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REPORT FROM KATESTONE ENVIRONMENTAL TO PIKE PIKE FENWICK

REVIEW OF LANE COVE TUNNEL PM₁₀ IMPACT ISSUES

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Review of Lane Cove tunnel air quality impact issues

Executive summary

Katestone Environmental was requested to investigate the suitability of techniques used in determining background concentrations of fine particulate matter in the Lane Cove Tunnel Environmental Impact Statement (EIS) and Representations Report. The Lane Cove Council is concerned that estimates using continuous (TEOM) monitors may lead to significant underestimates of true values and may not include properly the presence of secondary particles (very fine aerosols such as organic compounds, nitrates and sulphates) that are formed in the atmosphere after being emitted from combustion sources such as vehicles. The EIS used TEOM measurements from Lindfield. Information on secondary particle composition is not mentioned but is available for some sites in Sydney (e.g. Mascot, Liverpool). A literature search has shown that concerns on the underestimation of PM₁₀ by automatic monitors are widespread in other countries especially where transport of pollutants between airsheds is significant.

Current techniques for measuring particulate air quality are known to have deficiencies and may require correction factors to measurements, prior to being used for health assessments. Many air quality managers in city councils in the United Kingdom, Europe and elsewhere use factors that can depend on climate, air quality and type of instrumentation. Correction factors for continuous automatic PM₁₀ measurements vary from 0.8 – 2.0, with larger values recorded in wintertime near major road networks for some European countries. The correction factors are thought to be required because some inorganic and organic aerosols are inefficiently captured by filters and may be volatilised in subsequent measurement processes. At this stage, international studies have yet to confirm fully this assertion and better instrumentation to capture all primary and secondary particles is not widely available.

For the Lane Cove EIS, 1997 information from Lindfield was used for background air quality but no correction factors were applied to the TEOM measurements. For this report, comparisons of TEOM and high-volume air sampler (HVAS) information for 1997 show that the TEOM underpredicts HVAS by $11 \pm 7\%$ for all seasons but winter. Winter correction factors are in the range $29 \pm 7\%$. Similar but smaller seasonal variations were found recently for the M5 East network. Corrections based on air temperatures alone do not appear reasonable for most Sydney sites - of the past recommendations of a CSIRO report, preference should be given to using site-specific values, not the default values.

The variation is thought to reflect the differing amounts of the more volatile ammonium nitrate, organic compounds and primary nitrogen oxides at the various sites under different air quality conditions. Long-term measurements at Mascot by ANSTO using low-volume samplers show a ten-fold variation throughout the year in the mass of organic aerosols, a two-fold variation in ammonium sulphate and a two-fold variation in very fine particulates (PM_{2.5}) loading. Nitrate levels appear to be low and we believe that the variability of organic compounds is probably the main cause of TEOM variability for inner Sydney sites. Even HVAS sampling may result in some loss of nitrates and organics, depending on the laboratory procedures. Recent international studies show that the “true” values of PM₁₀ can be estimated in various independent ways and give reasonable agreement with corrected measurements.

We have applied the seasonal correction factors to Lindfield data for 1997 to determine the variability of “true” background levels of PM₁₀. The EIS choice of worst-case background 24 hour average PM₁₀ of 39.8 µg/m³ is likely to be too low on several days.

Whether the underestimation of background levels has a major significance depends on the potential errors involved in various other stages of the EIS assessment and the choice between air quality goals or risk assessment procedures to evaluate the health consequences of tunnel emissions. The accuracy of the predictions of the EIS and subsequent evaluations are discussed with respect to:

- (a) The choice of background PM₁₀ values.*
- (b) The likely accuracy of emission rates of PM₁₀ from vehicle exhaust and vehicle tyre wear.*
- (c) The need to include road dust in emission estimates, especially for confined situations such as tunnels and street canyons.*
- (d) The applicability and accuracy of dispersion modelling.*
- (e) The basis of health guidelines for PM₁₀.*
- (f) The importance of secondary aerosols for health assessments near roadways.*

The conclusions from these considerations are:

- Background levels of PM₁₀ have been underestimated by 11–40%, dependent on meteorological and air quality conditions.*
- The emission rates from the tunnel have probably been overestimated if road dust is neglected, and underestimated by up to 50% if road dust is included.*
- The dispersion modelling is likely to underestimate worst-case PM₁₀ concentrations on nearby buildings unless the ventilation air temperatures are well above ambient temperature (as for the M5 East tunnel). The degree of underestimation has not been quantified in this report, and will depend on final design configurations*
- Health guidelines have generally been based on various measurements (HVAS, TEOM, light scattering devices etc). British guidelines are based on uncorrected TEOM measurements. Australian guidelines are mainly based on uncorrected measurements of HVAS and light scattering instruments.*
- Australian TEOM results should therefore be corrected to use with recommended guidelines.*
- Some recent Australian research shows some health impacts at levels below the NSW PM₁₀ goal of 50 µg/m³ for a 24 hour average.*

