Stocktake of Air Quality in and around State Highway Tunnels

NIWA Client Report: AKL-2010-016

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Executive Summary

The New Zealand Transport Agency manages five major road tunnels: the Terrace and Mt Victoria tunnels in Wellington, the Lyttelton tunnel near Christchurch, the Homer tunnel which provides access to Milford Sound, and the Johnstone's Hill tunnels north of Auckland. NIWA has been commissioned by NZTA to conduct a desktop review of air quality in and around these tunnels. Monitoring has been conducted in the Wellington tunnels at various times between 1980 and 2003, and the results are summarised. We further review any other sources of data (available up to June 2008[1]) and, where possible, make estimates of current air quality in and around all five tunnels. We report those instances where it is not possible to make current estimates due to lack of data.

External air quality has been assessed against the National Environmental Standard and World Health Organisation guideline for nitrogen dioxide. Neither of these applies inside road tunnels or in vehicles. In-tunnel air quality has been judged relative to the guidelines recommended by NIWA in a previous NZTA report, and adopted by NZTA as "Interim Guidelines" at time of writing. These are summarised in Tables a and b, which follow.

Road tunnels generally pose greater air quality challenges internally than externally. External impacts are generally highly localised (tens to a few hundred metres range). The information available for this review was highly limited and insufficient to draw reliable conclusions. In the absence of specific monitoring data, this report speculates that there might be a small risk of significant localised impacts at the southern portal of the Terrace tunnel, the stacks of the Mt Victoria tunnel (especially the western stack at the adjacent school), and the southern end of the Lyttelton tunnel. Impacts at the Homer and Johnstone's Hill Tunnels are considered low due to the absence of an exposed population. We find no evidence suggesting that the tunnels lead to local breaches of ambient air quality targets or standards.

In-tunnel air quality is traditionally maintained by designing the tunnel ventilation system to maintain concentrations of carbon monoxide below a fixed limit. The limits applied to the Mt Victoria, Terrace and Lyttelton and Johnstone's Hill tunnels were all different, reflecting the state of knowledge regarding this pollutant's effects at the time of design. This means that each tunnel was designed with a different ventilation response to expected emissions which is no longer necessarily valid. Since their

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[1] Although the Johnstone's Hill Tunnels were not open by June 2008, the time-scope of this report has been extended to include traffic data from the first year of operation.

opening, traffic volumes have increased, average emissions per vehicle have decreased. In the Wellington tunnels levels of congestion have increased.

Current data are not available to determine whether either the original design specifications, or the Interim NZTA Guidelines, are met inside the five tunnels. However, we have extrapolated historic data from the Wellington tunnels to estimate current levels (see Table c which follows). We estimate that carbon monoxide (CO) concentrations remain below the recommended Interim NZTA Guidelines most or all of the time in the four older tunnels, with the Terrace tunnel complying by the smallest margin. The relative poor performance of the shorter Terrace tunnel may be related to the inefficient configuration of the ventilation system.

Carbon monoxide guidelines for management of in-tunnel air quality have a long history and are well-established worldwide. More recent developments in health research have led to an increasing attention on the effects of an additional pollutant – nitrogen dioxide (NO_2). This is reflected by the adoption of Interim NZTA Design Guidelines for NO_2.

The processes leading to the presence of elevated levels of NO_2 in a tunnel are complex and not well understood. There is much less information available regarding NO_2 in the five tunnels, and the determinants of NO_2. Consequently, it is very difficult at present to determine the demands placed on ventilation by the Interim NZTA Design guidelines for NO_2. We do note, however, that CO levels and NO_2 levels are not necessarily correlated, and our interpretation of the available science (in the absence of data) leads us to speculate that the relative demands of the Interim NZTA Guidelines for CO, visibility and NO_2 will vary between tunnels.

Smoke and dust are also more likely to demand further consideration.

At the end of this decade we find ourselves in the middle of a period of rapid change in vehicle emissions. Trends in in-tunnel concentrations in the Wellington tunnels support trends observed elsewhere, that improvements in vehicle and fuel technology have led to rapid reductions in the average rate of **per vehicle** emissions of CO and particulates from the New Zealand vehicle fleet. Fleet and emission modelling predict that this reduction will continue, albeit at a reduced rate, for at least a further decade. Whether this leads to reduced concentrations depends on whether it is offset by growth in traffic or increases in congestion. This means that judging the compliance of any tunnel against a guideline requires recent and accurate observational data.

Trends in the precursors of NO_2, however, are much less clear. There is emerging evidence that, in contrast to CO and PM, the trend is upwards. This means that complying with the Interim NZTA Design Guidelines for NO_2 may become progressively relatively more demanding than complying with the Interim NZTA Guidelines for CO in years to come, especially in tunnels where high or increasing numbers of diesel vehicles may operate. Therefore ensuring future compliance with in-tunnel guidelines requires careful consideration of future traffic and emission trends.

The quality and coverage of the data available for all five tunnels are insufficient to draw any firm conclusions at this point. For this reason we recommend a programme of consistent and inter-comparable high-quality monitoring is conducted **inside** all five tunnels. Monitoring campaigns are expensive. We recommend that the maximum benefit can be achieved by using such campaigns to also better understand the determinants of in-tunnel NO_2 and the demands the Interim NZTA Guidelines place on ventilation as traffic and emissions change. In order to future-proof the investment we recommend that campaigns include sufficient information to determine and track emission trends.

All five State Highway tunnels may suffer from visible smoke and odour problems. These have not conventionally been considered in air quality guidelines. We have insufficient data at present to evaluate these risks, but recommend that they be considered as related issues which need to be considered to provide a sense of wellbeing for tunnel users.

Table a: Interim NZTA Guidelines for occupational safety for the protection of healthy adults working in tunnels.

Contaminant	Threshold concentration	Averaging time	Notes
CO	200 ppm	15 minutes	equivalent to NZ Workplace Standard
CO	30 ppm	8 hours	widely adopted abroad, PIARC 1995 recommendation
NO_2*	1 ppm	15 minutes	equivalent to NIOSH Recommended Exposure Limit

* This particular guideline is only intended to inform ventilation system design at this stage

Table b: Interim NZTA Guidelines for all non-occupational users in tunnels.

Contaminant	Threshold concentration	Averaging time	Notes
CO	87 ppm	15 minutes	equivalent to WHO ambient guideline, widely adopted in Australia
NO_2*	1 ppm	15 minutes	PIARC proposal

* This particular guideline is only intended to inform ventilation system design at this stage

Table c: Summary of estimated pollutant concentrations in the tunnels.

Tunnel	Typical peak CO	Worst-case peak CO	Typical peak NO_2	Exceptional peak NO_2
Mt Victoria	30 – 40 ppm	~55 ppm	Insufficient data	Insufficient data
Terrace	36 – 58 ppm	~80 ppm	Insufficient data	Insufficient data
Lyttelton	< 55 ppm	< 55 ppm	< 0.3 ppm	Insufficient data
Homer	Insufficient data	Insufficient data	Insufficient data	Insufficient data
Johnstone’s Hill	Insufficient data	Insufficient data	Insufficient data	Insufficient data

Abbreviations

AADT	annual average daily traffic
AAQG	ambient air quality guidelines
AQNES	air quality national environmental standards
CO	carbon monoxide
HDV	heavy duty vehicle
LDV	light duty vehicle
NO	nitric oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen ($NO + NO_2$)
PIARC	Permanent International Association of Road Congresses
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 microns (millionths of a meter)
PM_{10}	particulate matter less than 10 microns (millionths of a meter)
ppb	parts per billion
ppm	parts per million
VEPM	Vehicle Emissions Prediction Model

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1. Introduction

1.1 Background

The New Zealand Transport Agency (NZTA) manages five major road tunnels in the State Highway Network:

- the Terrace and Mt Victoria tunnels in Wellington;
- the Lyttelton tunnel near Christchurch;
- the Homer tunnel which provides access to Milford Sound; and
- the Johnstone's Hill twin tunnels northwest of Orewa.

The NZTA is conducting a review and update of the management of these existing tunnels to assist in the design of future upgrades and to set policy to cover new tunnels. As part of the review, the NZTA has commissioned NIWA to produce two reports with the aims of providing advice on the management of air quality both in and around road tunnels, as follows:

Report 1. A review of the setting of air quality management guidelines and systems for road tunnels, and their implementation[2].

Report 2. Stocktake of the air quality in and around existing State Highway tunnels.

This report is the second of those two reports. It reviews the monitoring of air quality and other key parameters that has previously been undertaken for the existing tunnels and highlights the key gaps that need to be addressed to improve future tunnel management.

The NZTA intends for the report to provide a solid baseline for all State Highway tunnel reporting so the structure and the format have been future-proofed as far as is possible (hence the inclusion of the Johnstone's Hill tunnels which opened in January 2009). As a benchmark, this report will be used as the basis for further monitoring

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[2] Longley *et al* (pending). *Guidelines for the Management of Air Quality in and around Road Tunnels in New Zealand*, NIWA Report AKL-2008-058 prepared for NZ Transport Agency

campaigns, with the findings utilized for future upgrades of existing tunnels and in the design of new tunnels.

1.2 Objectives

The objective of this report is to review monitoring of air quality and other key parameters that has previously been undertaken for the five existing tunnels to establish:

- What is the baseline (i.e. existing) air quality both within the tunnel and in the vicinity of the tunnel?
- How does the baseline compare to existing standards and guidelines for external air quality, and the guidelines for in-tunnel air quality recommended in Report 1?
- What are the key air quality issues that need to be addressed to guide any tunnel ventilation upgrade?
- What further assessment, research or analysis is recommended to assist in quantifying and reducing the risks that are presented by the tunnels and inherent in their upgrade?

In addressing these questions, the report considers the confidence in conclusions and underlying uncertainties that reduce that confidence. Recommendations for further detailed assessment are made where it is felt that such studies would reduce these uncertainties, increase confidence in assessment and help to reduce the risks to health posed by the tunnels.

1.3 Scope

This report is principally a stocktake or desktop study collating historical data up to June 2008. However, a small amount of new data were opportunistically collected in the Mt Victoria and Lyttelton tunnels in late 2008 as part of other externally-funded projects and these have been included in this report. Preliminary data from 2009 have also been used of the Johnstone's Hill tunnels which only recently opened in January 2009.

The report covers air quality both within the tunnels and in their immediate external environment (i.e. on a scale of tens to hundreds of metres). It includes a consideration of the exposure of tunnel users to tunnel-originated air following passage through a tunnel. It includes a consideration of the protection of pedestrians and cyclists in the Mt Victoria tunnel, and the implications that has for air quality management and tunnel ventilation. It also considers management of occupational exposure of maintenance personnel.

1.4 Key features of the five state highway tunnels

The pertinent data describing the five existing State Highway tunnels are summarised in Table 1.1.

The oldest State Highway tunnel is the **Mt Victoria tunnel,** which opened in 1931. It has a single bi-directional tube with transverse ventilation, which was designed to keep in-tunnel carbon monoxide (CO) concentrations below 600 ppm. In 1983 the Ministry of Health advised that operators "should reasonably ensure CO levels do not exceed 100 ppm".

The **Homer tunnel** opened in 1953 and it has no mechanical ventilation. Although classified as bi-directional, the Homer tunnel has only one lane with passing bays and vehicles are controlled by lights so that only one direction of traffic travels at a time. Unlike other tunnels, the Homer tunnel experiences more uniform traffic flows regardless of the day of the week because it services Milford Sound, which is a tourist rather than a commuter destination.

The **Lyttelton tunnel**, which opened in 1964, is a bi-directional tunnel with transverse ventilation like the Mt Victoria. However, it was designed to meet a much more stringent requirement of an operational CO limit of 55 ppm, with tunnel closure required at 200 ppm. This corresponds to a general trend in applying more stringent exposure limits over the years as a result of improved health data on the effects of exposure to sub-emergency levels of pollutants.

Despite being opened over a decade later in 1978, the **Terrace tunnel** was designed to meet a less demanding target of 250 ppm of CO, with closure required at 400 ppm. However, the Terrace tunnel's ventilation system has been compromised from the day it opened as a longitudinal system was installed on the assumption that two uni-directional tubes would eventually be constructed. Only one was built and the resulting bi-directional tube has suffered from sub-optimum ventilation ever since.

Table 1.1: Details of the five existing State Highway tunnels

Tunnel	**Mt Victoria**	**Terrace**	**Lyttelton**	**Homer**	**Johnstone's Hill**
Opened	1931	1978	1964	1953	2009
Length (m)	623	460	1945	1270	380
Tubes/lanes	one bi-directional, 1 lane each way	one bi-directional, 2 lanes northbound, 1 lane southbound	one bi-directional, 1 lane each way	one bi-directional but only 1 lane / direction at a time	two uni-directional, 2 lanes southbound, 1 lane northbound
State Highway	SH1N	SH1N	SH74	SH94	SH1N
AADT in 2008 (vpd)	38,751	45,394	10,772	571	12,742 (2009)
Gradient	1:100	1:40	1:15	1:10	1:100
Ventilation	Transverse, on time switch	Longitudinal, triggered by 3 traffic speed detection	Transverse	Natural only	Longitudinal triggered by CO
% HDVs in 2008	5	5	12.8	16.8	10.2 (2009)
Special features	Regular congestion; pedestrians & cyclists permitted; high number of taxis but few buses	Regular congestion	Freight link between Christchurch and its port so high number of trucks	Tourist link to Milford Sound so high number of buses	Toll road extending northern motorway, bypassing Orewa and Wenderholm
Posted speed limit (km/h)	50	80	50	100	80

The Johnstone’s Hill tunnel, opened in January 2009, is actually two identical but separate uni-directional tunnels. The tunnels are 15 metres apart and are built to carry two lanes each but the northbound tunnel has only one in operation, because the highway north of the tunnel is currently only single lane. Each tunnel has longitudinal ventilation, which is triggered when levels of carbon monoxide (CO) reach 30 ppm. The Johnstone’s Hill tunnels are part of a toll road which offers a more direct route for vehicles travelling on State Highway 1 between the Orewa turnoff and Puhoi.

1.5 Report layout

The report is structured as follows:

- Chapter 2 covers the air quality issues that are common to all tunnels in terms of contaminants of concern, internal and external air quality, and mitigation options.

- Chapters 3 to 7 characterise each tunnel individually as follows by summarising the key features of each, reviewing their in-tunnel and external air quality based on previous data, highlighting the key air quality issues for the future.

    - Chapter 3 addresses the Mt Victoria tunnel;

    - Chapter 4 focuses on the Terrace tunnel;

    - Chapter 5 considers the Lyttelton tunnel;

    - Chapter 6 deals with the Homer tunnel;

    - Chapter 7 reports on the Johnstone’s Hill tunnels; and

- Chapter 8 presents Conclusions.

- There are three Appendices containing supporting technical information.

2. Common tunnel air quality issues

2.1 Contaminants of concern

2.1.1 Carbon monoxide

Tunnel air quality management has historically centred on keeping concentrations of carbon monoxide (CO) in the tunnel within guidelines set to protect human health. Inhalation of carbon monoxide can rapidly lead to a wide range of neurotoxic effects. Some groups are more vulnerable than others to these effects, in particular angina patients and pregnant women. Uptake of CO into the blood is more rapid for children and during deep breathing (i.e. for walkers or cyclists).

Carbon monoxide emissions arise from incomplete or inefficient combustion. Petrol engines tend to emit greater amounts of CO than diesel. Technological advances have substantially improved CO emissions from newer vehicles, such that CO emissions from the vehicle fleet have rapidly declined over the last decade and reductions are expected to continue over the next decade.

2.1.2 Nitrogen dioxide

Nitrogen dioxide (NO_2) is a pollutant associated with several adverse respiratory effects, especially in children. Asthmatics have been shown to be particularly vulnerable to these effects and have an increased sensitivity to particles and allergens subsequent to NO_2 exposure.

Inhalation of nitrogen dioxide in the presence of airborne particles can lead to respiratory symptoms in asthmatics at concentrations which can occur in some road tunnels. However, this finding is based on exposures of 30 minutes or more. The effect of shorter exposures is currently unknown. Long-term repeated exposure, as may be experienced by regular commuters, has been associated with reduced lung function and other adverse effects in children.

2.1.3 Hazardous air pollutants

The hazardous air pollutant (HAP) of most relevance to road traffic emissions in New Zealand is benzene.

Benzene is a carcinogen associated with long-term exposure and is present in vehicle exhaust arising as products of combustion and may also be emitted in unburnt fuel and oil. The emission rate of benzene from motor vehicles in New Zealand has fallen dramatically as a result of significant improvements in fuel quality and engine technology.

Other HAPs associated with motor vehicle emissions include 1,3-butadiene, benzo(a)pyrene, and formaldehyde

2.1.4 Fine particulates

There is substantial scientific evidence that exposure to elevated levels of particles derived from vehicle tailpipe emissions is a risk factor for exacerbations of cardiovascular disease (including mortality), and for cancer. There is also substantial evidence for effects on respiratory health. However, the causal pathways linking exposures to these effects are still active areas of research. Most of the evidence is focussed on exposures of hours, days or years, not seconds or minutes. Although it is toxicologically plausible that very brief exposures to very high levels of vehicle-related particulates (as is the case in a road tunnel) poses a risk to health, there is currently insufficient scientific evidence to quantify any risk and there are no associated guidelines.

2.1.5 Haze, smoke, visibility and odour

Aside from their direct health impact, particulate matter presents a nuisance and reduced amenity due to reduced visibility. Inside a road tunnel this presents a safety hazard. Visible smoke (which is generally more temporary than haze which tends to persist for longer periods) may also be considered both a nuisance in the outdoor atmosphere and a safety hazard inside a tunnel. Smoke and haze are often (but not always) accompanied by unpleasant odour, which constitutes a further nuisance.

2.2 In-tunnel air quality

2.2.1 Sources and determinants

Compared to a surface road or the ambient environment, the air quality as experienced by tunnel users is relatively poor, with the concentrations of traffic-related contaminants likely to be many times higher inside as opposed to outside the tunnel. The two main determinants of in-tunnel concentrations (and emissions from the tunnel openings into the external environment) are the rate of vehicle emissions and the rate of ventilation. Vehicle emission rates are related to vehicle volume, speed, the proportion of heavy duty vehicles, and road gradient. Carbon monoxide arises from tailpipe emissions, whilst nitrogen dioxide arises indirectly from the chemical oxidation of tailpipe emissions. Particulates arise from both tailpipe emissions, resuspension of road dust, tyre and brake wear and from material lost from truck loads. Oxides of nitrogen (which includes nitrogen dioxide – see section 2.2.2) arise from tailpipe emissions, with a bias towards diesel engines relative to carbon monoxide.

The tunnel ventilation rate may vary within a range that is unique for each tunnel and is effectively constrained at the design stage. The ventilation rate is generally determined by the objective of maintaining concentrations of a specific contaminant (most often carbon monoxide) below a limit value. In the long-term any growth or reduction in emissions (due to growth in traffic and improvement in vehicle technology respectively) will result in corresponding changes in in-tunnel air quality, unless the ventilation rate can be altered or upgraded. Reductions in the acceptable guideline limit value have also led to the need for increases in ventilation rates in older tunnels.

In recent years improvements in fuel specifications and vehicle technology has led to rapid reductions in the emission rates of CO and PM of new vehicles. NO_x emissions not arise from the reaction of the two main constituents of the atmosphere (nitrogen and oxygen) in the high temperatures of combustion, rather than any component of the fuel. Consequently, NO_x emission rates respond differently to fuel and technology change. In recent years NO_x emission rates have reduced much more slowly than for CO and PM, a trend which is expected to continue for some years to come.

2.2.2 Sources and determinants of nitrogen dioxide

Sources and determinants of nitrogen dioxide (NO_2) in the tunnel are more complex. NO_2 can be emitted directly from vehicle tailpipes, but mostly indirectly via the emission of nitric oxide (NO). Together these compounds are referred to as oxides of nitrogen (NO_x). Diesel vehicles are the dominant source, and the fraction of NO_x emitted directly as NO_2 is also greater for diesel vehicles. The dominant source of NO_2 is in-situ chemical formation from the reaction of nitric oxide (NO) with ozone (O_3). Ozone is a natural component of the atmosphere. The reaction between NO and O_3 to form NO_2 is rapid, especially in the dark. For this reason, emissions of NO suppress the availability of O_3 in urban areas. Other factors also influence O_3 levels, and on a short-term basis ambient O_3 can vary rapidly and unpredictably in response to meteorological conditions.

The potential for NO_2 formation inside tunnels is likely to depend on the external levels of ozone and how far it can penetrate into the tunnel before it is depleted. However, even if there is zero available ozone, NO_2 can still arise in the tunnel from two less significant sources: from external (ambient) sources or from limited direct emission from the tailpipe (particularly from diesel engines). All of these factors are complex and difficult to predict. In summary, however, there is greater potential for elevated NO_2 levels, relative to CO, in rural tunnels with high proportions of diesel vehicles.

2.2.3 Guidelines and standards

Guideline limit values need to be accompanied by appropriate averaging times. In-tunnel concentrations can vary quite rapidly, especially if the traffic characteristics are variable. Thus, concentrations may peak over a short period that is not representative of a longer time period. Guideline averaging times are related to the known biological mechanisms involved in relating exposure to health effects, and these mechanisms are pollutant-specific. For example, it is well-established that the effects of exposure to 10 ppm of CO for 1 minute are broadly equivalent to an exposure of twice the concentration for half the time. However, there is insufficient scientific understanding at present to state whether this is also true for nitrogen dioxide or particulates.

Short-term exposure limits are typically expressed as 1-hour or 15-minute averages. The tunnels covered by this report are all less than 2 km in length, implying exposures of 3 minutes or less. Pedestrian passage through the Mt Victoria tunnel, for example, would take most people less than 10 minutes. In general, no regular user should spend more than 15 minutes in any New Zealand State Highway tunnel.

NIWA has reviewed the available international guidelines, and the science behind them, and has made a number of recommendations for New Zealand (Longley *et al*, pending). The recommendations have been adopted by NZTA as interim guidelines and are summarised in Tables 2.1 and 2.2.

