MANAGING AIR QUALITY IN AND AROUND ROAD TUNNELS IN NEW ZEALAND

Rob Hannaby[1] and Barry Wright[2]

[1] Environment and Urban Design Manager, NZ Transport Agency, Auckland, New Zealand

[2] Structures Manager, NZ Transport Agency, Wellington, New Zealand

Abstract

Managing air quality in and around road tunnels efficiently and effectively can be a significant challenge for road controlling authorities. The NZ Transport Agency (NZTA) operates six major tunnels on the NZ state highway network. A seventh, the Waterview Tunnel in an urban area of west Auckland is currently under construction and at 2.5 km will be the longest in the country.

In 2007 the NZTA initiated a work programme to review the fire life safety of the Mt Victoria and Terrace Tunnels in Wellington. This work created a need to better understand in-tunnel air quality, including the development of NZTA criteria to inform the design and operation of new ventilation systems.

At the same time, work was underway in Auckland to consent the Waterview Tunnel project. Air quality associated with the operation of the tunnel was a significant issue for the Board of Inquiry (BOI) and submitters. Concerns were raised about portal air quality and the location of 15 metre stacks at each portal, one of which was to be sited close to the Waterview Primary School.

The BOI approved consents in 2011 and required the stack near to the school to be relocated so that it was further away from school children. The BOI also required air quality at each portal to meet the NZ ambient air quality standard for nitrogen dioxide at the designation boundary where it adjoins any air quality sensitive receptor.

Lessons learnt from the safety upgrades of the Wellington tunnels, the consenting of the Waterview Tunnel and associated operational policy work is currently being integrated into formal NZTA guidelines. This includes; the 'NZTA Guide to Road Tunnels[1]' (in preparation) and; the draft 'Guide to assessing air quality effects for state highway asset improvement projects[2]'. These guidelines are expected to be formally approved and published during 2013/14.

Keywords: tunnel, stack, portal, guidelines.

1. NZTA State Highway Tunnels

The NZ Transport Agency is a Crown entity responsible for managing almost 11,000 kilometres of state highways in New Zealand. This includes the operation and maintenance of six major road tunnels:

- Mt Victoria tunnel in Wellington which was opened in 1931.
- Homer tunnel which provides access to Milford Sound which was opened in 1953.
- Lyttelton tunnel near Christchurch which was opened in 1964.
- Terrace tunnel in Wellington which opened in 1978.
- Johnstone's Hill twin tunnels near Puhoi northwest of Auckland which was opened in 2009 and
- Victoria Park Tunnel in central Auckland which was opened in 2011.

In addition to these tunnels the Waterview Tunnel in west Auckland is currently under construction. At 2.5 km this will become the longest road tunnel in New Zealand. Planning is also underway for a new Additional Waitemata Harbour Crossing (AWHC) in Auckland. A tunnel has been confirmed as the preferred option to complement the 1959 Auckland Harbour Bridge which connects the CBD with Auckland's North Shore.

The move towards the development of new and longer urban tunnels in Auckland is a reflection of the significant transport challenges of developing new and enhanced land transport infrastructure in New Zealand's largest major urban centre.

2. Air Quality and Tunnels

Road tunnels are very complex and expensive pieces of infrastructure to build and to operate. There are many reasons why a road tunnel becomes the preferred transport solution. Sometimes it will be the physical constraints of the local topography, other times it may be a response to land use, community and environmental constraints. Often there are multiple reasons, one of which might be the need to address local air quality concerns.

Tunnels can be used to capture vehicle emissions and control their dispersion into the atmosphere providing a mechanism for reducing community exposure to elevated concentrations of air pollution. Conversely tunnels can also give rise to localised air quality issues. For example transport-related air pollution may become elevated near a tunnel portal or create localised 'hot spots' as a result of the discharge of emissions from ventilation points or stacks.

As a result ambient air quality around road tunnels needs to be managed to ensure relevant standards and guidelines are not exceeded and that sensitive receivers are protected from harmful levels of air pollution. In addition air quality inside tunnels also needs to be controlled to ensure the safety of road users as well as workers undertaking maintenance.