- *Secondary aerosols are very small in size (and hence penetrate into the lung) and may be more chemically reactive than larger particles, although available medical evidence suggests that sulphates and nitrates may be less of a problem than organic compounds. They should be considered for locations close to major sources of road emissions.*
- *In a ventilation tunnel, secondary aerosol production and particle coagulation may occur and result in enhanced rates of emissions of the very fine fraction (PM₁) compared to surface roadways.*
- *If the TEOM correction factors based on site-specific measurements are used for background estimation, they should account for much of the presence of secondary aerosols. Adding in an extra regional component is probably only necessary on very urbanised continents where emissions from other states and countries can influence air quality in a surrounded location. Adding an extra component is hard to justify for Australian urban areas, if care is taken with the choice of TEOM correction factors.*

Regardless of the air quality guidelines chosen, the EIS may underestimate maximum daily PM₁₀ exposures by up to 10 µg/m³ on winter days. This could have a quantifiable health impact for sensitive people in potential hotspots, based on recent epidemiological studies in cities throughout the world.

It is recommended that further consideration of the PM₁₀ impact should include:

- *Contact with the EPA and other experts to determine better estimates of PM₁₀ emission rates for the tunnel (taking into account better information on expected traffic flows, the use of improved traffic emission factors and treatment of vehicle type, roadspeed and slope and the presence of resuspended road dust).*
- *Consideration of the health risks, due to the smaller particulate matter expected in the tunnel exhaust compared to ambient air.*
- *Further evaluation of the likelihood of ventilation stack plumes impacting on nearby buildings.*

1. Introduction

This report has been prepared by Katestone Environmental in response to concerns of the Lane Cove Council (LCC) that the levels of fine particulates predicted in the Lane Cove Tunnel Impact Assessment may underestimate the true values of fine particulate matter (PM₁₀), leading to underestimates of the number of exceedances of the NSW Air Quality goals of 50 µg/m³ for 24 hour average PM₁₀. Other representations made to the RTA and LCC are that secondary aerosols (those formed by a variety of processes after gaseous material has been emitted by vehicle sources or that occurring by such processes from other sources in the Sydney air-shed) are likely to be important in any health assessment and should be included as a substantial background when evaluating the ventilation stack impact.

This report summarises the need and available evidence for correction factors to evaluate PM₁₀ measurements from TEOM and other types of instruments, investigates the correlation of TEOM measurements used in the Holmes Air Sciences (HAS) report with available high volume sampler measurements at Lindfield and sets the derived correction factors in light of past studies in Sydney and the very recent determinations for the M5 East monitoring network.

A literature review of the importance of secondary aerosols in urban air quality has been conducted, with particular emphasis on traffic-related emissions. Current health-related air quality guidelines have been based on epidemiological studies relating to response of sensitive members of the community with measured air quality levels. The degree to which secondary aerosols have or should be included in such evaluations is discussed briefly.

Using conservative correction factors for the Lindfield TEOM measurements, together with the dispersion modelling results presented by HAS, and an estimate of the likely errors in input parameters such as emission rates, a reassessment is given of the maximum PM₁₀ concentrations likely to occur with the proposed ventilation stacks operating.

This report provides recommendations if the LCC decide to proceed further with determining their level of objection to the past assessments of the project.

2. PM₁₀ and traffic emissions

The air quality assessment of the Lane Cove project has used emission estimation techniques together with a variety of dispersion models to evaluate the potential increment in ground-level concentrations of various pollutants likely to be caused by the change from mainly surface-based traffic to the majority of through traffic using the proposed tunnel. The dispersion modelling has necessarily used local meteorological information together with estimates of background air quality.

