissions controls) can directly reduce impacts on human health.

Primary strategies for air quality management should, of necessity, take priority.

We undertook conservative screening modelling of key pollutants using the NZTA air quality tool. We have used this modelling, coupled with an assumed significance criterion of 5% (of the national environmental standard) for PM_{10}, to propose separation distances for **new** regional arterials and strategic routes in Auckland as shown in Table E-1. We have also reviewed other jurisdictional approached to advise on recommended separation distances for service stations and drive-through facilities.

Table E-1 Recommended Separation Distances

New Sensitive Land Use	New Road/Activity	Separation Distance (to road edge)
Childcare centres, schools Hospitals, in-patient health care* Residential, including marae	Strategic routes**	150 m
	Regional arterials	70 m
	Service stations	100 m
	Drive-through facilities	30 m

Notes
* For example, maternity, aged care
** Motorways & non-motorways

In addition to the above, and in line with existing policy, we recommend the following for the Auckland Unitary Plan:

- Requiring best practice noise and air emission standards for heavy-duty vehicles on new motorways and tunnels.
- Only allowing heavy-duty diesel freight vehicles within liveable corridors if they meet best practice noise and air emission standards.
- Requiring all public transport vehicles on the rapid transit and quality transit networks to meet appropriate noise and air emission standards.
- Requiring all heavy duty diesel vehicles, including construction vehicles and stationary generators, operating within the urban area to be fitted with particulate filters and silencers, if they were not built to minimum noise and air emission standards.
- Implementing no-idling policy for heavy duty diesel vehicles at major transport hubs and terminals and for high traffic generating or sensitive land use activities, such as supermarkets, malls, hospitals, schools and early childhood education centres.
- Requiring best practice emission standards for all public transport contracts.
- Preferentially implementing electric and low noise and air emission vehicles for public transport that uses the rapid transit and quality transit networks.
- Promoting cleaner and quieter public transport options to reduce noise and air emissions.
- Including air quality in principles in corridor management plans.

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1.0 Problem Definition

Emissions from vehicles are an identified public health issue for Auckland. The *Review and Update of HAPINZ for the Auckland Region* (ARC, 2010) estimated the health costs of air pollution associated with vehicles in Auckland to be around $273 million per annum. These costs are largely due to around 160 premature deaths associated with exposure to particulate matter less than 10 micrometres in diameter (PM_{10}) and nitrogen dioxide (NO_2).

Previous evidence has suggested that these effects may be reduced with increasing distance from the roadside. If so, the use of separation distances, as a planning tool, *could* assist with reducing the harmful effects of vehicle emissions by:

- Minimising public exposure to vehicle emissions – especially for sensitive parts of the population; and
- Managing risk.

The issue, however, is made more complex by the drive in Auckland towards a more compact urban form. A key feature of the Auckland Regional Policy Statement is provision for the establishment of High Density Centres and Intensive Corridors with optimal population densities to support good local bus services and/or rapid rail.[1] Such goals conflict directly with separating people and roads to avoid adverse health impacts.

The objective of this project is to investigate the use of air quality separation distances (buffer zones), for roads and motorways in the Auckland Unitary Plan (currently under preparation).[2]

This report is structured as follows:

- Section 1 introduces the issue, briefly discusses the pollutants of concern and defines roads and motorways in the Auckland region.

[1] Post amendments to provide for the Regional Growth Concept. Auckland Regional Council, 2011.
[2] NB: Separation distances for large scale retail is outside the scope of this report.

- Section 2 frames the issue. This section describes the known health issues associated with vehicle emissions and then reviews recent literature to update our state of knowledge.
- Section 3 summarises the existing planning framework for Auckland as applicable to separation distances for roads.
- Section 4 considers other jurisdictional approaches to separation distances for roads. It further summarises key recommendations of a report prepared by an Inter-Agency Air Quality Advisory Panel,[3] convened in 2008/09 by the Auckland District Health Board on separation distances for early childhood education centres in Auckland.
- Section 5 discusses the issue in light of the Auckland context and considers proposed separation distances.
- Section 6 provides our recommendations.

[3] This report remains unpublished. The Auckland Regional Council was represented on the panel and contributed to the report preparation.

1.1 Vehicle emissions

The key pollutants that are emitted to air from vehicles that have adverse health impacts include:

- Carbon monoxide (CO);
- Nitrogen oxides (including nitrogen dioxide(NO_2);
- Particulate matter (including PM less than 10 micrometres in diameter PM_{10} and less than 2.5 micrometres in diameter $PM_{2.5}$);
- Sulphur dioxide (SO_2);
- Volatile organic compounds (including benzene);
- 1,3-butadiene; and
- Polycyclic aromatic hydrocarbons (benzo(a)pyrene, anthracene, etc).

Motor vehicles emit tiny amounts of hazardous air pollutants that collectively can be significant. Hazardous air pollutants are those pollutants that have the potential to cause serious adverse health effects in humans; for example, neurological, cardiovascular, liver, kidney, and respiratory effects or effects on the immune and reproductive systems. Motor vehicle exhaust contains numerous hazardous air pollutants, such as benzene, formaldehyde, 1,3-butadiene, polycyclic aromatic hydrocarbons and diesel particulate matter. Some additional hazardous air pollutants emitted by motor vehicles include acrolein, cadmium and chromium.

In addition to these pollutants directly emitted from vehicles, ozone and particles (from sulphates and nitrates) can form downwind of the point of emission by reacting with other gases in the atmosphere. These are called secondary pollutants.

Petrol vs diesel

In terms of emissions, diesel vehicles produce disproportionately more PM_{10} and nitrogen oxides (NO_X) than petrol vehicles for every kilometre driven. In turn, petrol vehicles produce disproportionately more carbon monoxide (CO). A typical diesel car can produce up to 20 times as much PM_{10} as a typical petrol car. Consequently diesel emissions dominate the health costs associated with vehicle emissions. It may also be noted that diesel particles have been identified as probably carcinogenic to humans.[4]

Over time, the emissions differences between petrol and diesel vehicles have been reducing but, even with Euro 4 standards, the limits for diesel vehicles are still more than three times higher for NO_X and around five times higher for PM_{10}.[5]

Since lowering the sulphur content in diesel in 2009, New Zealand is now able to have the latest Euro 5 diesel vehicles. These diesel vehicles are as clean as petrol vehicles in terms of PM_{10} emissions. Euro 5 diesel vehicles are, however, three times higher than petrol vehicles for NOx emissions.

1.2 Auckland roads

This report uses the road definitions in the Regional Arterial Road Plan as shown in Table 1. Motorways, strategic and regional arterial routes in Auckland are shown in Figure 1.

A strategic route is predominantly through traffic with more than 40,000 vehicles per day, has moderate to high speeds (50 – 100 km/h) with general segregation of pedestrian and cyclists from traffic.

A regional arterial route is also predominantly through traffic, may have more than 40,000 vehicles per day, has moderate speeds (50 km/hr) and also (generally) separates pedestrian and cyclists from traffic.

[4] (1989), Group 2A International Agency for Research on Cancer. www.iarc.fr

[5] This is why previous Auckland Regional Council fleet policy specified that all replacement vehicles must be petrol-fuelled unless there is sufficient justification and a special need for diesel.

Table 1 Classification of road types in Auckland*

Road type	Function	Operational Characteristics
Strategic routes - motorways	Highest category routes	4 - 8 lanes Generally >40,000 vehicles per day High speed 80-100 km/hr Pedestrian and cycle segregated
Strategic routes – non-motorway	Predominantly through traffic	2 - 6 lanes Generally >40,000 vehicles per day Moderate to high speed 50-80 km/hr Pedestrian and cycle generally segregated
Regional arterial routes	Predominantly through traffic	2-6 lanes May be >40,000 vehicles per day Moderate speed 50 km/hr Pedestrian and cycle generally segregated
District arterial routes	Internal district traffic between key nodes	2 or 4 lanes 5,000 – 25,000 vehicles per day Moderate speed 50 km/hr Some pedestrian and cycle segregation
Collector roads	Collect traffic from local roads to connect with district and regional arterials	2 or 4 lanes 3,000 – 10,000 vehicles per day Low to moderate speed (< 50 km/hr) Modest pedestrian and cycle segregation
Local roads	Lowest category routes	2 lanes 1,000 – 5,000 vehicles per day Low speed (< 50 km/hr) Low/no pedestrian and cycle segregation

* As defined in Table 2 of the Regional Arterial Road Plan (ARTA, 2009)

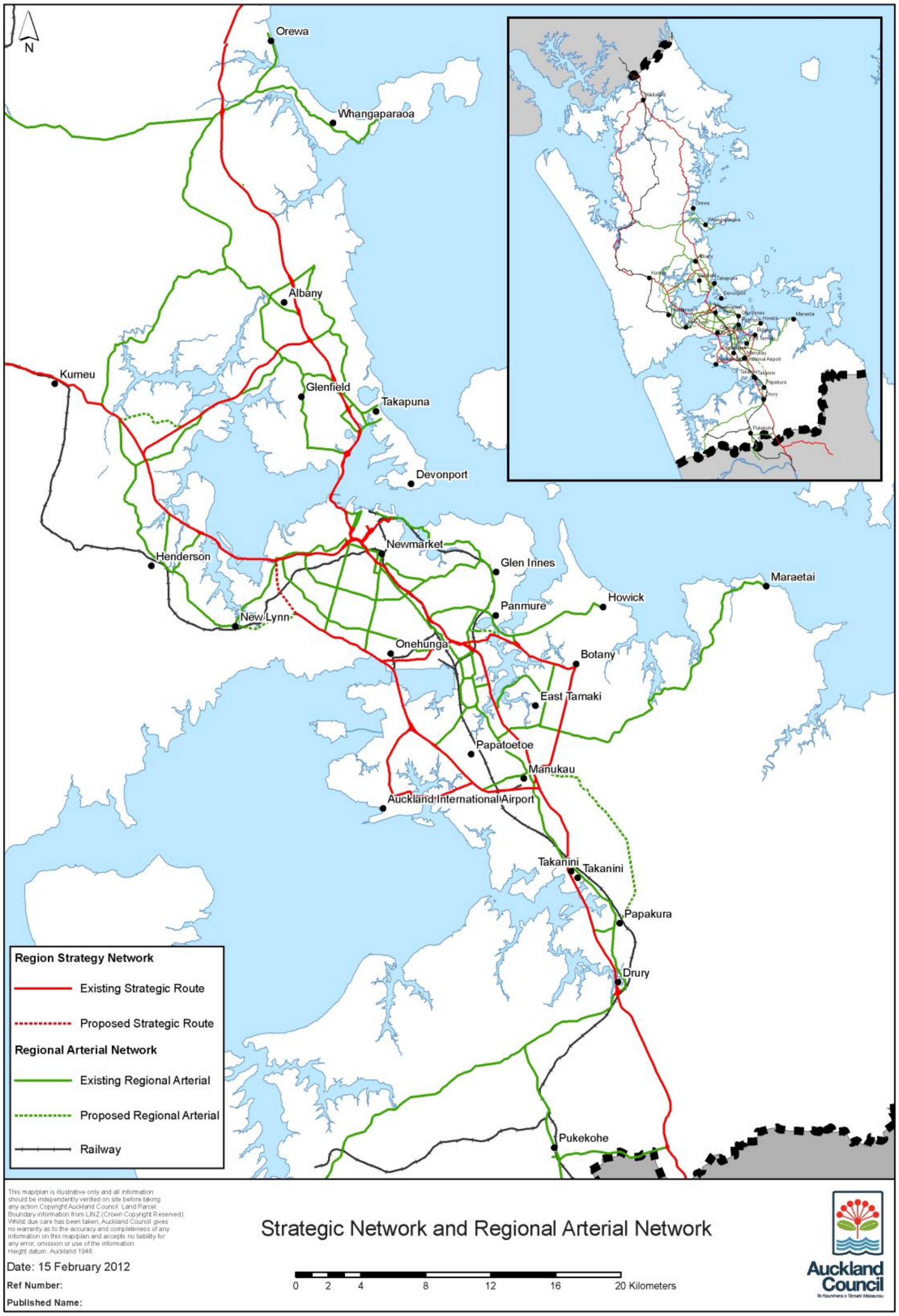

Figure 1 Strategic Network and Regional Arterial Network

2.0 Health Effects of Vehicle Emissions

There is a well-established body of epidemiological evidence on the adverse health effects of air pollution. National air quality policy and regulation has focussed heavily on PM_{10} in the last decade. This is because in even small towns throughout New Zealand, ambient levels of PM_{10} regularly exceed national standards.

In Auckland PM_{10} levels also exceed national standards but less often than other urban areas (i.e. < 10 times a year). Of concern, however, are $PM_{2.5}$ levels in Auckland which are often close to, or exceed the regional air quality target of 25 µg/m^3 as a 24-hour average. This regional target is equivalent to the World Health Organisation guideline for $PM_{2.5}$.

For this project we have summarised the health effects of air pollution, as related to vehicle emissions, as follows:

- Section 2.1 updates a summary of the health effects of particulate matter (as an indicator of vehicle emissions) written by Dr Deborah Read. [6] It further discusses real life interventions where improved air quality has resulted in improved health outcomes.

- Section 2.2 summarises some recent research on air pollution, and research on proximity to roads, with a focus on weight of evidence to determine causality.

The importance of a determination of causality cannot be overstated. Causality means that one thing caused another thing to occur, in this case - air pollution *causes* adverse health effects. Put simply, this means that people suffer adverse health effects (i.e. morbidity and mortality) *because* they are exposed to air pollution. In other words, a person would not have been made sick, or died at that time, if they had not been exposed to air pollution.

[6] Annex 8 - Air Quality Technical Advisory Group, 2009

As a result, the bar for determining causality is set reasonably high. Good science requires that causality be determined by three things:

- A strong association – e.g. a study showing a statistically significant result;
- Consistent findings – typically multiple studies with similar findings, usually using a variety of methods and different populations with respect to ethnicity, location, etc; **and**
- Biological plausibility – there must be some mechanism by which A can have caused B to occur.

With respect to air pollution, the body of evidence is significant. With respect to proximity to roads, uncertainties and confounding factors provide a more complex picture.

2.1 Particulate Matter

The health effects of particulate matter are predominantly respiratory and cardiovascular ranging from subclinical functional changes (e.g. reduced lung function) to symptoms, impaired activities (e.g. school or work absenteeism), doctors' or emergency room visits through to hospital admissions and death (Table 2).[7]

In 2005, the World Health Organisation Regional Office for Europe Working Group (WHO, 2005) concluded that evidence was sufficient to infer a causal relationship between particulate matter and:

- post-neonatal (infants from 1 month – 1 year) respiratory mortality;
- adverse effects on lung function development (reversible acute lung function deficits and chronically reduced lung growth rates and lower function levels);
- aggravation of asthma; and
- increased prevalence and incidence of cough and bronchitis.

WHO further concluded that evidence was suggestive of a causal relationship between particulate matter and low birth weight.

[7] Ibid.

Table 2 Outcomes reported to be associated with PM exposure

- Physiological changes e.g. ↓ lung function, ↑ heart rate, ↓ heart rate variability, blood coagulation factors, inflammatory mediators, blood vessel reactivity, blood pressure, blood vessel structure
- Low birth weight
- Infant (especially post-neonatal) mortality
- Respiratory symptoms e.g. cough
- Exacerbations of asthma, chronic bronchitis
- School/work absenteeism
- Respiratory mortality
- Cardiovascular mortality
- Myocardial infarction (heart attack)
- Stroke
- Cardiac arrhythmia (abnormal heart rhythm)
- Lung cancer
- Reduced lung growth
- Reduced life expectancy
- Respiratory and cardiovascular disease medication use, hospital admissions, emergency department visits, primary care visits

Air Quality Technical Advisory Group (2009).

These effects are not distributed evenly with the largest proportion of the population affected by less severe outcomes (e.g. symptoms, reduced lung function) and much less people being affected by more severe outcomes such as hospital admissions and death. This uneven distribution is known as a 'pyramid' of health effects as shown in Figure 2.[8]

It is usually the more susceptible groups who experience the more severe outcomes. Susceptible groups include the very young (in particular babies, infants and children), pregnant women, the health-compromised (eg diabetics, asthmatics and people suffering from cardio-pulmonary disease) and the elderly.

Importantly, although the relative risks for cardiovascular disease for ambient particulate matter exposure are small (as compared to say tobacco smoking or obesity), the resulting health burden is large because the entire population is exposed (24/7).[9] This effect is magnified down the health effect 'pyramid' (Figure 2) with tiny changes in the population average of physiological measures such as lung function, resulting in substantial increases in the number of people with clinical conditions.

[8] Air Quality Technical Advisory Group, 2009
[9] Relative risk refers to the percentage change in health outcome per unit change in PM concentration.

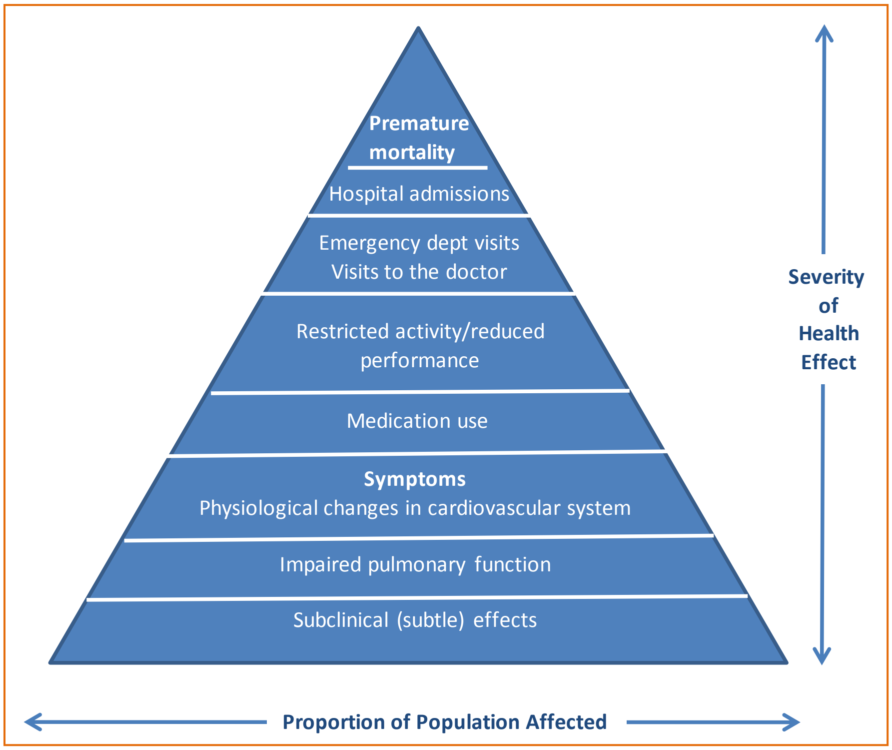

Figure 2 Disproportionate Health Effects of Air Pollution

The exposure-response relationship is regarded as essentially linear (ie, increasing particulate matter exposure is associated with an increased frequency of effects). The studies do not indicate any apparent threshold below which effects do not occur.

In simple terms, this means that there is no 'safe' level of particulate matter.

2.1.1 Who is affected?

Susceptibility depends on factors that are unique for each individual (e.g. age, health status, genetic makeup) as well as exposure (e.g. time spent outside, proximity to major roads).

In short-term studies, the effects of particulate matter on mortality and morbidity are strongest on elderly and people with pre-existing respiratory and cardiovascular disease and Type 2 diabetes.[10] In particular, the increases in mortality are greatest among the elderly. It is not clear whether this is a result of increased age per se or the high prevalence of underlying

[10] Air Quality Technical Advisory Group, 2009

cardiovascular disease and other risk factors. Asthmatics show increased symptoms, larger lung function changes and increased medication use.

Long term studies suggest groups with low socioeconomic or educational status experience increased mortality and morbidity due to air pollution.[11] This may relate to limited access to health care, higher exposures, nutritional status and more risk factors for the health effects of particulate matter.