Air quality in and around a road tunnel is influenced by numerous factors which include:

- tunnel geometry,
- tunnel length,
- traffic flow,
- vehicle fleet mix,
- vehicle emission standards,
- traffic speed,
- road gradient,
- tunnel ventilation system design and operation,
- tunnel traffic operation procedures,
- surrounding topography,
- background air quality,
- local meteorology and,
- the location of any highly sensitive air pollution land uses near the tunnel, e.g. residences, schools, hospitals, etc.

It is essential to understand the relative importance of all these different factors to ensure optimal in-tunnel and ambient air quality outcomes. This is a challenge that requires multi-disciplinary input as it is also critical that measures taken to manage air quality do not create other inappropriate or perverse outcomes such as excessive energy use to operate tunnel ventilation systems or socio-economic issues resulting from regulating the use of tunnels.

3. Air Quality and Tunnel Operational Policy

3.1. Background

The NZTA State Highway Environmental Plan[3] includes a number objectives relating to air quality. In the context of road tunnels and air quality the Plan states that the NZTA should 'maintain and operate all air quality management/air pollution mitigation measures, such as road tunnel ventilation systems, correctly to ensure they continue to provide the designed level of mitigation'.

In addition to the requirement in the Environmental Plan, in 2007 the NZTA (then Transit NZ) commenced a programme to review the fire life safety of the various state highway tunnels that it was responsible for at the time. The review considered the design standards applied to the various tunnels at the time of construction, current operational practices and also sought to take on board lessons learnt from overseas tunnel safety issues such as the Mt Blanc Tunnel fire in 1999.

The review recognised that air quality is a fundamental consideration in the design, and operation of road tunnels. As a result a number air quality initiatives relating to road tunnels were initiated as part of this review.

3.2. In-tunnel air quality guidelines

As part of this work the National Institute of Water and Atmosphere (NIWA) were commissioned to undertake a research to help develop guidance for the management of air quality inside state highway tunnels. Although ambient air quality around road tunnels in NZ is subject to the requirements of the Resource Management Act 1991 and the National Environmental Standard for Air Quality, air quality inside road tunnels is the responsibility of the relevant Road Controlling Authority (RCA). The NZTA is the RCA for state highways tunnels. Prior to the NIWA work the NZTA had used overseas guidance and criteria, in particular standards published by the World Road Association (PIARC)[4].

The NIWA work, which was peer reviewed by CSIRO, resulted in a NZTA research report 'Guidance for the management of air quality in road tunnels in New Zealand[5]'. This guidance informed the development of a set of interim NZTA in-tunnel air quality guidelines (see Appendix A) intended to provide protection for tunnel users and workers undertaking maintenance.

The interim guidelines were applied to the tunnel safety upgrade work undertaken at the Mt Victoria and The Terrace tunnels in Wellington by the 'Wellington Tunnels Alliance' between 2010 and 2012. The guidelines have also been used as a design parameter for the new Waterview Connection tunnel in Auckland which is currently (2013) being constructed by the 'Well Connected Alliance'.

In 2011 the NZTA undertook a targeted consultation process with stakeholders from local and central government seeking feedback on the interim guidelines. The comments received have been considered as part of the development of the 'NZTA Guide to Road Tunnels[1]' which will provide a home for the guidelines.

3.3. Guide to Road Tunnels

Where the NZTA does not have its own standards and guidelines it will use relevant overseas documents. For road tunnels guidance developed by PIARC[4] and in particular Austroads is often used. Austroads (the association of Australian and NZ road transport and traffic authorities) have published a series of engineering guides that the NZTA has formally integrated into their business. This includes the 'Austroads Guide to Road Tunnels[6]'. Austroads guides by their nature are relatively generic covering a broad range of common issues across roading authorities.