Table 2.1: Interim NZTA In-Tunnel Air Quality (Carbon Monoxide and Nitrogen Dioxide) Guidelines for the protection of healthy adults working in tunnels.

Contaminant	Guideline	Averaging Time	Protection	Application	Notes
Carbon Monoxide	200 ppm	15 minutes	Workplace	Design and Compliance Monitoring Guideline	equivalent to NZ Workplace Standard
	30 ppm	8 hours	Workplace		widely adopted abroad, PIARC 1995 recommendation
	87 ppm	15 minutes	General population		
Nitrogen Dioxide	1 ppm	15 minutes	Workplace and General Population	Design Guideline Only	equivalent to NIOSH Recommended Exposure Limit

Note: All interim NZTA guidelines are based on NIWA recommendations apart from the nitrogen dioxide guideline which is based on the NIWA recommended level (1 ppm) and French averaging period (15 min). Also note that the interim guideline for NO_2 is only intended to inform ventilation system design (at this stage).

Table 2.2: Interim NZTA In-Tunnel Air Quality (Carbon Monoxide and Nitrogen Dioxide) Guidelines for the protection of all non-occupational users in tunnels.

Contaminant	Guideline	Averaging Time	Notes
CO	87 ppm	15 minutes	equivalent to WHO ambient guideline, widely adopted in Australia
NO_2	1 ppm	15 minutes	PIARC proposal

Note: All interim NZTA guidelines are based on NIWA recommendations apart from the nitrogen dioxide guideline which is based on the NIWA recommended level (1 ppm) and French averaging period (15 min). Also note that the interim guideline for NO_2 is only intended to inform ventilation system design (at this stage).

Visibility guidelines were not within the scope of the NIWA review. However, the World Road Congress (PIARC) recommends five visibility limits and these have been adopted by NZTA as interim guidelines, as detailed in Table 2.3.

Table 2.3: Interim NZTA In-Tunnel Air Quality (Visibility) Guidelines for the protection of all users in tunnels.

Traffic Situation	Guideline	Averaging Time
	Extinction Coefficient K/m	Transmission (beam length 100m) %
Fluid peak traffic (50 - 100 km/h)	0.005	60
Daily congested traffic (standstill on all lanes)	0.007	50
Exceptional congested traffic (standstill on all lanes)	0.009	40
Planned maintenance work in a tunnel under traffic	0.003	75
Closing of the tunnel	0.012	30

Note: The interim NZTA guidelines for visibility are based on PIARC recommendations. The guideline provides a surrogate measure for particulate matter and is primarily intended to manage potential road safety issues inside tunnels by ensuring adequate visibility is maintained in front of vehicles.

2.2.4 Monitoring methods

Several classes of instruments are available for in-tunnel monitoring, which are summarised in Table 2.4. They range in quality and suitability.

In terms of data quality, sensors compliant with Australia/New Zealand Standards (A/NZS) for ambient air quality monitoring are preferred. However, their use is logistically limited by their need for high-pressure gas cylinders for calibration and general bans on the transport of such cylinders inside a road tunnel for safety reasons. These analysers also require regular attention by specialists, especially in polluted environments. As far as is practical, these analysers should be operated in accordance with the *Good Practice Guide for Air Quality Monitoring and Data Management 2009* (MfE, 2009), unless there is a convincing argument why exceptions should be made. Further details on A/NZS-compliant monitoring are provided in section 2.4.3.

Because of these restrictions most permanent monitoring systems use open-path spectroscopic technologies in instruments specially designed for the tunnel environment. In general, these provide lower-quality data than A/NZS-compliant ambient monitors. Short-term campaign-based observations are generally based on electrochemical cell technologies.

Table 2.4: Comparison of instrument types available for air quality monitoring inside road tunnels.

Instrument type	Quality[3]	Suitable uses	Examples	Pros	Cons
Passive samplers	Low	Screening	NO_2 diffusion tubes BTEX badges	Inexpensive	Poor temporal resolution Capture averages and not peaks
Electrochemical sensors	Low to Medium	Screening Permanent	Aeroqual Draeger Interscan Scott Instruments	Usually small and easily mounted in tunnel Moderately inexpensive	Are not readily comparable to external data Prone to drift and temperature errors Need gas cylinder for calibrations
Open-path spectroscopic sensors	Medium	Compliance Permanent	CODEL Vicotec DOAS Opsis	Many specifically designed for tunnels	Need careful maintenance Still need calibrating
A/NZS-compliant ambient analysers	High	Compliance Research	Thermo API Ecotech	Comparable to ambient data Complies with MfE GPG recommendations	Need gas cylinder for calibration Can be difficult to site in tunnels Can malfunction in tunnels due to high concentrations

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[3] 'Quality' is crudely defined. Quality is a balance between reliability, accuracy, precision, stability, ruggedness and range. Some instruments offer higher quality against some criteria and lower quality against others.

2.3 External air quality

2.3.1 Emissions and concentrations

A road tunnel has an impact on external air quality because nearly all of the air pollutants emitted by vehicles within the tunnel are, at some point, vented into the ambient atmosphere, either via the portals, and/or via one or more stacks. This has the potential to lead to localised degraded air quality and the potential for exceedances of national standards or Interim NZTA Guidelines, as discussed later.

For a tunnel without stacks, contaminated air is vented at the exit portals. Tunnel portal emissions are complex and difficult to assess. However, the extent of the affected zone is typically of the order of 100 – 200 m. If this localised impact is too high the tunnel air can be vented elsewhere, at a ventilation station, and possibly via a tall stack. In some cases this stack is some distance from the tunnel so that tunnel air may be vented into the atmosphere in a non-residential location. Stacks are remarkably efficient at dispersing pollutants. Concentrations at ground level are strongly reduced when stacks are used, and very tall stacks can have minimal to zero impact in their local vicinity. One of the great advantages of road tunnels is the opportunity to deliberately site portals (or stacks) away from sensitive receptors so that road transport emissions may be removed from dense residential areas improving local air quality.

In urban areas, ventilation design and tunnel management may require a trade-off between different in-tunnel and external requirements. In most cases these requirements do not conflict. Where they do several options exist, including increased stack height, stack relocation, traffic management and air treatment.

2.3.2 Standards and guidelines

For road transport-related air pollution, the relevant National Environmental Standards for Air Quality (AQNES) are listed in Table 2.5. These standards apply to all locations in the open air “where people are likely to be exposed to the contaminant” (MfE, 2005).

The AQNES are effectively a subset, with legal status, of the wider ranging Ambient Air Quality Guidelines (AAQG). The current AAQG were published in 2002 (MfE 2002) and are shown in Table 2.6.

Table 2.5: Relevant Air Quality National Environmental Standards for road transport-related air contaminants (MfE, 2005).

Contaminant	Threshold concentration	Permissible excess
Carbon monoxide	10 mg/m^3 as a running 8-hr mean	One 8-hr period in 12 months
Nitrogen dioxide	200 µg/m^3 as a 1-hr mean	9 hours in 12 months
PM_{10}	50 µg/m^3 as a 24-hr mean	One 24-hr period in 12 months

Table 2.6: Relevant Ambient Air Quality Guidelines for road transport-related air contaminants (MfE, 2002).

Contaminant	Value*	Averaging Time
Carbon monoxide	30 mg/m^3	1-hour
Nitrogen dioxide	100 µg/m^3	24-hour
Fine particles (PM_{10})	20 µg/m^3	Annual
Fine particles ($PM_{2.5}$)	25 µg/m^3	24-hour (monitoring guideline only)
Benzene	3.6 µg/m^3	Annual

* All values apply to the gas measured at standard conditions of temperature (0º C) and pressure (1 atmosphere).

In addition, most Regional Councils set specific regional ambient air quality guidelines or targets, which are outlined in their regional air plans. These are described in the relevant sections for each tunnel.

2.3.3 Monitoring methods

All external air quality monitoring campaigns should be designed and executed in accordance with the *Good Practice Guide for Air Quality Monitoring and Data Management 2009* (MfE, 2009), unless there is a convincing argument why exceptions should be made.

In general, any external monitoring for purposes other than screening assessments should use A/NZS-compliant techniques to permit comparison with ambient guidelines and standards, and to ensure a high standard of quality control. A summary of the permitted instruments is presented in Table 2.7. It should be noted that it is not sufficient to select an A/NZS-compliant instrument – the instrument must also be operated in accordance with the requirements of the Standard.

Table 2.7: Methods for ambient air quality monitoring permitted by Australian/New Zealand Standards and recommended by the MfE Good Practice Guide (MfE, 2009).

Contaminant	Standard	Recommended Method	Permitted Alternatives
CO	AS3580.7.1-1992	Gas Filter Correlation Infra Red (GFC-IR)	Non-dispersive infra-red gas chromatograph with flame ionisation detector
NO_2	AS3580.5.1-1993	Chemiluminescence	
PM_{10}	AS/NZS3580.9.6:2003		
PM_{10} (equivalent method)	US Code of Federal Regulations Title 40, Part 50 Appendix L	Beta Attenuation Monitor (BAM)	
		Tapered Element Oscillating Microbalance (TEOM)	
		Partisol[4]	
		High volume gravimetric sampler (Hi-Vol)	

Screening assessments, i.e. assessments used to provide indicative air quality but not for assessment of compliance, are less demanding in terms of accuracy and precision. Passive samplers are a low-cost option for capturing medium to long-term (week/months/years) spatial variation in concentrations, especially around portals and stacks. NZTA maintains a national network of passive diffusion tubes which provide monthly average concentrations of nitrogen dioxide (NO_2). The network has rapidly expanded in the last few years and includes some sites around the Wellington and Lyttelton tunnels. A low-cost technology also exists for passive monitoring of benzene, toluene, ethylbenzene and xylene: these are referred to as “BTEX badges”.

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[4] Not all Partisols have reference method designation for compliance monitoring – see USGPO, 1998a and 1998b

2.4 Mitigation options

2.4.1 Driver education

Several research studies, including studies conducted recently by NIWA, have shown that closing the windows and setting the vents to ‘recirculate’ is highly effective in reducing pollutant exchange between the vehicle cabin and the exterior environment (Longley & Kelly, 2008). The New South Wales Road Traffic Administration has issued a brochure that states:

> “*Some people with asthma are particularly sensitive to air pollution. To reduce exposure to vehicle emissions in peak periods, close your windows and switch your vehicle ventilation to re-circulate*.” (NSWRTA, 2006)

The Impact Assessment for the Brisbane North-South Bypass Tunnel states that

> “*…for this project, traffic management programs will be required to be implemented to ensure that prolonged exposure (>15 minutes) is not experienced by any motorist. In the event that those circumstances are not possible, then motorists who may be susceptible to asthmatic symptoms should be advised, via the tunnel communication system, to close their car windows while they wait*.” (SKM Connell Wagner, 2005)

Once a vehicle has left a tunnel, it retains some of the tunnel air which infiltrated the cabin, leading to an extended exposure. Thus, pollutant exposure can actually be minimised by switching to recirculation **only** whilst inside the tunnel, reverting to open vents once the tunnel is exited.

2.4.2 Tunnel ventilation

An increase in ventilation rate for a given tunnel will lead to lower in-tunnel and external concentrations because of the extra dilution. The scale of the increase in ventilation is limited by the need to keep in-tunnel wind speeds below a limit (which is conventionally 10 m/s).

2.4.3 After-treatment

After-treatment options for mitigating the effects resulting from the operation of a tunnel include:

- Electrostatic precipitation
- Denitrification
- Absorption
- Biofiltration
- Agglomeration
- Scrubbing
- High temperature incineration

After-treatment is very expensive, especially if retrofitted, and is not widely implemented unless other mitigation options are insufficient. Use of electrostatic precipitation to remove particulates has been applied most in Norway and Japan. New generation filtration systems have been recently installed in Madrid. Technology to reduce NO_2 in tunnel air is at a relatively earlier stage of development. Two rival systems are currently being trialled in Tokyo.

2.4.4 Exposure management/restrictions

There are a number of ways of limiting **occupational** exposure to ensure that the exposure of any person working within the tunnel to carbon monoxide does not exceed both 15-minute and 8-hour Interim NZTA Guidelines. These approaches can be characterised as:

- Restrictions on working hours to coincide with low concentrations,
- Increased ventilation during maintenance,
- Restrictions on duration of exposure.

In general, one might expect low CO concentrations to coincide with low levels of traffic (i.e. at night), but this cannot be assumed if mechanical ventilation is operating at a reduced rate, or is non-operational at night. Exposure may be permitted at concentrations above the Interim NZTA Guidelines for durations shorter than the guideline specifies. Details are provided in the *Guidelines for the Management of Air Quality in and around Road Tunnels in New Zealand* report (Longley *et al*, pending).

3. Mount Victoria tunnel

3.1 Tunnel metadata

3.1.1 Tunnel purpose and location

The Mt Victoria tunnel was opened in 1931 to provide traffic access from the Wellington Central Business District to the Eastern suburbs. It is located on the eastern edge of central Wellington and carries SH1N through Mt Victoria to providing access to Wellington Airport, as well as the suburbs of Kilbirnie, Miramar, Seatoun and Lyall Bay as shown in Figure 3.1.

Figure 3.1: Satellite map showing the location of Mt Victoria Tunnel (red line in centre of image).

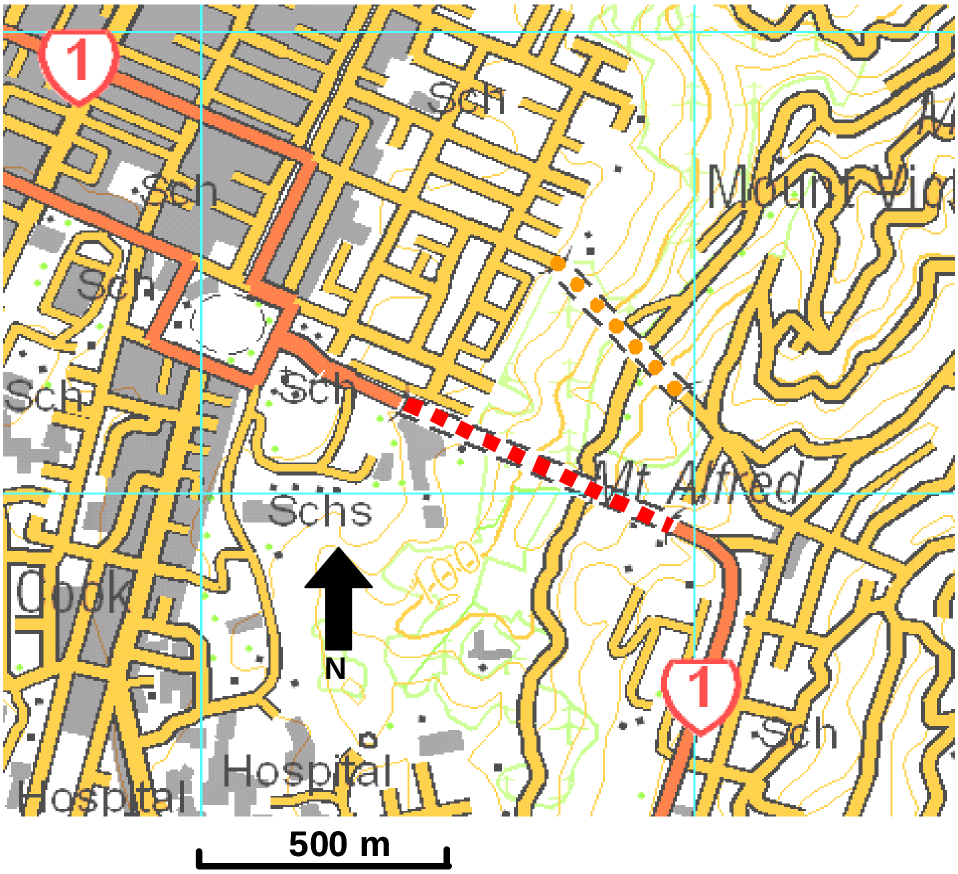

Figure 3.2: Road map showing the location of the Mt Victoria Tunnel (red dashed line) and the Hataitai bus tunnel (orange dotted line to the north).

The Mt Victoria tunnel is open to all vehicular traffic (except dangerous goods), as well as pedestrians and cyclists. Some buses are diverted through the nearby Hataitai single lane tunnel of 388 m, which opened in 1854 for trams but is now operated by Wellington City Council for buses only. This is located 200 to 400 m north of the Mt Victoria Tunnel as shown in Figure 3.2.

3.1.2 Geometry and ventilation

The tunnel is a single semi-circular bi-directional tube, approximately 4.4 m in radius, 8 m wide (approximately 41 m^2 cross-sectional area) and 623 m long, with a 1:100 gradient. It has one lane of traffic each way plus an elevated pedestrian walkway (shown in Figure 3.3).

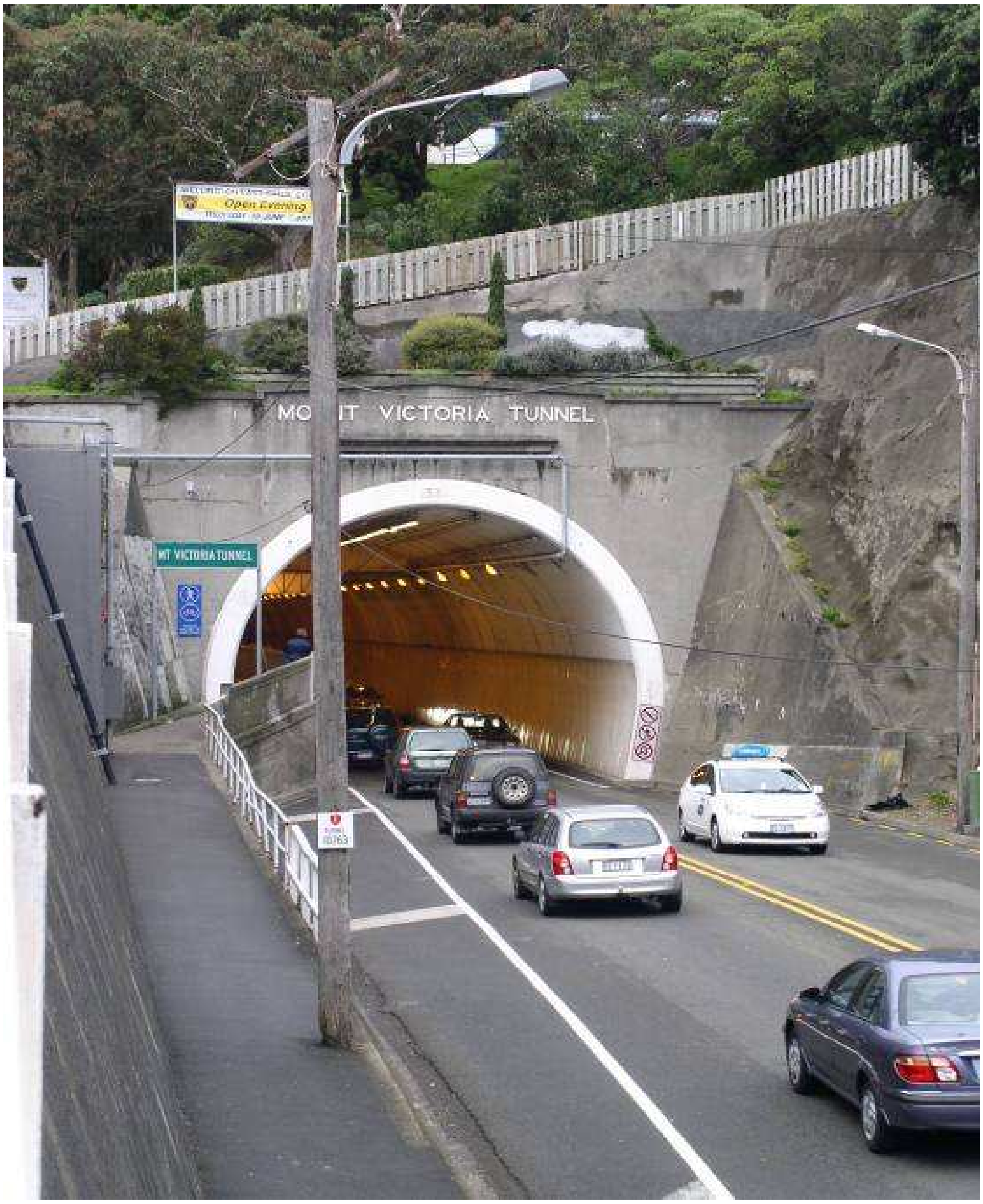

Figure 3.3: Western portal of the Mt Victoria Tunnel showing pedestrian walkway.

The ventilation system is transverse, with two supply and two exhaust fans. Fresh air is entrained by fans near each portal and is supplied along a duct underneath the pedestrian walkway. Air enters the main bore at road level through slots along the full length of the tunnel. Polluted air is removed into a void space in the roof along the full tunnel length and drawn into two vertical exhaust shafts by fans. Exhaust air is then vented into the ambient atmosphere without the aid of stacks. The fan houses are located on the Mt Victoria hillside, the eastern one at 62 m height and the western at

32 m height. The exhaust shafts are positioned at approximately “quarter points” along the length. The four fans are operated on a timeswitch.

3.1.3 Traffic flow and fleet composition

Annual average daily traffic (AADT) for the Mt Victoria tunnel in 2008 was 38,751 vehicles per day, with the proportion of heavy duty vehicles (HDVs) at approximately 5%[5]. The fraction of HDVs is lower than in surrounding streets because buses travelling between the city and Hataitai typically use the separate buses only tunnel rather than the main tunnel. A high number of taxis tend to use the tunnel as it is the most direct route to and from the airport. Approximately 4% of the light vehicles using the tunnel were found to be taxis in a limited visual survey undertaken by NIWA in June 2008.

The hourly weekday traffic counts in Figure 3.4 show typical peaks for morning and evening commuter traffic but are still relatively high throughout the day. The weekend flows are also high but maintain a more constant level for the middle of the day.