2.1.2 Mechanisms for effects

Generally, larger (coarse) particulate matter (between 2.5 and 10 µm) deposits in the upper airways whereas smaller (fine) particulate matter (< 2.5 µm, PM2.5) deposits in the very small airways deep in the lung. Inhaled very small (ultrafine, < 0.1 µm) particulate matter may enter the blood circulation. Fine particulate matter is more hazardous than coarse particulate matter in terms of mortality associated with cardiovascular and respiratory outcomes.

Children are particularly susceptible to air pollution because they have a higher respiration rate, their lungs are not fully matured and they have incomplete metabolic systems, immature defence mechanisms and high respiratory infection rates. These factors coupled with a higher intake per unit of body weight, and increased outdoor activities, can lead to higher exposure and higher doses reaching the lungs. Lung injury during childhood due to air pollution may have life-long effects and make people more susceptible to illness later in life (WHO, 2005a).

There is increasing evidence that supports the possibility that much of the morbidity and mortality related to air pollution in children occurs via interactions with respiratory infections, which are common among children.12 Asthma is also common among New Zealand children with Maori and Polynesian children disproportionately represented.

Airway deposition models suggest those with pre-existing respiratory and cardiovascular disease receive higher doses of particulate matter in their airways and lungs compared to healthy people.

Understanding of the biological mechanisms by which particulate matter leads to health effects is incomplete. Several plausible mechanisms including inflammation, oxidative processes, and dysfunction of the autonomic nervous system have been described.

[11] Ibid.
[12] Ibid.

Experimental studies in animals and humans suggest particulate matter may have adverse effects on blood vessels, the heart and respiratory system.[13] Exacerbations of symptoms have been seen in those with pre-existing respiratory and cardiovascular disease following controlled inhalation of particulate matter at concentrations above ambient levels. Studies suggest these effects are due to induction of lung inflammation, alterations in blood viscosity (thickness), oxygen deprivation, and disturbances in heart rhythm.[14]

2.1.3 "Harvesting"

One of the questions directed at the mortality findings of the initial particulate matter daily time-series studies was that increases in particulate matter may only be hastening the deaths of frail people by a few days and hence of limited public health significance. This short-term forward temporal shift in mortality rate is known as mortality displacement or harvesting.

If air pollution only advances deaths by a few days, we would expect an increase in daily numbers of deaths due to air pollution to be followed shortly by a decline. Similarly, if there is short-term displacement (only), then an association between particulate matter and mortality would only be detected at shorter but not at longer timescales. In practice, however, studies reveal that more than short-term displacement of mortality occurs and that longer lag periods up to about 40 days are associated with higher relative risks of cardiopulmonary mortality.

In considering this issue, Schwartz (2000) concluded that overall, the time series study results which have been published underestimate rather than overestimate the number of early deaths that are associated with air pollution. Further that the mortality is brought forward by nontrivial amounts of time (i.e. not just harvesting).

2.1.4 Real life interventions

Improvements in ambient air quality are known to result in reduced mortality and morbidity. This section is adapted from the WHO Air Quality Guidelines Global Update 2005 (WHO, 2006).

There have been some epidemiological studies that have attempted to evaluate the health effects of actions that have resulted in improved air quality. These include studies that examined the effects of interventions aimed at controlling and reducing levels of air pollution over urban areas or studies of "natural experiments", i.e. interventions not designed for air pollution control but that have resulted in a reduction in pollution levels. In general terms, these studies compare periods before and after the intervention and the impact of the observed reduction in pollution on the mortality and morbidity of the population.

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[13] Ibid.
[14] Ibid.

In Utah Valley, a reduction in air pollution levels caused by a year-long strike at a local steel mill was associated with reductions in total deaths and respiratory admissions (Pope 1989, 1992 as reported in WHO, 2006).

During the Olympic Games held in Atlanta in 1996, city-wide changes in transportation patterns reduced vehicle exhaust and related air pollutants (such as ozone) by about 30%, the number of acute asthma attacks fell by 40%, and paediatric emergency admissions dropped by 19% (Friedman 2001).

Clancy et al. (Clancy 2002 as reported in WHO, 2006) examined the impact of a ban on coal sales in Dublin and found an 8% fall in mortality associated with a sustained reduction in average particulate air pollution levels.

In Hong Kong, China, a restriction introduced over just one weekend, requiring that all power plants and road vehicles use fuel with lower sulphur content, led to an immediate fall in ambient sulphur dioxide levels and a substantial reduction in seasonal deaths. The average annual trend in deaths from all causes declined by 2% and that in death from respiratory causes by 3.9% (Hedley 2002).

Notably, the observed impact of the ban on using coal in Dublin was nearly twice as large as those predicted by models using estimates obtained from traditional time series studies and applied to the observed scenario of air pollution reduction (Clancy 2002). This suggests that the time series approach does not capture the full range of effects attributed to air pollution exposure, which includes effects of short- and long-term exposures. Consequently, it will underestimate the benefits of outdoor air pollution control interventions.

2.2 Recent research

Boothe and Shendell (2008) reviewed 29 epidemiological studies evaluating residential proximity to traffic and respiratory effects. Notable findings were:

- 25 (out of 29) reported statistically significant associations with at least one of the following adverse health effects:
    - Increased prevalence and severity of symptoms of asthma and other respiratory diseases;
    - Diminished lung function;
    - Adverse birth outcomes (discussed further below);

- Childhood cancer; and/or
- Increased mortality risks.

- The studies were from geographically diverse locations including Alaska, Canada, California, Colorado, France, Germany, Italy, New York, Ohio, Taiwan, the Netherlands and the United Kingdom.
- Distance to, and density of, traffic were important factors. The majority, but not all, of the studies reported associations for distances up to 200 m but not for greater distances. Adverse effects were reported for traffic counts as low as 5,000 – 9,000 vehicles/day, 10,000 vehicles/day and approximately 24,000 vehicles/day as well as for busy highway averages of up to 93,000 vehicles/day.

Boothe and Shendell (2008) stopped short of determining causality but concluded that a “weight-of-evidence” finding suggests that residential proximity to traffic can be associated with adverse health effects and poses a public health threat. The authors recommended that sensitive uses (e.g. schools, daycare centres, nursing homes) not be located within 300 m of a busy road.

As an aside, a recent study of mice exposed to traffic fumes was linked with brain damage, including signs associated with memory loss and Alzheimer's disease (Morgan et al, 2011).

2.2.1 Adverse pregnancy outcomes

Whilst the cardiovascular and respiratory effects of air pollution are well documented, there is a growing body of literature suggesting that ambient air pollution during pregnancy negatively influences foetal growth.

Šrám notes that the study of birth outcomes is an important emerging field of environmental epidemiology. Birth outcomes are important in their own right because they are important indicators of the health of the newborns and infants. In addition, low birth weight, intrauterine growth retardation, and impaired growth in the first years of life are known to influence the subsequent health status of individuals, including increased mortality and morbidity in childhood and an elevated risk of hypertension, coronary heart disease, and non-insulin-dependent diabetes in adulthood (Barker 1995, Osmond and Baker 2000).

Šrám further explains that it is increasingly apparent that there is a critical period of development when the timing of exposure and the dose absorption rate can be even more important for the biologic effects than is the overall dose (Axelrod et al. 2001). Fetuses, in particular, are considered to be highly susceptible to a variety of toxicants because of their exposure pattern and physiologic immaturity (Perera et al. 1999, Šrám 1999). Their developing organ systems can be more vulnerable to environmental toxicants during critical windows (sensitive periods of development) because of higher rates of cell proliferation or changing metabolic capabilities (Calabrese 1986). Evidence strongly indicates that prenatal exposure to environmental pollution can result in some adverse reproductive outcomes, similar to the association between maternal active and passive smoking and impaired reproductive outcomes (Misra and Nguyen 1999, Salihu et al. 2004).

Recently, two recent Brisbane studies found the following:

- Ambient O_3, SO_2 and PM_{10} during early pregnancy were associated with reductions in foetal biometry (i.e. growth) during mid-pregnancy, with the two conspicuous pollutants being PM_{10} and SO_2 (Hansen et al, 2008); and

- Pregnant women experienced a reduction in gestation time of almost two weeks (4.4 per cent) associated with an increase in freeways within 400 metres of the women's home (Barnett et al, 2011). The findings indicated that the negative effects of traffic on gestation were largely associated with main roads within 400 metres of the home, with much of the effect for roads within 200 metres.

Similarly:

- Yorifuji et al. (2011) found that living within 200 m of major roads increased the risk of births before 37 weeks by 1.5 times (95% CI = 1.2-1.8), birth before 32 weeks by 1.6 times (1.1-2.4) and births before 28 weeks by 1.8 times (1.0-3.2). Proximity specifically increased the risk of preterm births with preterm premature rupture of the membranes and with pregnancy hypertension.

These studies have important implications when considering separation distances for roads and motorways in Auckland.

2.3 Limitations of studies

We note the following limitations of the various reviews of epidemiological studies, and of the studies themselves:

- Personal monitoring is prohibitively expensive at the population scale needed for an epidemiological study. Consequently, researchers use surrogate exposure metrics to estimate exposure. These range from crude (e.g. geocoding based on post code) to the sophisticated (GIS mapping of residential address).

- Confounding factors (housing conditions, exposure to tobacco smoke, various measures of socioeconomic status, age, gender) are accounted for (or not) in different ways.

- There is further the important confounding effect of noise which has adverse effects on cardiovascular physiology (Berglund 1996).

- Meteorology and/or ambient air quality data may not even be included in some studies.

- Exposure misclassification (e.g. due to people moving).

- Some of the overseas studies may not be directly applicable to Auckland where we have different traffic volumes and a different fleet mix with different emissions characteristics.

2.4 Conclusions

Despite the above limitations, in general there is remarkable consistency in the findings of the studies, conducted in a range of different populations and using both spatial and time-series study designs. Based on our literature review, we are confident that residential proximity to traffic is associated with adverse health effects and poses a public health threat. Whilst the studies stop short of determining causality (between the proximity to roads and adverse health effects), we consider it to be a reasonable hypothesis.

3.0 Regulatory Framework

We have reviewed the current regulatory framework with a focus on recommending policy to take forward. This includes the following documents:

- Auckland Regional Policy Statement
- Auckland Regional Air, Land and Water Plan
- Auckland Regional Land Transport Strategy
- Auckland Regional Freight Strategy
- Auckland Regional Arterial Road Plan
- Auckland Council policy
- NZTA Environmental Plan

In general terms, development planning policy in Auckland is based on the separation of certain classes of activities by using land-use zones to achieve a number of desired outcomes. Included in these outcomes, is the protection of protect human health in Urban Air Quality Management Areas, and in particular sensitive sectors of the population, from the adverse effects of air discharges.

In practice, however, there are no separation distances for roads or motorways specified anywhere in any of the relevant planning or transport documents for Auckland. As a result, in May 2011 the Environment Protection Authority issued consent for a new motorway in Auckland without considering separation distances (State Highway 20 Waterview Connection).

The new motorway will pass 20 m from a house.[15]

The following section summarises the existing planning framework for Auckland as applicable to separation distances. A key focus is the planned increase in urban density and the conflict this raises with adverse health impacts from vehicles on people.

[15] Waterview Connection EPA Lodgement Documents and Supporting Information, Supplementary evidence of Gavin Fisher at para 17, February 2011. Available at: http://www.waterviewapplication.nzta.govt.nz/DesktopModules/Bring2mind/DMX/Download.aspx?EntryId=31642&PortalId=2&DownloadMethod=attachment

3.1 Draft Auckland Regional Policy Statement

A draft update of the Auckland Regional Policy Statement was prepared in 2010 to give effect to the Regional Growth Concept and Integrating Landuse and Transport (Auckland Regional Council, 2011). This section allows for these changes.

A key feature of the Regional Policy Statement is provision for the establishment of High Density Centres and Intensive Corridors with optimal population densities to support good local bus services and/or rapid rail.[16] This is a shift in land use patterns towards a more compact urban form which:

> *"…focuses growth in the northern, western and southern passenger transit corridors and near main arterial roads".[17]*

Importantly, to support this, the draft Regional Policy Statement notes the importance of the highest densities occurring closer to the transport interchange, graduating to lower densities towards the edge of the centre (p 2-47).

High density centres and intensive corridors conflict directly with the need to increase separation between people and roads to avoid adverse health impacts.

This is because, for the foreseeable future, the private car will continue to dominate transport in Auckland. Unless the vehicles somehow reduce their emissions, increasing the number of people in locations closer to vehicles will only increase adverse health impacts from vehicles.

Further, increasing public transport (as proposed for High Density Centres) does not necessarily solve the problem. Buses run on diesel and are often disproportionate emitters of particulate matter. Locating more people closer to more buses, such as in High Density Centres and Intensive Corridors, would increase associated adverse health impacts.

The Regional Policy Statement specifically recognises this issue:

> *Intensification of existing urban areas has the potential to expose more people to high levels of air pollution if the emission sources are not managed appropriately and effectively. There is a need to ensure that air emissions are controlled at source (e.g. vehicles tuned and with catalysts, industrial process control equipment, domestic fires meeting NZ standards etc) to a practicable level.*
>
> *There is also a need to ensure appropriate separation between pollutant sources and sensitive activities through the use of Air Quality Management Areas and appropriate placement of transport routes.[18]*

[16] Post amendments to provide for the Regional Growth Concept. Auckland Regional Council, 2011.
[17] Section 2.3 The Auckland Regional Growth Strategy, p 2-7, Auckland Regional Council 2011.

Despite a number of objectives and policies that outline the need to avoid, remedy or mitigate the adverse effects of transport on air quality, there are no concrete methods to ensure that this will be achieved. In practice, the Regional Policy Statement devolves management of increased adverse impacts on air quality from increased intensification to the Regional Land Transport Strategy (Section 3.2).

A Strategic Result anticipated from the Regional Policy Statement is 30% of the total regional population being contained within High Density Centres and Intensive Corridors. That is, by 2050, more than a 500,000 people could be living in higher density, multi-unit accommodation.

Considering the adverse impacts of vehicle emissions on human health, this outcome may come at a significant health cost.

Rapid rail, provided it was electrified - could avoid the problems inherent above.

3.2 Auckland Regional Land Transport Strategy

The Auckland Regional Land Transport Strategy 2010 - 2040 (Transport Strategy) has a strong environmental sustainability focus with an emphasis on safe, clean and quiet transport (Auckland Regional Council, 2010a). The vision, as outlined in the Transport Strategy includes the following (relevant to this report):

- The transport supports vibrant, well designed, attractive and environmentally sustainable urban and rural centres, business and economic activity, and access to social, cultural and recreational activities.
- The natural environment and human health are protected and enhanced.
- The transport resources are used efficiently, supported by sustainable, innovative design practices.

Whilst the Transport Strategy includes objectives to protect and promote public health and to ensure environmental sustainability, it has no outcomes or targets related to separation distances.

Importantly, the Transport Strategy seeks to improve arterial roads and the regional strategic freight network. This is anticipated to result in an increase in travel by heavy vehicles per capita

[18] Issue 2.4.2, p 2-10, Auckland Regional Council 2011.

as the freight task increases but with less potential to be met by other modes (presumably this means rail).[19]

Whilst improvements in technology in the last decade have reduced emissions from vehicles significantly, these gains have been offset to a large extent by an increase in traffic volume. This trend looks set to continue – freight shifted in Auckland is forecast to grow by 68% by 2031 versus 2006 with the vast majority of this occurring by road (Auckland Regional Council, 2009, 2010b). Increased freight traffic in Auckland as planned for in the Transport Strategy will likely, therefore, be accompanied by increased fine particulate ($PM_{2.5}$) emissions and associated adverse health impacts. This conflicts with the Transport Strategy policy of protecting human health (unless exposure to those emissions can be reduced).

The Transport Strategy includes the following policies (relevant to air quality and separation distances):

Policy 1.4

> *1.4 Ensure that the design of streets and transport infrastructure contributes to quality liveable environments, and takes account of the different roles and character of particular locations.*
>
> > *1.4.1 Incorporate good design principles and context sensitive design from an early stage in planning projects, including consideration of …, environmental standards … and where appropriate lowered vehicle speed.*

In the absence of specified separation distances, '*good design principles*' may not alleviate adverse health impacts from vehicle emissions.

Policy 1.5

> *1.5 Encourage land use activities and urban design that reduces the exposure to adverse effects from transport activities.*
>
> > *1.5.1 Require high traffic-generating activities to adopt "good sustainability practice" into land use developments.*
> >
> > *1.5.2 Ensure that proposals for new major trip generating developments are subject to an integrated assessment.*
> >
> > *1.5.7 Encourage district plans to consider reverse sensitivity effects relating to transportation activities.*

[19] Section 4.4 Main components of the strategy, p61, Auckland Regional Council, 2010.

Provided that '*integrated assessment*' incorporates national air quality standards and regional targets, this policy may assist in preventing adverse health impacts from vehicle emissions. Similarly, Policy 1.5.7 that encourages consideration of reverse sensitivity effects is critical in preventing sensitive land uses being located close to roads and/or motorways.

Policy 1.7

1.7 Discourage high trip-generating activities from developing in locations where transport options are limited, or where there are adverse effects on the safety and efficiency of the transport network.

1.7.3 Where possible, avoid locating sensitive land uses such as hospitals, schools, childcare facilities, aged care facilities, marae and playgrounds close to roads on the regional freight network.

Policy 1.7.3 directly addresses the issue of locating sensitive land uses close to roads and/or motorways. This policy is however, located subordinate to a policy on discouraging high-trip generating activities from being located in limited transport-option locations. It may not, therefore, achieve its intended purpose.

We strongly recommend this policy be elevated in priority in the Auckland Unitary Plan.

Policy 5.2

5.2 Develop the transport network and vehicle fleet in a way that reduces reliance on fossil fuels and reduces production of greenhouse gas emissions.

5.2.1 Advocate for changes to vehicle fleet composition and fuel composition to reduce the consumption of non-renewable transport fuels, improve air quality, and reduce greenhouse gas emissions.

This policy of advocacy to central government to reduce emissions from vehicles through regulation has been highly successful to date.

We recommend updating this policy to one of support for government regulatory initiatives on vehicle emissions.

Policy 5.3

5.3 Improve the environmental performance of operation of the transport network.

5.3.1 Advocate for regular effective emissions and noise testing as part of warrant of fitness and certificate of fitness.

5.3.2 Incorporate best practice emissions standards for public transport contracts.

5.3.4 Investigate and implement funding measures to mitigate the adverse effects caused by existing transport networks, where they are environmentally and economically justified, including retrofitting existing sites, innovative pavement design and source control solutions.

Policy 5.3.2, requiring best practice emission controls in public transport contracts, is a highly effective way to address adverse health impacts from vehicle emissions. Furthermore, it may mitigate, if not avoid, our concerns about increasing density closer to transport nodes as required under the Growth Concept for Auckland.

The detail, of course is always important. We understand this policy has been embedded in the Passenger Transport Network Plan which requires, by 2016 the following limits for buses, ferries **and** trains:

- Euro IV (or equivalent) on rapid transit network
- Euro III (or equivalent) on quality transit network
- Euro III (or equivalent) on local connected network

Similarly, NZTA requirements for buses **new** to urban service in New Zealand are (NZTA, 2011):

- Maximum permitted vehicle age ≤ 20 years
- Must meet current Ministry of Transport vehicle emission exhaust rules:
    - All new heavy duty diesel vehicle to meet Euro V from 1 Jan 2012; and
    - All used heavy duty diesel vehicles to meet Euro IV from 1 Jan 2010.[20]
- Average fleet age
    - ≤ 12.5 years by 1 Jan 2012
    - ≤ 10 years by 1 Jan 2017

Further, NZTA requires existing buses (registered prior to 1 Jan 2009) to be:

- Maximum permitted vehicle age < 20 years

[20] This rule expires in 2013 and is currently being reviewed to put in a Euro V date for used imports.