In order to address local issues, road authorities often produce supplements to Austroads guides and the NZTA is currently (2013) drafting a 'Guide to Road Tunnels[1]'. This will provide specific guidance regarding the design, operation and maintenance of state highway road tunnels in New Zealand. As indicated, the Guide will include the NZTA in-tunnel guidelines as well as other air quality related guidance including:

- statutory obligations
- tunnel ventilation
- ventilation stacks and portal emissions
- monitoring of in-tunnel air quality
- air pollution control

This air quality guidance captures the findings from a number recent research and monitoring initiatives investigating air quality in and around tunnels as well as lessons learnt from the consenting of the Waterview Connection tunnel in 2010.

3.4. Guide to Assessing Air Quality for State Highway Asset Improvement Projects

In addition to the Guide to Road Tunnels the NZTA has also used the research referred to above to inform the development of a complimentary air quality assessment guide. This guide is primarily for use when planning and consenting roading projects, including road tunnels.

The 'Guide to Assessing Air Quality for State Highway Asset Improvement Projects[2]' was issued as a consultation document in 2012 and is currently (2013) being finalised. The guide promotes the Waterview tunnel portal air quality consent requirements as 'model' designation

conditions for application to longer urban road tunnels.

4. Tunnel Air Quality Monitoring Programme

As part of their 2007 commission, NIWA prepared a 'Stocktake of the air quality in and around existing state highway tunnels[7]'. This report was published in 2010 and reviewed the monitoring of air quality and other key parameters that had been undertaken by the NZTA for state highway tunnels existing at the time and highlighted the key gaps that needed to be addressed to improve future tunnel-related air quality management.

Subsequently the NZTA has initiated a series of tunnel air monitoring campaigns at Mt Victoria and The Terrace Tunnels in Wellington in 2008[8], Johnstone's Hill Tunnel north of Auckland in 2010[9] and a campaign at Victoria Park Tunnel in central Auckland is currently (2013) underway.

4.1. Mt Victoria and The Terrace Tunnels, Wellington

Monitoring of in-tunnel air quality was undertaken at the 623m long Mt Victoria and the 460m long The Terrace tunnels in Wellington between September and December 2008. The exercise was designed to inform the development of the interim NZTA in-tunnel air quality guidelines referred to above as well as the safety upgrade work being planned for these tunnels at that time. The results[8] demonstrated:

- Compliance with the interim NZTA in-tunnel air quality guidelines for carbon monoxide and nitrogen dioxide during the monitoring period.
- In-tunnel air quality had improved since a previous monitoring campaign in 2003 reflecting improvements in vehicle emission standards.
- External wind speed and direction had a significant influence on in-tunnel air quality.
- Observed concentrations of carbon monoxide reflected variations in traffic volume (2009 AADT 38,800 and 45400 respectively).

4.2. Johnstone's Hill Tunnel, Auckland

Air quality in and around the 380m long Johnstone's Hill Tunnel north of Auckland was undertaken between March and July 2010[9]. Measurements of carbon monoxide, nitrogen dioxide and particulates (PM10) were made inside the tunnel. Measurements of nitrogen dioxide were also taken outside the tunnel which is located in a rural area north of Auckland.

The purpose of the monitoring programme was to assess in-tunnel air quality, to identify and understand the influence of key parameters such as traffic flow on in-tunnel as well investigating how future monitoring campaigns might be best designed to ensure consistency, efficiency and effectiveness. Results[9] from the monitoring exercise indicated that:

- Air quality inside the tunnel is well within NZTA guidelines.
- Air quality near the tunnel exit is elevated but rapidly disperses and dilutes with distance.
- The key traffic parameters affecting air quality in and around tunnel the tunnel are; traffic volume (2009 AADT 12,700) and composition - especially the amount of heavy vehicles.
- Sources of particles inside the tunnel are approximately one-third heavy vehicles, one-third road dust and one-third natural (sea salt, etc).

4.3. Victoria Park Tunnel, Auckland

An air quality monitoring campaign commenced at the Victoria Park Tunnel in central Auckland in April 2013. Unlike the Wellington and Johnstone's Hill monitoring campaigns, the research at Victoria Park Tunnel is focussed upon tunnel portal air quality.