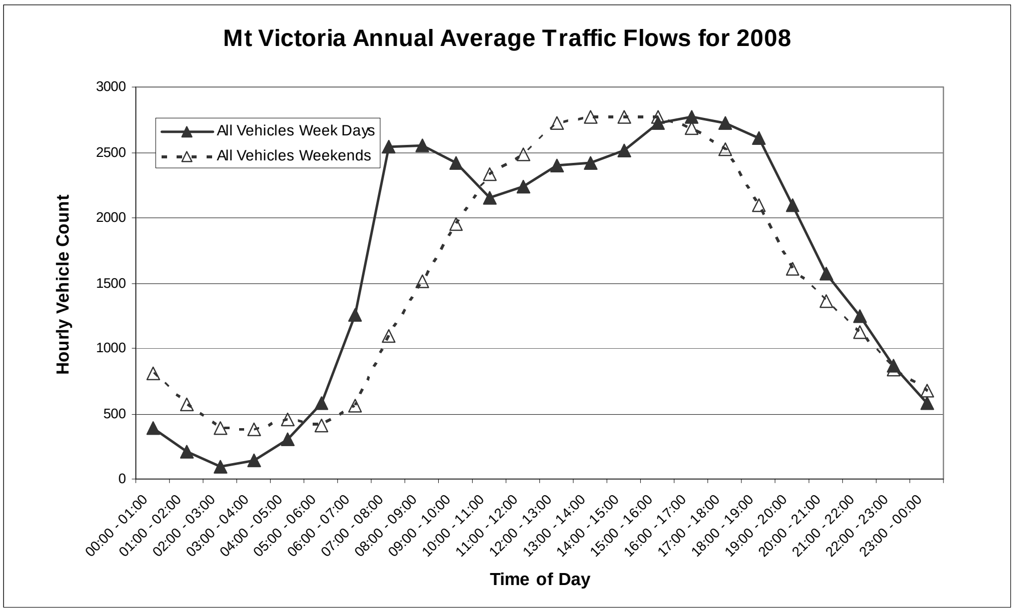

Figure 3.4: Annual average daily traffic (AADT) flow for the Mt Victoria tunnel in 2008.

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[5] NZTA (2009). *State Highway Traffic Data Booklet 2004-2008*, NZ Transport Agency

The traffic volume has been between 36,000 and 39,000 vehicles per day since monitoring began in 1997, with annual average daily counts for the past five years shown in Table 3.1.

Table 3.1: Annual average daily traffic in the Mt Victoria tunnel for 2004-2008.

Year	2004	2005	2006	2007	2008
Counts	37,995	37,702	38,077	38,663	38,751
Change	---	-0.8%	+1.0%	+1.5%	+0.2%

The posted speed limit is 50 km/h but congestion regularly reduces speeds well below this.

3.1.4 Tunnel monitoring

The nearest traffic monitoring site is a single loop at Patterson Street, south of the Basin Reserve (NZTA ref.01N01076) which measures traffic flow for both directions but is unable to provide speed or heavy duty vehicle splits.

There are no sensors for wind speed/direction or in-tunnel air quality installed for the Mt Victoria tunnel.

3.1.5 Receiving environment

The air from the interior of the Mt Victoria tunnel is vented to the atmosphere through the two fan houses, which are located on the ridge of Mt Victoria at an altitude of 80–100 m (see Figures 3.5, 3.6 and 3.7).

The **western** fan house (Figure 3.5) is located within the grounds of Wellington East Girls' College. The nearest residences are 60 m to the north-west and at ~ 30 m lower altitude, whereas most residences in the Mt Victoria district, which lie to the north of the fan house, are lower on the slopes.

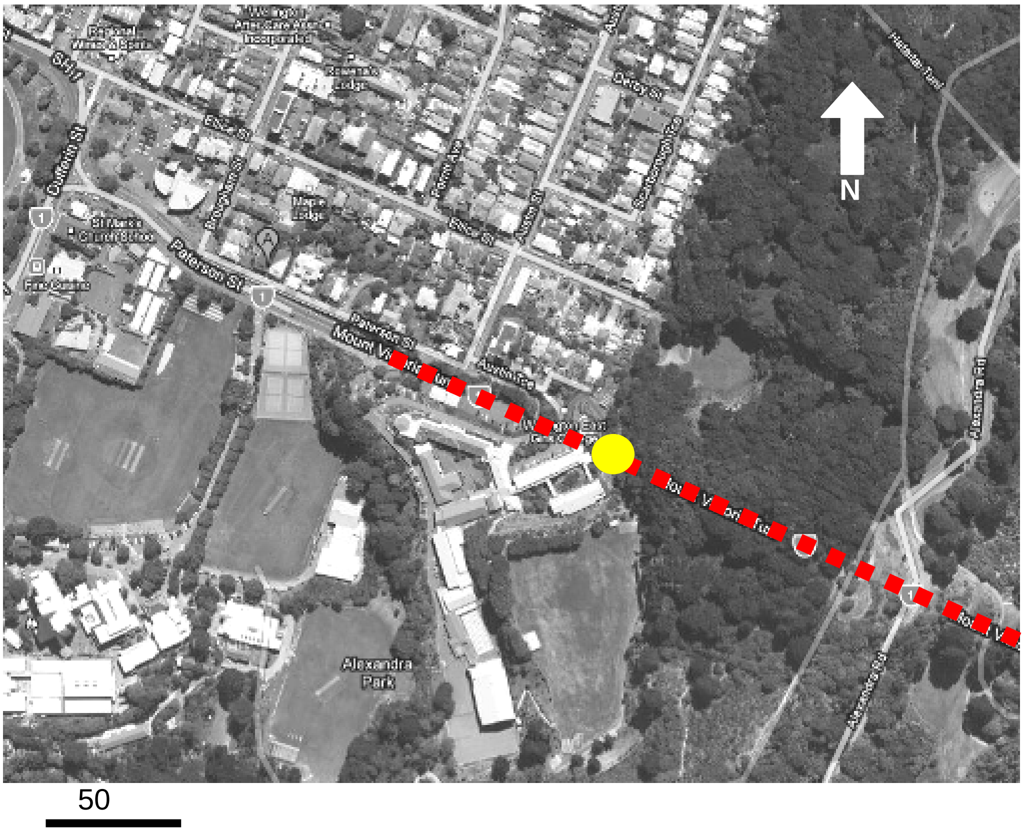

Figure 3.5: Detail of the western end of the Mt Victoria Tunnel. The yellow circle marks the western fan house. The complex immediately to the south of the fan house and portal is Wellington East Girls' College. The area north of the portal is entirely high-density residential.

The nearest residences to the **eastern** fan house (Figure 3.6) are due east at a distance of 160 m and ~ 40 m lower on the slope. There is an early childhood centre (Hataitai Kindergarten) on Taurima Street, ~100m east of the eastern portal.

Figure 3.6: Detail of the eastern end of the Mt Victoria Tunnel. The yellow circle marks the eastern fan house. The blue rectangle is Hataitai Kindergarten. The area north-east of the portal is residential. To the south is Hataitai Park, where an athletics track and tennis courts can be seen.

Adverse impacts from the fan houses on local residences are unlikely due to the substantial height difference and favourable prevailing wind directions.

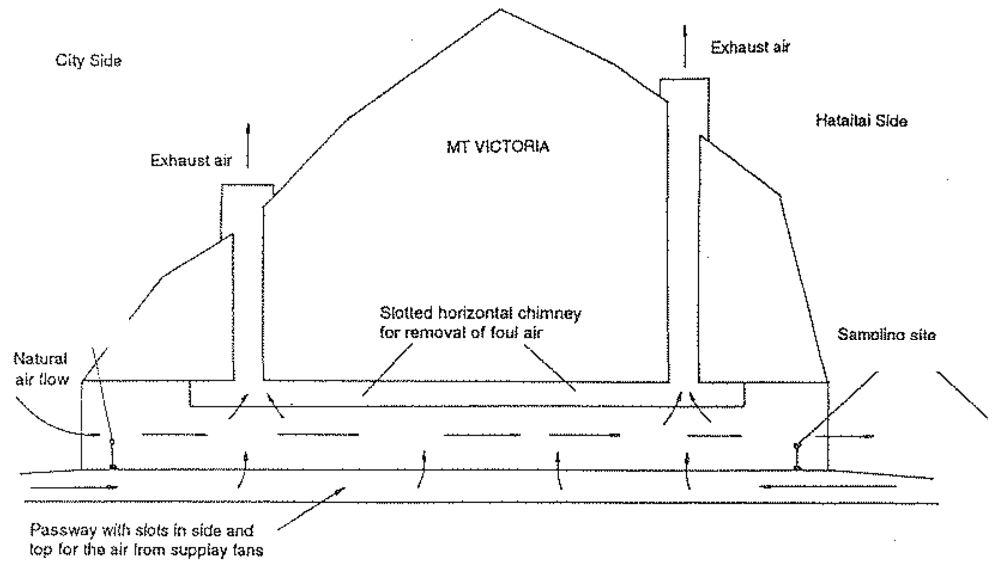

Figure 3.7: Cross section of the Mt Victoria tunnel showing the location of the fan houses (Dravitzki and Kvatch, 1996). Note: the vertical scale is exaggerated.

3.1.6 Meteorological conditions

There is no local meteorological monitoring undertaken at the Mt Victoria tunnel.

The two nearest stations are Wellington Airport and Kelburn which straddle Mt Victoria. The wind rose for Wellington Airport (Figure 3.8) shows a predominance of relatively strong winds from either the north or south. In comparison the wind rose from Kelburn reveals more north-west winds (Figure 3.9).

Mt Victoria forms a north-north-east/south-south-west aligned ridge separating the Wellington airshed into two distinct sectors. Winds on the eastern side are more likely to be represented by the Wellington Airport data and winds on western side by the Kelburn data but this is unable to be confirmed.

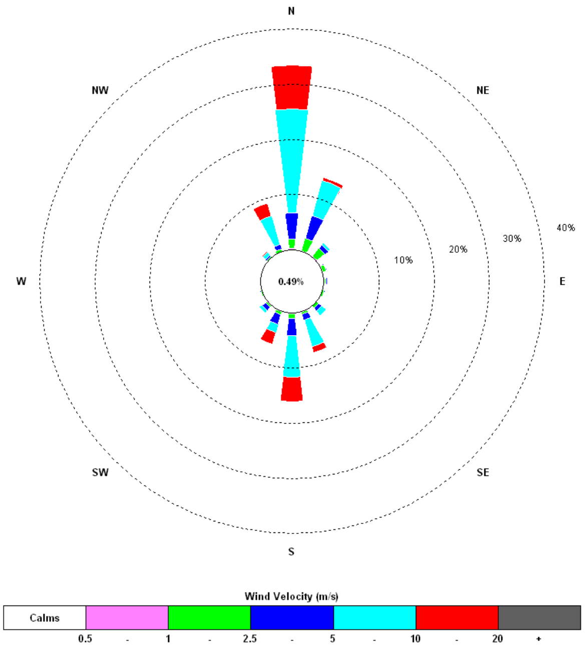

Figure 3.8: Wind rose for Wellington Airport based on hourly data (January 2005 to December 2009 inclusive).

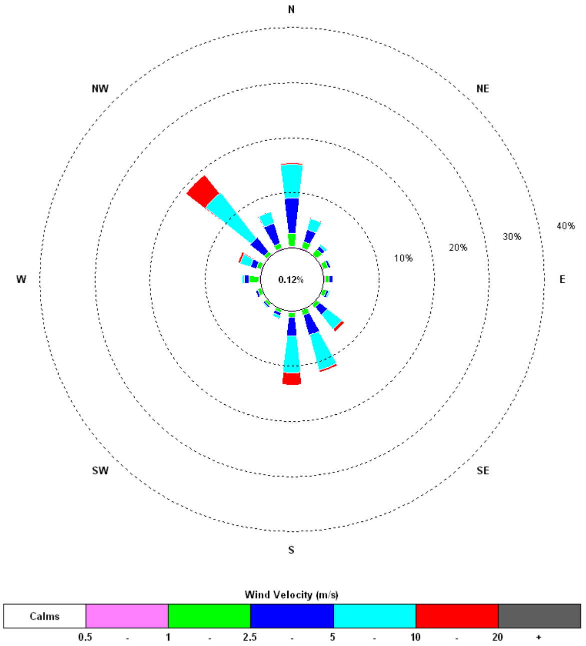

Figure 3.9: Wind rose for Kelburn based on hourly data (January 2005 to December 2009 inclusive).

3.1.7 Baseline air quality in Wellington

The Greater Wellington Regional Council (GWRC) monitors air quality continuously at several locations in the region, including within the basin containing the city centre (i.e. to the west of Mt Victoria).

The nearest location is the “Corner V”[6] roadside peak monitoring site in central Wellington. Air quality at Corner V was characterised by GWRC as “excellent” or “good” (in terms of NO_2) 90% of the time in 2006 with no reported exceedances of the AQNES.

However, the Corner V site is not necessarily representative for the communities most likely to be directly affected by emissions from the Mt Victoria Tunnel.

3.2 In-tunnel air quality

3.2.1 Carbon monoxide

Historic observations of CO in the Mt Victoria tunnel

CO has been monitored several times in the Mt Victoria Tunnel on a campaign basis, as summarised in Table 3.2. The most recent monitoring was conducted between 2 December 2002 and 28 February 2003 (MWH, 2003). **None** of the campaigns was conducted using the recommended method (see section 2.2.3) and results must be interpreted with care.

At most times during the 2002/3 campaign CO levels in the tunnel appeared to be below the NIWA-recommended guidelines, but occasional potential exceedances were observed. Concentrations were generally correlated with traffic volume, with concentrations in the range 40 – 60 ppm regularly observed during weekday traffic peaks. Some peak concentrations were observed at night, shortly after the fans were switched off.

Compared to a previous campaign in 1997, it was reported that mean CO concentrations had more than halved and peak values had fallen by 38%. It is unclear if this was due to improvements in the ventilation system made in 2000 or improvements in vehicle emission technology.

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[6] Corner V: intersection of Vivian Street and Victoria Street

There appeared to be no time during which the occupational guideline of a maximum of 30 ppm was achieved for a continuous 8 hour period.

Table 3.2: Summary of CO observations in the Mt Victoria tunnel since 1980.

Year	Method	Mean CO (ppm)	Max CO (ppm)	Reference
1980	Not reported	63	110	Pilgrim & Nichol, 1982
1981	Not reported	90	130	Pilgrim & Nichol, 1982
1993	Passive tubes[7]	105	200	Kingston Morrison Ltd, 1993
1995	Electrochemical cell[8]	30	54	Dravitzki & Kvatch, 1996
1997	Electrochemical cell[9]	39.2	147	MWH, 1997
2002/03	Electrochemical cell[10]	14.8	91	MWH, 2003

Current levels/estimates of CO in the Mt Victoria tunnel

The method for estimating 2008 concentrations based on 2003 data is described in Appendix 1.

2008 concentrations are expected to differ from 2003 due to the continued penetration of lower-emission vehicles into the New Zealand fleet. On the assumption that fleet composition, average speed and traffic volume are largely unchanged over this period, we estimate a ~40% reduction[11]. In summary, since 2003 we may expect the mean CO concentration in the tunnel to have fallen from 15 ppm to **~9 ppm**. The resulting extrapolated maximum concentration would be **~55 ppm**. Furthermore, we estimate that typical weekday traffic-peak concentrations in 2008 are approximately **30 - 40 ppm**.

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[7] Gastec

[8] Interscan

[9] Citicel 3E/F

[10] Scott Instruments Freedom 5000

[11] Based on output from the ARC's Vehicle Emissions Prediction Model

Duration of exposure

The posted speed limit in the tunnel is 50 km/h. Travelling at this speed a vehicle should remain inside the tunnel for 44 seconds. However, congestion in and around the tunnel has been reported since at least 1982 and actual speeds in the tunnel can be much lower, and hence exposure times can be longer. A study by the University of Otago in 2001 noted a typical journey time of 50 seconds (Wellington School of Medicine & Health Sciences, 2001). At an average 10 km/h the journey time is 224 seconds (i.e. approx. 4 minutes), i.e. exposure durations are well below the 15-minute averaging period applied in most exposure limits, including the Interim NZTA Guidelines.

Comparison with guidelines

The Interim NZTA Guideline for CO for all non-occupational users does not appear to be exceeded at present. We cannot conclude that it is not exceeded on rare or atypical occasions.

It appears unlikely that concentrations exceeding the 15 minute **occupational** exposure limit of 200 ppm occur in normal operation, although we cannot comment on abnormal situations, such as ventilation failure or accidents or blockages within the tunnel. However, it is probable that the 8-hour **occupational** limit of 30 ppm is currently exceeded on a regular basis.

3.2.2 Nitrogen dioxide

Historic observations of NO_2 in the Mt Victoria tunnel

NO_2 has been measured in the Mt Victoria Tunnel in 1982, 1996 and 1997. Results are summarised in Table 3.3. Total oxides of nitrogen (sum of NO and NO_2) were also measured in 1980 and 1981 (Pilgrim & Nichol, 1982) and in 1995 (Dravitzki & Kvatch, 1996).

The measurements of the 1980s were brief and can only be considered to provide a screening assessment. The 1996 and 1997 campaigns of four and two months (respectively) potentially provide a more comprehensive and representative assessment but the results are of questionable quality due to suspected sensor degradation. Consequently all of the historic NO_2 data must be treated with caution.

Table 3.3: Summary of NO_2 observations in the Mt Victoria tunnel since 1978.

Year	Method	Mean NO_2 (ppm)	Max NO_2 (ppm)	Reference
1982	Not reported	0.18	0.3	Pilgrim & Nichol, 1982
1996	Electrochemical cell [12]	Not reported	Not reported (approx 1.7)	Petersen *et al*., 1996
1997	Electrochemical cell [13]	0.286*	1.93*	MWH, 1997

* Data may not be reliable due to suspected sensor degradation.

Current levels/estimates of NO_2 in the Mt Victoria tunnel

An estimate of current NO_2 levels is very difficult to make with any degree of certainty, due to both lack of data and a lack of understanding of the determinants of NO_2 in road tunnels, in general, and the Mt Victoria Tunnel, in particular.

Duration of exposure

The physiological and toxicological effects of NO_2 cannot be described in the same level of detail as CO. For that reason exposures and the respective impacts upon drivers, pedestrians and cyclists cannot be compared as they can for CO exposure.

Comparison with guidelines

Currently, there is insufficient information to draw conclusions about whether the Mt Victoria Tunnel likely complies with the Interim NZTA Design Guidelines for NO_2.

3.2.3 Fine particulates

Historic observations of fine particulates in the Mt Victoria tunnel

Fine particulates have been measured in the Mt Victoria tunnel five times in the past. Summary details are shown in Table 3.4.

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[12] EIT Sensor Stik

[13] EIT Series 4500 Sensor Stik

Table 3.4: Summary of fine particulate observations in the Mt Victoria tunnel since 1996.

Year	Mean PM_{10} ($\mu g/m^3$)	Max PM_{10} ($\mu g/m^3$)	Mean $PM_{2.5}$ ($\mu g/m^3$)	Max $PM_{2.5}$ ($\mu g/m^3$)	Reference	Method
1996	155	172	Not measured	Not measured	Petersen *et al.*, 1996	MiniVol (filter)
1996	74	669[14]	Not measured	Not measured	MWH, 1997	MIE DataRAM (nephelometer)
1999	311	390	220	287	Dravitzki & Kvatch, 2000	Filter
2001	116*	Not reported	36	Not reported	Davy *et a*l., 2002	GENT sampler (stacked filter)
2003	34	486[15]	Not measured	Not measured	MWH, 2003	MIE DataRAM (nephelometer)

* Sum of the $PM_{10-2.5}$ and $PM_{2.5}$ average concentrations

Monitoring in 1997 and 2003 was conducted continuously by an optical scattering technique. The monitoring from 1996 and 1999 involved filter sampling providing an average loading over the whole sample time. None of these techniques are optimal or mutually consistent such that the data should be considered to be of indicative "screening" quality only.

PM_{10} and $PM_{2.5}$ concentrations were measured in the Mt Victoria Tunnel over 5 days (4 – 5 hours each day) in 1999 (Dravitzki & Kvatch, 2000). Concentrations ranged from 189 to 287 $\mu g/m^3$ for $PM_{2.5}$ and from 241 to 390 $\mu g/m^3$ for PM_{10}. $PM_{2.5}$ emission rates were found to be 75% of PM_{10} emission rates.

A source apportionment study was undertaken in the tunnel in 2001 (Davy *et al.*, 2002). Particulate matter was collected on a total of 33 filters (split by $PM_{10-2.5}$ and $PM_{2.5}$ size fractions) from February to May 2001. $PM_{10-2.5}$ concentrations (average 80 $\mu g/m^3$) were generally higher in the tunnel than $PM_{2.5}$ concentrations (average 36 $\mu g/m^3$). It was found that motor vehicle exhaust-derived particulate matter dominated the $PM_{2.5}$ fraction.

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[14] As a 15-minute average

[15] As a 15-minute average

Current levels/estimates of fine particulates in the Mt Victoria tunnel

The 1999 monitoring was very limited and the representativeness of the data is unknown. However, the Vehicle Emission Prediction Model predicts that PM emission rates should have fallen by ~34% between 1999 and 2008. Background concentrations were not reported which prevents us determining what proportion of the measured in-tunnel concentration would be affected by that fall. However, if we assume that the annual median PM_{10} concentration for Central Wellington, which was 14 $\mu g/m^3$ in 2006 (GWRC, 2007), is typically representative of the contribution of non-tunnel sources to in-tunnel concentrations, then we estimate that peak PM_{10} levels in 2008 could be ~250 $\mu g/m^3$.

Comparison with guidelines

Air quality standards for fine particulates apply to exposures of 24 hours and are therefore not relevant for road tunnel interiors.

3.2.4 Visibility

To date there have been no measurements of visibility in the Mt Victoria Tunnel.

3.3 External air quality

3.3.1 Nitrogen dioxide

Historic observations of NO_2 near the Mt Victoria tunnel

No continuous ambient air quality monitoring has ever been conducted in areas likely to be affected by the Mt Victoria tunnel.

Current levels/estimates of NO_2 near the Mt Victoria tunnel

There is currently no information available to make estimate levels of NO_2 in the areas likely to be affected by tunnel exhaust emissions (Hataitai, Mt Cook, Mt Victoria).