- Meet Euro II minimum or fit with a particulate filter where feasible to do so.

If these requirements were rigorously enforced in Auckland and reviewed regularly (to match increasingly stringent Euro 4 or 5 requirements) then Policy 5.3.2 would represent best practice.

We recommend Policy 5.3.2 be adopted in the Auckland Unitary Plan.

Policy 5.4

5.4 Manage the transport network to facilitate the safe and efficient movement of people and goods.

5.4.4 Prepare and implement corridor management plans for developing the strategic, regional and district arterial networks and corridors (taking into account the principles and priorities in Appendix H, and the need to contribute to quality liveable environments as outlined in Policy 1.4).

Policy 5.4.4 has been taken forward in the Auckland Regional Arterial Road Plan (discussed later in Section 3.5). We consider corridor management plans, as envisaged in Policy 5.4.4, to be an important tool in the planning and implementation of improvements to regional arterial roads. We are not certain, however, that in practice this is the case. This is discussed further in Section 3.5.

Policy 13.1

13.1 Ensure that new transport projects meet environmental and public health standards.

13.1.1 Ensure that integrated assessments are undertaken for all significant trip generating activities and an assessment of effects for transport projects. The assessment of effects should include consideration of environmental and public health impacts in accordance with those matters identified in Appendix I Health Impact Assessment.

13.1.2 Ensure the proposed options for new transport projects or redevelopment of transport infrastructure specifically consider the construction, operation and maintenance effects of the project on air quality…

13.1.5 Ensure that new transport projects and the management of the existing network meet environmental and public health standards.

Given the Auckland airshed already exceeds the national air quality standard for PM_{10}, of which 47% arises from transport (Auckland Regional Council, 2006a), it is hard to see how new transport projects could be ensured to meet it. Similarly, given the known adverse health impacts of the existing transport network, it is hard to see how Policy 13.1.5 will be realised in practice.

Policy 13.1.1 and 13.1.2 are, however, essential regulatory requirements to ensure that integrated assessments are undertaken against air quality standards.

Policy 13.3

13.3 Develop, maintain and manage the transport network in a way that avoids, remedies or mitigates adverse effects on the environment.

On the face of it, Policy 13.3 provides a clear mandate to address the adverse health impacts from vehicles.

At time of writing, the future status of Regional Land Transport Strategy is unclear. The *Land Transport Management Act 2008* requires the Strategy to be updated by 2016.

3.3 Auckland Regional Plan: Air, Land and Water

At time of writing, Auckland Council intends to adopt many of the provisions of the Auckland Regional Plan: Air, Land and Water (ARP: ALW)[21] within the Unitary Plan.[22] Accordingly, this section simply notes key aspects of the ARP:ALW with respect to separation distances for roads.

The ARP: ALW acknowledges reverse sensitivity issues as the primary driver for the creation of Air Quality Management Areas. The purpose of these areas is to integrate the management of land use planning, set out in the district plans, and air quality in terms of the (then) Auckland Regional Council's responsibilities.

Objectives and Policies

With respect to separation distances from roads, the Regional Plan specifies the following objectives:

4.3.3 To avoid, remedy or mitigate the cumulative and synergistic impacts of discharges into air from individual sources, in particular from mobile sources and domestic fire in urban areas.

4.3.4 To avoid or minimise competing and incompatible land uses that aggravate any adverse effects from discharges of contaminants into air.

[21] Auckland Regional Council, 2010c.
[22] Personal comm. Janet Petersen, February 2012.

4.3.5 *To avoid reverse sensitivity conflict from the discharge of contaminants into air where sensitive activities that have differing air quality expectations are located in close proximity to activities that discharge contaminants into air.*

4.3.6 *To minimise the discharge of contaminants into air from mobile sources while enabling sustainable development and protecting the health and social well-being of the people of the Auckland Region.*

These, in turn, are supported by the following policies:

4.4.7 *To avoid or minimise adverse effects from competing and incompatible land uses, including reverse sensitivity, activities shall:*

a. *Locate within the Air Quality Management Area suitable to the nature of the activity; and/or*

b. *Manage the effects of their discharges of contaminants into air in a manner that is commensurate with the receiving environment (including the relevant provisions of the underlying District Plan zones); and/or*

c. *Maintain adequate separate distances.*

Importantly, however, discharges to air from motor vehicles are a permitted activity. Furthermore, there are no separation distances for roads and/or motorways.

3.4 Auckland Regional Freight Strategy

The Auckland Regional Freight Strategy (Freight Strategy) proposes "*possible roading links for inclusion in (the) strategic freight network*" (Auckland Regional Council, 2006). These continue their proposed status when included in the Regional Arterial Road Plan (Auckland Regional Transport Authority, 2009).

The vision, as outlined in the Freight Strategy includes the following (relevant to this report):

- Transport supports vibrant town centres; and
- The environment and human health are protected.

There is only one objective to support this vision, that of "*ensuring environmental sustainability*".

Whilst the Freight Strategy notes the:

> *"need to consider reverse sensitivity issues to ensure that land uses which are sensitive to the impacts of the movement of freight are kept at an appropriate distance away from the strategic freight network and other major freight routes (for both road and rail)".*

Practical applications, through policy as expressed in the Freight Strategy, to make this a reality, are limited:

- Policy 4.2 "Develop supportive land-use planning to support the strategic freight network" has the following action items:
    - Study existing and future provision of land for storage, distribution and high freight-generating industry.
    - Liaise with territorial authorities to consider need for complementary supportive activity to avoid reverse sensitivity issues.
- Policy 5: Local Area Freight Management seeks to develop initiatives to better manage the impact of freight on adjacent residential areas;
    - Policy 5.3 "Facilitate best-practice design for freight routes and site layout" requires the development of best-practice guidelines.
- Policy 6: Promote a freight system that is clean, quiet and safe.
    - Policy Action 6.5 – Reduce the environmental impacts of freight routes and traffic (no specific action items).
    - Policy Action 6.6 – Mitigate the impact of freight on adjacent land use. This refers to the use of buffer zones (albeit with a focus on light intensity and noise generation).
    - Policy Action 6.7 – Encourage low-emission freight vehicles and clean fuels. Action items include considering preferential access and/or parking/loading concessions to incentivise low-emission vehicles in sensitive areas.

3.5 Auckland Regional Arterial Road Plan

The regional arterial road plan:

- defines the existing and future role and function of regional arterial roads
- provides a framework for the integrated management of regional arterial roads
- provides a basis for project prioritisation

- discusses a rationale for funding for regional arterial roads.

The regional arterial road plan recognises "the environmental effects of transport will significantly influence the future development of transport networks". The purpose of the proposed framework is to integrate management of regional arterial roads and their interaction with surrounding land uses and other parts of the network.

Importantly, the regional arterial road plan proposes the development of corridor management plans for **all** arterial roads in accordance with a set of guiding principles. Unfortunately the guiding principles do not include air quality. At time of writing, corridor management plans are being prepared for:[23]

- Great South Road (Drury to Manukau Central)
- East Coast Road (Forrest Hill Road to Hibiscus Coast Highway)
- Khyber Pass Road
- Broadway, Newmarket
- Hibiscus Coast Highway review

We recommend the inclusion of air quality in the guiding principles for the preparation of corridor management plans.

3.6 Council Policy

Auckland Council policy on reverse sensitivity for roads is provided in Working Paper 20 *Environmental Sustainability and Public Health Policies,* a paper prepared to support the development of the Regional Land Transport Strategy (Auckland Regional Council, 2010d). Elsewhere, council policy on separation distances refers only to industrial activities.

Working Paper 20 recognises the adverse health impacts from vehicles on air quality as a principal challenge:

> *With current and future population growth, it will be increasingly important that subdivision and land use development are managed in a manner which ensures that sensitive land uses are not significantly adversely affected by discharges of contaminants into air from major transport routes, heavy duty freight corridors, public transport corridors, other arterial roads and highways and high traffic generating land use activities.*
>
> *Although separation distances work well for new developments, for existing developments (such as residential housing already sited on major transport routes) the main option left to*

[23] Personal comm. Chris Smith, Auckland Council, 17 April 2012.

reduce population exposure is source control. Examples of source control that can be employed include:

- *only allowing heavy-duty diesel freight vehicles within liveable corridors if they meet appropriate noise and air emission standards,*
- *requiring all public transport motor vehicles used on the rapid transit and quality transit networks to meet appropriate noise and air emission standards,*
- *requiring all heavy duty diesel vehicles, including construction vehicles and stationary generators, operating within the urban area to be fitted with particulate filters and silencers, if they were not built to minimum noise and air emission standards,*
- *implementing no-idling policies for heavy duty diesel vehicles on major transport routes and for high traffic generating land use activities, such as supermarkets and malls,*
- *promoting cleaner and quieter public transport options to reduce noise and air emissions,*
- *preferentially implementing electric and low noise and air emission vehicles for public transport that uses the rapid transit and quality transit networks.*

The document further notes the limitations inherent in this approach:

> *In reality, it is likely that a combination of separation distance and source control policies will need to be adopted to achieve the targets for reduced population exposure. In the worst cases, where this combination is insufficient, mitigation options such as retrofitting acoustic double glazing and installing filtered air ventilation will be necessary but preferably only after all options for source control and separation have been exhausted.*

We consider this is sound policy that should be taken forward in the Auckland Unitary Plan.

3.7 NZTA Policy

The New Zealand Transport Agency Planning policy manual has a specific policy for reverse sensitivity (NZTA, 2007). This includes buffer zones for road noise effects on *new* developments (only) as shown in Tables 3 and 4.[24] Table 5 summarises this policy using the road classifications used in this document.

[24] Appendix 5D – Reverse Sensitivity.

Table 3 **NZTA Environmental Buffers and Road Noise Effects**

All new development to be designed and constructed to meet internal sound levels of AS/NZ 2107:2000

Traffic Profile	Environmental Buffer Area	Road Noise Effects Area
A	10 m	40 m
B	20 m	80 m
C	40 m	100 m

Notes

1. Distances are measured from road edge (measured from left edge line of nearest traffic lane) to building line.
2. The above table has been based on current AADT figures; for new or planned road designations the traffic volumes should be based on the design level of the road.
3. Traffic profiles detailed in Table 4.

Table 4 **Traffic Profile Type (flow and speed)**

Traffic Flow (Vehicles per day)	**Speed** (km/hr)	
Annual Average Daily Traffic	< 70 km/hr	> 70 km/hr
> 25,000	C	C
10,000 – 25,000	B	C
< 10,000	A	B

Table 5 **NZTA Noise Effects Distances (new developments only)**

Road type*	Noise Effects Distances
Strategic routes (motorway and non-motorway)	140 m
Regional and district arterial routes	100 m
Collector & local roads	50 m

* Road classifications from Table 1

4.0 Jurisdictional Review

This report builds on reviews undertaken by other parties namely:

- Inter-Agency Air Quality Advisory Panel (convened in 2008/09 for the Auckland District Health Board) - *Air quality and early childhood education centres: An assessment process and background paper,* (unpublished – Auckland Regional Council was a contributing member) May 2009.
- Dr Bob Nosal, Medical Officer of Health, Halton Region Health Department – *Protecting Health: Air Quality and Land Use Compatibility*, February 2009.

These reviews double up to some extent as there is limited guidance internationally, on separation distances for roads and motorways.

We are not aware of any overseas national requirements for separation distances, however, a number of states and local authorities have either mandated or recommended separation distances as discussed below.

4.1 California

The State of California has had separation distances for locating new schools enshrined in planning legislation for some time. Section 17213, subdivision (a) of the Education Code prohibits new schools being located on a:[25]

- Current or former hazardous waste disposal site;
- Solid waste disposal site (unless wastes removed);
- Hazardous substance release site; or
- A site that contains one or more hazardous, or extremely hazardous, substance pipelines (excluding natural gas supplying the school or neighbourhood).

Section 17213, subdivision (b) further requires the School Board to work with local agencies to identify any incompatible land uses within 400 m (a quarter mile) of the proposed site including:

- Permitted and non-permitted facilities (industry);
- Freeways and other busy traffic corridors;

[25] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=edc&group=17001-18000&file=17210-17224

- Large agricultural operations; and/or
- Railyards.

The definition of a "freeway or other busy traffic corridors" is:

> *"roadways that, on an average day, have traffic in excess of 50,000 vehicles in a rural area … or 100,000 vehicles in an urban area."*

In Auckland terms, a freeway is equivalent to a strategic route, motorway and non-motorway, or a heavily used regional arterial route (e.g. spaghetti junction, Auckland Harbour Bridge).

Following identification and consultation, the (US school) board must make a finding that either:

- the health risks do not, and will, not constitute an actual or potential endangerment of public health to pupils or staff; or
- corrective measures required under an existing order by another governmental entity will mitigate all chronic or accidental hazardous air emissions to levels that do not constitute an actual, or potential, endangerment of public health to pupils or staff; or
- for a site with a boundary within **150 m** (500 feet) of the edge of the closest traffic lane of a freeway or other busy traffic corridor, analysis of dispersion modelling shows there to be neither short-term nor long-term significant health risks to pupils (only);[26] or
- there are no suitable alternative sites due to a severe shortage of sites that meet the requirements of subdivision (a) (i.e. hazardous waste site, etc).

4.1.1 Sacramento

There are a number of air quality management districts in California that provide guidance to cities and counties within their jurisdiction. With respect to roads, the Sacramento Metropolitan Air Quality Management District has published a *Recommended Protocol for Evaluating the Location of Sensitive Land Uses Adjacent to Major Roadways* (Sacramento Metropolitan Air Quality Management District, 2011).

[26] Analysis pursuant to paragraph (2) of subdivision (b) of Section 44360 of the Health and Safety Code (analysis in accordance with guidelines established by the Office of Environmental Health Hazard Assessment).

This document provides a detailed cancer risk calculation method for sensitive land uses located within the 150 m (500 feet) State requirement for freeways and other busy traffic corridors. The guidance indicates when a site specific health risk assessment is needed and how it should be performed.

This guidance may be of interest to Auckland Council. The method could easily be adapted for Auckland and made public for developers wishing to make informed decisions about the location of sensitive land uses in proximity to roads and motorways in Auckland. The guidance is available here:

http://www.airquality.org/bod/2008/OctRoadwayProtocolRevision.pdf

4.1.2 The importance of trees

A number of regulatory authorities (California Air Resources Board, Ontario Public Health Association) note that trees have both positive and adverse impacts on air quality and climate change as follows.

Positive Effects

- Cooling - reducing the "urban heat island" effect (climate change adaptation);
- Cooling - slowing down the speed of chemical reactions that lead to the formation of ozone and particulate matter;
- Reducing energy use - which reduces emissions that contribute to air pollution and climate change;
- CO_2 removal - directly reducing greenhouse gases that contribute to climate change;
- Pollutant removal - leaves and needles have surface area that can allow for removal (deposition) of ozone, nitrogen dioxide, and to a lesser extent particulate matter;
- Shading - preventing skin cancer by reducing exposure to sun;
- Lowering vehicle speed – street trees, landscaping and on-street parking have been shown to reduce vehicle speeds with associated reduced emissions and increase safety (Ontario Public Health Association, 2011); and

- Improved amenity and real estate values.

Negative Effects

- Biogenic emissions – trees emit hydrocarbons which can react with nitrogen oxides that are emitted by other sources (e.g. cars) which can then react to form ozone and particulate; and

- Biogenic allergens – pollen from grasses, weeds, shrubs, and trees causes allergic reactions in sensitive people.

There appears to be limited research on trees and their impacts on air quality and climate change to date. This is an area that may be worth further investigation.

4.2 British Columbia

British Columbia published guidelines in 2006 for separation distances for roads (Ministry of the Environment, 2006). The recommendations focused on:

- buildings where people spend large amounts of time – seven to eight hours per day; and

- buildings that primarily house vulnerable populations (infants, children, pregnant women, the elderly and those who are ill).

Recommended separation distances for roads are:

1. **Setbacks:** 150 m (500 feet) setback from "busy roads" for buildings such as schools, hospitals, long-term care facilities and residences.

2. **Truck Routes**: Special consideration should be applied for buildings located on major truck routes. Avoiding development on truck routes, or additional setbacks, are recommended. Elevated air pollutant concentrations are measurable as far as 750 m from truck routes. Heavy-duty trucks generally emit larger quantities of air pollutants, including diesel-exhaust particulate, a *probable* human carcinogen, and likely the most harmful vehicle-related pollutant.[27]

3. **Street Canyons:** Avoid locating buildings within street canyons (Table 6), which can trap air pollution. To avoid creating street canyons, stagger buildings that are perpendicular to the predominant wind direction or site high-rise buildings on only one side of the street (when perpendicular to the predominant wind direction).

[27] Group 2A – International Agency for Research on Cancer. www.iarc.org

British Columbia defines a busy road as a road with greater than 15,000 vehicles/day based on annual daily average traffic counts. A street canyon is defined by calculating the ratio of the height of the buildings and the width of the street as shown in Table 6.

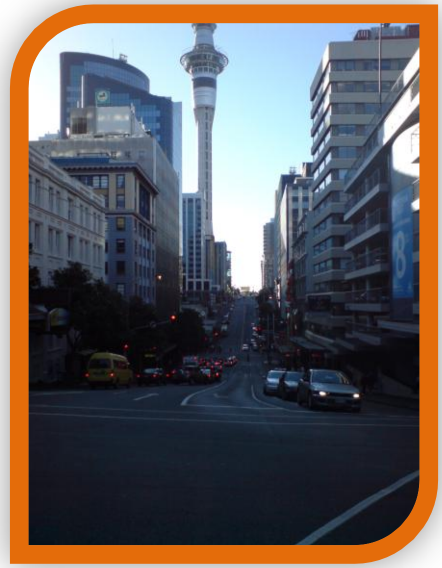


Table 6 Definition of a Street Canyon

Building Height/ Street Width Ratio	Type of Roadway
< 0.3	Wide street
0.3 – 0.7	Canyon street **without** risk of pollution accumulation
>0.7	Canyon street **with risk** of pollution accumulation

The guidelines also include the following considerations:

Site (Outdoor) Considerations

4. **Trees**: On a local scale, trees have little impact on air quality, although on a city-wide, regional scale, they increase carbon dioxide conversion to oxygen and promote cooling. Trees are important from a site-quality and greenspace perspective, however, and should still be considered a valuable feature of land development.

Building Construction/Design

5. **Idling/Loading Dock Locations**: Air intakes for buildings must not be located near loading docks or where vehicles are often idling. Similarly, building intakes should not be located on a side of a building near a busy traffic corridor where vehicles may be idling in traffic congestion. This will help avoid indoor air quality problems.

6. **Filters**: Where proximity to traffic is unavoidable, the use of high-efficiency particulate air (HEPA) filters (room or centralized units) for vulnerable populations will reduce exposure to particulate air pollution.

4.3 Ontario

In 2009 the Halton Region Health Department published *Protecting Health: Air Quality and Land Use Compatibility* (Halton Region Health Department, 2009). This 67-page report provides the health arguments for addressing land use compatibility from an air quality perspective. It reviews guidance for separation distances (largely based on industry) in Ontario, British Columbia, California, the United Kingdom, and Australia. Notably, it recommends the following:

- Sensitive land uses **not** be located closer than 150 m to highways anticipated to have greater than 100,000 vehicles per day based on ultimate planned capacity.
- Sensitive land uses not be located closer than 30 m to roads with greater than 30,000 vehicles/day annual average daily traffic (AADT) based on ultimate planned capacity. Exceptions to this guidance are condominiums and mixed-use buildings, which could locate closer than 30 m provided appropriate controls are incorporated into the building design to protect indoor air quality for the occupants.
- When applying this guidance, future road widening should be taken into consideration.

Ostensibly, the report was successful in supporting new policies for air quality in an amendment to the Regional Plan, and is being used to inform the development of two new implementation guidelines for the Regional Official Plan (Ontario Public Health Association, 2011).