Although Victoria Park Tunnel is relatively short in length (450m), over 150,000 vehicles per day use the Central Motorway Junction (CMJ) which is situated immediately to the south of the tunnel. Vehicles travelling northbound from CMJ use the tunnel whilst those travelling south use a viaduct.

The amount of vehicles using Victoria Park Tunnel and the elevated levels of transport-related air pollution in Auckland CBD[10] provides an ideal location for research investigating tunnel portal air quality. This research is in direct response to the

portal air quality consent conditions applied to the Waterview Tunnel in Auckland (see below).

5. Portal Emissions and Waterview Tunnel, Auckland

The Waterview Connection project in Auckland is the largest roading project in New Zealand in recent times. The project is currently (2013) under construction and is being built in a sensitive urban and coastal environment in west Auckland. It includes 4.5 km of new state highway connecting State Highway 20 with State Highway 16, of which 2.5 km will be in tunnels, as well as alterations to 7 km of the existing SH16. The section of the project between SH20 and SH16 is expected to carry more than 80,000 vehicles per day whilst the existing SH16, which includes a causeway, will be improved to cater for more than 130,000 vehicles per day.

In 2010, the NZTA sought to obtain designations and resource consents for the project. It was the first roading project which involved applications for resource consents and notices of requirement for designations being submitted to the Environmental Protection Authority (EPA) under the provisions of the RMA national consenting process. A Board of Inquiry (BOI) was appointed and met in 2011 to consider the NZTA application.

The project has a high air quality risk largely due to the sensitive urban receiving environment (central west Auckland) and the high traffic volumes using SH20 and SH16 (some of the busiest sections of motorway in NZ). In addition, the management of air quality in and around the tunnel, especially near the proposed northern portal which is close to Waterview Primary School, ensured consenting of the project had a high public profile from the very early stages.

Concerns were raised by the BOI and by submitters about the location of 15 metre stacks at each portal, one of which was to be sited close to the Waterview Primary School as well as portal air quality. In August 2011, the BOI approved consents[11] which included a requirement to relocate the northern stack near to the school so that it was further away from school children. Conditions were also specified to ensure air quality at each portal does not exceed relevant criteria (see Appendix B).

Throughout the BOI hearing the NZTA actively sort to ensure that any designation conditions relating to portal air quality did not preclude the flexible operation of the tunnel ventilation system. The primary reason for this was to ensure that energy usage can be actively managed by either reducing the speed or turning off the ventilation fans during periods of low traffic volumes – providing air quality criteria inside and outside the tunnel can still be met.

The final designation conditions relating to tunnel portal air quality include performance-based criteria to ensure that air quality (nitrogen dioxide) effects are appropriately managed at the boundary of the state highway designation adjoining any pollution sensitive receiver without dictating how the criteria should be achieved. This means the design of the tunnel ventilation system can be further refined and optimised during the detailed design phase prior to construction.

A complimentary designation condition requiring a 'Tunnel Traffic Operation Plan' requires the NZTA to demonstrate how the ventilation system will be managed to ensure portal air quality complies with the performance-based criteria.

6. Future Challenges

6.1. In-tunnel Air Quality

Air quality monitoring inside state highway tunnels to date indicates that the interim NZTA guidelines, especially the carbon monoxide criteria, are readily met. However there remain challenges, for example NZTA measurements of roadside levels of nitrogen dioxide[10], particularly in the major urban areas of NZ suggest that concentrations have been steadily increasing since 2007.

It is too early to say whether or not this is a trend but if it is genuine then compliance with the nitrogen dioxide in-tunnel guideline may become more demanding in the future. In addition to the challenges of meeting the nitrogen dioxide criteria it is noted that the NZTA (as is generally the case internationally with most other road controlling authorities) does not have any guidelines, other than for visibility, relating to levels of particulates inside tunnels. This will need to be reviewed, if and when, further research and evidence justifying such a guideline becomes available.