Two sites alongside SH1N on either side of the Tunnel form part of NZTA's National NO_2 diffusion tube network, providing monthly average NO_2 concentrations. However, the concentrations reported are indicative of the impact of the surface sections of SH1N, not the tunnel. Results for the first full year of deployment are summarised in Table 3.5.

Table 3.5: Summary of NO_2 concentrations reported from NZTA passive samplers in the vicinity of the Mt Victoria tunnel for the first full year of deployment (September 2007 to August 2008 inclusive).

	Paterson Street	Tapiri Street
Distance to SH1N (m)	20	10
Distance to Mt Victoria Tunnel (m)	100	250
Annual mean NO_2 (µg/m^3)	14	22
WHO guideline for annual NO_2 (µg/m^3)	40	

It should be noted that passive samplers (such as diffusion tubes) cannot directly provide an indication of 1-hour peak NO_2 concentrations.

Comparison with guidelines

No exceedances of the AQNES or WHO Guidelines for NO_2 have ever been recorded in Wellington city. Compliance in areas near the tunnel exhaust fan houses is unknown.

3.3.2 Particulate matter

No ambient air quality monitoring of particulate matter has ever been conducted in areas likely to be affected by the Mt Victoria tunnel.

A brief survey of heavy metals in soil and plant matter on the grounds of Wellington East Girls' College was conducted in 1994 (Bowden, 1994). A further review was conducted to evaluate whether the potential contribution of the tunnel to the observed levels. The review concluded that:

> "*…the levels of zinc, cadmium and nickel within the Wellington East Girls' College do not pose an environmental hazard nor can they solely be attributed to emissions from the tunnel vent or that the tunnel vent is the major source.*" (Davy, 1995)

3.4 Key air quality issues for future upgrades

3.4.1 In-tunnel compliance monitoring of Mt Victoria tunnel

High historic concentrations, rapid evolution of vehicle technology and the low quality techniques used in previous monitoring means that current compliance cannot be reliably assessed.

The ventilation system of the Mt Victoria Tunnel is ageing and designed to historic guidelines which are inappropriate with respect to current health guidelines, traffic levels or vehicle technology. Due to the current lack of data regarding the relationships between traffic characteristics, air flow and air quality, future compliance of both the current ventilation regime and any alternative upgraded system cannot currently be assessed.

Consequently, a campaign of high quality CO measurements, supported by simultaneous, detailed and continuous monitoring of traffic flow, speed and composition and air flow is recommended as a first priority. An interim objective should be to evaluate or adjust a tunnel-specific emission model for prediction of future ventilation demand.

3.4.2 Ambient air quality monitoring near Mt Victoria tunnel

There is no existing information on the impact of emissions from the Mt Victoria Tunnel stacks on the surrounding communities. The fan houses are elevated relative to most of Wellington, but they are not tall and there are significant receptors close to both stacks which may be adversely affected.

We recommend a screening assessment is conducted in a ~200m radius around both fan houses and portals based on a network of NO_2 diffusion tubes at exposure-relevant sites (including Wellington East Girls' College, Ellice Street, Hapua Street and Hataitai Kindergarten). If screening reveals problematic "hot-spots" then more detailed monitoring may be necessary to determine the likelihood of AQNES exceedance.

4. Terrace tunnel

4.1 Tunnel metadata

4.1.1 Tunnel purpose and location

The Terrace tunnel was opened in 1978 and originally represented the southern end of SH2. Alterations at the Ngauranga SH1/SH2 interchange in 1984 connected SH1 to the motorway; although SH1 continued off the Aotea Quay off ramp until 1996. In 1996, Transit extended the SH1 status to the entire route from the end of the Wellington Urban Motorway to Wellington International Airport. The Terrace tunnel now forms part of the Inner City Bypass on SH1N in central Wellington and is situated as shown in Figures 4.1 and 4.2.

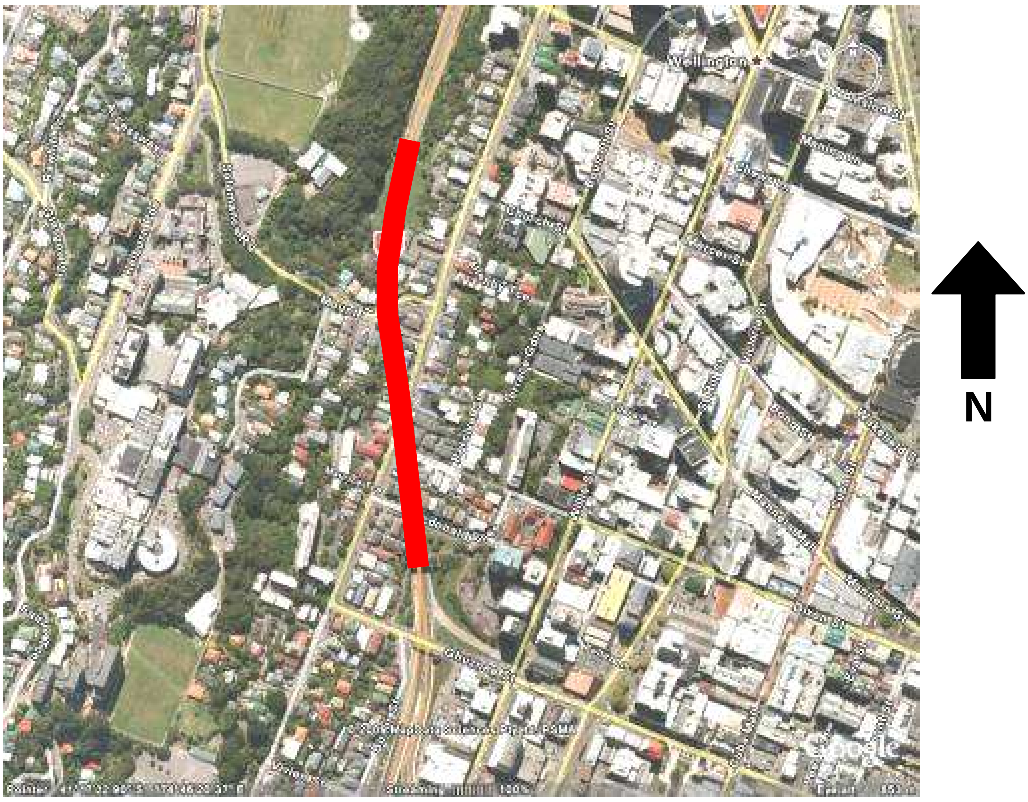

Figure 4.1: Satellite map showing the location of the Terrace tunnel.

The Terrace tunnel is open to all vehicular traffic (except dangerous goods).

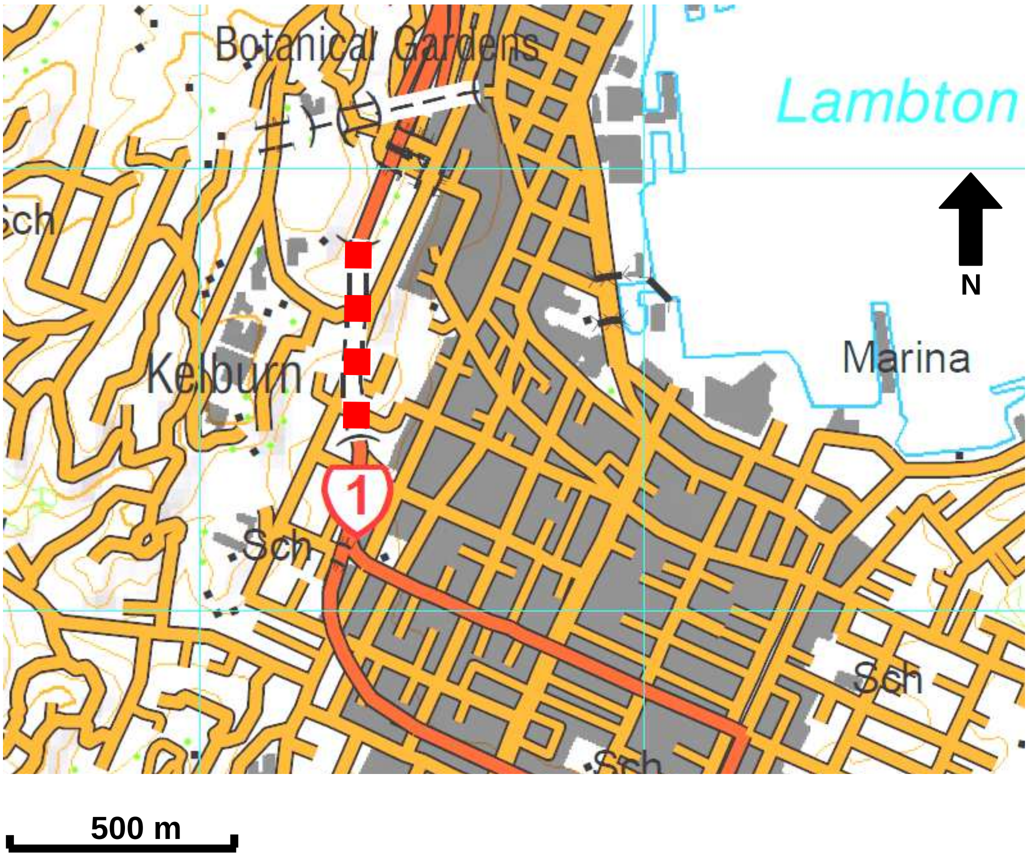

Figure 4.2: Road map showing the location of the Terrace tunnel (red dashed line).

4.1.2 Geometry and ventilation

The tunnel is a single semi-circular bi-directional tube, approximately 6.6 m in radius, 11 m wide (65.8 m^2 cross-sectional area) and 460 m long, with a 1:40 (3%) gradient. It has two northbound lanes and one southbound lane as shown in Figure 4.3.

The ventilation system is longitudinal, which is unusual for a single bi-directional tube. The original tunnel design involved two three-lane uni-directional tubes, for which longitudinal ventilation is appropriate. However, only one tube was constructed and the present layout has been a “temporary” running solution since 1978. To compensate, the ventilation system has been set up to operate in either direction in an attempt to aid the prevailing windflow. The system consists of 18 reversible axial flow fans mounted in groups of three in six recessed ceiling bays.

Figure 4.3: The southern portal of the Terrace tunnel (looking north).

The operation of the fans was originally controlled by feedback from three CO sensors, but this system was replaced with one based on observations of traffic speed and wind speed/direction (previously measured by a wind vane but now detected by an ultrasonic sensor).

The air from the tunnel interior is vented to the atmosphere through the two portals. These are located on a hillside, although the presence of tall buildings to the east effectively forms a north-south oriented valley. Given the predominant northerly and southerly winds in Wellington, this valley probably acts to further steer local winds into a direction parallel to the tunnel.

4.1.3 Traffic flow and fleet composition

Annual average daily traffic (AADT) for the Terrace tunnel in 2008 was 41,031 vehicles per day, with the proportion of heavy duty vehicles (HDVs) at approximately 5%.[16]

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[16] NZTA (2009). *State Highway Traffic Data Booklet 2004-2008*. NZ Transport Agency

The hourly weekday traffic counts in Figure 4.4 show typical peaks for morning and evening commuter traffic but are still relatively high throughout the day. The weekend flows are also high but maintain a more constant level for the middle of the day.

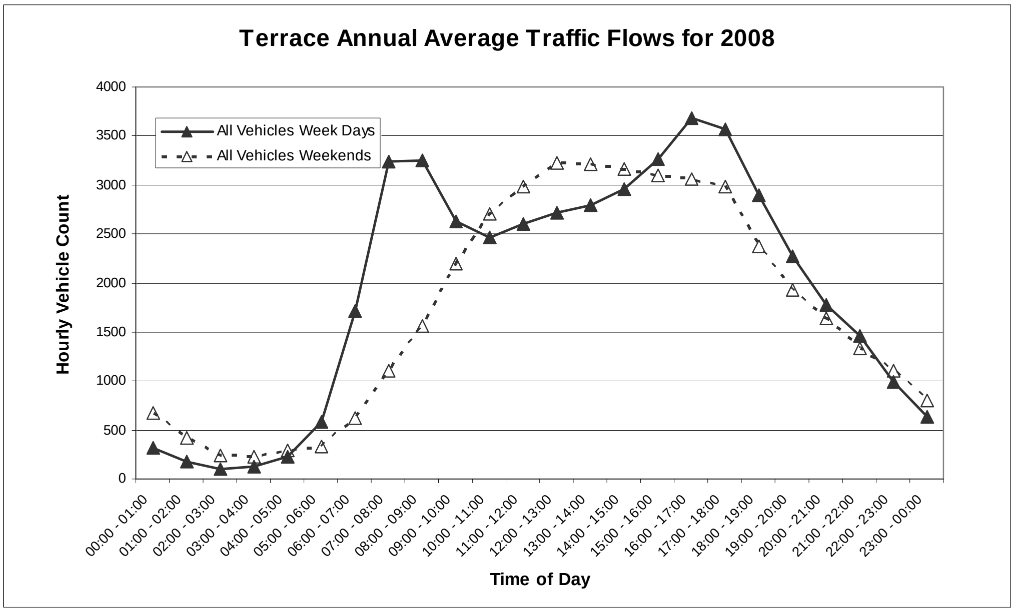

Figure 4.4: Annual average daily traffic (AADT) flow for the Terrace tunnel in 2008.

The traffic volume has been over 40 000 vehicles per day since 1998, with annual average daily counts for the past five years shown in Table 4.1.

Table 4.1: Annual average daily traffic in the Terrace tunnel for 2004-2008.

Year	2004	2005	2006	2007	2008
Counts	40,569	41,095	41,031	43,688	45,394
Change	---	+1.3%	-0.2%	+6.5%	+3.9%

The posted speed limit was originally 100 km/h and has recently been reduced to 80 km/h but southbound congestion regularly reduces speeds well below this.

Although the tunnel has a traffic speed sensor, the information is not recorded and cannot be used to generate speed profiles.

4.1.4 Tunnel monitoring

The nearest traffic monitoring sites are two single loops in the northbound and southbound lanes of the Terrace tunnel (NZTA ref.01N11074 and NZTA ref.01N21074) which measure traffic flow for each direction but are unable to provide speed or heavy duty vehicle splits.

There is a fan sensor in the Terrace tunnel and an ultrasonic wind sensor was installed in December 2009. As mentioned, traffic speed is measured but not logged. There are no sensors for in-tunnel air quality installed for the Terrace tunnel.

4.1.5 Receiving environment

The north portal is adjacent to Kelburn Park which occupies the hillside to the west. There are a small number of residences within 100 m of the southern portal on the north and western sides. An early childhood centre (Capital City Preschool) is located approximately 100 m east-north-east of the southern portal (see Figure 4.5).

Figure 4.5: Detail of the Terrace tunnel showing the southern portal (left) and the northern portal (right). The blue rectangle is the Capital City Preschool.

4.1.6 Meteorological conditions

The nearest permanent meteorological station to the Terrace tunnel is the Kelburn site.

Although data from this site presented in Figure 4.6 indicate a northerly prevailing wind, NZTA tunnel operating staff report[17] that the wind within the tunnel almost always blows from the south. This may be due to the rise of the roadway to the north, creating a 'chimney effect'. A new additional meteorological monitoring site close to the motorway and the northern portal, dedicated to the needs of tunnel management, would help to confirm this.

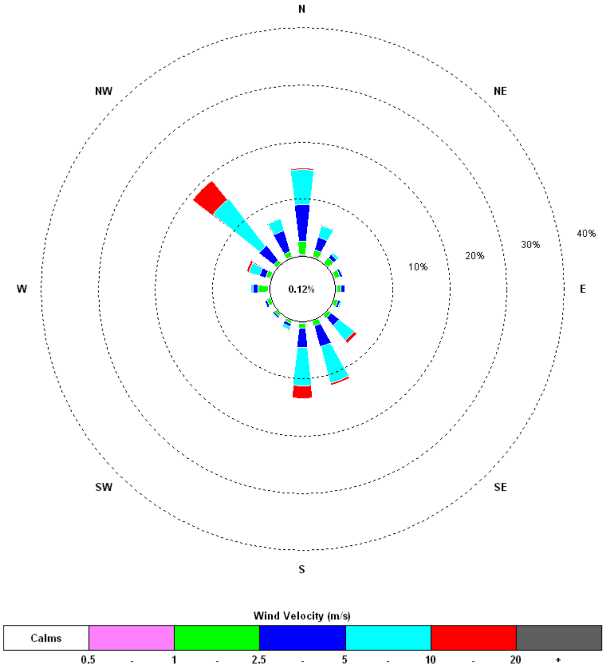

Figure 4.6: Wind rose based on hourly data from Kelburn (January 2005 to December 2009 inclusive).

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[17] *Pers comm.*. Richard Mowll, NZTA, February 2010

4.2 In-tunnel air quality

4.2.1 Carbon monoxide

Historic observations of CO in the Terrace tunnel

CO was measured in the Terrace tunnel during two campaigns in 1979 and 2003. Summary data are presented in Table 4.2.

Table 4.2: Summary of CO observations in the Terrace tunnel.

Year	Method	Mean CO (ppm)	Max CO (ppm)	Reference
1979	IR analyser	Not reported	>250	Pilgrim & Nichol, 1982
2003	Not reported[18]	26	135	MWH, 2003b

The 1979 campaign revealed multiple faults in the ventilation system and the observed concentrations from this campaign may not necessarily be taken as representative of the 'correct' operation of the system (as well as representing vehicle emission profiles from three decades ago).

By 2003 the ventilation control system had been changed and was no longer based on in-tunnel CO monitoring. Over the 2003 campaign CO concentrations were typically within the Interim NZTA Guidelines but were in excess ~1% of the time. These concentrations are high for such a short tunnel, and higher than those observed around the same time in the longer Mt Victoria tunnel. However, it was still noted that the fans could have been operating in the wrong direction on a number of occasions.

Current levels/estimates of CO in the Terrace tunnel

The method for estimating 2008 concentrations based on 2003 data is described in Appendix 1.

2008 concentrations are expected to differ from 2003 due to the continued penetration of lower-emission vehicles into the New Zealand fleet. On the assumption that fleet composition, average speed and traffic volume are largely unchanged over this period,

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[18] Likely to be electrochemical cell

we estimate a ~40% reduction[19]. In summary, since 2003 we may expect the mean CO concentration in the tunnel to have fallen from 26 ppm to **~16 ppm**. The resulting extrapolated maximum concentration would be **~81 ppm**. Furthermore, we estimate that typical weekday traffic-peak concentrations in 2008 are approximately **36 - 58 ppm**.

Duration of exposure

The posted speed limit in the tunnel is 80 km/h. Travelling at this speed a vehicle should remain inside the tunnel for 20 seconds. However, southbound traffic can become congested, and may slow below the speed limit due to the traffic signals shortly beyond the southern portal, whereas northbound traffic may still be accelerating upon entering the tunnel, hence actual speeds in the tunnel can be much lower than 80 km/h, and hence exposure times can be longer. At an average 30 km/h the journey time is 55 seconds, i.e. exposure durations are well below the 15-minute averaging period applied in most exposure limits, including the interim CO standard.

Comparison with guidelines

Our estimates indicate that the Interim NZTA Guideline for CO for all non-occupational users is probably not being exceeded on a typical day in the tunnel. However, given the inherent uncertainty in our estimated peak concentration of 81 ppm, there appears to be a significant risk that this standard is exceeded on some occasions.

It also seems likely that the short-term occupation limit (200 ppm over 15 minutes) is not being exceeded in normal operation; however there remains a risk that it could be exceeded during ventilation failure, or in the case of blockages or accidents. It appears likely that the 8 hour occupational limit of 30 ppm is being regularly exceeded.

4.2.2 Nitrogen dioxide

Historic observations of NO_2 in the Terrace tunnel

To date there have been no measurements of NO_2, NO or NO_x in the Terrace tunnel.

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[19] Based on output from the ARC's Vehicle Emissions Prediction Model

Current levels /estimates of NO_2 in the Terrace tunnel

An estimate of current nitrogen dioxide levels is very difficult to make with any degree of certainty, due to both lack of data and a lack of understanding of the determinants of NO_2 in road tunnels in general and the Terrace tunnel in particular.

Comparison with guidelines

There is currently insufficient data to draw conclusions about whether the Terrace tunnel likely complies with the Interim NZTA Guidelines for NO_2.

4.2.3 Fine particulates

Air quality standards for fine particulates apply to exposures of 24 hours and are therefore not relevant for road tunnel interiors.

To date there have been no measurements of fine particulates in the Terrace tunnel.

4.2.4 Visibility

To date there have been no measurements of visibility in the Terrace tunnel.

4.3 External air quality

4.3.1 Nitrogen dioxide

Historical observations of NO_2 near the Terrace tunnel

No continuous ambient air quality monitoring has ever been conducted in areas likely to be affected by the Terrace tunnel.

Current levels/estimates of NO_2 near the Terrace tunnel

There are currently no monitoring data available to make estimate levels of NO_2 in the areas likely to be affected by tunnel emissions (i.e. areas shown in Figure 4.5)

One site alongside SH1N north of the tunnel forms part of NZTA’s National NO_2 diffusion tube network, providing monthly average NO_2 concentrations. However, the concentrations reported are indicative of the impact of the surface sections of SH1N, not the tunnel. Results for 2007 are summarised in Table 4.3.

Table 4.3: Summary of NO_2 concentrations reported from NZTA passive samplers in the vicinity of the Terrace tunnel for 2007.

	Bolton Street
Distance to SH1N (m)	30
Distance to Terrace Tunnel (m)	750
Annual mean NO_2 ($\mu g/m^3$)	16
WHO guideline for annual NO_2 ($\mu g/m^3$)	40

It should be noted that passive samplers (such as diffusion tubes) cannot directly provide an indication of 1-hour peak NO_2 concentrations.

Comparison with guidelines

All estimated annual average NO_2 concentrations reported above are well below the WHO guideline of 40 $\mu g/m^3$. No exceedances of the AQNES for NO_2 have ever been recorded in Wellington city. Compliance in areas near the tunnel portals is unknown.

4.3.2 Particulate matter

No ambient air quality monitoring of particulate matter has ever been conducted in areas likely to be affected by the Terrace tunnel.