4.3.1 Air monitoring study re: secondary highway

In 2009, the Halton Region Health Department conducted an air monitoring study along a secondary highway travelled by more than 30,000 vehicles per day (HRHD, 2009). The results showed a substantial spatial and temporal variability in the concentrations of nitric oxide (NO), nitrogen dioxide (NO_2), oxides of nitrogen (NOx) and fine particulate matter ($PM_{2.5}$) based on proximity to a secondary highway.[28]

Outdoor air levels of NO and NOx were distinguishably higher closer to the road and decreased with distance and height from the road. NO_2 was relatively stable within 30 m distance, but demonstrated the same diurnal peak in the early morning hours observed for NO and NOx.

Height above ground had a mitigating influence on the levels of NO, NO_2, and NOx. Measured concentrations of NO, NO_2 and NOx at 10 m distance from the road and 9 m height were equal to or less than those measured at 30 m distance at ground-level.

For $PM_{2.5}$ the contribution of traffic was evident however less consistent, with elevated levels close to the road, at further distance from the road, and pronounced at height above ground, relative to simultaneous monitoring conducted at 30 m distance and ground-level.

[28] There was no evidence to suggest any measurable traffic impacts on outdoor concentrations of sulphur dioxide (SO_2), ground-level ozone (O_3), or carbon monoxide (CO) based one-hour average measurements at distance or height from the road.

4.3.2 Drive-through decision

We note the adoption of a recommendation by the Halton Region Health Department as follows:

> *A drive-through was proposing to locate the queuing lane within six meters of a row of houses. The health department recommended that a minimum 30 meter separation distance should be provided between the queuing lanes and the houses using an Ontario Municipal Board decision on the same issue as the precedent. The site plan was revised so that the queuing lane was re-located further from the houses*. (Ontario Public Health Association, 2011).

We think that a similar approach may be suitable for new drive-through facilities in Auckland. This is a precautionary approach based on consideration of:

- Emissions from fewer vehicles (ie, non-peak) may coincide with the time of day when there is less dispersion (eg, late at night, early hours of morning); **and**
- Emissions from more vehicles (ie, peak) may coincide with other sources (eg, rush-hour).

4.4 New South Wales

There are no separation distances required in New South Wales however, a number of local authorities require either impact assessment and/or mitigation for the location of early childhood education centres near busy roads.

This is summarised in Table 7.

Table 7 New South Wales Local Government Controls for Childcare Centres near Roads*

Policy	Traffic count limit	Distance limit	Action required if exceeds limit
North Sydney Development Control Plan 2002, Section 12 Childcare Centres	5,000 vehicles/day (average daily traffic), major roads (including state and regional)	'located on' these roads	Demonstrate reduction measures such as double glazing on windows, air conditioning systems and play areas located away from noise and pollution sources
	Comment:	Another trigger is 'sites where the external noise level exceeds 55 dB(a) (L90 24 hours)	
Muswellbrook Shire Draft Development Control Plan, Section 18 Child Care Centres	5,000 vehicles/day (average daily traffic), major roads (including state and regional)	On or within 50 m	Demonstrate reduction measures such as double glazing on windows, air conditioning systems and play areas located away from noise and pollution sources in an environmental report
	Comment:	Also restricts childcare centres within 200 m of service station or 100 m of high voltage transmission lines or mobile phone towers 'or the like' unless hazard risk assessment done	
Maitland City Wide Development Control Plan, Child Care Centres 2006	Arterial road	< 125 m	Submission of a report detailing the results of air quality and noise level testing
	Comment:	Also restricts childcare centre location with respect to service station (200 m), heavy industry (100 m), rural industries, swamps or creeks (100 m), brothels (100 m or in view), aircraft noise exposure area (20ANEF or greater), above ground high voltage transmission lines (100 m)	

* Inter-Agency Air Quality Advisory Panel, 2009. NB: Controls specified in the 2001 Sutherland Shire Council Development Control Plan for Childcare Centres appear to have been removed from the 2006 version hence are not included here.

4.5 Auckland

In 2008 the Auckland District Health Board convened a panel of experts to investigate the issue of traffic-related air pollution in relation to the location of early childhood education centres. The panel report was not published, however, its recommendations are available in a Technical Summary.[29] The recommendations are that early childhood education centres should be located:

- *At least 60 m from any arterial roads (5-day weekday average traffic count >7,000)*
- *At least 150 m from any motorways, freight routes or other strategic routes.*
- *At least 100 m from a petrol station*

Further early childhood education centres should not be located inside enclosed car parks (e.g. parking buildings).

We understand that the distances should be measured from the boundary to the nearest point on the early childhood education centre site where children may be present for significant periods of time.

We further understand the recommendations were based on modelling that demonstrated exposure would not exceed 5% of the ambient standard (for PM_{10}) for approximately 95% of roads. This modelling in turn, however, assumed dispersion characteristics based on carbon monoxide and may not have taken into consideration the lack of decay of PM_{10} with distance from a road. This is discussed in more detail in Section 5.5.

4.5.1 District plans

Almost all the district plans in Auckland require buildings and structures in the industrial, business and commercial zones to be set back from the road boundary.[30] Generally this set back ranges from 2 to 3 metres through to 10 metres; depending on the nature of the activity and the specific road boundary. Similar provisions apply for residential areas through minimum verge and footpath width specifications.[31]

[29] http://www.arphs.govt.nz/Portals/0/About%20us/Technical%20summaries/Technical%20summaries%202012/Jan%202012/Air%20Quality%20-%20Technical%20Summaries.pdf
[30] http://www.qualityplanning.org.nz/qp-research/provisions-jul06/html/page2.php
[31] For example, see Section 8A, City of Auckland District Plan. Available at: http://www.aucklandcity.govt.nz/council/documents/subdivision/docs/08aroaddesign.pdf

We also note that the City of Auckland District Plan refers to separation distances when assessing discretionary activities in relation to adjacent residential areas (Rule 12.9.2.5).[32] This is limited, however, to amenity (i.e. visual and aural privacy) only.

[32] http://www.aucklandcity.govt.nz/council/documents/district/Part12b.pdf

5.0 Discussion

5.1 Time and Distance

With respect to air quality, the sphere of influence of roads and motorways is dependent on:

- what is emitted (pollutant, vehicle, fuel, volume, congestion, speed of traffic, trip distance, etc);
- where/when it is emitted (distance to receptors, local topography, time of day); and
- how/which way the wind blows (prevailing meteorology, dispersion characteristics).

The prevailing wisdom, as evident in our literature review, appears to be that the concentration of pollutants rapidly decline with distance and that the impacts of traffic are largely confined to within 150 - 300 m of the road in question. However, there is a growing body of evidence that this is not adequate. This section discusses both monitoring data, observed effects (themselves often being limited to near field by study design) and recent research further afield.

A review by Brugge et al. 2007 notes the following:

5.1.1 Monitoring – within 400 m

- Zhu et al. (2002, 2002a) observed an exponential decrease in relative concentrations of carbon monoxide, black carbon, and total particle number concentration between 17 and 150 m downwind from highways in Los Angeles. At 300 m ultrafine particle number concentrations were the same as at upwind sites.
- Similar observations were made by Zhang et al. (2004) who demonstrated "road-to-ambient" evolution of particle number distributions near highways 405 and 710 in both winter and summer.
- Two studies in Brisbane (Australia) highlight the importance of wind speed and direction as well as contributions of pollutants from nearby roadways in tracking highway-generated pollutant gradients. Hitchens et al. (2000) observed that the distance from highways at which number and mass concentrations decreased by 50% varied from 100 to 375 m depending on the wind speed and direction. Morawska et al. (1999) observed that

ultrafine particle number concentrations were highest <15 m from highways, while 15–200 m from highways there was no significant difference in ultrafine particle number concentrations along either horizontal or vertical transects – presumably due to mixing of highway pollutants with emissions from traffic on nearby, local roadways.

- Roorda-Knape et al (1998) measured $PM_{2.5}$, PM_{10}, black smoke (which is similar to black carbon), nitrogen dioxide, and benzene in residential areas < 300 m from highways (80,000–152,000 vehicles/day) in the Netherlands. Roorda-Knape reported that outdoor concentrations of black smoke and nitrogen dioxide decreased with distance from highways, however, $PM_{2.5}$, PM_{10}, and benzene concentrations did not change with distance.

5.1.2 Effects – within 500 m

- Hoek et al. (2002) modelled exposure to nitrogen dioxide and black smoke for about 5,000 participants in the Netherlands Cohort Study on Diet and Cancer. Modelled exposure took into consideration proximity to freeways and main roads (100 m and 50 m, respectively). Cardiopulmonary mortality was associated with both modelled levels of pollutants and living near a major road with associations less strong for background levels of both pollutants.

- Recent child asthma studies have focused on major highways instead of street traffic (van Vliet et al. 1997, Venn et al. 2001, McConnell, 2006, Nicolai et al. 2003, Ryan et al. 2007). All of these studies have found statistically significant associations between the prevalence of asthma or wheezing and living very close to high volume vehicle roadways. The combined evidence suggests that living within 100 meters of major highways is a risk factor, although smaller distances may also result in graded increases in risk.

- Brunekreef et al. (1997) used distance from major roadways, considered wind direction and measured black smoke and nitrogen dioxide inside schools. They found the largest decrements in lung function in girls living within 300 m of the roadways.

- A longitudinal study of children (average age at start = 10 years) in Southern California reported results at 4 (Gauderman, 2000) and 8 years (Gauderman, 2005). In 2007, it was reported from this same cohort that living within 500 m of a freeway was reported to be associated with reduced lung function (Gauderman, 2007). The analysis could not indicate whether the effects seen were reversible or not (Merkus 2005).

Based on these studies, Brugge concluded that people living within about 30 m of highways are likely to receive much higher exposure to traffic-related air pollutants compared to residents living >200 m (+/- 50 m) from highways. This appears not to have considered the Yang et al (2003) findings of significant risk of preterm birth within 500 m of a major freeway.

Other studies have focussed on effects within 200 m:

- McConnell et al (2006) found that children who lived within 75 meters of a major road were approximately 1.5 times more likely to report asthma or wheezing compared to those living 300 meters or more from a major road. Among children with no parental history of asthma, those who had resided at an address close to heavy traffic since before age 2 experienced even higher risks (2.5-fold for asthma and 2.7-fold for wheezing), suggesting that a cumulative lifetime exposure to traffic pollutants may raise health risks. Girls showed a greater association between living near a major road and the health outcomes measured, for unknown reasons.

- As noted elsewhere, Barnett et al (2011) found negative effects of traffic on gestation were largely associated with main roads within 400 metres of the home, with much of the effect for roads within 200 metres. Notably, this study found no associations with distance to road.

- A Canadian review similarly concluded that the majority of pollutants are usually concentrated within 150 m of freeways and busy roadways (Ministry of Environment, 2006).

5.1.3 Monitoring and Effects > 500 m

Elevated levels of pollutants, and statistically significant correlations, have, however, been reported further afield.

- Hu et al. (2009) found that measured concentrations before sun-rise of ultrafine particulate matter (i.e. < 0.1 micrometres in diameter) did not reach background levels until a distance of about 2,600 m downwind. They were also elevated over background levels up to 600 m upwind of a freeway in California. Hu notes that these findings have important exposure assessment implications since they demonstrate extensive roadway impacts on residential areas during pre-sunrise hours, when most people are at home.

- The Canadian review (Ministry of the Environment, 2006) also noted that elevated pollutant concentrations occur as far away as 750 m from truck routes.

- Maheswaran and Elliot (2003) reported elevated mortality risks (from stroke) at a distance of up to 1,000 m from the centroid of the residential enumeration district. This study looked at 113,465 districts in England and Wales.

- As noted above, Roorda-Knape et al (1998) found that $PM_{2.5}$, PM_{10}, and benzene concentrations did not change with distance (< 300 m from highways) in the Netherlands.

- Also, as noted above, Gauderman (2007) reported that living within 500 m of a freeway was associated with reduced lung function in Southern California.

We conclude that we cannot be confident that pollutant concentrations and their associated adverse effects are limited to within 150 - 300 m of roads and motorways.

5.1.4 Auckland "background" levels

Auckland Council has published a draft guidance document for consultation that includes the following distances for 'background' levels of air quality (Auckland Council, 2011) as shown in Table 8. In other words, at these distances, the road may be assumed not to intrude on normal, background levels of ambient air quality.

Table 8 Locations where Default (Background Air Quality) Values Apply

Road *	Contaminant	Distance between receptor and road edge
Motorway or strategic arterial	NO_2	300 m
	CO, SO_2, benzene, PM_{10}, $PM_{2.5}$	150 m
Regional arterial	NO_2	150 m
	CO, SO_2, benzene, PM_{10}, $PM_{2.5}$	70 m

* Strategic arterial and regional arterial roads are defined in the Regional Arterial Road Plan (ARTA, February 2009).

5.2 Location of Sensitive Receptors

When considering separation distances for roads and motorways we must first consider the existing situation. There have been a number of reviews on the proximity of sensitive land uses with roads overseas.

Brugge et al. (2007) noted that approximately 11% of US households are located within 100 m of a 4-lane highway. The Interagency Panel report noted the following (Inter-Agency Air Quality Advisory Panel, 2009):

- Appatova et al. (2008) found that 10% of surveyed US schools were within 100 m of a highway, and 30% were within 400 m. For some metropolitan areas almost half of the student population attended schools near (≤400 m) major roadways, resulting in a potentially increased risk for asthma and other chronic respiratory problems, especially in schools representing the urban fringe locale.

- Houston et al. (2006) found that 7% of the available capacity of childcare centres in California was located within 200 m of a roadway with >50,000 vehicles/day, with another 21% near a roadway with 25,000 – 50,000 vehicles/day. Importantly, facilities providing care to infants or preschool-aged children and facilities located in disadvantaged areas were more often situated in medium or high-traffic areas.

- Green et al. (2004) found that 2% of Californian schools were located within 150 m of roadways with >50,000 vehicles/day, and 7% near roadways with 25,000 – 50,000 vehicles/day. Similar to Houston et al, traffic exposure was disproportionately related to race/ethnicity and lower socioeconomic indicators. For example, the overall percentage of nonwhite students was 78% at the schools located near high-traffic roads versus 60% at the schools with very low exposure (no streets with counted traffic data within 150 m).

- Wu and Batterman (2006) also examined roads carrying high proportions of trucks, and found that 2.8% of (US) schools were located within 150 m of roads carrying at least 5,000 trucks per day. In Wayne County, students attending schools near high traffic roads are more likely to be Black or Hispanic, to be enrolled in a meal program, and to reside in a poor area.

A recurring feature of these studies is the disproportionate exposure of disadvantaged sectors of the population to traffic pollution. Ponce et al, 2005 investigated the interaction of residential air pollution with neighbourhood economic hardship and impacts on pre-term birth. The findings were that traffic-related air pollution exposure disproportionately affected low socioeconomic status neighbourhoods in the winter.

When considering separation distances for sensitive land uses in Auckland, extra care should be taken with lower socioeconomic areas.

5.2.1 Auckland early childhood education centres

The Inter-Agency Air Quality Advisory Panel report found that, in 2008, 24% of existing early childhood education centres in Auckland were within 60 m of arterial roads and within 150 m of strategic routes including motorways (Inter-Agency Air Quality Advisory Panel, 2009).

Based on licensing data, there are approximately 50,000 children attending early childhood education centres for an average 18 hours per week in Auckland. This equates to approximately 12,000 Auckland babies, infants and children in early childhood education centres exposed to elevated levels of air pollution from traffic for just under 20 hours per week.

We note the focus on children in the draft Auckland Plan (Auckland Council, 2011a). We consider the existing location of schools and early childhood education centres so close to busy roads seriously hampers the ability of planning documents to deliver improved outcomes for Auckland's children.

5.2.2 Auckland schools

Based on GIS data from Auckland Council we located 52 schools within 150 m of a motorway and 70 m of a regional arterial route as shown in Auckland (Table 9).

This represents **35,457 Auckland children spending at least 30 hours a week in areas with elevated levels of air pollution due to emissions from transport.**[33]

These schools are located on Figures 9 - 15 in Section 5.6.

[33] Dilworth junior campus is a boarding school so exposure will be 24/7.

Table 9 Auckland Schools within 150 m of a motorway or 70 m of a regional arterial [a]

Within 150 m of a motorway		Within 70 m of a regional arterial	
School	**Roll**	**School**	**Roll**
Auckland Grammar	2461	Carey College	30
Dilworth (junior campus)	192[b]	City Impact Church Secondary School	9
Mangere Central	465	Corwall Park District School	619
Manurewa East	384	Don Buck School	220
Mt Roskill Grammar	2160	Edmonton School	294
Newton Central	272	Forrest Hill School	351
Newmarket	249	Henderson Intermediate	504
Redoubt North	681	Hobsonville School	569
Riverina	217	Howick Intermediate	474
Royal Road	304	Kelston Girls' College	887
Sancta Maria College	848	Kings School (Remuera)	696
Sancta Maria Catholic Primary	231	Kristin School	1,638
St Peters College	1127	Manurewa Central	524
Takapuna Normal Intermediate	599	Marcellin College	699
Westlake Girls High	2088	Massey High	2,359
Subtotal	**12,278**	Massey Primary	467
		Mt Hobson Middle School	63
		Northcross Intermediate	1,119
		One Tree Hill College	760
		Oteha Valley School	305
		Panmure District	169
		Papakura High	1,003
		Papakura South	92
		Papatoetoe Central	664
		Papatoetoe Intermediate	863
		Rangitoto College	2,871
		St Joseph's Grey Lynn	92
		St Joseph's Takapuna	368
		St Kentigern School for Girls - Corran	113

Within 150 m of a motorway		Within 70 m of a regional arterial	
		St Mark's Pakuranga	244
		St Mary's Northcote	423
		St Paul's Massey	340
		St Therese Three Kings	141
		St Thomas	668
		Takapuna School	261
		Westlake Boys' High	2,100
		Westminster Christian School	180
		Subtotal	**23,179**
Total all schools within 150 m of a motorway or 70 m of a regional arterial:			**35,457**

Notes:
[a] Source: most recent Education Review Office report at www.ero.govt.nz
[b] Dilworth Junior campus numbers from en.wikipedia.org. NB: Dilworth is a boarding school.

5.3 Future Trends

Current policies have, and will continue to, result in improved air quality.

Vehicle emissions have substantially dropped as a direct result from measures introduced by various regulatory agencies over the last decade. These include:

- increasingly stringent emission limits for new and used vehicles (NZTA, 2011a);
- increasingly stringent fuel regulation (NZTA, 2011a); and
- better road management (NZTA, 2010).

Nevertheless, if there is significant growth in traffic volumes then this could undermine the benefits to urban air quality from the above measures.

The World Health Organisation considers that alternative vehicle technologies are unlikely either to become important in the market in the next decade or to have a significant impact on air quality (WHO, 2005).

Locally, the Regional Policy Statement recognises that even with significant increases in public transport patronage, the majority of trips will be made by private transport in the foreseeable future (Auckland Regional Council, 2011). The Freight Strategy similarly notes that road freight is anticipated to dominate for the foreseeable future, regardless of efforts to increase freight transport by rail or sea (Auckland Regional Council, 2006).

As at time of writing, we estimate that a significant proportion of the Auckland population will continue living in areas with elevated particulate matter and nitrogen dioxide levels, mainly due to road-traffic emissions. We therefore, recommend responsible separation of the worst traffic emitters (heavy duty diesel) from the most sensitive receptors (children). This could be achieved in a reasonable timeframe (eg 10-15 years) through requirements for new licences for early childhood education centres.