6.2. Portal Air Quality

Internationally the management of air quality around road tunnel portals in urban areas has traditionally relied upon on the dispersion and dilution of portal emissions. Increasingly in Australia and NZ planning and environmental conditions of consent applied to new urban road tunnels require portal emissions have reduced the ability to rely on traditional management options by effectively requiring tunnel ventilation systems to be designed and operated so that they provide greater certainty as to the state of air quality in the vicinity of road tunnel portals.

Achieving compliance with portal emission / portal air quality conditions of consent can have a significant impact on the capital and in particular the operational expenditure (electricity use and fan maintenance costs) associated with road tunnel ventilation systems. In recent times many new Australian road tunnels have had to be designed to achieve compliance with 'no portal emission' conditions resulting in the design, construction and operation of complex ventilation systems that capture vehicle emissions at the portal and continuously emit them to atmosphere via tall stacks instead.

As discussed above, unlike the 'no portal emission' conditions applied to Australian road tunnels, the Waterview Tunnel conditions of consent effectively require performance-based air quality criteria to be achieved at the nearest sensitive receivers to each portal. This enables the effect of dispersion and dilution to be taken in account whilst still requiring a clearly defined air quality outcome to be achieved.

The research currently (2013) being undertaken at Victoria Park Tunnel in Auckland will help to inform the NZTA as to how it might best achieve such an outcome. Management options could include, for example:

- Operating the ventilation system at fixed time intervals according to traffic flow.
- Using intelligent transport systems to manage in-tunnel ventilation and portal air quality.
- Controlling what vehicles can use a tunnel and when.
- Improving emission standards of vehicles using a particular tunnel.
- Enhancing compliance with emission standards of vehicles a particular tunnel.
- Educating vehicle owners and drivers about vehicle emissions.

Fundamentally the response to such challenges cannot rest with a single entity or solution. It requires a multi-disciplinary and integrated approach.

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[10]NZTA 2012, ‘Ambient air quality (nitrogen dioxide) monitoring network report 2007 – 2011’, *Wellington*

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Appendix A

Interim NZTA In-tunnel Air Quality Guidelines

Interim NZTA In-Tunnel Air Quality (Carbon Monoxide and Nitrogen Dioxide) Guidelines

Air Pollutant	Standard (ppm)	Averaging time	Protection	Application
Carbon monoxide	200	15 min	Workplace	Design and Compliance Monitoring Standard
	30	8 hours	Workplace	
	87	15 min	General Population	
Nitrogen dioxide	1.0	15 min	Workplace and General Population	Design Standard Only

Note:

All interim NZTA standards are based on NIWA recommendations apart from the nitrogen dioxide standard which is based on the NIWA recommended level (1 ppm) and French averaging period (15 min).

Interim NZTA In-Tunnel Air Quality (Visibility) Guidelines

Traffic Situation	Standard	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 NZTA interim visibility standard is based on PIARC recommendations. The standard 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.

Appendix B

Waterview Tunnel, Auckland – Air Quality Designation Conditions

OA.8 The tunnel ventilation system shall be designed and operated to ensure that any air emitted from the tunnel portals does not cause the concentration of nitrogen dioxide (NO_2) in ambient air to exceed 200 micrograms per cubic metre, expressed as a rolling 1 hour average, at any point beyond the designation boundary that borders an air pollution sensitive land use.

Advice Note: The above standard reflects the National Environmental Standard for Nitrogen Dioxide (NO_2) concentration in ambient air.

OT.2 The NZTA shall prepare a Tunnel Traffic Operation Plan in consultation with the Auckland Transport and Auckland Council. The Plan shall include, but not be limited to:

(e) Procedures for the operation of tunnel fans and the management of portal emissions.

The Tunnel Traffic Operation Plan shall be completed and provided to Auckland Transport and to the Major Infrastructure Team Manager, Auckland Council (in respect of Condition OT.2(e)), prior to operational use of the tunnelled section of SH20.

Advice note: The operation and maintenance of the air quality monitoring equipment inside the tunnel shall follow manufacturer's recommendations.