4.4 Key air quality issues for future upgrades

4.4.1 In-tunnel compliance monitoring of Terrace tunnel

High historic concentrations, rapid evolution of vehicle technology and the low quality techniques used in previous monitoring means that current compliance cannot be reliably assessed.

The ventilation system of the Terrace tunnel is properly sub-optimal due to the use of longitudinal ventilation in a bi-directional tunnel and the potential for ventilation in the less efficient direction. Due to the current lack of data regarding the relationships between traffic characteristics, air flow and air quality, future compliance, in the case of both the current ventilation regime and any alternative upgraded system, cannot currently be assessed.

Consequently, a campaign of high quality CO measurements, supported by simultaneous, detailed and continuous monitoring of traffic flow, speed and composition and air flow is recommended as a first priority. An interim objective should be to evaluate or adjust a tunnel-specific emission model for prediction of future ventilation demand.

4.4.2 Ambient air quality monitoring near Terrace tunnel

There is no existing information on the impact of emissions from the Terrace tunnel portals on the surrounding communities.

We recommend that the effect of portal emissions is assessed via a screening monitoring campaign based on a network of NO_2 diffusion tubes as exposure-relevant sites around the portals (e.g. Ghuznee Street, Macdonald Crescent, The Terrace). If screening reveals problematic “hot-spots” then more detailed monitoring may be necessary to determine the likelihood of AQNES exceedance.

5. Lyttelton tunnel

5.1 Tunnel metadata

5.1.1 Tunnel purpose and location

The Lyttelton tunnel was opened in 1964 to connect the town and port of Lyttelton with Christchurch and the rest of the national State Highway network. It passes through the Port Hills and forms part of SH74 as shown in Figure 5.1.

Figure 5.1: Location of the Lyttelton tunnel.

The Lyttelton tunnel is open to all vehicular traffic (except certain classes of dangerous goods). A separate rail tunnel of 2595m, which was opened in 1867, also links the port with Christchurch city (see Figure 5.2).

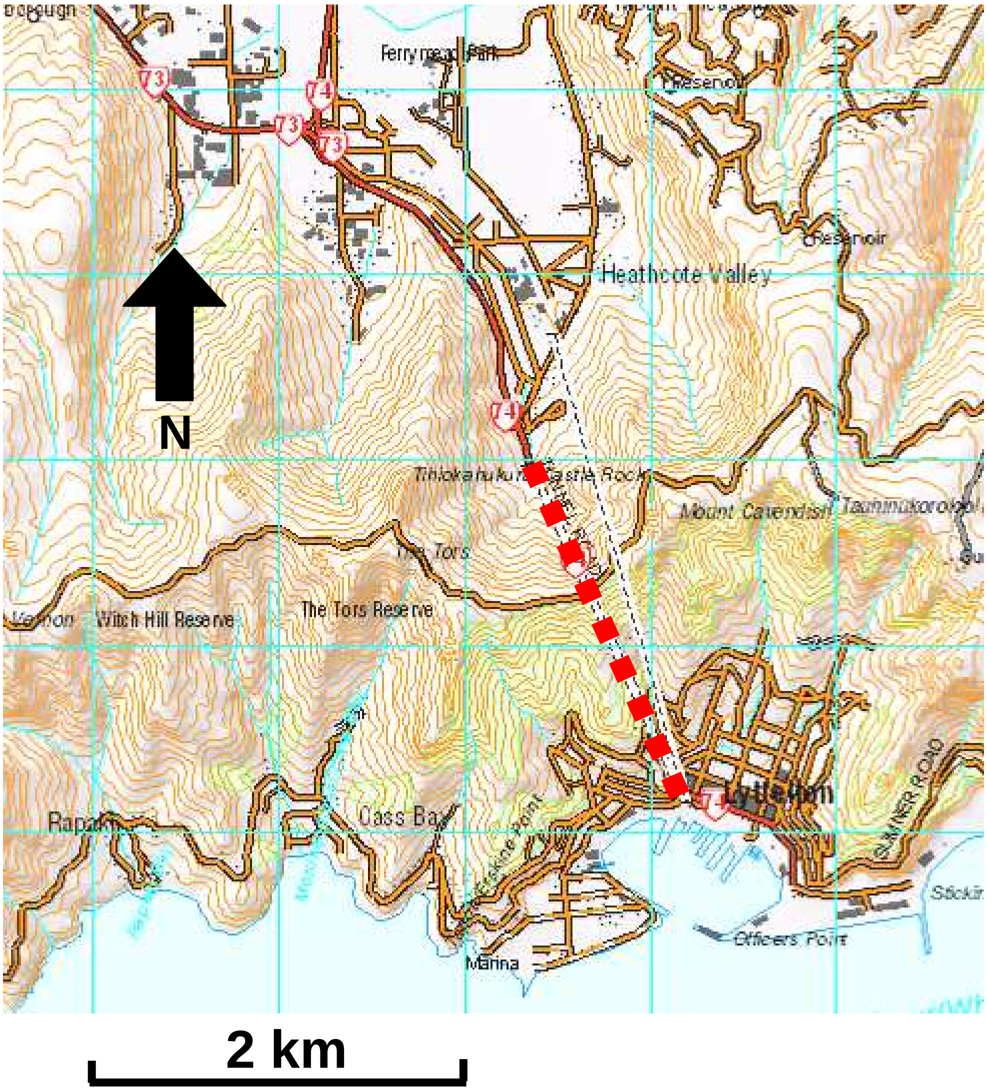


Figure 5.2: Map of the Lyttelton road tunnel (red squares) and rail tunnel (dashed line).

5.1.2 Geometry and ventilation

The tunnel is a single semi-circular bi-directional tube, approximately 4.3 m in radius, and 1945 m long, with a 1:15 (uphill northbound) gradient. It has one lane of traffic each way.

The ventilation system is transverse. The intake and exhaust ducts are located parallel to each other in the ceiling space above the roadway. The tunnel is ventilated in two halves with bulkhead doors at the tunnel mid-point. Each half has an intake fan and an exhaust fan adjacent to each other at each end, as shown in Figure 5.3. Each fan is controlled independently by an operator at the tunnel control room. Intake air is pushed into the tunnel bore at 25 feet intervals through slots in the tunnel walls, entering the tunnel at road level. Exhaust air is drawn into the exhaust duct through slots in the ceiling. It is vented through stacks at both ends.

Figure 5.3: Christchurch end of the Lyttelton tunnel. The screens stand in front of the intake (left) and exhaust (right) fans, with the exhaust stack visible top right of centre.

The Lyttelton tunnel ventilation system was designed for a maximum CO limit of 55 ppm. Mechanical ventilation system is operated manually with CO concentrations from two points in the tunnel constantly fed back to the controller. Operations staff have informed us that CO reported by this system rarely exceeds 20 ppm.

5.1.3 Traffic flow and fleet composition

Annual average daily traffic (AADT) for the Lyttelton tunnel in 2008 was 10,772 vehicles per day, with the proportion of heavy duty vehicles (HDVs) at 12.8% which is high due to the tunnel being the key road freight link to the port.

The hourly weekday traffic counts in Figure 5.4 show typical peaks for morning and evening commuter traffic but are still relatively high throughout the day. The weekend flows are also high but maintain a more constant level for the middle of the day. The number of HDVs is much higher on a typical weekday compared to typical weekend day.

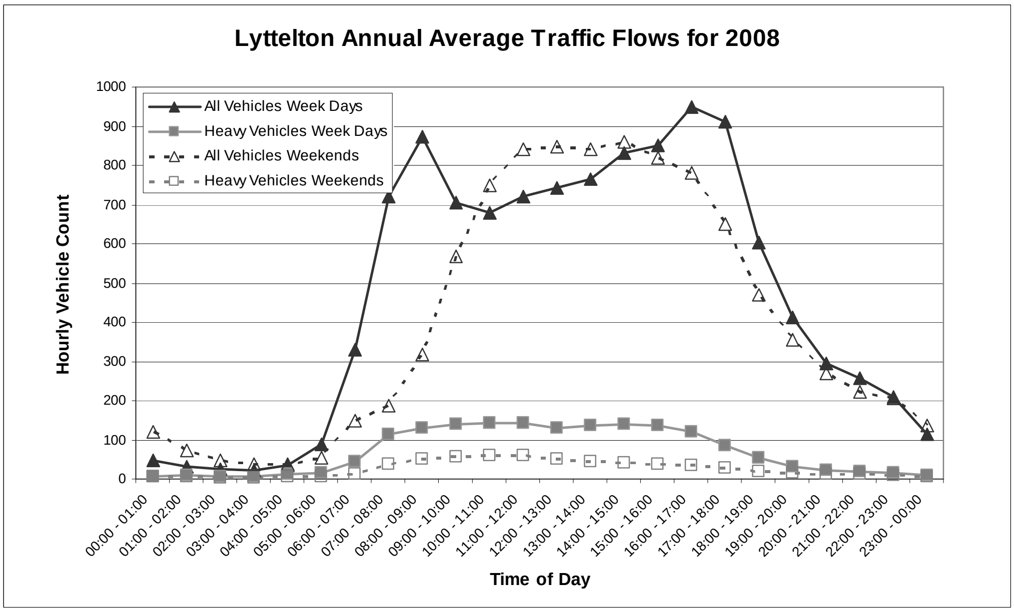


Figure 5.4: Annual average daily traffic (AADT) flow for the Lyttelton tunnel in 2008.

The annual average daily counts for the past five years are shown in Table 5.1.

Table 5.1: Annual average daily traffic in the Lyttelton tunnel for 2004-2008.

Year	2004	2005	2006	2007	2008
Counts	9,489	9,799	10,558	10,881	10,772
Change	---	+3.2%	+7.7%	+3.1%	-1.0%

The posted speed limit is 50 km/h and congestion does not occur except in exceptional circumstances.

5.1.4 Tunnel monitoring

The nearest traffic monitoring site is a dual loop in the tunnel portal at Heathcote (NZTA ref.07409023) which measures traffic flow for each direction and is able to provide speed and heavy duty vehicle splits.

There are carbon monoxide sensors installed in the Lyttelton tunnel as part of the ventilation control system. These are Draeger electrochemical sensors, with sensors located in both the northern and southern halves of the tunnel. These sensors provide online "live" data to the tunnel operator but are not logged.

5.1.5 Receiving environment

Figures 5.5 and 5.6 show the location of the tunnel portals relative to other features in the area. There are no residences or sensitive receptors at the northern portal of the tunnel and it seems reasonable to assume that the tunnel poses no external air quality exposure risk at this end.

The southern portal and stack are located at approx. 28 m above sea level. The Port Hills rise up to approximately 500 m. There are tens of homes within 200 m north and west of the stack at altitudes above 50 m (approximately 10 homes within 80 m distance), and to the east of the stack at altitudes comparable to the tunnel portal. It is possible that these homes (especially those to the west and north of the stack) may be impacted by stack emissions, but there are currently no data to confirm or quantify this.

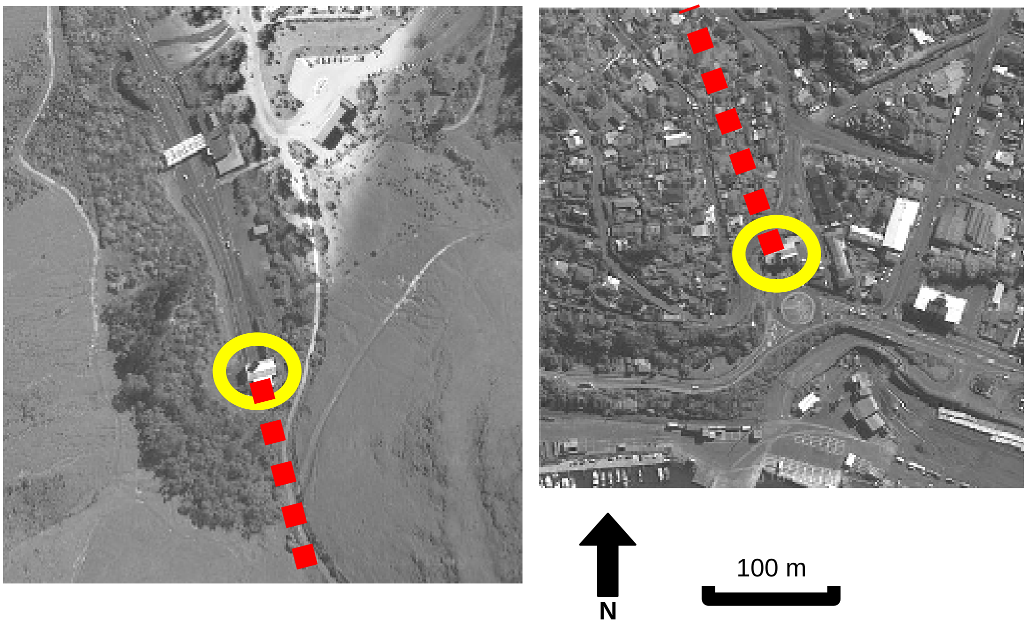


Figure 5.5: Detailed location of the Lyttelton tunnel portals and stacks (in yellow circles). Northern portal shown left, southern portal shown right.

Figure 5.6: View of the southern portal of the Lyttelton tunnel showing the stack, looking north-east. The homes in the middle distance are approximately 100 m away.

5.1.6 Meteorological conditions

The nearest permanent meteorological station to the Lyttleton tunnel is at Lyttelton itself.

Data from this site, presented in Figure 5.7, indicate a predominance of winds from the WSW and ENE directions. However, given the topography of the surrounding area in general and the influence of the Port Hills in particular, it is difficult to say whether these would be the prevailing wind directions for the tunnel.

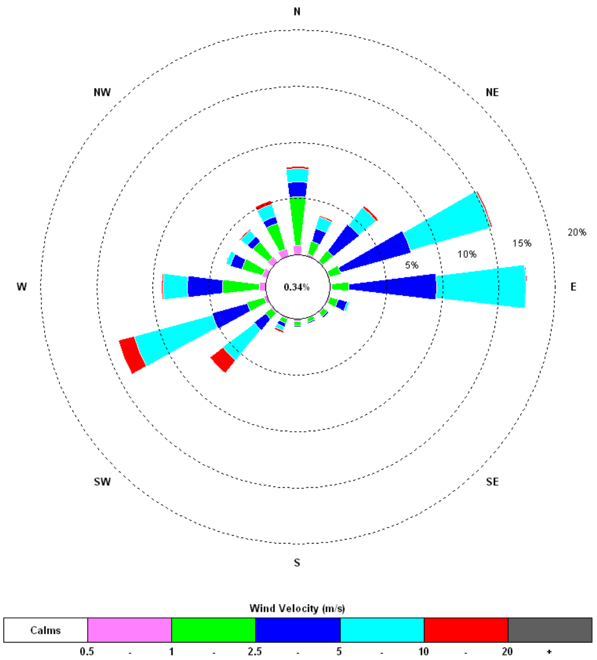


Figure 5.7: Wind rose based upon hourly data from Lyttelton (January 2005 to December 2009 inclusive).

5.2 In-tunnel air quality

5.2.1 Carbon monoxide

Historic observations of CO in the Lyttelton tunnel

The Lyttelton tunnel has permanent monitoring of levels of CO at two locations in the tunnel. The tunnel ventilation is operated so that CO concentrations do not exceed 55 ppm. The data from these sensors are not recorded.

We are not aware of any other historical observations of CO in the Lyttelton tunnel.

Current levels/estimates of CO in the Lyttelton tunnel

Brief observations of CO have twice recently been gathered by NIWA in the Lyttelton tunnel using a car-based drive-through system, as described in Appendix 2. These data must be considered to provide a screening assessment as they represent a “snapshot” of conditions on two days. A summary is presented in Table 5.2.

Table 5.2: Comparison of 1-second average CO concentrations observed per transit through the Lyttelton tunnel.

	September 2008	February 2009
Mean CO (ppm)	11	10
Maximum CO (ppm)	16	15

Duration of exposure

The posted speed limit in the tunnel is 50 km/h. Travelling at this speed a vehicle should remain inside the tunnel for 2 minutes and 20 seconds (i.e. 140 seconds). In NIWA's drive-through surveys, tunnel transits lasted between 120 and 150 seconds. Congestion is not expected on a regular basis. Exposure durations are therefore expected to be well below the 15-minute averaging period applied in most exposure limits, including the CO minimum guideline recommended by NIWA for use in road tunnels.

Comparison with guidelines

The operating principles of the ventilation system ensure that the NZTA Interim Guidelines for CO are not exceeded.

NIWA's brief observations of CO concentrations indicate that the standard is unlikely to be breached in normal operation.

5.2.2 Nitrogen dioxide

Historic observations of NO_2 in the Lyttelton tunnel

There are no published data reporting air quality within the Lyttelton tunnel.

Current levels/estimates of NO_2 in the Lyttelton tunnel

Brief observations of NO_2 have recently been gathered in the Lyttelton tunnel using a car-based drive-through system, as described in Appendix 2. These data must be considered to provide a screening assessment as they represent a “snapshot” of conditions on two days.

Comparison with guidelines

NIWA’s very brief observations indicate that NO_2 concentrations were far below the 1 ppm level adopted as Interim NZTA Guidelines for NO_2.

5.2.3 Fine particulates

Historic observations of fine particulates in the Lyttelton tunnel

There are no published data reporting air quality within the Lyttelton tunnel.

Current levels/estimates of fine particulates in the Lyttelton tunnel

NIWA has briefly recorded measurements of particulate matter during a single passage through the tunnel as part of an unrelated project. A PM_{10} concentration of 240 $\mu g/m^3$ was recorded using a non-A/NZS-compliant instrument mounted in an enclosure on the vehicle roof.

Anecdotal evidence from Christchurch and Lyttleton residents suggests that trucks which frequently carry bulk materials (e.g. fertiliser or gypsum) through the tunnel generate considerable amounts of dust. A black coating visible on the tunnel walls attests to the high level of particulate emissions within the tunnel. These observations suggest that dust emissions (including fugitive emissions from truck loads) and smoke from tailpipes of northbound vehicles may be a potentially significant air quality and visibility issue for the tunnel.

Comparison with guidelines

Air quality standards for fine particulates apply to exposures of 24 hours and are therefore not relevant for road tunnel interiors.

5.2.4 Visibility

To date there have been no measurements of visibility in the Lyttelton tunnel.

5.3 External air quality

5.3.1 Nitrogen dioxide

Historic observations of NO_2 near the Lyttelton tunnel

No continuous ambient air quality monitoring has ever been conducted in areas likely to be affected by the tunnel.

Current levels/estimates of NO_2 near the Lyttelton tunnel

Two sites alongside SH74, at either end of the tunnel, form part of NZTA's National NO_2 diffusion tube network providing monthly average NO_2 concentrations. Concentrations have been reported at Heathvale Place near the northern portal and at Hawkhurst Road in Lyttelton since September 2007. Results for the first full year of deployment are summarised in Table 5.3.

Table 5.3: Summary of NO_2 concentrations reported from NZTA passive samplers in the vicinity of the Lyttelton tunnel for the first full year of deployment (September 2007 to August 2008 inclusive).

	Heathvale Place (north end)	Hawkhurst Road (south end)
Distance to SH74 (m)	100	80
Distance to portal and exhaust stack (m)	100	350
Annual mean NO_2 (µg/m^3)	10	14
WHO guideline for annual NO_2 (µg/m^3)	40	

It should be noted that passive samplers (such as diffusion tubes) cannot provide an indication of 1-hour peak NO_2 concentrations.

Comparison with guidelines

All estimated annual average NO_2 concentrations reported above are well below the WHO guideline of 40 µg/m^3. No exceedances of the AQNES for NO_2 have been recorded in Canterbury since 1997.

5.3.2 Particulate matter

No ambient air quality monitoring of particulate matter has ever been conducted in areas likely to be affected by the Lyttelton tunnel.

5.4 Key air quality issues for future upgrades

5.4.1 External assessment of Lyttelton tunnel stacks

The impact of the tunnel stacks on the town of Lyttelton is currently unknown.

We recommend a screening assessment using a network of NO_2 diffusion tubes distributed around the residential streets in an arc up to 200 m distant from the stack.

5.4.2 In-tunnel compliance monitoring of Lyttelton tunnel

The Lyttelton tunnel has a permanent in-tunnel monitoring system for CO. Although it is subject to a routine maintenance schedule, it is based on an electrochemical technology that we consider to offer relatively low quality.

We recommend that the performance of this system is benchmarked against a higher quality technology during an in-situ monitoring campaign.

Due to the current lack of data regarding the relationships between traffic characteristics, air flow and air quality, future compliance, in the case of both the current ventilation regime and any alternative upgraded system, cannot currently be assessed.

Consequently, a campaign of high quality CO measurements, supported by simultaneous, detailed and continuous monitoring of traffic flow, speed and composition and air flow is recommended as a first priority. An interim objective should be to evaluate or adjust a tunnel-specific emission model for prediction of future ventilation demand.

5.4.3 Visibility monitoring in Lyttelton tunnel

The Interim NZTA Guidelines for visibility are potentially more challenging for the Lyttelton tunnel compared to others due to the higher proportion of heavy duty (diesel) vehicles. Due to current trends in vehicle emissions with a faster rate of reductions in CO emissions relative to PM emissions, it is possible that increasing levels of PM (and visibility reduction) may be permitted for the same level of CO. Thus the Interim NZTA Guidelines for CO could become increasingly more permissive in terms of visibility reduction. However, there are currently no data to support this hypothesis.

We recommend a detailed observational campaign to address these risks. This campaign should be designed so as to inform the potential impacts of increased use of diesel vehicles in all NZTA-operated road tunnels. A key component is detailed capture of vehicle volume and speed information, and especially vehicle class, as the proportion and operating parameters of the variety of goods vehicles in this tunnel are likely to be major determinants of in-tunnel air quality.

6. Homer tunnel

6.1 Tunnel metadata

6.1.1 Tunnel purpose and location

The Homer tunnel was opened in 1953 as the sole road providing access to Milford Sound in Southland. It forms part of SH94 as shown in Figures 6.1 and 6.2.