5.4 Auckland Monitoring Data

5.4.1 Early childhood education centre monitoring

In 2008, the Auckland Regional Public Health Service undertook ambient air quality monitoring for a range of pollutants at an early childhood education centre located on a busy arterial route in South Auckland.[34] The Inter-Agency Air Quality Advisory Panel, provided a technical synopsis of this monitoring and found that (Inter-Agency Air Quality Advisory Panel, 2009a):

- There were a number of measured exceedances of several air quality guideline values (PM_{10}, $PM_{2.5}$), including an exceedance of the national ambient air quality monitoring guideline for $PM_{2.5}$.
- Meteorological conditions during the monitoring period were favourable compared with other years. This means that pollutant concentrations would be expected to be even higher in other years with less favourable meteorological conditions.
- Elevated pollutant levels at this site are primarily due to its location on the corner of two major roads, rather than the suburb in which it is located. Analysis by the Panel suggests that air quality elsewhere in this suburb, at sites less exposed to traffic, is likely to be substantially better.
- Monitoring results show that emissions from local traffic on the two roads next to the centre substantially elevate the levels of pollutants at this site, especially during the centre’s opening hours
- Comparing monitoring results from this site with results from other regional monitoring sites shows that air pollution levels at this site are among the highest in the Auckland region, on a par with other peak traffic sites

[34] Monitoring was for six months between June and December for the following pollutants: PM_{10}, $PM_{2.5}$, CO, NO_2, and benzene using methods in accordance with Schedule 2 of the national environmental standards for air quality (excepting benzene which was passively monitored on a monthly basis).

- In summary, exposure to traffic at the centre was very high, due to its location on the intersection of two major roads with high traffic volumes.

5.4.2 Monitoring downwind from motorways

Auckland Council has two publicly available monitoring studies that have investigated how traffic pollutant concentrations change with distance from the road.

The Auckland Regional Council compared pollutant concentrations with distance from the motorway in Penrose between March 2004 and January 2006 (Auckland Regional Council 2008). Monitoring was carried out during different time periods and using different methodologies at the different locations. However, the limited data indicate that, even at 200 m, concentrations of nitrogen dioxide were still higher than the urban background.

A passive monitoring study undertaken in 2007 showed similar results (Auckland Regional Council, 2007). In this study, nitrogen dioxide was measured using passive samplers at varying distances either side of the motorway at three locations:

- SH20 at Mangere (July to September 2006);
- SH1 at Penrose (July to September 2006); and
- SH1 at Otahuhu (mid-November 1997 to mid-February 1998).

The results for the Mangere site are shown in Figure 3.

By subtracting monitoring results from one side of the motorway from the other, a rough estimate was made of the motorway contribution to ambient air quality. This is noted as likely to be an underestimate because, dependent on the wind direction, the motorway contributes to all sites. Figure 4 illustrates that NO_2 concentrations generally decreased away from roads in the form of:

- linear functions at Mangere and Penrose (sampling in winter); and
- a logarithmic function at Otahuhu (sampling in summer).

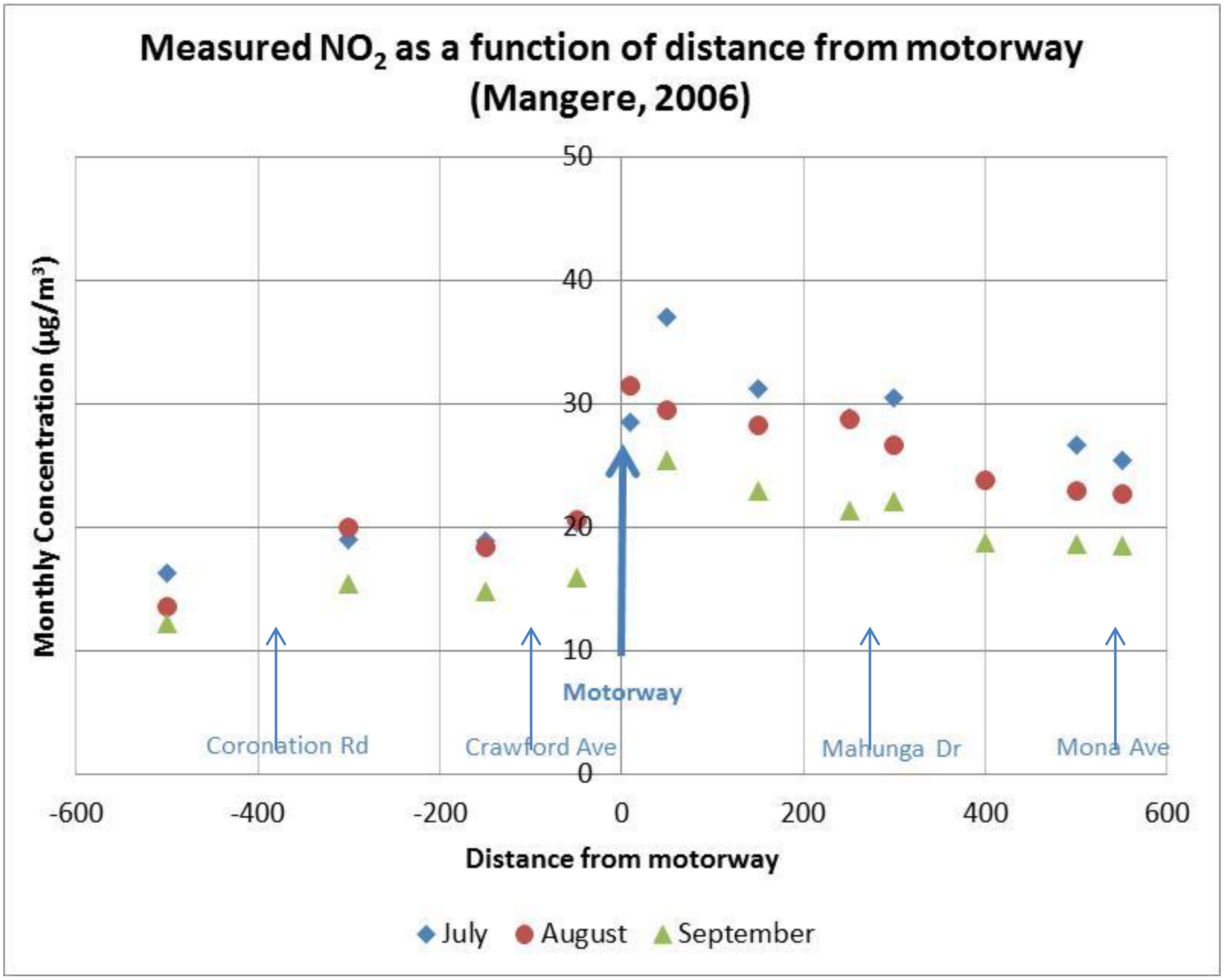


Figure 3 Monthly NO_2 concentrations at the roadside of SH20 at Mangere

The positive distance indicates the eastern side, negative the western side. The arrow (↑) indicates the position of the motorway and local roads.

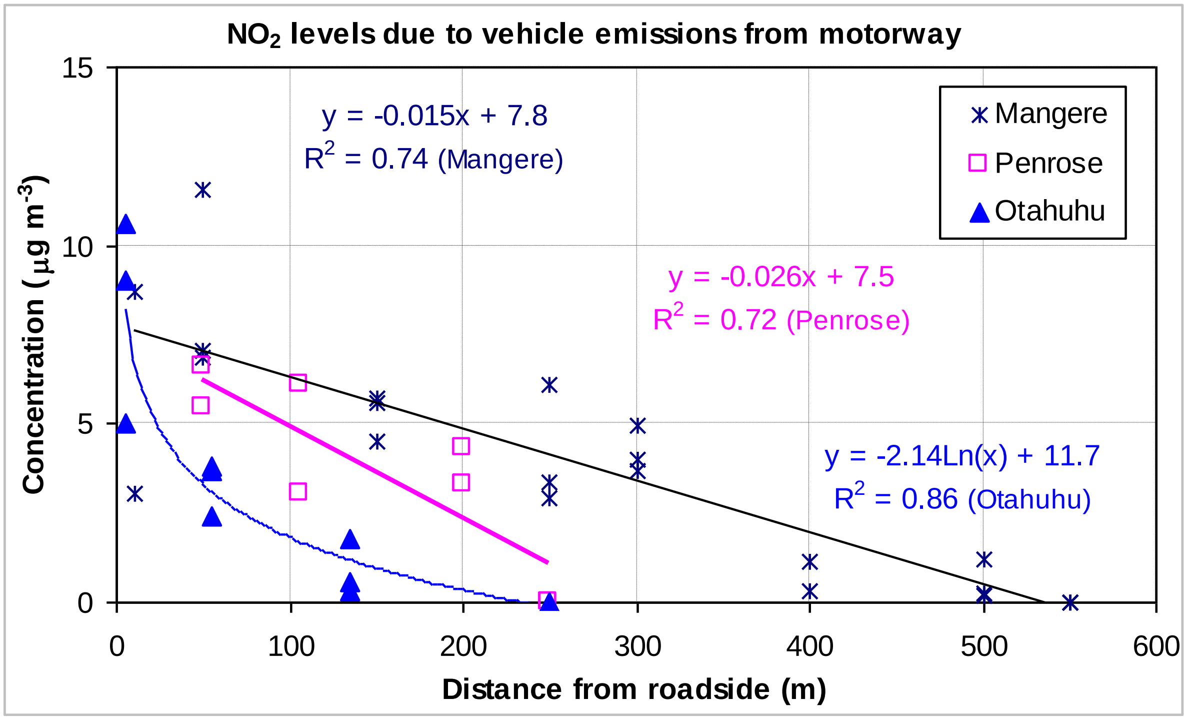


Figure 4 **Roadside NO2 concentrations due to vehicle emissions from the motorway (SH20 at Mangere, SH1 at Penrose and SH1 at Otahuhu).**

Importantly, the Mangere results show elevated concentrations of nitrogen dioxide out to 300 m (Penrose and Otahuhu only measured out to 250 m). The study concluded that:

- There is a general downward trend of NO_2 concentrations with increasing distances from the roadside.
- The relationship between nitrogen dioxide concentrations and distances from roadsides could be linear or logarithmic. Further, the relationship may be location or season dependent.
- On average concentrations are higher on the downwind side of the motorway.
- The contributions from the motorway can remain elevated up to at least 300 m away from the roadside.

5.5 NZTA Air Quality Screening Tool

NZTA has recently developed an air quality screening assessment tool that is available online at:

http://air.nzta.govt.nz/node/add/calc-screening-assessment

The air quality screening tool is designed to provide a conservative (worst case) assessment of air quality risk from a single road.[35] Using this screening tool, we modelled typical regional arterial roads and strategic routes in Auckland as shown in Table 10.

Table 10 Screening Model Inputs (Regional Arterial and Strategic Routes in Auckland)[36]

Input Parameter	Regional Arterial		Strategic Route	
	95%ile	All	95%ile	All
Average Annual Daily Traffic	33,474	65,504 (max)	153,379	243,417 (max)
Heavy Duty Vehicles	5.2%	5.2%	7.5%	7.5%
Average vehicle speed	36 km/h	36 km/h	68 km/h	68 km/h

Figures 5 - 8 show the conservative screening model results for PM_{10}, $PM_{2.5}$ and nitrogen dioxide for regional arterial and strategic routes in Auckland. The figures plot the concentration of each pollutant as a percentage of the relevant criteria as a function of distance downwind for each type of route. The relevant criteria are:

- WHO: 40 µg/m^3 - World Health Organisation global guideline for nitrogen dioxide as an annual average;
- RAQT: 25 µg/m^3 – Regional air quality target for $PM_{2.5}$ as a daily average;
- NES: 50 µg/m^3 – National environmental standard for PM_{10} as a daily average.

[35] The tool recommends obtaining specialist advice for more complex situations. Further information about the NZTA assessment process, including a definition for Tier 2 and Users Guide for the screening tool, is available on the website.
[36] Auckland Regional Transport Model, Version 3.

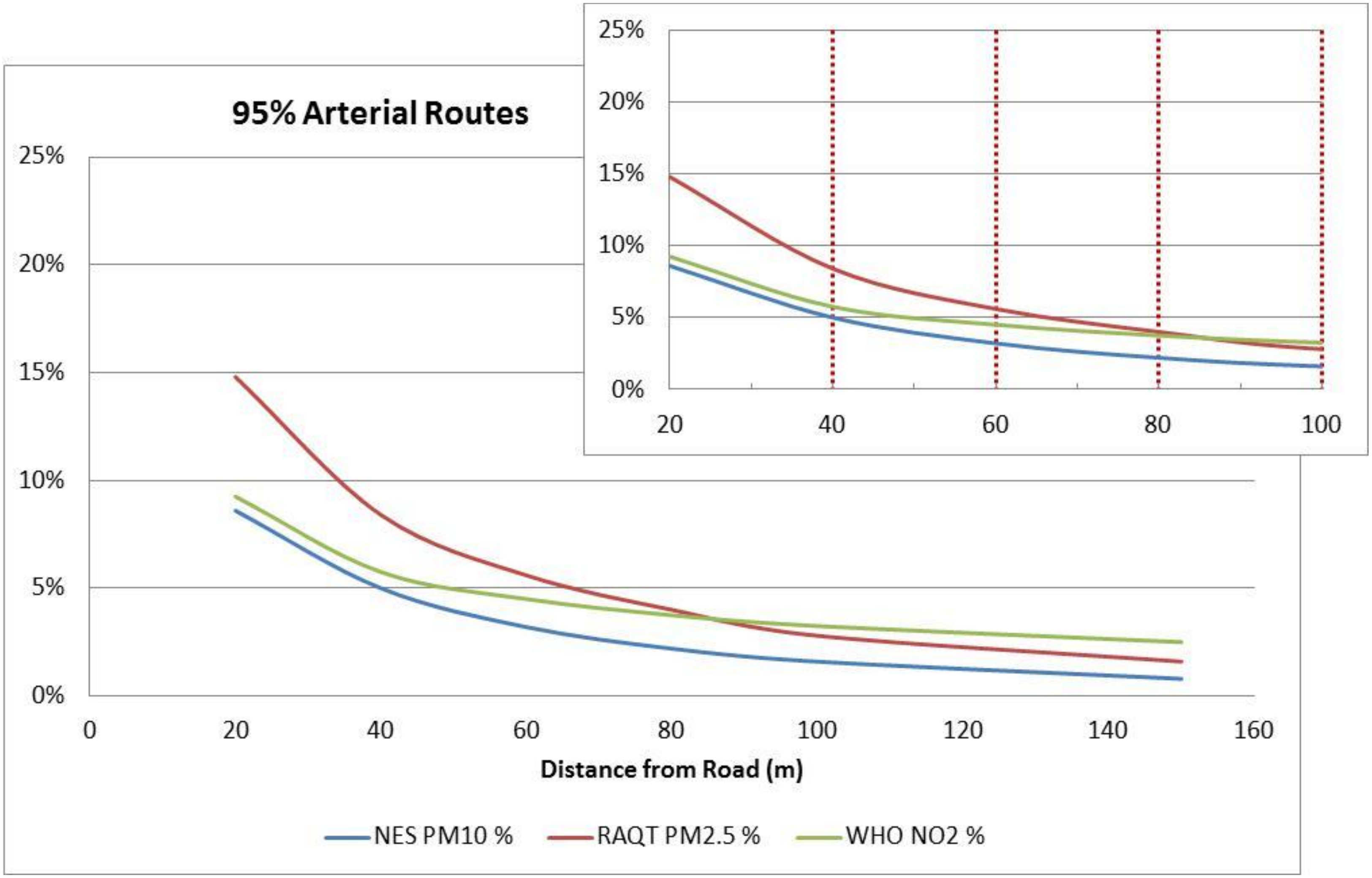


Figure 5 Screening model results (PM_{10}, $PM_{2.5}$, NO_2) for 95% of regional arterial routes in Auckland

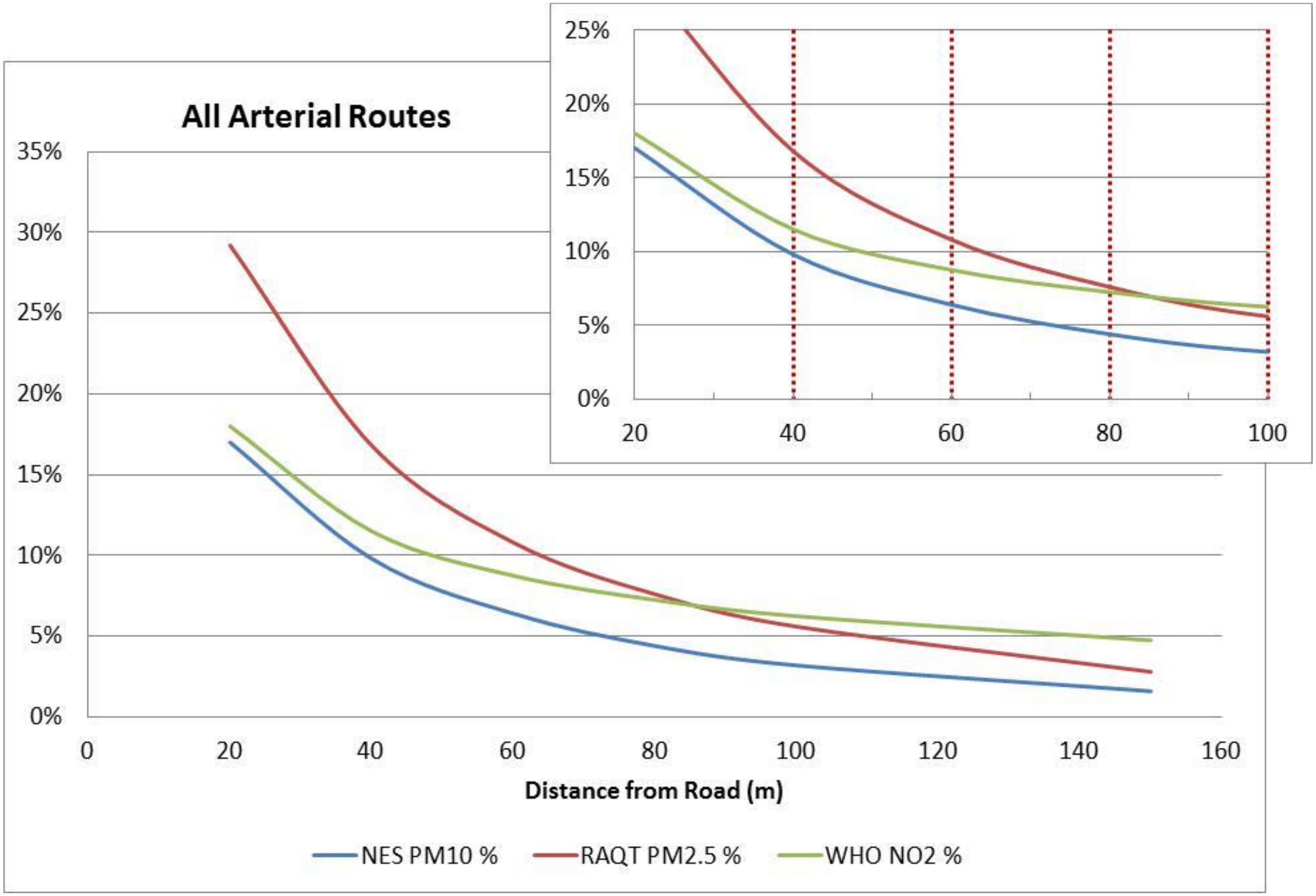


Figure 6 **Screening model results (PM_{10}, $PM_{2.5}$, NO_2) for all regional arterial routes in Auckland (maximum AADT)**