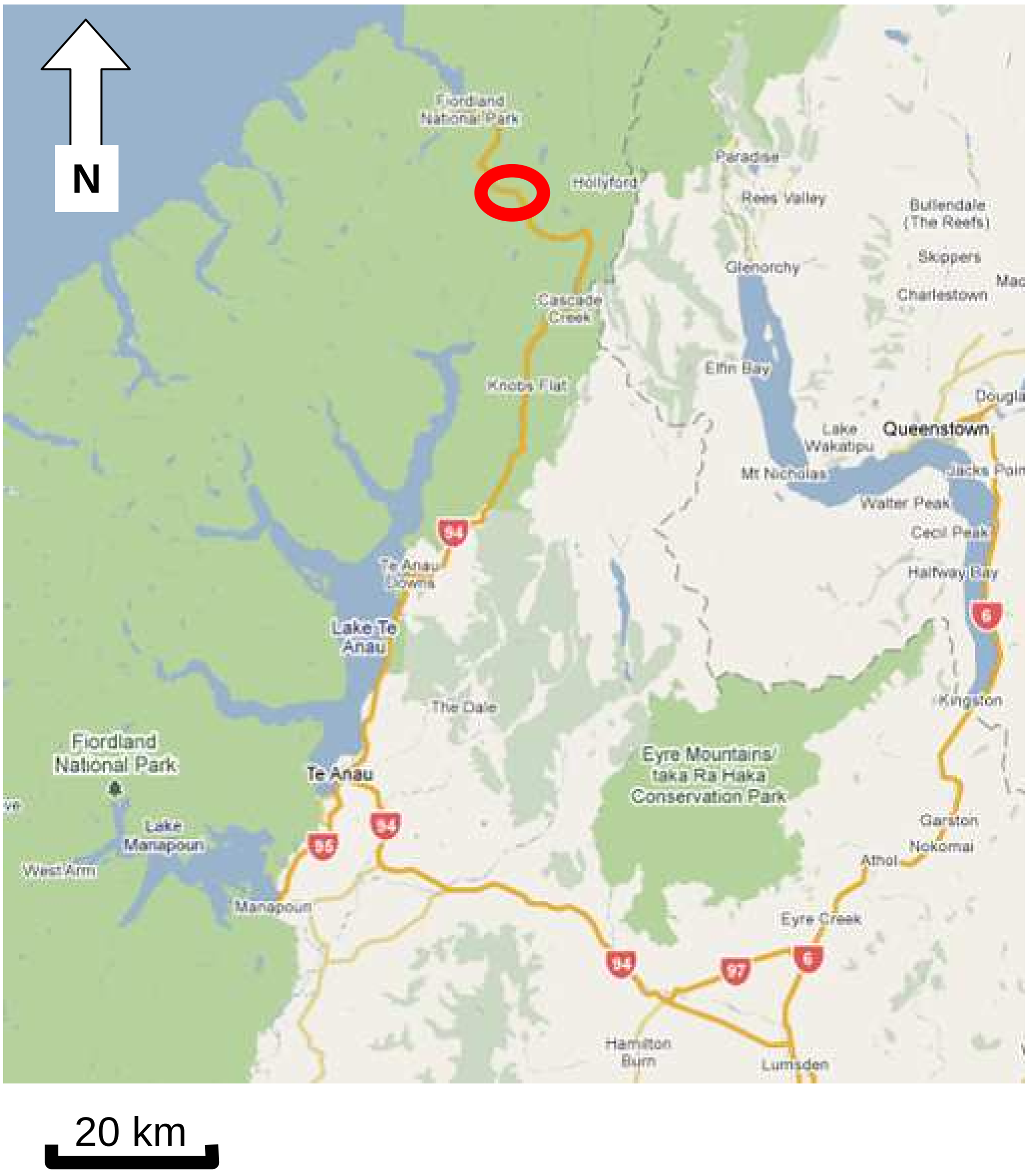


Figure 6.1: Location of the Homer tunnel (red circle) on SH94 to Milford Sound.

The Homer tunnel is open to all vehicular traffic (except dangerous goods) and carries a high proportion of tourist buses, especially during the summer months.

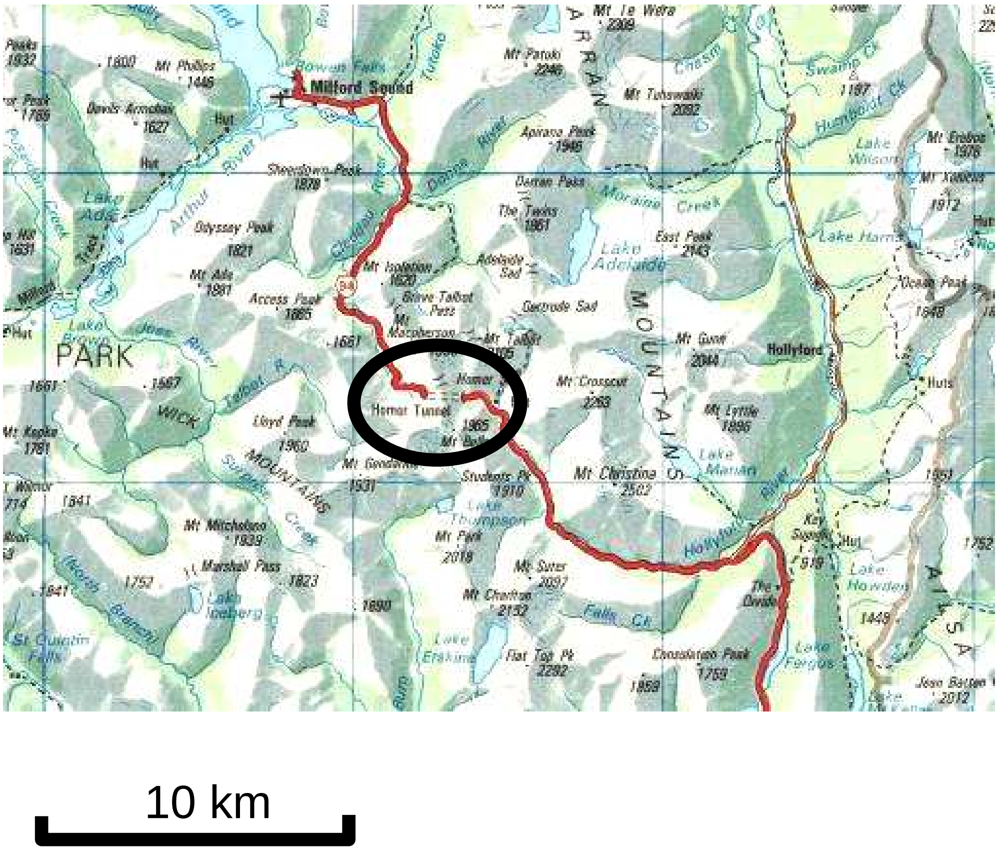


Figure 6.2: The location of the Homer tunnel (centre).

6.1.2 Geometry and ventilation

The tunnel is 1270 m long and is a single semi-circular bi-directional tube with a minimum height of 3.8 m and a minimum width of 6.0 m (see Figures 6.3, 6.4 and 6.5). The tunnel is at an altitude of 850 m (west portal) to 1040 m (east portal) creating a 1:10 gradient. Although bi-directional, the tunnel is only wide enough for a single lane with two 50 m passing bays. During May to October, when there is an avalanche risk and traffic volumes are low, tunnel access is uncontrolled. Outside this season, traffic flow is controlled by traffic signals in nominally 20 minute phases between the hours of 9am to 6pm (Figure 6.6).

The tunnel has no mechanical ventilation. The eastbound direction (which is busier in the afternoon) is uphill and is expected to lead to greater emissions in the tunnel. Maintenance staff do not undertake any general work in the tunnel after about 11am due to the fume build up in the eastern end of the tunnel. Work is programmed with early starts (4am to 5am) to ensure that the tunnel atmosphere is clear.

Figure 6.3: Milford Sound (western) end of the Homer tunnel.

Figure 6.4: Homer tunnel at the Te Anau (eastern) portal.

Figure 6.5: Homer tunnel interior view.

Figure 6.6: Typical summer traffic queue at the Te Anau end of the Homer tunnel.

6.1.3 Traffic flow and fleet composition

Annual average daily traffic (AADT) for the Homer tunnel in 2008 was 571 vehicles per day, with the proportion of heavy duty vehicles (HDVs) at 16.8% which is high due to the tunnel being the only tourist link to Milford Sound.

The hourly weekday traffic counts in Figure 6.7 show traffic building in the morning and remaining high between 11am and 6pm before dropping off. There is very little difference between weekday and weekend traffic volumes due to Milford Sound being a tourist rather than a commuter destination. As expected the proportion of HDVs, most likely buses rather than trucks, is high for all days.

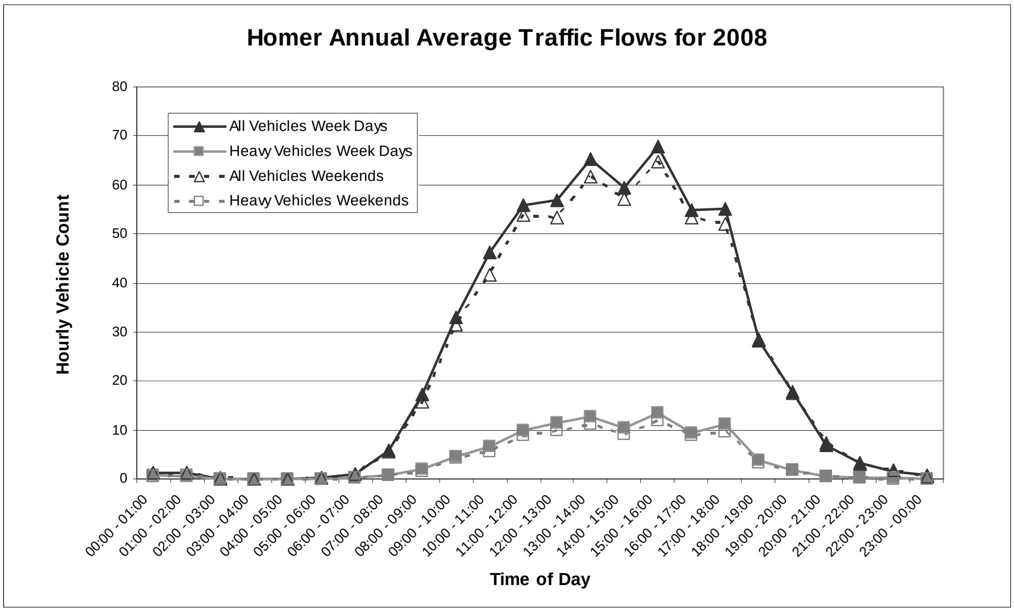


Figure 6.7: Annual average daily traffic (AADT) flow for the Homer tunnel in 2008.

In addition to a strong diurnal pattern in the traffic, there is also a strong seasonal pattern. Figure 6.8 shows traffic peaking at approximately 1500 vehicles per day in summer but reducing to only 200 vehicles per day in winter.

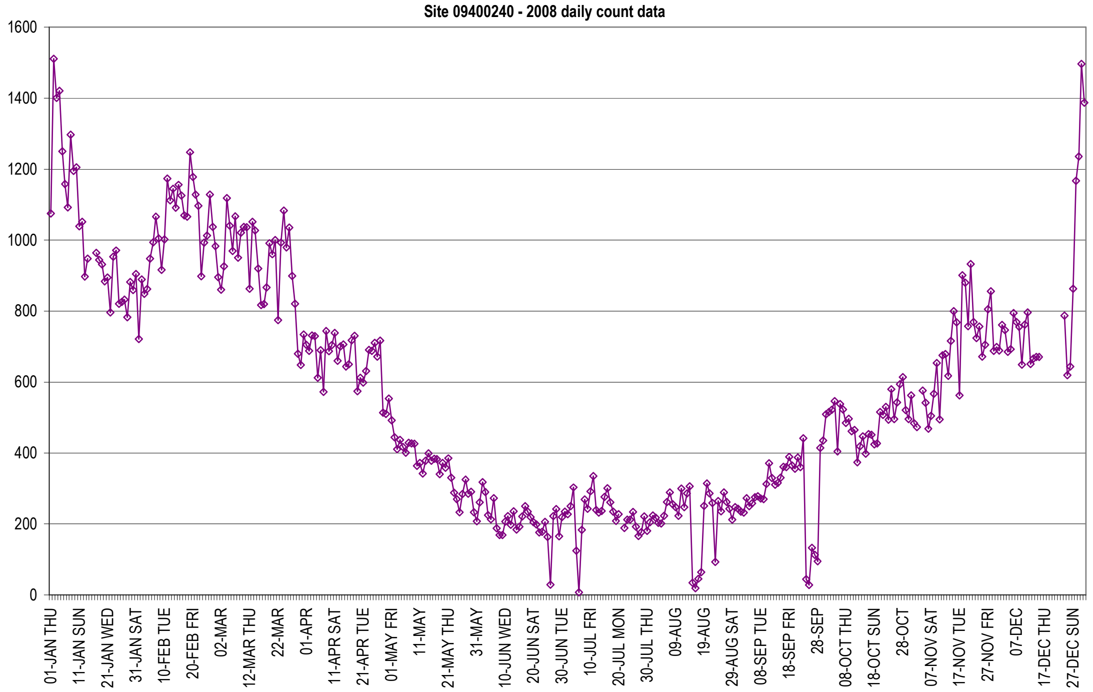


Figure 6.8: 2008 daily traffic counts for Homer tunnel showing marked seasonality.

The traffic volume has varied between 400 and 700 over the last few years, with annual average daily counts for the past two years shown in Table 6.1. In November 2007, a permanent continuous traffic counter was established for the tunnel and information relating to traffic flow is considered more reliable form this time.

Table 6.1: Annual average daily traffic in the Homer tunnel for 2007-2008.

Year	2007	2008
Counts	600	571
Change	---	-4.8%

The posted speed limit is theoretically 100 km/h but the restricted size of the tunnel and the severe gradient constrain the speed to a more realistic 70 km/h.

6.1.4 Tunnel monitoring

The nearest traffic monitoring site is a dual loop about 565m before the tunnel (NZTA ref.09400240) which measures traffic flow in each direction and is able to provide speed and heavy duty vehicle splits.

There are no sensors in the Homer tunnel.

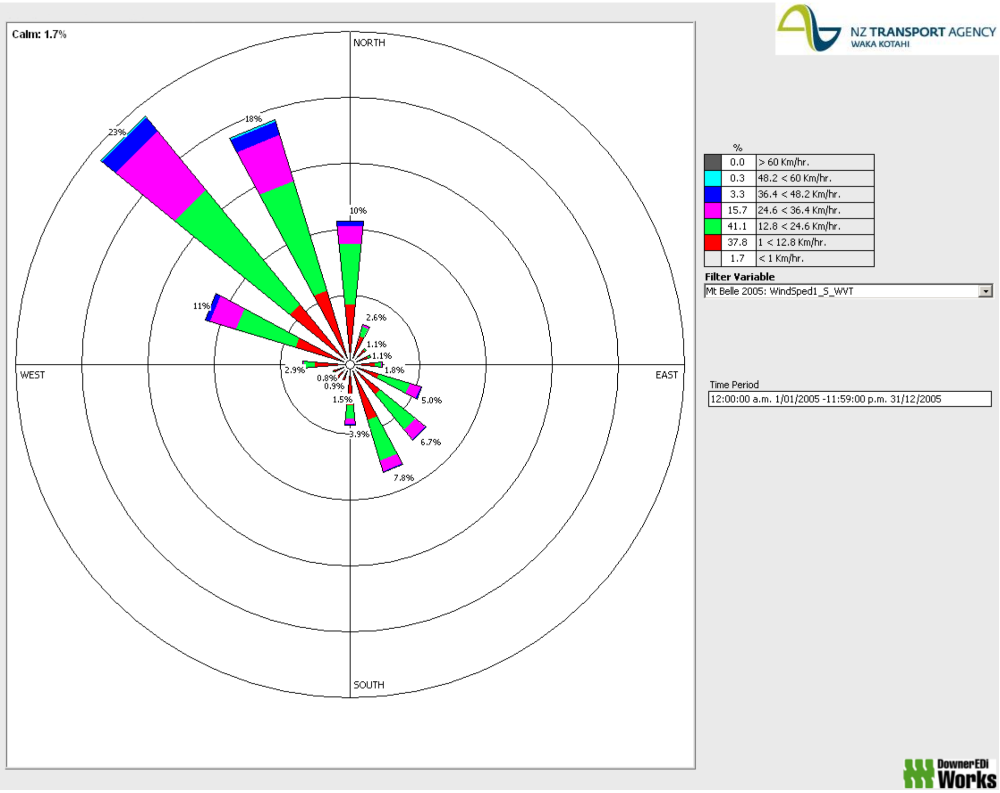
6.1.5 Receiving environment

The Homer tunnel is in an entirely rural location with no human receptors in its vicinity. It is located within the Fiordland National Park and alpine flora and fauna are evident around the tunnel.

6.1.6 Meteorological conditions

The nearest meteorological station is at Mount Belle. This station is part of an avalanche monitoring network operated for the NZTA.

Figure 6.9 shows a typical wind rose for the Homer tunnel area, showing a strong predominance of north-westerly winds.



	%	
⬛	0.0	> 60 Km/hr.
🟦	0.3	48.2 < 60 Km/hr.
🟦	3.3	36.4 < 48.2 Km/hr.
🟪	15.7	24.6 < 36.4 Km/hr.
🟩	41.1	12.8 < 24.6 Km/hr.
🟥	37.8	1 < 12.8 Km/hr.
⬜	1.7	< 1 Km/hr.

Filter Variable
Mt Belle 2005: WindSped1_S_WVT

Time Period
12:00:00 a.m. 1/01/2005 -11:59:00 p.m. 31/12/2005

Figure 6.9: Wind rose based upon hourly data from Mt Belle (January to December 2005 inclusive).

6.2 In-tunnel air quality

6.2.1 Carbon monoxide

Historic observations of CO in the Homer tunnel

We are not aware of any historical observations of CO in the Homer tunnel.

Current levels/estimates of CO in the Homer tunnel

Brief observations of CO have twice recently been gathered in the Homer tunnel by NIWA using a car-based drive-through system. Details are provided in Appendix 3. These data must be considered to provide a screening assessment as they represent a "snapshot" of conditions on two days. A summary of the results is presented in Table 6.2.

Table 6.2: Comparison of 1-second average carbon monoxide concentrations observed per transit through the Homer tunnel

	September 2008	February 2009
Mean CO (ppm)	1.2	3.1
Maximum CO (ppm)	4.2	10.2
Daily traffic volume on days of observation	365	1006, 1023

Concentrations (and traffic volumes) were generally 2 to 3 times higher in February compared to September, which is consistent with the seasonality in traffic counts shown previously in Figure 6.8.

Duration of exposure

At a typical speed of 30 km/h a vehicle should remain inside the tunnel for approximately 2½ minutes (i.e. 150 seconds). Extended durations can occur with slow-moving large vehicles. Also, during bi-directional operation, vehicles may find themselves unable to pass in the tunnel leading to one having to reverse. This manoeuvre can considerably extend the time a vehicle spends in the tunnel in a way that is unpredictable. Exposures of vehicle users can be extended when vehicles progress in convoys. In this situation users can be exposed to vehicle emissions from the vehicle in front in queues to enter the tunnel and after exit from the tunnel.

Comparison with guidelines

During NIWA's brief observations, CO concentrations were far below the Interim NZTA Guidelines.

6.2.2 Nitrogen dioxide

Historic observations of NO_2 in the Homer tunnel

We are not aware of any historical observations of NO_2 in the Homer tunnel.

Current levels/estimates of NO_2 in the Homer tunnel

Atmospheric nitrogen chemistry is complex and NO_2 concentrations can be hard to predict in road tunnels (see section 2.2.2). This is especially true in the Homer tunnel due to its unknown and presumably quite variable (natural) ventilation, lack of data on ambient ozone levels, and a lack of any understanding of NO emissions and ozone penetration inside the tunnel. Consequently, we are currently unable to speculate on NO_2 levels in the tunnel.

6.2.3 Fine particulates

Historic observations of fine particulates in the Homer tunnel

We are not aware of any historical observations of fine particulates in the Homer tunnel.

Current levels/estimates of fine particulates in the Homer tunnel

There is no currently available data upon which to base an estimate of current levels of fine particulates in the Homer tunnel.

Comparison with guidelines

Air quality standards for fine particulates apply to exposures of 24 hours and are therefore not relevant for road tunnel interiors.

6.2.4 Visibility

We are not aware of any historical observations of visibility in the Homer tunnel.

6.3 External air quality

Historic observations

No external measurements of air quality around the Homer tunnel have previously been conducted.

Current levels/estimates

Due to its rural, highland location, air quality is not considered to be an issue requiring monitoring near the Homer tunnel. We would expect minimal concentrations of all relevant pollutants.

6.4 Key air quality issues for future upgrades

6.4.1 Establishing the key air quality determinants in Homer tunnel

Screening assessments conducted by NIWA appear to indicate low levels of CO with respect to the Interim NZTA Guidelines. However, we recommend that these observations are updated using A/NZS-compliant instruments and techniques.

Due to the highly seasonal nature of traffic, observations of air quality in the Homer tunnel need to be undertaken at least during peak traffic periods (i.e. peak summer), although we also recommend limited monitoring throughout the year to verify that summer conditions lead to peak concentrations.

With no mechanical ventilation it is probable that in-tunnel air quality is more sensitive to external winds (and their penetration into the tunnel) and the details of individual vehicle movements and emission characteristics than other tunnels.

Thus, measurement of external and in-tunnel winds, traffic flow and vehicle fleet composition are particularly important in the Homer tunnel.

6.4.2 Factors influencing nitrogen dioxide formation in Homer tunnel

Were the Interim NZTA Design Guidelines for NO_2 to be applied to a future ventilation system for the Homer Tunnel it would be important to take into account the potential role of elevated ozone in the ambient atmosphere. Ozone levels are typically elevated in rural areas relative to urban areas and this could lead to increased potential for formation of NO_2 inside the tunnel from oxidation of NO emissions. This potential is further enhanced by the relatively low traffic volumes and higher than average proportion of diesel vehicles.

7. Johnstone's Hill tunnels

7.1 Tunnel metadata

7.1.1 Tunnel purpose and location

The Johnstone's Hill twin tunnels were opened in January 2009 to improve travel times on SH1 north of Auckland, The tunnels bypass the seaside townships of Orewa, Hatfield's Beach, Waiwera, and the Wenderholm Regional Park (see Figures 7.1.and 7.2) and reduce travel times by between 10 and 30 minutes. The section of SH1N between the Orewa turnoff and Puhoi is a toll road but vehicles are able to travel free by using the old coastal route (SH17).

Figure 7.1: Location of the Johnstone's Hill tunnels.

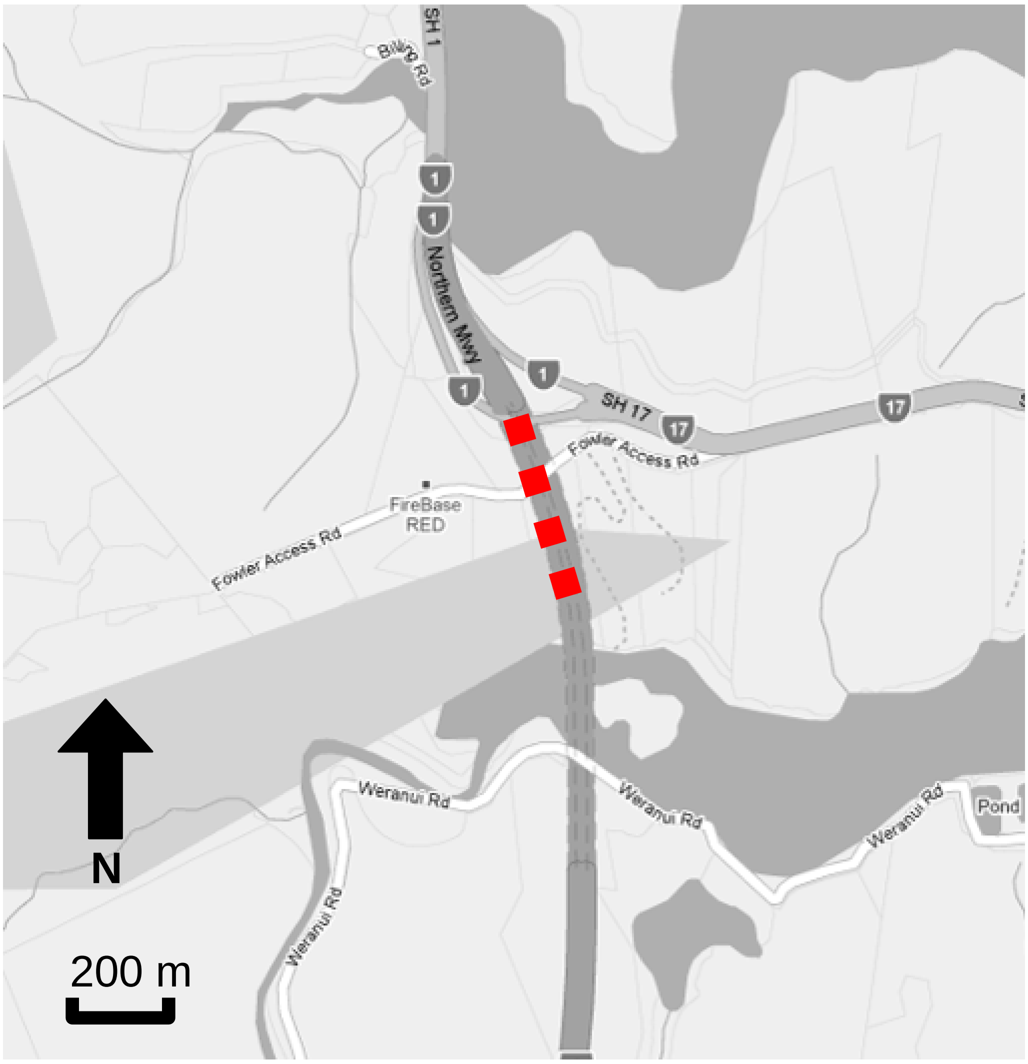


Figure 7.2: Road map of the Johnstone's Hill tunnels.

The Johnstone's Hill tunnels are open to all vehicular traffic.

7.1.2 Geometry and ventilation

The tunnels are two identical semi-circular uni-directional tubes, approximately 12 m wide, 9 m high and 380 m long, with a 1:100 gradient from each portal to the tunnel midpoint. The tunnels are 15 metres apart (see Figure 7.3) and are both built to carry two lanes each, plus a shoulder and an emergency pathway. The northbound tunnel has only one lane open due to the merging of the traffic into a single lane after the tunnel. The southbound lane has two lanes open.

Figure 7.3: View of the Johnstone's Hill twin tunnels from the northern end.

Each tunnel has longitudinal ventilation, with each tunnel running three banks of paired jet fans. The fans are triggered when CO levels reach 30 ppm.

7.1.3 Traffic flow and fleet composition

Based on the traffic volumes for the ten months (late January to late November 2009) the annual average daily traffic (AADT) for the Johnstone's Hill tunnels in 2009 is estimated to be approximately 12,742 vehicles per day, with the proportion of heavy duty vehicles (HDVs) at 10.2%.

The hourly weekday traffic counts in Figure 7.4 suggest some influence of commuter travel with broad peaks in the morning and in the evening. However, the hourly counts are significantly higher for the weekend days when drivers use the road to travel to and from holiday or day trip destinations in the northern part of the Auckland region and Northland. The proportion of HDVs on weekend days is much lower than on weekdays.

The posted speed limit is 80 km/h.

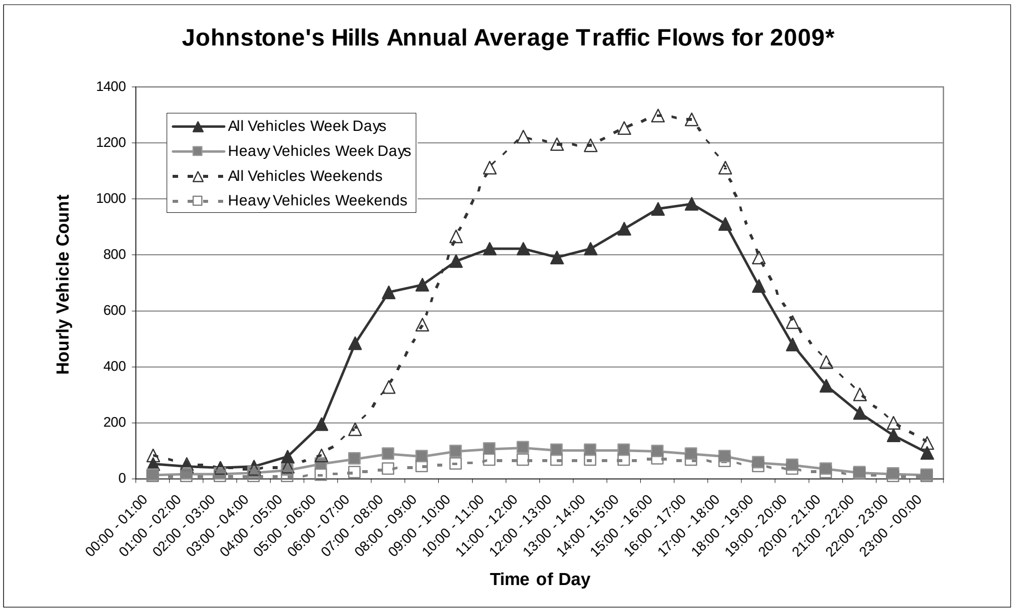


Figure 7.4: Estimated annual average daily traffic (AADT) flow for the Johnstone's Hill tunnels in 2009 (* for 10 months only).

7.1.4 Tunnel monitoring

The nearest traffic monitoring devices are four over height detectors which have traffic loops connected to the system. Southbound, the first (OHD101) is just after the toll machines turnaround and the second (OHD102) is just after the Waiwera turnoff but before the road splits into two lanes. Northbound, the first (OHD202) is on the SH1 motorway before the Grand Dr Exit (392) and the second (OHD201) is at the start of the Waiwera Viaduct just before the traffic merges into one lane.

Unfortunately, none of these sites is likely to be representative of the traffic flow behaviour in the tunnel. Going south as the road widens to two lanes, traffic will tend to accelerate on approach and through the tunnel so the OHD102 readings will be lower than the traffic speed through the tunnel. Conversely, northbound traffic will tend to slow down going across the Waiwera viaduct as it merges into one lane meaning the northbound tunnel speeds will be lower than recorded on OHD201.

Because the tunnels are toll roads, video surveillance is in place to record licence plates of vehicles using the tunnels. The images are captured and stored, and therefore could be interrogated to get more detailed fleet information.

In-tunnel sensors are installed as part of the ventilation control system. A Vicotec 412 CO sensor and a Flowsic 200 air flow sensor are located approximately 35 m from the exit of each tunnel. The CO sensor measures concentrations in the tunnel using an infrared beam and the flow sensor uses ultrasonic technology to establish the air velocity. These sensors provide online "live" data to the tunnel operator but are not continuously logged. At any time a three month running record is available but this is updated and over-written each day.

7.1.5 Receiving environment

The tunnels are in a rural setting with very few human receptors nearby. There is a property adjacent to SH1 ~500 m north of the northern portal and scattered properties on Fowler Access Road which follows the ridge of Johnstone's Hill (see Figure 7.2).

7.1.6 Meteorological conditions

The nearest meteorological site is the Warkworth EWS[20] located at the Satellite Station approximately 11.5 km north of the tunnels (36.43435°S, 174.66766°E).

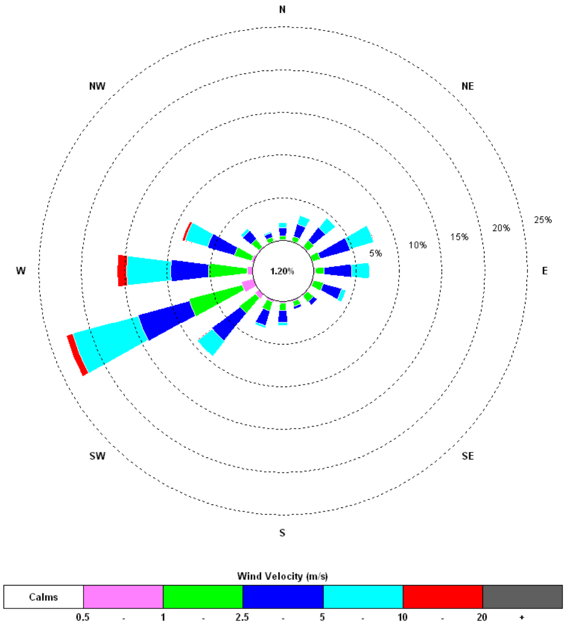


Figure 7.5: Wind rose based upon hourly data from Warkworth EWS (January 2003 to December 2009 inclusive).

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[20] Electronic Weather Station

However, the wind is measured at the top of a transmission tower 32 m above ground level and therefore the predominant directions shown in Figure 7.5 may not be representative of the winds experienced at the tunnels.

7.2 In-tunnel air quality

To date there have been no reported measurements of air quality or visibility in or near the Johnstone's Hill tunnels.

An investigation of the running record for the tunnel sensors shows that maximum CO concentrations in the southbound tunnel are around 16.5 ppm and around 7.2 ppm in the northbound tunnel.

7.3 External air quality

To date there have been no reported measurements of air quality in or near the Johnstone's Hill tunnels.

7.4 Key air quality issues for future upgrades

7.4.1 In-tunnel compliance monitoring of Johnstone's Hill tunnels

There is currently in-tunnel air quality data available for this tunnel. Permanent CO sensors are installed, but there are currently no observations of visibility. The acceptable performance of the CO sensors has not been verified. Therefore the compliance of the tunnel with the Interim NZTA guidelines is unknown. A high quality observational campaign of CO and visibility is recommended.

7.4.2 Traffic monitoring at Johnstone's Hill tunnels

The traffic monitoring currently available does not adequately support an understanding of the performance of the tunnel with regards to air quality. Detailed traffic monitoring should be implemented at the tunnel itself with the capability to capture the nature of changes to volume, fleet and speed during peak periods, and in congested conditions.

8. Discussion and conclusions

8.1 National perspective

8.1.1 In-tunnel air quality with respect to Interim NZTA Guidelines for CO

In-tunnel air quality is traditionally maintained by designing the tunnel ventilation system to maintain concentrations of carbon monoxide below a fixed limit. The limits applied to the Mt Victoria, Terrace and Lyttelton and Johnstone's Hill tunnels are all different, reflecting the state of knowledge regarding this pollutant's effects at the time of design. This means that each tunnel was designed with a different ventilation response to expected emissions, which is no longer necessarily valid. Since their opening, traffic volumes have increased and average emissions per vehicle have decreased. In the Wellington tunnels at least, levels of congestion have increased.

There has been no systematic approach to in-tunnel monitoring to date, with each tunnel being considered in isolation. Our review of available data on in-tunnel air quality revealed that data was generally of a low quality, patchy or unavailable. Low quality monitoring technologies, inconsistent methods and limited duration of monitoring were the main limitations of data from the Wellington tunnels, whereas no robust data were available at all for the Lyttelton and Homer tunnels.

Consequently, as of June 2008, current data are not available to determine whether either the original design guidelines, or the Interim NZTA Guidelines, are met inside the five tunnels. We have estimated current levels of CO in Wellington by extrapolating 2003 data based on recent emission trends, and derived estimates for the Lyttelton and Homer tunnels based on very limited data. We estimate that CO concentrations remain below the recommended Interim NZTA Guidelines most or all of the time in the four older tunnels, with the Terrace tunnel complying by the smallest margin. The relatively poor performance of the shorter Terrace tunnel may be related to the inefficient configuration of the ventilation system. However, given the low quality, coverage and age of most of the data available, we have a relatively low level of confidence in this conclusion.

At the end of this decade we find ourselves in the middle of a period of rapid change in vehicle emissions. Trends in in-tunnel concentrations in the Wellington tunnels support trends observed elsewhere, that improvements in vehicle and fuel technology have led to rapid reductions in the average rate of **per vehicle** emissions of CO and particulates from the New Zealand vehicle fleet. Fleet and emission modelling predict that these reductions will continue, albeit at a reduced rate, for at least a further decade. Whether this leads to reduced concentrations depends on whether it is offset by growth in traffic or increases in congestion. This means that judging the compliance of any tunnel against a guideline requires recent and accurate observational data.

For these reasons we recommend a programme of consistent and inter-comparable high-quality in-tunnel monitoring is conducted in all five tunnels. In order to get the most value for the investment this would require we recommend that monitoring is aimed as much at future as at current compliance. This implies capturing sufficient information about traffic flows (volumes, fleet composition, speed and congestion) to enable determination of emission rates and tracking of emission trends.

8.1.2 In-tunnel air quality with respect to Interim NZTA Design Guidelines for NO_2

Carbon monoxide guidelines for management of in-tunnel air quality have a long history and are well-established worldwide. More recent developments in health research have led to an increasing attention on the effects of an additional pollutant – nitrogen dioxide. This is reflected in the inclusion of a NO_2 guideline in the Interim NZTA Guidelines.

NO_2 and CO do not have the same sources. The sources and processes leading to the presence of high levels of NO_2 in a road tunnel are more complex, requiring the presence of precursor compounds to drive chemical reactions in the tunnel air. The detailed science is not fully understood, but it is well-established that high levels of CO are mostly related to petrol vehicles whilst high levels of NO_2 are related to diesel vehicles. The implications are that CO and NO_2 levels are not necessarily correlated, that changes in the balance between petrol and diesel vehicles in a given tunnel changes the relative importance of the Interim NZTA Guidelines for that tunnel, and that the long-term trends in emissions, concentrations and compliance for CO and NO_2 are different.

Unlike the clear long-term downward trend in vehicular CO emissions, the trends in precursors of NO_2[21] are much less clear. There is some emerging evidence that, in contrast to CO and PM, the trend in NO_2 is upwards. This means that the Interim NZTA Guidelines for NO_2 may become relatively more demanding than the Interim NZTA Guidelines for CO in years to come, especially in tunnels where high or increasing numbers of diesel vehicles may operate. Therefore ensuring future

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[21] Principally nitric oxide (NO) and nitrogen dioxide (NO_2) itself from vehicle tailpipes, and background ozone (which reacts with NO to form NO_2)

compliance with Interim NZTA Guidelines requires careful consideration of future traffic and emission trends.

Determining the ventilation requirements for a tunnel to meet the Interim NZTA Design Guidelines for NO_2 at the design stage is poorly supported by available data at present. By applying general principles of atmospheric nitrogen chemistry we can hypothesise that in-tunnel levels of NO_2 are likely to be elevated for a number of scenarios summarised in Table 8.1.

Table 8.1: Summary of scenarios which have potential for elevated levels of in-tunnel NO_2

Scenario	**Reasoning**
Higher traffic volumes	Higher emissions of NO_x
Greater proportion of diesel vehicles	Greater proportion of NO_x as direct NO_2 (i.e. non-ozone-limited)
Tunnels with longer air residence times (i.e. longer tunnel and/or lower airflows)	Longer time available for in-situ chemical formation
Deeper penetration of ambient ozone (may be case with transverse ventilation)	Ozone delivered to greater depth (rather than depletion near portals) to promote conversion of NO to NO_2
Rural location	Higher levels of ambient ozone

However, there are currently insufficient data to test or quantify these hypotheses. Compared to CO, there is very little information regarding NO_2 in the five tunnels. However, the five State Highway tunnels, when viewed together, offer an opportunity to investigate these hypotheses in a systematic way. This is because they represent a range of traffic volumes, different petrol/diesel and LDV/HDV splits, different lengths, rural, semi-rural and urban settings and ventilation designs.

In order to inform how the Interim NZTA Design Guidelines for NO_2 might be met for upgrades to current tunnels and future tunnels in New Zealand, we recommend a co-ordinated programme of consistent and inter-comparable high-quality in-tunnel monitoring to be conducted in all five tunnels. This campaign should be aimed using the variability between existing tunnels to help understand the determinants of in-tunnel NO_2 concentrations. This objective requires a wider scope of monitoring to capture likely determinants, including ozone availability and penetration. It will also benefit from long-term monitoring or repeated campaigns to track long-term changes in emission trends, especially the relative trends in CO, NO_x and direct NO_2.

To assist in developing a process-based understanding of in-tunnel NO_2, we also recommend that in-tunnel monitoring of NO and VOCs are included, supplemented by near-tunnel (e.g. intake) ambient monitoring. NO is the dominant precursor of NO_2 concentrations. It is also much easier to measure in the tunnel environment than NO_2, with commercial tunnel NO monitoring instruments available and widely deployed. Monitoring of NO offers a potential means of progressing from a design guideline to a compliance monitoring guideline for NO_2 if the relationship between NO and NO_2 can be established. Volatile organic compounds (VOCs) are also present in vehicle exhausts (as well as solvents and potentially other substances which may be found in road tunnels). The presence of VOCs can stimulate the formation of NO_2 without the depletion of ozone. We recommend that capturing data on VOCs would require minimal additional investment but could substantially increase our understanding of the processes of NO_2 formation in tunnels. Simultaneous ambient or intake monitoring is required to understand the role played by ambient contributors (background NO_2 levels and ozone input into the tunnel).

8.1.3 External air quality around road tunnels

Road tunnels generally pose greater air quality challenges internally than externally. External impacts are generally highly localised (tens to a few hundred metres range). There has been no systematic approach to monitor air quality near any of the five tunnels to date. With the exception of Wellington East Girls College, the only data available for this review were data captured for purposes unrelated to the tunnels. As the tunnel impact is expected to be highly localised, most of the monitoring was conducted in locations which are unable to inform the issue of tunnel impacts.

The data available for this review were highly limited and insufficient to draw reliable conclusions. In the absence of specific monitoring data this report speculates that there might be a small risk of significant localised impacts at the southern portal of the Terrace tunnel, the stacks of the Mt Victoria tunnel (especially the western stack at the adjacent school), and the southern end of the Lyttelton tunnel. Impacts at the Homer and Johnstone’s Hill tunnels are considered low due to the absence of an exposed population. Within the limited and generally unsuitable data available, we find no data suggesting that the tunnels lead to local breaches of ambient air quality targets or standards. However, the nature of these data makes it impossible for us to draw general conclusions about compliance or otherwise.

The localised nature of the potential risk is well-suited to a co-ordinated approach to screening assessment, at the three urban tunnels at least (Mt Victoria, Terrace and Lyttelton). We recommend that an assessment based on passive monitoring is conducted in the first instance to evaluate the possible presence of "hot-spot" impacts around the tunnel portals and/or stacks.

8.2 Issues specific to individual tunnels

8.2.1 Mt Victoria tunnel

Due to the climate of the Mt Victoria area, the tunnel's location and height of the stacks relative to much of residential Wellington the tunnel is likely to have minimal and possibly negligible impact on ambient air quality. Highly localised impacts could occur and should be studied further.

We find that current levels of CO inside the Mt Victoria tunnel are unlikely to exceed the recommended Interim NZTA Guidelines, although the margin of compliance may be small. Exposure to CO in the tunnel does not present a risk to the safety of road users due to the low exposure times (less than 1 minute for the vast majority). The risk to pedestrians is approximately an order of magnitude higher, but still well within Interim NZTA Guidelines. There is a significant risk that the tunnel does not currently comply with 8-hour occupational exposure limits.

8.2.2 Terrace tunnel

The Terrace tunnel's portals are in sheltered valley locations with reduced potential for dispersion. This is likely to result in highly localised elevated concentrations of contaminants within tens of metres of the portals. A small number of properties, especially around the southern portal, may experience increased levels of traffic-related air pollutants as a result. There are currently no data to confirm or quantify this. A diffusion tube survey is recommended to address this.

We find that current levels of CO inside the Terrace tunnel are unlikely to exceed the recommended Interim NZTA Guidelines on a typical day, and that exposure to CO in the tunnel does not present a risk to the safety of users. However, it seems plausible that the Interim NZTA Guidelines might be exceeded on some occasions when high emissions combine with poor ventilation. There is a high risk that the tunnel is currently not compliant with 8-hour occupational exposure limits. Monitoring data are required to determine if there are extended periods during which the tunnel complies and maintenance could be preferentially scheduled.