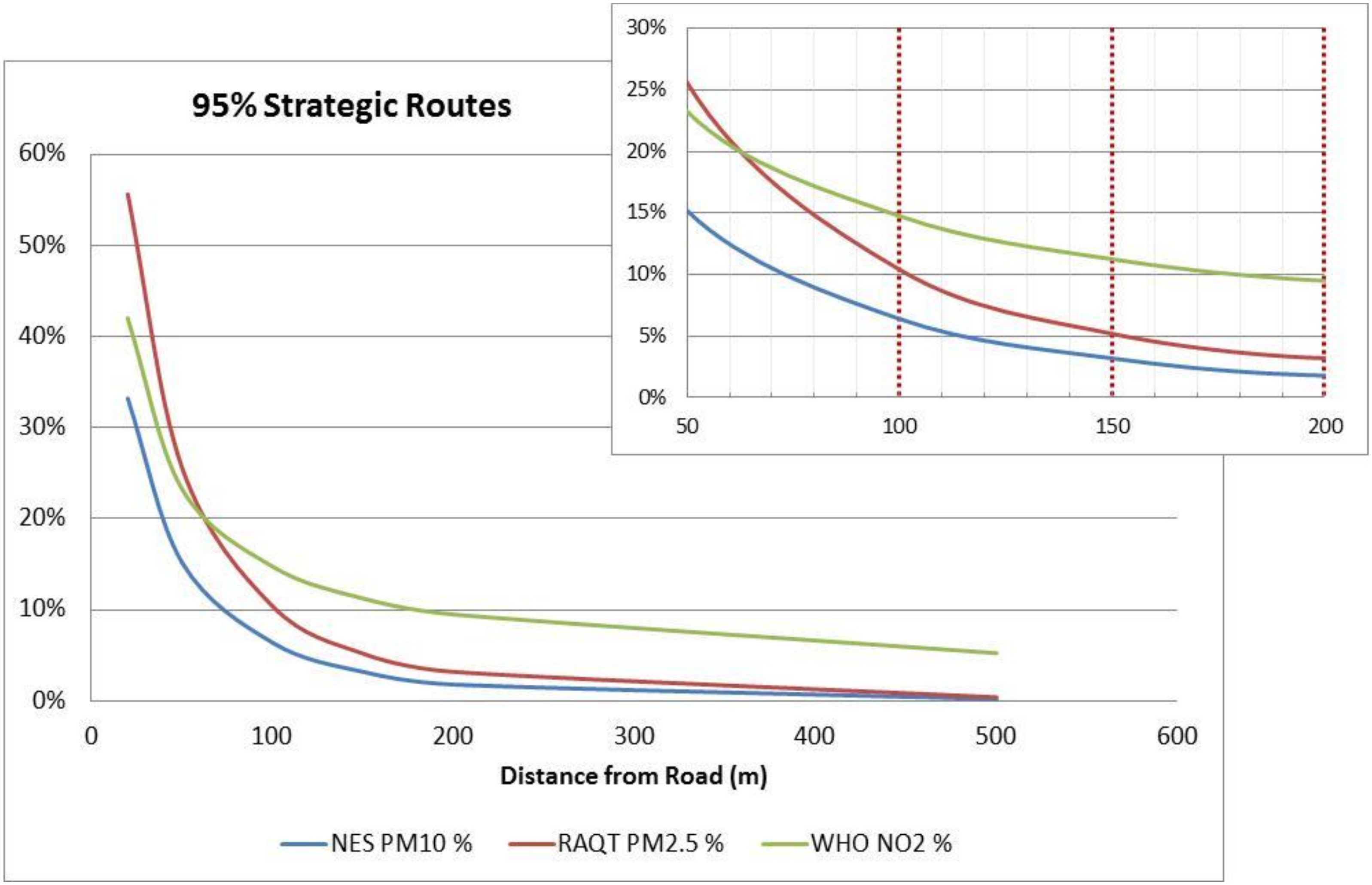


Figure 7 **Screening model results (PM_{10}, $PM_{2.5}$, NO_2) for 95% of strategic routes in Auckland**

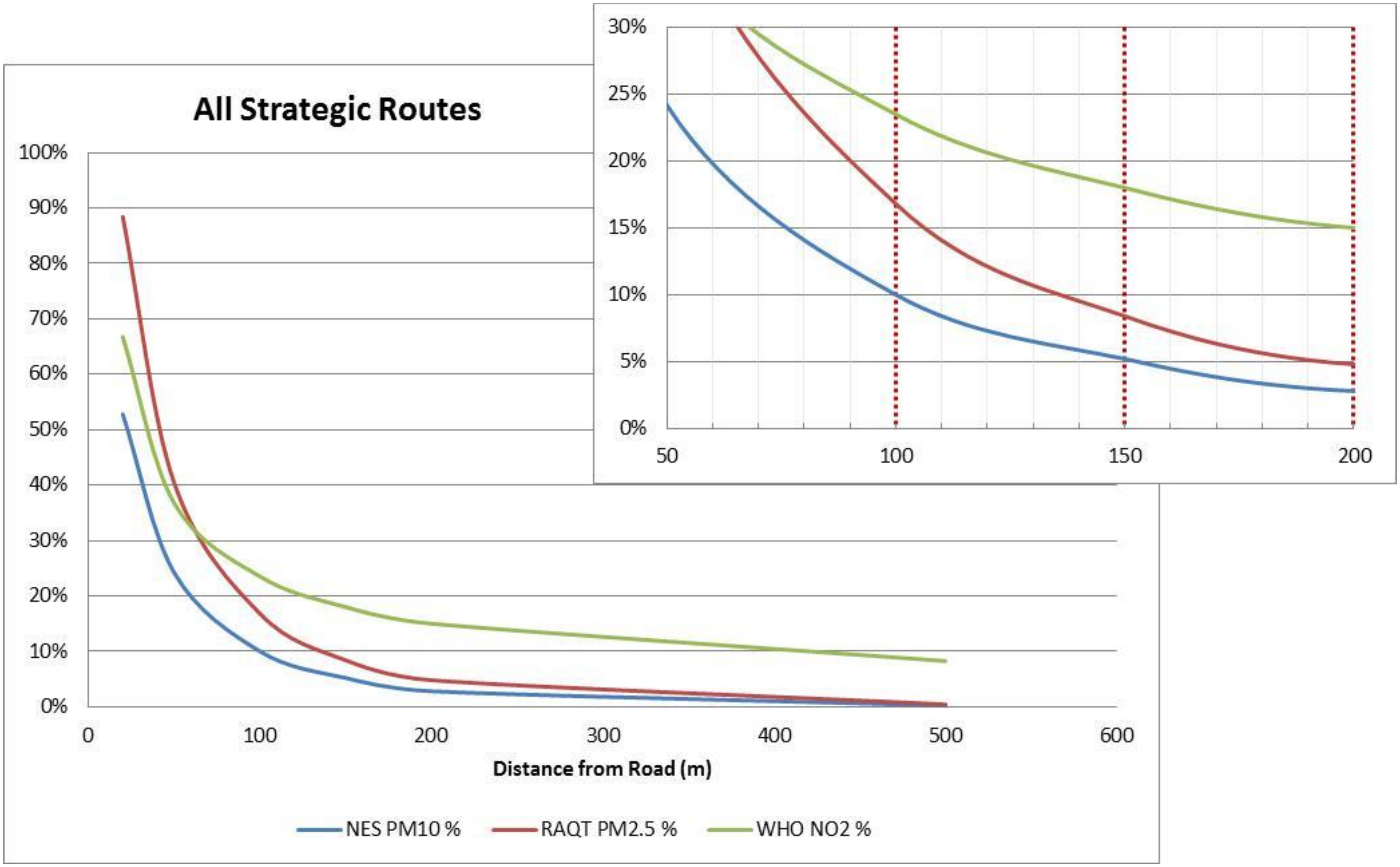


Figure 8 **Screening model results (PM_{10}, $PM_{2.5}$, NO_2) for all strategic routes in Auckland (maximum AADT)**

5.6 Proposed Separation Distances

The screening modelling in section 5.5 predicts downwind concentrations of key transport pollutants as a function of distance. We have used this modelling, coupled with an assumed significance criterion of 5% (of the national environmental standard) for PM_{10}, to propose separation distances for new roads and land uses in Auckland as follows:

- **Strategic routes: 150 m**
- **Regional arterial routes: 70 m**

The assumed significance criterion of 5% is consistent with the Ministry for the Environment *Good Practice Guide for Assessing Discharges to Air from Land Transport* which states:

> ***PM_{10} and $PM_{2.5}$ 24-hour average:*** *The thresholds are set at **5%** of the national ambient air quality standard and/or guidelines (where standards do not apply). Longer-term exposure to these pollutants has a more serious health effect, and is consequently set at a relatively low percentage.*[37]

Of the pollutants modelled, PM_{10} is arguably the key policy driver because it has a mandatory national environmental standard. Table 11 shows the (conservative) predicted concentrations of key pollutants for our proposed separation distances. The results have been rounded to the nearest 5% because the modelling is conservative and not overly accurate.

Table 11 Screening Model Results (Regional Arterial and Strategic Routes in Auckland)

Pollutant	Regional Arterial (70 m)		Strategic Route (150 m)	
	95%ile	All	95%ile	All
PM_{10}	<5% NES	**5% NES**	<5% NES	**5% NES**
$PM_{2.5}$	**5% RAQT**	<10% RAQT	**5% RAQT**	10% RAQT
NO_2	<5% WHO	<10% WHO	~10% WHO	20% WHO

Table 11 shows that beyond the proposed separation distances:

- Daily PM_{10} concentrations are at, or below, 5% of the national environmental standard for all regional arterial routes;
- Daily $PM_{2.5}$ concentrations are at, or below, 5% of the regional air quality target for 95% of regional arterial routes;

[37] Ministry for the Environment, 2008. At p51

- Daily PM_{10} concentrations are at, or below, 5% of the national environmental standard for all strategic routes;
- Daily $PM_{2.5}$ concentrations are at, or below, 5% of the regional air quality target for 95% of strategic routes;

Figures 9 – 15 plot the proposed separation distances for regional arterial and strategic routes in the Auckland Urban Airshed.[38] This information was generated by Auckland Council as detailed in Appendix B.

Readers should note that the maps of proposed separation distances are indicative only. This is because regional arterial and strategic are based on classifications in the Regional Road Plan (ARTA, 2009). For example, some regional arterial routes may not experience the traffic volumes to justify the proposed separation distance.[39]

38 Available at: http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/nes/auckland/

39 A strategic route is predominantly through traffic with more than 40,000 vehicles per day, has moderate to high speeds (50 – 100 km/h) with general segregation of pedestrian and cyclists from traffic. A regional arterial route is also predominantly through traffic, may have more than 40,000 vehicles per day, has moderate speeds (50 km/hr) and also (generally) separates pedestrian and cyclists from traffic.