That such a short tunnel appears to perform so poorly in terms of in-tunnel air quality is most probably due to the inappropriate ventilation system (longitudinal assisted ventilation in a bi-directional tunnel). The unconventional ventilation system makes it unusually difficult to predict concentrations within the tunnel, and this is confounded by traffic congestion. An improved prediction of internal concentrations and exposure will depend upon a detailed observational campaign of traffic, air flow, CO, NO_x and NO_2 levels over an extended period. Upgrade options which introduce a more rational, efficient and predictable ventilation regime will generate greater confidence in the systems ability to meet the Interim NZTA Guidelines and reduce the risk to tunnel users.

8.2.3 Lyttelton tunnel

Emissions in the Lyttelton tunnel are probably dominated by heavy duty vehicles, especially climbing uphill in the northbound tube. Trucks work hard to accelerate into this gradient at the southern portal. This portal is surrounded by tens of homes within 100 – 200 m which may be subject to locally raised concentrations of pollutants on occasions when the local wind transports the stack plume towards them. A diffusion tube survey would be an efficient way of confirming and quantifying this effect. The impact on the rest of the town of Lyttelton, however, will be indistinguishable from the impact due to surface traffic and shipping emissions from the port in general.

The ventilation system was designed on the assumption that inhalation of carbon monoxide poses the greatest risk. In the Lyttelton tunnel, this may not be true because of the greater proportion of heavy duty vehicles (whose emissions are more biased towards NO_x and PM than CO), and the additional risks to visibility posed by smoke and fugitive dust emissions arising from these vehicles. An observational campaign will be required to identify and quantify the major causes of smoke and dust and relate these emissions to measurements of visibility.

8.2.4 Homer tunnel

The Homer tunnel is unlike the other tunnels in terms of air quality. This is due to the sporadic, discontinuous and unpredictable nature of emissions. These are dominated by heavy duty vehicles especially operating in the uphill direction. Exposure is strongly influenced by the probability of following such a vehicle. Although emissions are relatively low due to low traffic volume, this is countered by the lack of both mechanical ventilation and ‘piston effect’ ventilation due to vehicle movements.

8.2.5 Johnstone's Hill tunnels

No data were available for these new tunnels at time of writing. Due to the operating parameters of the ventilation system, these twin tunnels will comply with the Interim NZTA Guidelines for CO but their compliance with the other Interim NZTA Guidelines for NO_2 and visibility is unknown.

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Appendix 1: Estimates of current levels of CO in the Mt Victoria and Terrace tunnels

Mt Victoria tunnel

Our best estimate of current (June 2008) levels of CO in the tunnel is based on the following assumptions:

a) the 2003 data were generally representative of that year,

b) traffic volumes and fleet composition have not substantially changed since then (NZTA traffic count data corroborates the volume assumption),

c) vehicle emission factors have reduced in accordance with the predictions of the Vehicle Emissions Prediction Model (VEPM) as a result of increased penetration of lower emission technology vehicles into the fleet.

Our knowledge regarding changes in emission factors is uncertain. However, some general trends can be stated with reasonable certainty. Firstly, emission factors for carbon monoxide have continued to fall significantly since 2003. VEPM predicts a ~40% reduction between 2003 and 2008 for a national average fleet (at 40 km/h). In summary, since 2003 we may expect the mean CO concentration in the tunnel to have fallen by ~40% from 15 ppm to ~9 ppm. The resulting extrapolated maximum concentration would be ~55 ppm. It must be noted that predictions of peak concentrations are inherently more uncertain as they are necessarily rare events.

The 1980 to 1993 peak-period data suggest that the ratio of the maximum concentration to the mean during peak traffic periods is 1.4 – 1.9. Combining this pattern with the expected drop on emissions per vehicle we infer that typical peak time concentrations in 2008 are approximately 30 - 40 ppm. This assumes no change in the level of congestion in the tunnel. An increase in congestion would imply a relative increase in CO emissions.

Terrace tunnel

A diurnal mean CO concentration profile for a ‘typical’ weekday covering periods when the natural draught was 0 – 1.5 m s^{-1} was presented in the report.. It showed CO concentrations peaking at 8 am at just over 100 ppm. Daytime concentrations were typically 40 – 60 ppm, with a secondary peak at 7 pm of ~90 ppm. It was noted that the maximum allowable design concentration of 250 ppm was exceeded “on numerous occasions”.

Between 1979 and 2003, traffic volume in the tunnel more than doubled from ~16 000 to 43 000. We estimate that CO emissions per vehicle fell by ~ 60% over the same period. These combined effects should have roughly balanced each other leading to no net change in CO emissions from traffic in the tunnel, assuming no change in level of service.

Appendix 2: Drive-through measurements of CO and NO_2 in the Lyttelton tunnel

Observations were conducted by NIWA on Monday 15 September 2008 between 1pm and 4pm. Data were collected on 18 journeys through the tunnel (9 southbound and 9 northbound). Further observations were conducted on Monday 17 February 2009 between 9am and 3pm local time. Data were collected on 46 journeys through the tunnel (23 southbound and 23 northbound).

On each occasion, traffic flow was not monitored, but we have no reason to believe that the traffic flow (volume, speed and fleet mix) was abnormal. Journeys were conducted randomly, so that our vehicle followed cars, buses or trucks.

There was some limited variability between individual runs for CO. As the operation of the ventilation system is unlikely to have changed between runs, this variability is most likely associated with the effect of following different vehicles through the tunnel. There was no evidence of accumulation of CO over time, which is also to be expected considering the relatively high ventilation flow rate.

The time series of CO concentrations are shown in Figures A.2-1 to A2-3, with general statistics describing the maximum concentrations recorded during each tunnel transit presented in Table A2.1. There was little change between the two campaigns.

Table A2.1: Comparison of 1-second average carbon monoxide concentrations observed per transit through the Lyttelton tunnel.

	September 2008	**February 2009**
Mean CO (ppm)	11.2	9.6
Minimum CO (ppm)	5.0	6.1
Interquartile range CO (ppm)	9.2 – 13.5	7.7 – 11.3
Maximum CO (ppm)	16.3	14.8

Observations of NO_2 were conducted by NIWA on Monday 15 September 2008 between 1pm and 4pm. Data were collected on 6 journeys through the tunnel (3 southbound and 3 northbound). These data showed a relatively constant level of NO_2 of 40 ppb in the tunnel.

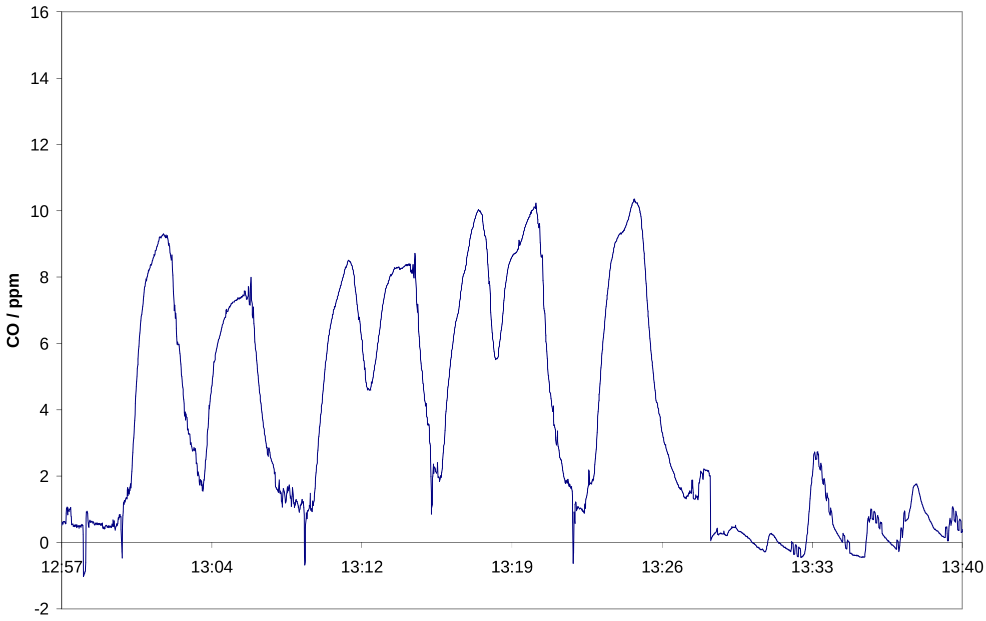

Figure A2.1: CO concentrations measured externally to the test vehicle for the first 7 runs in the Lyttelton tunnel. The characteristic "M" shape is caused by the test vehicle reaching the southern portal, turning round and re-entering the tunnel northbound before the sensor has had time to respond to the ambient concentration.

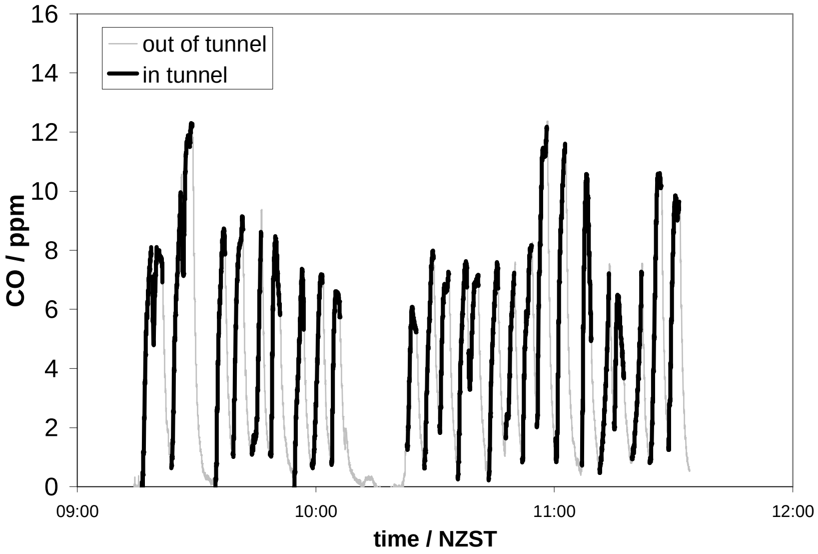

Figure A2.2: 1-second CO concentrations in the Lyttelton tunnel (morning of 17 February 2009). Black line identifies periods inside tunnel.

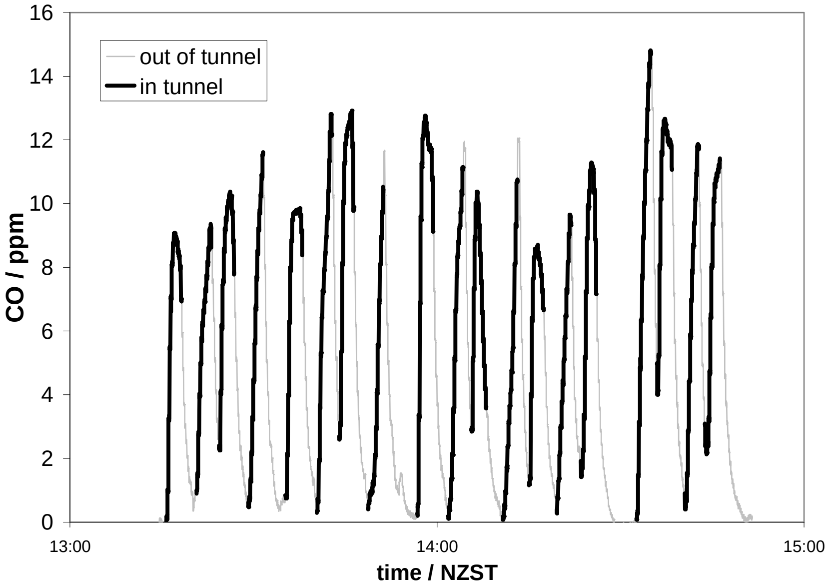

Figure A2.3: **1-second CO concentrations in the Lyttelton tunnel (afternoon of 17 February 2009). Black line identifies periods inside tunnel.**

A comparison of NO_2 and CO concentrations is shown in Figure A2.4.

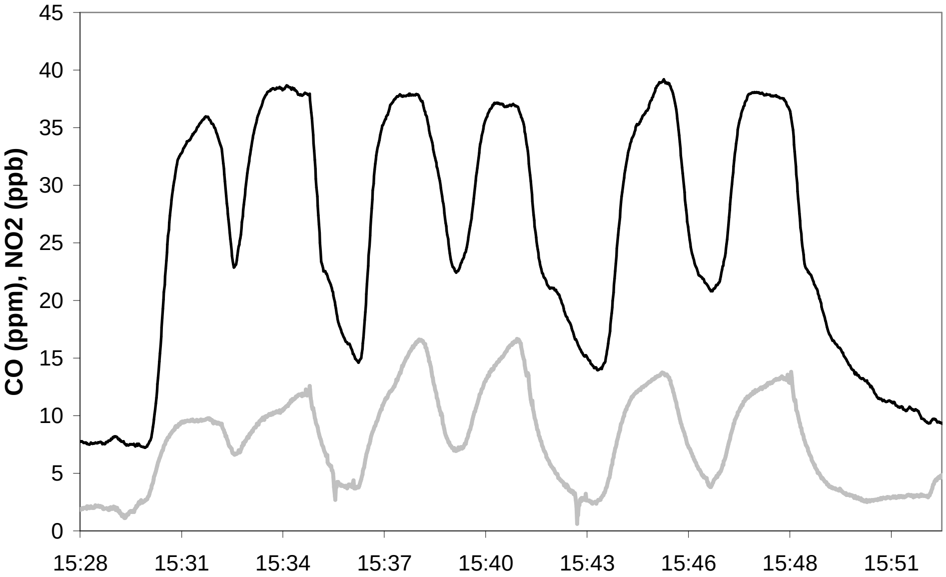

Figure A2.4: **CO (grey line) and NO2 (black line) in the Lyttelton tunnel.**

The low level of variability in NO_2 compared to the variability in CO and the relatively low concentrations suggest that production of NO_2 in the tunnel was being limited by the lack of available oxidant. In ambient atmospheres abundant ozone (O_3) usually acts as an oxidant to produce NO_2 from primary NO emissions. In the tunnel we should expect NO to be far in excess of O_3, such that NO concentrations are limited (as observed). What cannot be determined from our “snapshot” observations is whether O3 can enter the tunnel system, or whether air residence times are ever long enough for a reaction with oxygen to be sufficiently vigorous to provide an alternative source of NO_2.

Appendix 3: Drive-through measurements of CO in the Homer tunnel

Observations were conducted by NIWA on Thursday 18 September 2008 between noon and 3pm. Data were collected on 14 journeys through the tunnel (7 eastbound and 7 westbound). Further observations were conducted on Monday 17 February 2009 between 9am and 3pm local time. Data were collected on 46 journeys through the tunnel (23 southbound and 23 northbound).

On each occasion, traffic flow was not monitored, but limited visual counts were performed.

In September, traffic flow was light, with approximately one vehicle per minute. During a 40 minute visual traffic count 58% of vehicles were cars, the remainder being mostly larger cars (MPVs) and leisure vehicles (RVs). Only one HDV and one bus were observed. Access to the tunnel was unrestricted. Journeys were conducted semi-randomly, i.e. on some occasions other vehicles were deliberately followed to simulate the effects of vehicle convoys.

In February, traffic signals were operating so that vehicles passed in only one direction at a time. The consequences of this were regular queuing of vehicles to use the tunnel and vehicles passing through the tunnel in “convoys” following the traffic signal cycles.

Time series data are presented in Figures A3.1 to A3.3, with summary results shown in Table A3.1.

Table A3.1: Comparison of 1-second average carbon monoxide concentrations observed per transit through the Homer tunnel.

	September 2008	**February 2009**
Mean CO (ppm)	1.2	3.1
Minimum CO (ppm)	0.3	0.7
Interquartile range CO (ppm)	0.6 – 1.3	1.4 – 4.1
Maximum CO (ppm)	4.2	10.2
Daily traffic volume on days of observation	365	1006, 1023

For each transit (single passage through the tunnel) we extracted the maximum observed 1-second concentration. Concentrations were generally 2 – 3 times higher in

February compared to September. Traffic volumes in February were 2.8 times those in September (data provided by NZTA). Concentrations were quite variable between runs and changed rapidly between runs. For instance, a peak concentration of 4 ppm had reduced to < 1ppm in a run only 10 minutes later. Low concentrations (< 0.5 ppm) were observed when the tunnel was empty of other traffic. This implies that concentrations were determined only by the vehicles in the tunnel at any given time. There appears to have been little or no "accumulation" of pollutants in the tunnel in either campaign.

This very limited dataset is unable to show whether this is the norm for the tunnel. External winds were light to moderate – lighter winds may lead to less dispersion in the tunnel and accumulation of pollutants.

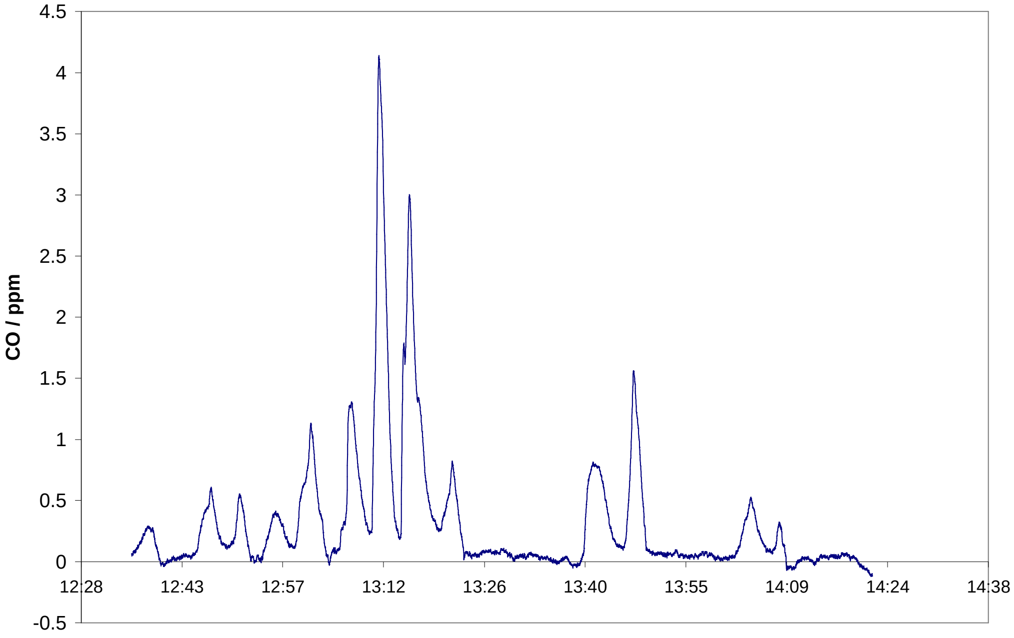

Figure A3.1: CO concentrations measured externally to the test vehicle in the Homer tunnel. 13 peaks are visible corresponding to the first 13 runs through the tunnel (the 14th run was some time later and is not shown).

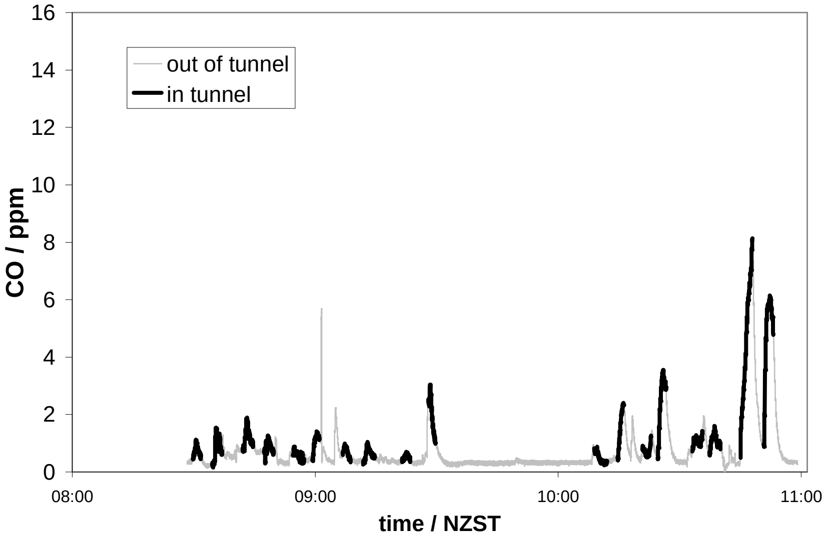

Figure A3.2: 1-second CO concentrations measured during the Homer tunnel campaign (12 February 2009). Black line identifies periods inside tunnel.

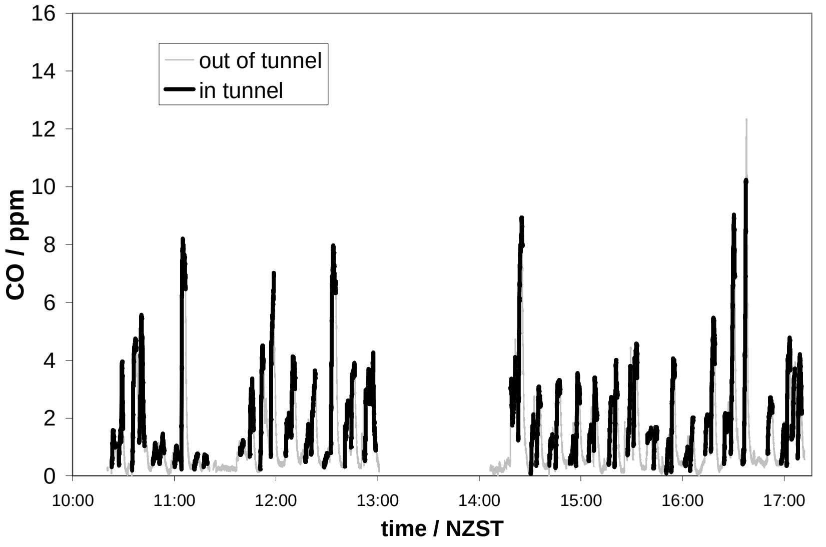

Figure A3.3: 1-second CO concentrations measured during the Homer tunnel campaign (13 February 2009). Black line identifies periods inside tunnel.