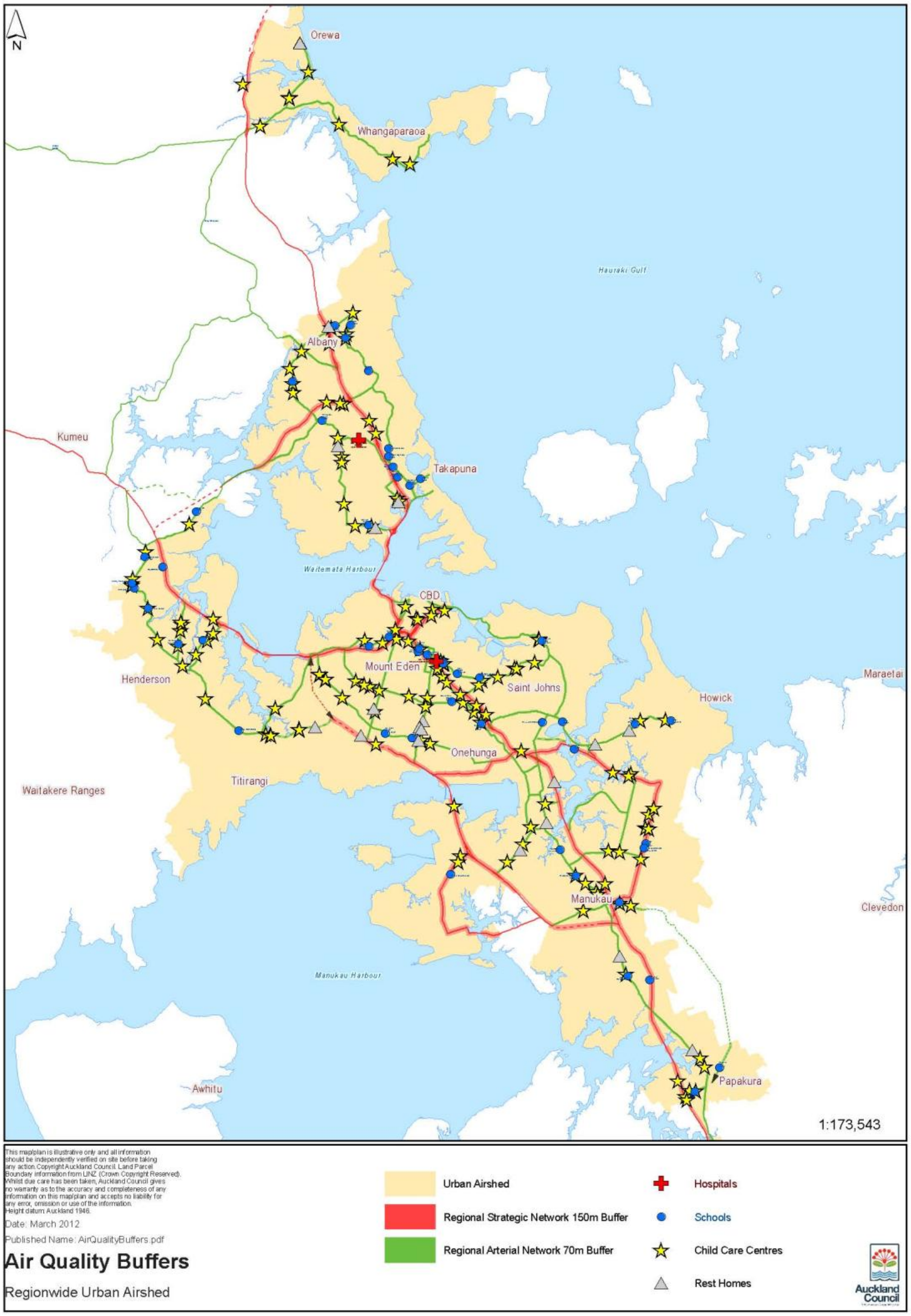


Figure 9 Proposed Separation Distances – Auckland Urban Airshed

Figure 10 Proposed Separation Distances – Auckland Urban Airshed Central

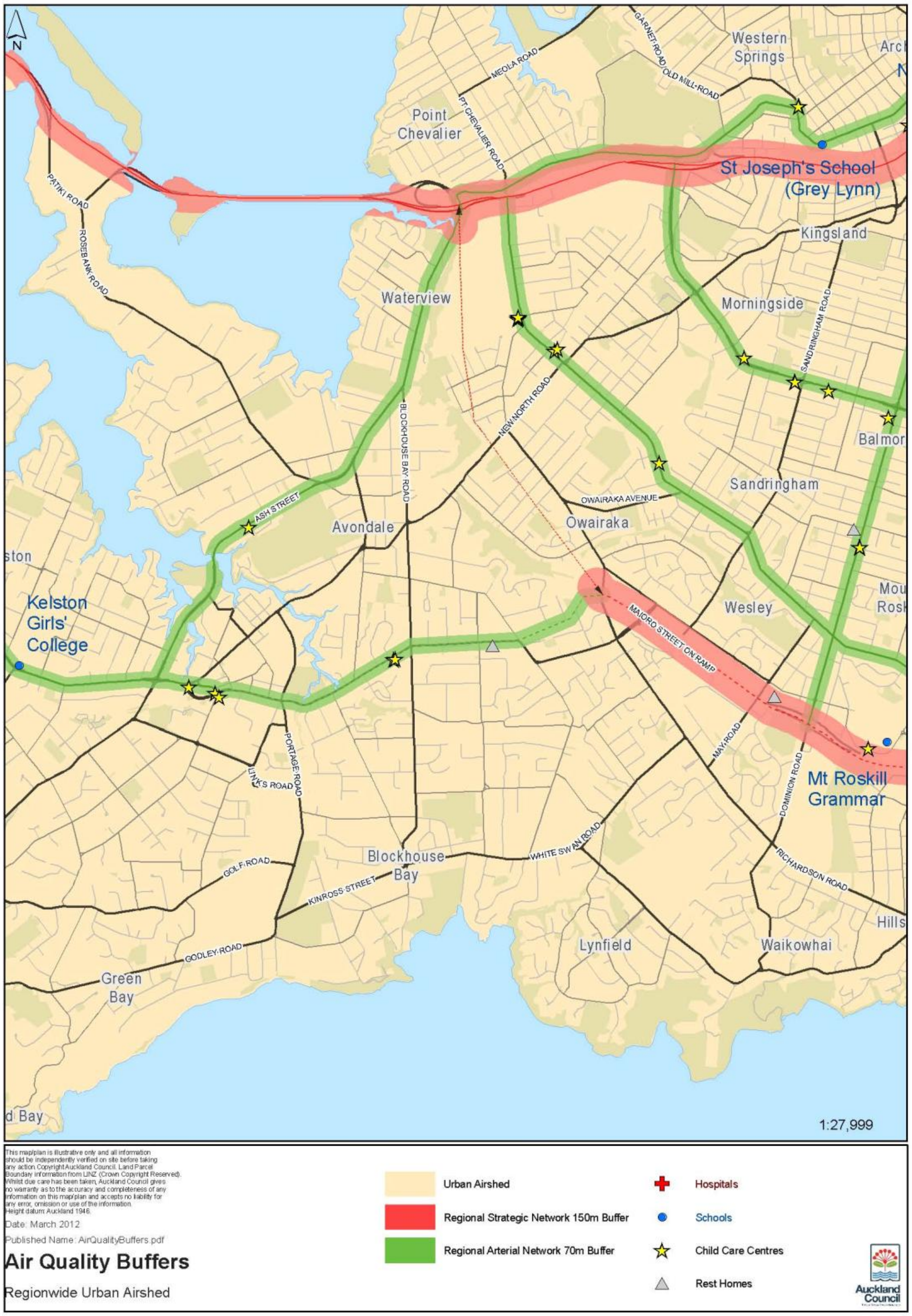


Figure 11 Proposed Separation Distances – Auckland Urban Airshed Inner West

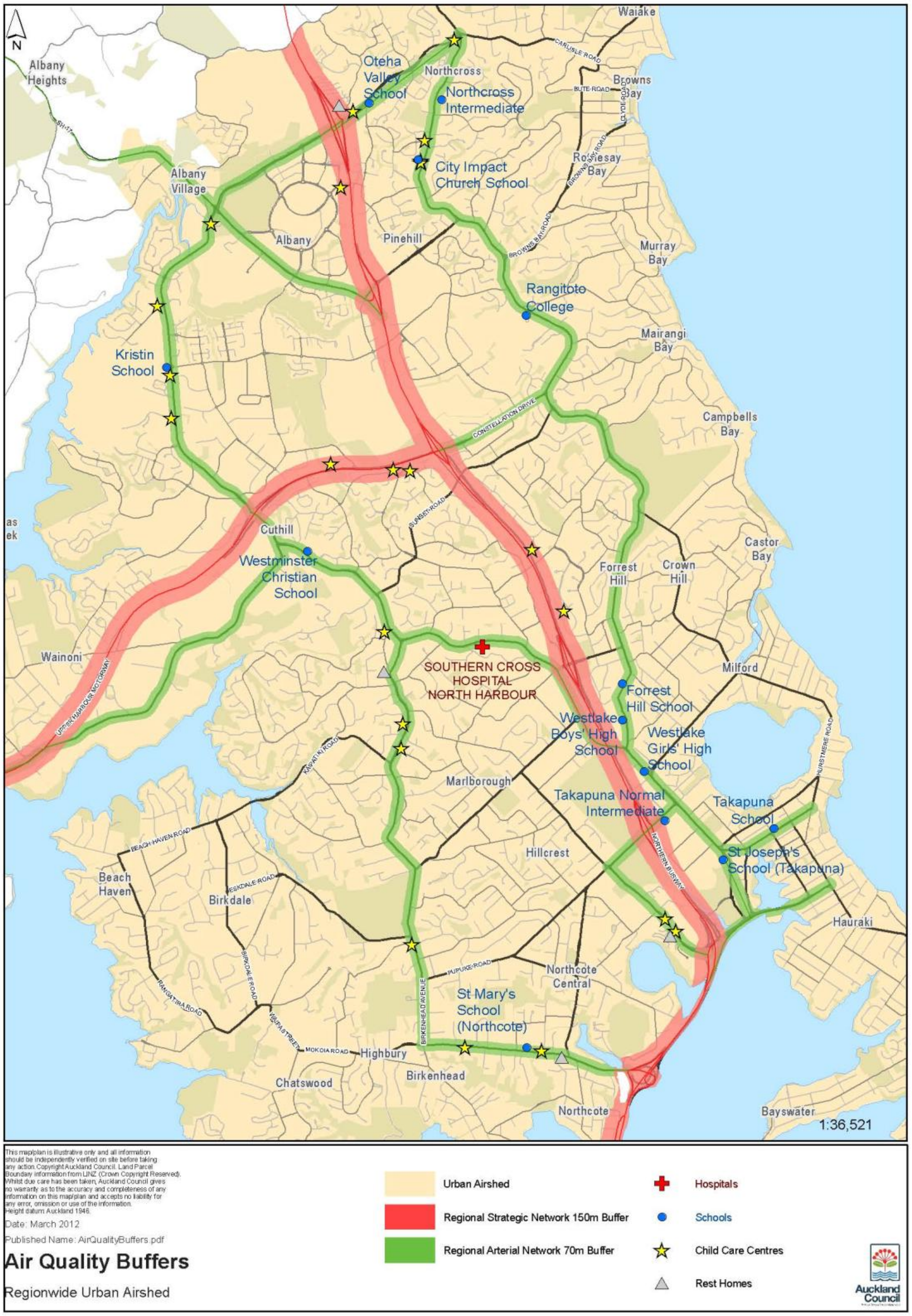


Figure 12 Proposed Separation Distances – Auckland Urban Airshed North

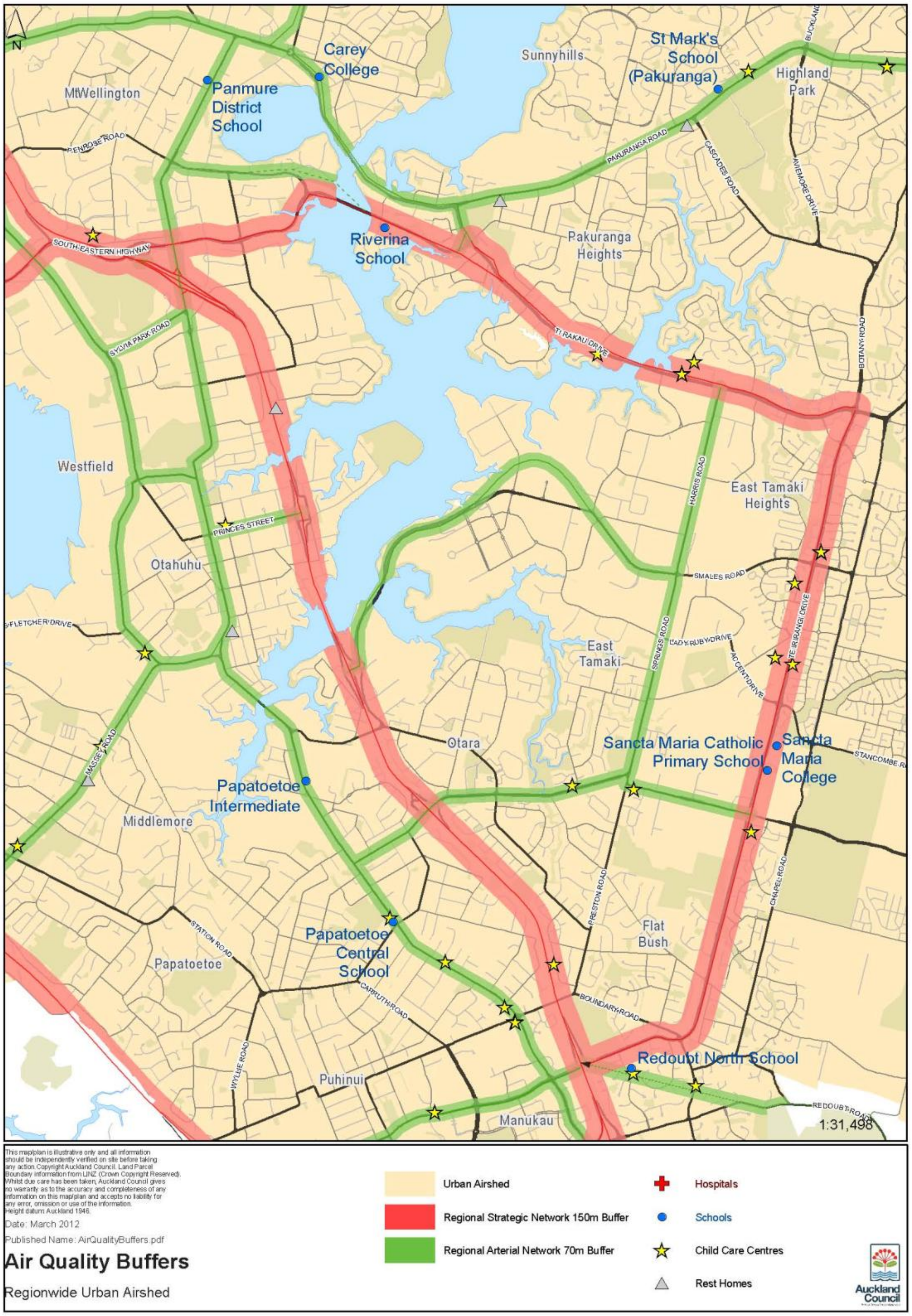


Figure 13 Proposed Separation Distances – Auckland Urban Airshed East

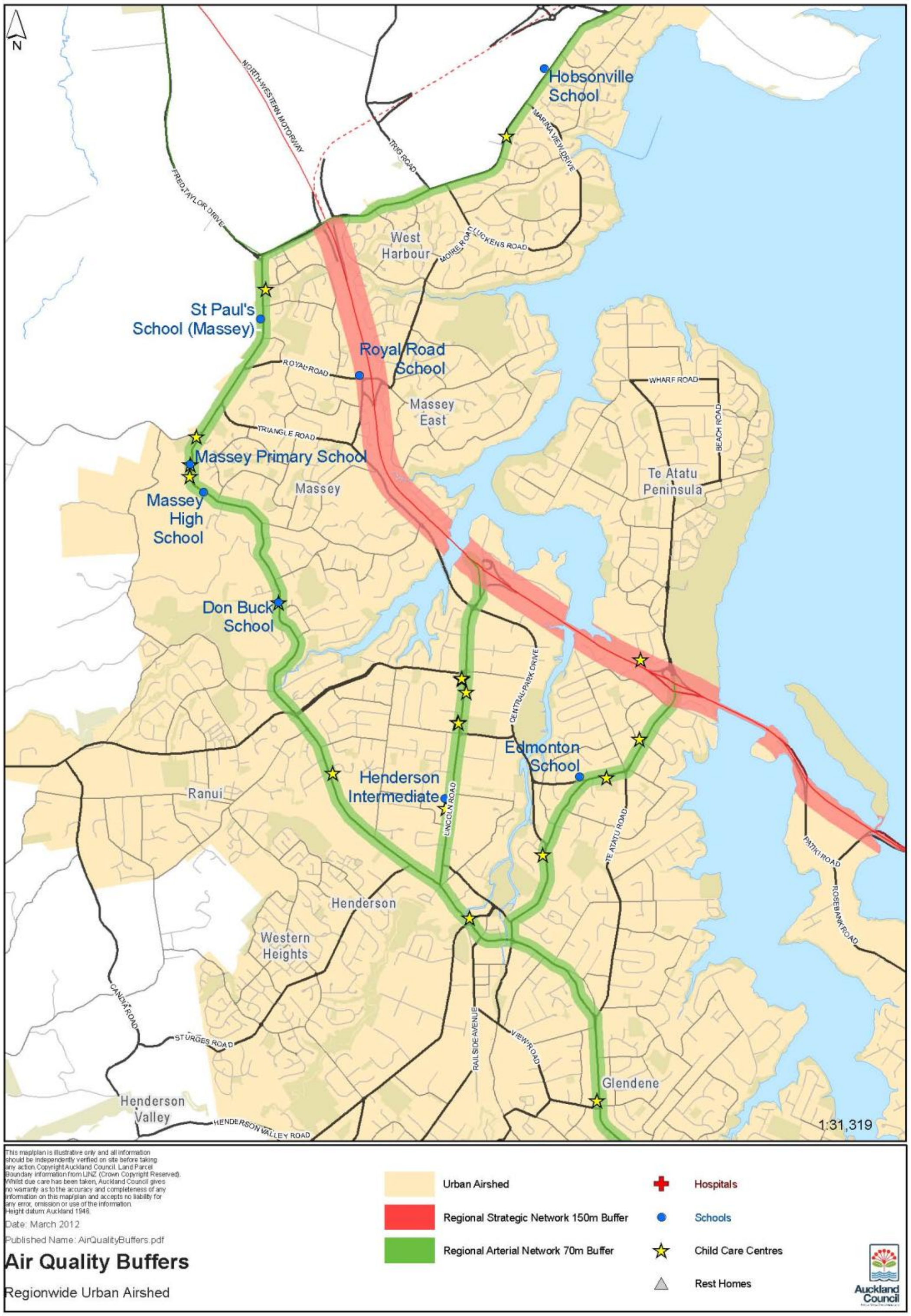


Figure 14 Proposed Separation Distances – Auckland Urban Airshed West

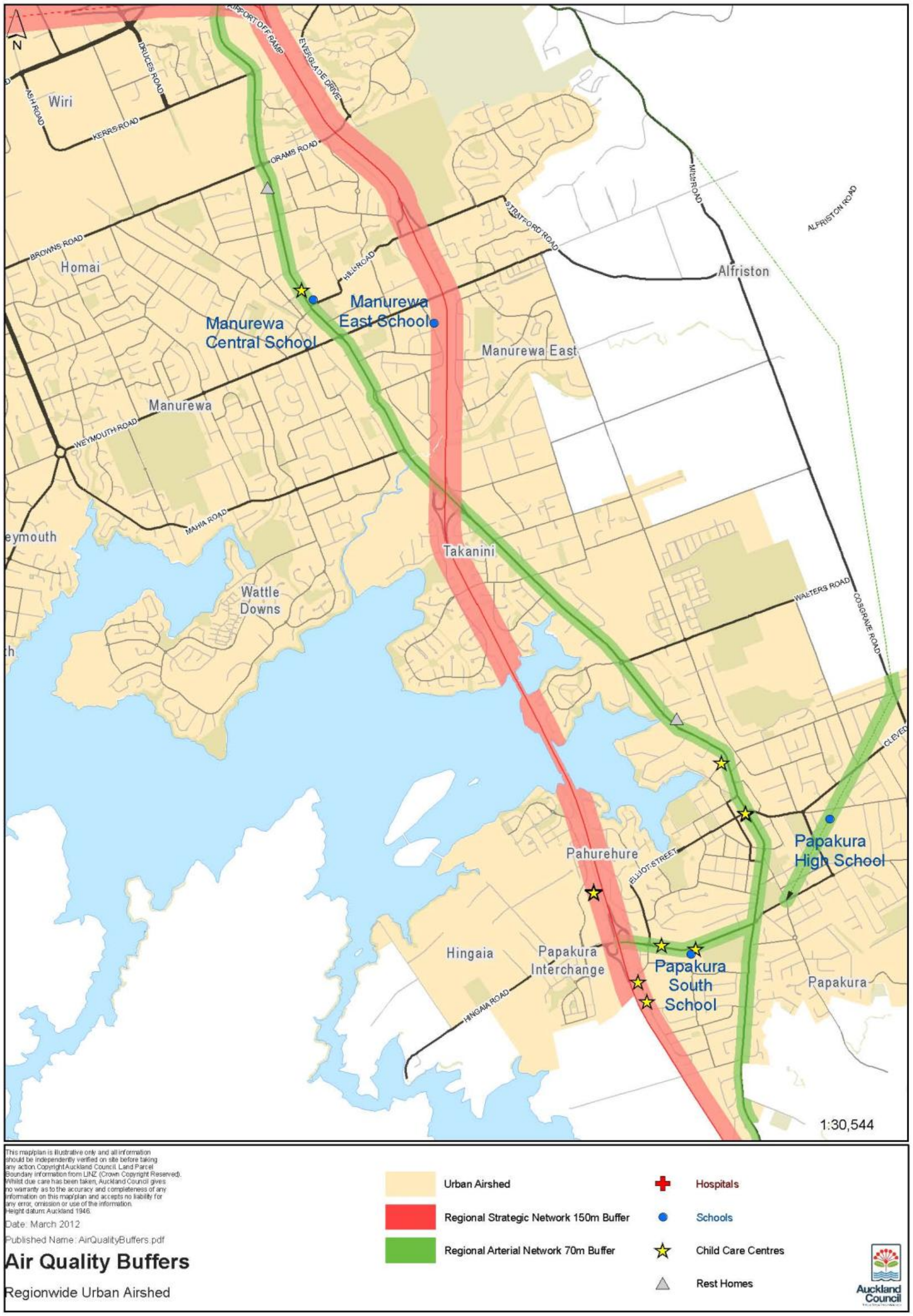


Figure 15 Proposed Separation Distances – Auckland Urban Airshed South

Table 12 shows the vulnerable populations within the proposed separation distances.[40]

Table 12 Vulnerable populations within proposed separation distances

Land Use (Urban Airshed Only)*	Strategic Routes	Regional Arterials	Both **
Separation Distance	**150 m**	**70 m**	**70 m and 150 m**
Schools	15	37	52
Early childhood centres	49	117	162
Hospitals	1	2	2
Occupied private dwellings	25,373	24,894	49,561
Age 0 – 14	17,398	12,414	32,367
Age over 65	6,023	7,564	14,999
Adults 15 – 65	55,961	48,340	136,759
Vulnerable population	**23,421**	**19,977**	**47,366**

*Orewa, North Shore, Auckland Central/South/West
** Total not cumulative - some child centres located within proposed distances of regional arterials and strategic routes

Table 12 shows that there are 52 schools and 162 early childhood education centres within either 70 m of a regional arterial route or 150 m of a strategic route in Auckland.

For an average 25 children in each early childhood education centre, this equates to around 4,000 babies, infants and children exposed to elevated levels of air pollution from traffic for just under 20 hours per week. **This is 8% of the estimated 50,000 children in care** (Inter-Agency Air Quality Advisory Panel, 2009).

Table 12 also shows that nearly 50,000 people, or nearly 4% of the Auckland population, live within the proposed separation distances. These figures are based on 2006 census data and will have increased since that time.[41]

[40] Statistics New Zealand 2006 Census of Population and Dwellings, http://www.stats.govt.nz
[41] Ibid.

6.0 Summary and Recommendations

There is a well-established body of research on the adverse health effects of air pollution on people including stroke, chronic respiratory disease, reduced lung function and premature mortality. The *Review and Update of HAPINZ for the Auckland Region* (Auckland Regional Council, 2010) estimated the health costs of air pollution associated with vehicles in Auckland to be around $273 million, per annum. These costs are largely due to around 160 premature deaths associated with exposure to particulate matter less than 10 micrometres in diameter (PM_{10}) and nitrogen dioxide (NO_2).

However, our review of the recent literature has provided even more sobering and compelling data. The weight of evidence approach indicates causality for a wide range of adverse health effects ranging from prevalence of asthma and wheeze to adverse pregnancy outcomes, such as child mortality and low birth weight (as a result of exposure to air pollution). Despite noted study limitations, in general there is remarkable consistency in the findings of the studies, conducted in a range of different populations and using both spatial and time-series study designs.

There is also a strong body of evidence that led us to conclude that residential proximity to traffic is associated with adverse health effects and poses a public health threat. Whilst the studies stop short of determining causality (between the proximity to roads and adverse health effects), we consider it to be a reasonable hypothesis. Notably, where investigated, a recurring feature of the studies was the disproportionate exposure of disadvantaged sectors of the population to traffic pollution and the associated disproportionate adverse health effects.

The above needs to be considered in the Auckland context where:

- air quality consistently approaches, and sometimes exceeds, regional targets and national standards for air quality. This means that whilst exceedances are not regular, background levels are regularly elevated (i.e. annual public exposure may be significant);

- asthma rates are high by international standards. The most recent health survey by the Ministry of Health indicates that one in seven children aged 2-14 years (15%) and one in nine adults (11%) had been diagnosed with asthma and were taking medication for this condition (Ministry of Health, 2008). This means a significant percentage of the Auckland population may be classified as vulnerable to air pollution.

- road freight is anticipated to dominate for the foreseeable future and is forecast to grow by over 65% by 2031 compared with 2006;

- even with significant increases in public transport patronage, the majority of trips will be made by private transport in the foreseeable future;

- there are 162 early childhood centres within either 70 m of a regional arterial route or 150 m of a strategic route in Auckland. For an average 25 children in each centre, this equates to around 4,000 babies, infants and children exposed to elevated levels of air pollution from traffic for just under 20 hours per week.

- there are 52 schools that are within 70 m of a regional arterial route or 150 m of a strategic route in Auckland. This is around 35,000 children exposed to elevated levels of air pollution from traffic for at least 30 hours per week.

- nearly 50,000 people, around 4%, of the Auckland population, live 70 m of a regional arterial route or 150 m of a strategic route in Auckland. These figures are based on 2006 census data and will have increased since that time.

- the EPA recently approved a new motorway extension to pass within 20 m of a house.

The existing policy framework, as expressed in Working Paper 20 *Environmental Sustainability and Public Health Policies* does provide sound policy. It rightly focuses efforts on source reduction, improved public transport and cleaner road freight. However, we consider these provisions require significant strengthening. Given the recent decision to grant consent to construct a motorway within 20 m of a house, we recommend elevating this policy in priority in the Auckland Unitary Plan. We further recommend the adoption of separation distances for roads and motorways in Auckland.

We find it difficult, however, to select a separation distance that is protective of human health yet does not 'sterilise' land required to meet the mixed use, higher density development targets specified in the Auckland Growth Concept. Separation distances, by their very nature, conflict directly with a compact urban form and the need to avoid community severance.

Consistent with existing council policy, therefore, we recommend separation distances to be a 'secondary' strategy for air quality management. Separation distances can only limit or minimise, as far as reasonably practicable, the impact of vehicle emissions on human health whereas primary strategies (e.g. vehicle emissions controls) can directly reduce impacts on human health. Primary strategies for air quality management should, of necessity, take priority.

6.1 Recommendations for the Unitary Plan

Given the existing location of sensitive land uses in very close proximity to roads and motorways in Auckland, and as Auckland continues to grow, we think it more likely that sensitive land uses will encroach on motorways and roads, than the other way around. In such cases, we recommend the sensitive land use provide the buffer required for an appropriate separation distance. This is a similar approach to that adopted by NZTA in their Reverse Sensitivity policy.

Specifically, we recommend there should be a separation distance between **new** sensitive land uses and existing roads. Further, that there should be a separation distance between **new** roads and existing sensitive land uses. Our recommended separation distances are provided in Table 13.

Table 13 Recommended Separation Distances

New Sensitive Land Use	New Road/Activity	Separation Distance (to road edge)
Childcare centres, schools Hospitals, in-patient health care* Residential, including marae	Strategic routes**	150 m
	Regional arterials	70 m
	Service stations	100 m
	Drive-through facilities	30 m

Notes
* For example, maternity, aged care
** Motorways & non-motorways

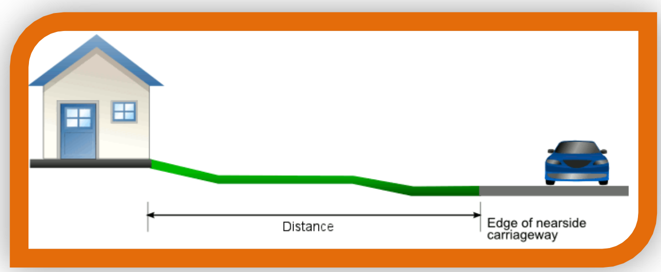
We have limited our classification of sensitive land uses to focus on long-term (i.e. > 24-hour average) protection of the young (childcare centres, schools), the infirm (hospitals) and the wider general public (residential). We have further only recommended separation distances for roads classified as regional arterial routes or strategic routes. This reflects our concerns over the valid reasons for a drive to a more compact urban form.

It is further important to note that these recommendations are for **new** sensitive land uses only (existing activities have existing use rights under the RMA).

As an aside, we have not recommended mitigation. Whilst limited options are available (eg, enclosing buildings and installing high efficiency particulate arrestors (HEPA) filters and air conditioning, locating air intakes as far away from roads as possible) the majority of measures will not ameliorate pollutants from roads and motorways.

As noted above, we recommend separation distances be supported by primary strategies to directly reduce vehicle emissions. Specifically, we recommend updating existing council policy on source control, as expressed in Working Paper 20 *Environmental Sustainability and Public Health Policies,* for adoption in the Auckland Unitary Plan as follows:

- Requiring best practice noise and air emission standards for heavy-duty vehicles on new motorways and tunnels.
- Only allowing heavy-duty diesel freight vehicles within liveable corridors if they meet best practice noise and air emission standards.
- Requiring all public transport vehicles on the rapid transit and quality transit networks to meet appropriate noise and air emission standards.
- Requiring all heavy duty diesel vehicles, including construction vehicles and stationary generators, operating within the urban area to be fitted with particulate filters and silencers, if they were not built to minimum noise and air emission standards.
- Implementing no-idling policy for heavy duty diesel vehicles at major transport hubs and terminals and for high traffic generating or sensitive land use activities, such as supermarkets, malls, hospitals, schools and early childhood education centres.
- Requiring best practice emission standards for all public transport contracts.
- Preferentially implementing electric and low noise and air emission vehicles for public transport that uses the rapid transit and quality transit networks.
- Promoting cleaner and quieter public transport options to reduce noise and air emissions.
- Including air quality in principles for corridor management plans.



6.2 Other Recommendations

There are a number of ways to put separation distances into practice. In addition to inserting policies and rules into the Auckland Unitary Plan, we also recommend:

- Requiring new sensitive land use activities to consider air quality and, specifically, the recommended separation distances. As a minimum, this should be required for early childhood education centres, schools and hospitals. This could be coupled with the use of the NZTA Air Quality Screening Tool (refer section 5.6) as a 'trigger' for the need for further air quality assessment.
- Considering the use of notes (vis a vis reverse sensitivity for air quality) on Land Information Memorandum reports.
- Considering updating the Regional Land Transport Strategy.
- Providing copies of this report to the Auckland Regional Public Health Service, the Ministry of Health, the Ministry of Education and NZTA for investigation of other supporting policy and regulatory options.

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Appendix A Air Pollution and Pregnancy Outcomes

There is a growing body of literature suggesting that ambient air pollution during pregnancy negatively influences fetal growth. This section draws heavily on the findings of two reviews (Šrám 2005; Boothe and Shendell 2008).

A.1 Postneonatal and Infant mortality

Table A1 summarises recent studies confirming the impacts of air pollution on children's mortality (Šrám, 2005).

Table A1 Air pollution and child mortality*

Mortality	Pollutant	Results	Reference
Postneonatal respiratory mortality	TSP	AOR = 2.41 (95% CI, 1.10–5.28) comparing highest vs. lowest quintile AOR = 3.91 (95% CI, 0.90–3.50) for 50 μg/m^3 increase	Bobak and Leon 1992
Postneonatal respiratory mortality	TSP	AOR = 1.95 (95% CI, 1.90–3.50) for 50 μg/m^3 increase	Bobak and Leon 1999a
	SO_2	AOR = 1.74 (95% CI, 1.01–2.98) for 50 μg/m^3 increase	
	NO_x	AOR = 1.66 (95% CI, 0.98–2.81) for 50 μg/m^3 increase	
Postneonatal infant mortality	PM_{10}	AOR = 1.10 (95% CI, 1.04–1.16) comparing high vs. low exposure	Woodruff et al. 1997
Respiratory death groups	PM_{10}	AOR = 1.40 (95% CI, 1.05–1.85) comparing high vs. low exposure with normal birth weight	
Sudden infant death	PM_{10}	AOR = 1.26 (95% CI, 1.14–1.39) comparing high vs. low exposure groups	
Intrauterine mortality	NO_2	Strong association (coefficient = 0.0013 μg/m^3, $p < 0.01$)	Pereira et al. 1998
	SO_2	NE	
	CO	NE	
		Significant association using pollution index $NO_x + SO_2 + CO$	
	O_3	NE	
	PM_{10}	NE	
Infant mortality	NO_2	NE	Loomis et al. 1999
	SO_2	NE	
	CO	NE	
	O_3	NE	
	PM_{10}	6.9% excess (95% CI, 2.5–11.3%) for 10 μg/m^3 increase	
Perinatal and infant mortality		NE between residence near coke works	Dolk et al. 2000

Abbreviations: AOR, adjusted odds ratio; NE, no effect; PM_{10}, particulate matter < 10 μm; TSP, total suspended particulate.

* Šrám, 2005

Šrám (2005) noted that the consistency of these studies, conducted in a range of different populations and using both spatial and time-series study designs, was remarkable. The three largest studies produced very similar estimates of relative risk (Bobak and Leon 1992, 1999a; Woodruff et al. 1997). Perhaps the only alternative explanation that may affect the interpretation of these studies is confounding by maternal smoking. But the minimal differences between crude and adjusted estimates, similarity of results for spatial and time series studies and the significantly different locations (China, United States, Brazil to Czech Republic) indicated that it is unlikely that the distribution of socioeconomic disadvantage or maternal smoking would be similar enough to produce the same pattern of results.

Šrám (2005) therefore, concluded that the evidence is sufficient to infer causal relationship between particulate air pollution and respiratory deaths in the postneonatal period.

A.2 Low birth weight

Table A2 presents the potential effects of air pollutants on birth weight (Šrám, 2005).

Šrám noted that in terms of the magnitude of the effect, the results were consistent in suggesting that the effects are relatively small. However, Šrám concluded that the evidence suggests causality of the effect of air pollution on birth weight.

Wilhelm and Ritz (2003, as reported in Boothe and Shendell, 2008) similarly found a higher risk of low birth weight during winter and autumn for mothers who lived within 229 m (750 ft) of the highest quintile of heavy-traffic roadways.

Table A2 Air pollution and birth weight*

Outcome	Pollutant	Results	Reference
LBW	SO_2	AOR = 1.21 (95% CI, 1.06–1.16) for 100 μg/m^3 increase	Wang et al. 1997
	TSP	AOR = 1.10 (95% CI, 1.05–1.14) for 100 μg/m^3 increase	
LBW	TSP	OR = 1.04 (95% CI, 0.96–1.12) for 50 μg/m^3 increase	Bobak and Leon 1999b
	SO_2	OR = 1.10 (95% CI, 1.02–1.17) for 50 μg/m^3 increase	
	NO_x	OR = 1.07 (95% CI, 0.98–1.16) for 50 μg/m^3 increase	
LBW	NO_x	NE	Bobak 2000
	SO_2	AOR = 1.20 (95% CI, 1.11–1.30) for 50 μg/m^3 increase in the first trimester	
	TSP	AOR = 1.15 (95% CI, 1.07–1.24) for 50 μg/m^3 increase in the first trimester	
LBW	O_3	NE	Ritz and Yu 1999
	NO_2	NE	
	PM_{10}	NE	
	CO	OR = 1.22 (95% CI, 1.03–1.44) for CO > 5.5 ppm in the first trimester	
VLBW	TSP + SO_2	AOR = 2.88 (95% CI, 1.16–7.13) comparing highest vs. lowest exposure groups (56.7 vs .9.9 μg/m^3)	Rogers et al. 2000
LBW	CO	AOR = 1.43 (95% CI, 1.18–1.74) for 1 ppm increase in first trimester AOR = 1.75 (95% CI, 1.50–2.04) for 1 ppm increase in first trimester in African Americans	Maisonet et al. 2001
	SO_2	AOR = 1.18/1.20 (95% CI, 1.02–1.36) ppm increase in all trimesters in whites	
LBW	SO_2 + NO_2 + PM_{10}	AOR = 1.77 (95% CI, 1.00–3.12) comparing petrochemical and control municipalities	Lin et al. 2001b
LBW	CO	AOR = 1.08 (95% CI, 1.04–1.12) in the first trimester	Ha et al. 2001
	NO_2	AOR = 1.07 (95% CI, 1.03–1.11) in the first trimester	
	SO_2	AOR = 1.06 (95% CI, 1.02–1.10) in the first trimester	
	TSP	AOR = 1.04 (95% CI, 1.00–1.08) in the first trimester	
LBW	POM	OR = 1.31 (95% CI, 1.21–1.43) comparing highest vs. lowest exposure groups	Vassilev et al. 2001b

Abbreviations: AOR, adjusted odds ratio; NE, no effect; VLBW, very low birth weight (< 1,500 g).

* Šrám, 2005

A.3 Preterm birth

Table A3 presents recent studies investigating the association between air pollution and preterm birth (Šrám, 2005).

Table A3 Air pollution and preterm birth*

Pollutant	Results	Reference
SO_2 TSP	AOR = 1.21 (95% CI, 1.01–1.45) for 100 μg/m^3 increase AOR = 1.10 (95% CI, 1.01–1.20) for 100 μg/m^3 increase	Xu et al. 1995
SO_2 TSP	AOR = 1.27 (95% CI, 1.16–1.39) for 50 μg/m^3 increase in the 1st trimester AOR = 1.18 (95% CI, 1.05–1.31) for 50 μg/m^3 increase in the 1st trimester	Bobak 2000
CO NO_2 O_3 PM_{10}	NE NE NE RR = 1.16 (95% 1.06–1.26) for 50 μg/m^3 increase in the 1st trimester	Ritz et al. 2000
$SO_2 + NO_2 + PM_{10}$	AOR = 1.41 (91% CI, 1.08–1.82) comparing petrochemical and control municipalities	Lin et al. 2001a

Abbreviations: AOR, adjusted odds ratio; NE, no effect.

* Šrám, 2005

Šrám (2005) concluded that, as with studies of birth weight and preterm births, the reviewed studies of intrauterine growth retardation produced inconsistent results, and the interpretation is complicated by multiple comparisons (Bobak 2000; Liu et al. 2003) and mutual correlations of exposures. Šrám further noted that the results by Dejmek et al. (1999, 2000) and Liu et al. (2003) suggest that the first month was the most sensitive period for the effect of air pollutants and that further studies should clarify this issue.

Boothe and Shendell (2008) identified additional studies with similar findings to those above:

- Yang et al. (2003) found that maternal residence within 500 m of a major freeway in Taiwan was a significant risk factor for preterm birth.
- Wilhelm and Ritz (2003) reported that California mothers who lived within 229 m (750 ft) of the highest quintile of heavy-traffic roadways during pregnancy were more likely to have a preterm baby. Higher risks were reported for babies born in the fall and winter months (presumably due to the impact of increased incidence of inversions with associated increased exposure during these months). These higher risks during winter were confirmed by Ponce et al. (2005).

More recent research

Recently, two recent Brisbane studies found the following:

- ambient O_3, SO_2 and PM_{10} during early pregnancy were associated with reductions in foetal biometry (i.e. growth) during mid-pregnancy, with the two conspicuous pollutants being PM_{10} and SO_2 (Hansen et al, 2008); and

- pregnant women experienced a reduction in gestation time of almost two weeks (4.4 per cent) associated with an increase in freeways within 400 metres of the women's home (Barnett et al, 2011). The findings indicated that the negative effects of traffic on gestation were largely associated with main roads within 400 metres of the home, with much of the effect for roads within 200 metres.

Similarly:

- Yorifuji et al. (2011) found that living within 200 m of major roads increased the risk of births before 37 weeks by 1.5 times (95% CI = 1.2-1.8), birth before 32 weeks by 1.6 times (1.1-2.4) and births before 28 weeks by 1.8 times (1.0-3.2). Proximity specifically increased the risk of preterm births with preterm births with preterm premature rupture of the membranes and with pregnancy hypertension.

These studies have important implications when considering separation distances for roads and motorways in Auckland.

A.4 Air pollution and birth defects

Šrám's review (2005) found only one report on the relation between outdoor air pollution and birth defects.

Ritz et al. (2002) evaluated the effect of CO, NO_2, O_3, and PM_{10} on the occurrence of birth defects in Southern California for the period 1987–1993. The average monthly exposure for each pollutant throughout pregnancy was calculated. Dose–response patterns were observed for CO exposure in the second month of gestation and ventricular septal defects (adjusted odds ratio for the highest vs. lowest quartile of exposure, 2.95; 95% CI, 1.44–6.05) and for exposure to O_3 in the second month and aortic artery and valve defects (adjusted odds ratio, 2.68; 95% CI, 1.19–6.05).

Šrám considered the evidence to be insufficient to draw conclusions about causality.

A.5 Polycyclic aromatic hydrocarbons

Šrám (2005) noted increasing concerns about polycyclic aromatic hydrocarbons, particularly those that were carcinogenic.

- Dejmek et al. (2000) investigated the association between carcinogenic polycyclic aromatic hydrocarbons and intrauterine growth retardation in two Czech districts: Teplice and Prachatice. In the Teplice data, there was a highly significant increase of intrauterine growth retardation with exposures to carcinogenic [42] polycyclic aromatic hydrocarbons above 15 ng/m^3.

  The effect was specific for the first gestational month.

- The adjusted odd ratios were 1.59 (95% CI, 1.06–2.39) for medium levels of carcinogenic polycyclic aromatic hydrocarbons and 2.15 (95% CI, 1.27–3.63) for high exposure levels. [43] Using a continuous measure of exposure, a 10 ng/m^3 increase in carcinogenic polycyclic aromatic hydrocarbon level was associated with an adjusted odd ratio of 1.22 (95% CI, 1.07–1.39).

- Although there was no effect of PM_{10} on intrauterine growth retardation found in Prachatice, the association between carcinogenic polycyclic aromatic hydrocarbons and intrauterine growth retardation was close to that found in Teplice. Again, the only consistent association between carcinogenic polycyclic aromatic hydrocarbons and intrauterine growth retardation was observed in the first gestational month.

- Compared with the lowest category of exposure to carcinogenic polycyclic aromatic hydrocarbons, the adjusted odd ratios of intrauterine growth retardation was 1.63 (95% CI, 0.87–3.06) in the medium category and 2.39 (95% CI, 1.01–5.65) in the highest category.

- Vassilev et al. (2001a) examined the association of polycyclic organic matter in outdoor air with "small for gestational age" births (the definition is identical to that of intrauterine growth retardation). Information from birth certificates in New Jersey (USA) from 1991 through 1992 was combined with data on air toxicity derived from the U.S. EPA Cumulative Exposure Project, using the predicted polycyclic organic matter concentrations from annual exposure estimates. The adjusted odd ratios for intrauterine growth retardation in the highest exposure tertile (0.61–2.83 µg/m^3, which includes about 89% of births in the state of New Jersey) was 1.22 (95% CI, 1.16–1.27).

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[42] Benz[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*g*,*h*,*i*]perylene, benzo[*a*]pyrene, chrysene, dibenz[*a*,*h*]anthracene, and indeno[1,2,3-*c*,*d*]pyrene.

[43] An odds ratio is ratio of two odds and is used to compare probabilities. A ratio for an individual subgroup is "specific" (to that subgroup). A ratio for the total population, without regard to the variation across subgroups, is "crude". A ratio for the total population, but which makes an allowance for the variation across subgroups is "adjusted". Thus an adjusted odds ratio compares two probabilities and allows for the variation in subgroups (in this instance, differing polycyclic aromatic hydrocarbon exposure levels).

Šrám (2005) concluded the data suggests that residential exposure to airborne polycyclic organic matter is associated with an increased prevalence of intrauterine growth retardation and hypothesised that polycyclic aromatic hydrocarbons may play a critical role. It is possible that carcinogenic polycyclic aromatic hydrocarbons are responsible for the biologic activity of complex mixtures adsorbed to respirable air particles that can result in intrauterine growth retardation.

With increasing traffic, the significance of polycyclic aromatic hydrocarbons in Auckland is growing, but their monitoring remains scarce. At present, we consider the evidence is insufficient to infer causality but recommend adopting a precautionary approach.

A.6 Biological plausibility

[Excerpt from Šrám (2005)]

> *"The molecular epidemiologic studies suggest biologic mechanisms for the effect of air pollution on birth outcomes. It has been shown that the levels of DNA adducts are positively related to risk of intrauterine growth retardation (Dejmek at al 2000; Šrám et al. 1999), birth weight, birth length, and head circumference (Perera et al. 1998, 1999), and hypoxanthine-guanine phosphoribosyltransferase (HPRT) locus mutation frequency in infants (Perera et al. 2002).*
>
> *Polycyclic aromatic hydrocarbons and/or their metabolites may bind to the aryl hydrocarbon receptor (AhR) and accumulate in the nucleus of cells, resulting in increased rates of mutagenesis. Because polycyclic aromatic hydrocarbons bind to the AhR, it may result in anti-estrogenic activity through increased metabolism and the depletion of endogenous estrogens (Carpenter et al. 2002), thus disrupting the endocrine system by altering steroid function. Bui et al. (1986) hypothesized that benzo[a]pyrene exposure may interfere with uterine growth during pregnancy because of its antiestrogenic effects, thereby disrupting the endocrine system. Fetal toxicity may be further caused by DNA damage resulting in activation of apoptotic pathways (Nicol et al. 1995) or binding to receptors for placental growth factors resulting in decreased exchange of oxygen and nutrients (Dejmek et al. 2000).*
>
> *The finding of higher DNA adduct levels in the infant compared with the mother suggests an increased susceptibility of the developing fetus to DNA damage (Perera et al. 1999). With respect to intrauterine growth retardation, it appears that the increased risk is principally due to exposure to carcinogenic polycyclic aromatic hydrocarbons. This finding is consistent with the idea of a primary role for carcinogenic polycyclic aromatic hydrocarbons in fetal growth modulation (Guyda 1991; MacKenzie and Angevine 1981; Rigdon and Rennels 1964; Zhang et al. 1995). Perera et al. (2003) labeled polycyclic aromatic hydrocarbons as significant independent determinants of birth outcomes. In*

addition, there appears to be an interaction between exposure to polycyclic aromatic hydrocarbons and genotypes that produce DNA adducts (Whyatt et al. 2001).

Although the specific steps of these pathways need to be further clarified, the molecular epidemiology studies and the similarity of effects of air pollution to those of smoking (Adriaanse et al. 1996; Windham et al. 1999) support the biologic plausibility of the effects."

Appendix B Map Generation

Maps were generated within the Auckland urban airshed (only) as follows:

- Orewa, North Shore and Central/South/West Auckland.
- Population/dwelling data used comes from the 2006 Census, mesh block data.[44]
- Where a mesh block extended beyond the boundaries of the buffer, the value within that mesh block has been normalised using the following equations to account for the expected population within the buffer. This assumes that population is evenly distributed within the mesh block.

For Age Group Data:

$$\frac{\textit{Area\_of\_mesh\_block\_within\_buffer}}{\textit{Area\_of\_mesh\_block}} \quad \text{X} \quad \text{age group population of the mesh block}$$

For Occupied Private Dwelling Data (houses):

$$\frac{\textit{Area\_of\_mesh\_block\_within\_buffer}}{\textit{Area\_of\_mesh\_block}} \quad \text{X} \quad \text{occupied private dwellings of the mesh block}$$

[44] Statistics New Zealand 2006 Census of Population and Dwellings, http://www.stats.govt.nz