Of particular concern from a health viewpoint are the levels of fine particulate matter, especially in the light of recent laboratory and epidemiological studies that show changes in mortality and morbidity rates with levels of fine particulates (HEI (2002) and included here in Appendix 1 as a very good summary of past and current research). This change in emphasis of the severity of particulate pollution arose from major studies conducted in the early 1990's in American and European environments and received confirmation from similar studies in a large number of studies worldwide (see Aben et al 2002 which is a very recent (October 2002) and comprehensive report to the Netherlands Government on the health impacts of fine particulates – including the investigation of traffic impacts). In the last 5 years there has been considerable reanalysis of the original datasets and publications of various reviews of the significance of available information (Brunekreef and Holgate 2002). Recent Australian studies (Johnstone et al, 2002) have reported a significant increase in hospital presentations for asthma during days when bushfire smoke raised levels of PM₁₀ by 10 µg/m³ for a 24 hour average. Strongest effects were seen on days when 24 hour average PM₁₀ levels exceeded 40 µg/m³.

The measurement and analysis of particulate pollution is greatly complicated by particulate matter arising in a number of forms, varying in both size distribution and chemical composition. Traditional emphasis has been given to those particulates with aerodynamic diameters less than 10 microns (PM₁₀) although recent studies have generally confirmed that PM_{2.5} and perhaps even PM₁ or PM_{0.1} are more responsible for most of the health-related impacts.

To set the context, the following passages from the Aben et al 2002 report are given below:

“Particulate Matter (PM) has both a *primary* component, which is emitted directly by sources, and a *secondary* component, which is formed in the atmosphere via chemical reactions of gases. Examples of primary man-made sources are traffic and industry, while natural sources include soil particles blown by the wind, and sea salt. The most important secondary particulate matter derives from sulphur dioxide, oxides of nitrogen, ammonia and volatile organic carbon compounds. Both primary and secondary PM can be of natural or man-made (anthropogenic) origin. PM can also be the vehicle for heterogeneous chemical reactions of gases, which produce new and sometimes highly reactive components like nitrous acid.

PM can be emitted and exist in the atmosphere in a wide range of particle sizes. Particles with an aerodynamic diameter of 10 µm or less are called inhalable, as this is the fraction that is inhaled by humans. Particulate Matter within a specific size range, a 50% cut-off diameter of 10 µm, is referred to as PM₁₀. Particles with a 50% cut-off diameter of less than approximately 4 µm can end up deep in the lungs. Even from a human health point of view, PM generally larger than 10 µm in diameter and forming a large part of TSP (Total Suspended Particulates) is probably of less concern, because we do not inhale it. From the point of view of nuisance dust, large particles or TSP can be a problem. Though information on the PSD (Particle Size Distribution) is essential to understand the potential health effects of PM. The deposition of PM in the respiratory tract and lungs (inhaled dose) varies with particle size. Apart from its size distribution, the chemical speciation and bioavailability of PM is information that is also needed to understand the health effects of PM. For an understanding of the current health-related problems of PM, a distinction is generally drawn between three size ranges. The smallest particles are the ultrafine particles or ultrafines (UF), which are less than 0.1 µm in diameter. The next size class is that of the particles smaller than 2.5 µm (but bigger than 0.1 µm) and the largest is the coarse fraction of PM₁₀ in the range between 2.5 and 10 µm.

Other particle measures are sometimes reported as well. In the USA, measurements taken using nephelometers have been used to estimate $PM_{2.5}$. In the past, Black Smoke (BS) measurement, based on the decreased reflectance or increased light absorbance of filters loaded with soot, was used to indicate the total particulate matter concentration. The US alternative, the coefficient of haze (CoH), seems to be a less reliable parameter. BS particles are mostly smaller than a few μm . The calibration curve for BS is based on the measured concentrations of PM in the UK in the 1950s. Although the ambient mix of PM has changed, the original calibration curve is still used, as nothing better is available.

Primary fine PM emitted by diesel engines is of a carbonaceous nature. It is also known as DEP (Diesel Exhaust Particulate) or 'soot'. Coarse particles, and to a lesser extent fine particles as well, are linked more to primary emissions from mechanical processes or the handling of dusty materials. Crustal material re-suspended as a result of turbulence caused by traffic, wind-blown soil particles or PM caused by sea spray and wood burning also result in fairly coarse particles. However, there is no strict relationship between size distribution and source of emissions, as natural emissions of sea salt, for example, contain both fine and coarse particles. Ultrafine particles are formed during high-temperature combustion processes of either mobile sources or fossil fuel-based power production. However, in the summer UF also forms as a result of photochemical reactions. The atmospheric residence times and hence ranges of travel of these different size fractions vary considerably ranging from more than sixty hours to less than two hours for different size classes.

Apart from its size range and emission sources, PM can also be characterised by its chemical composition. The chemical composition of PM in ambient air depends on the contribution made by both anthropogenic and natural sources. The natural sources mainly consist of primary emissions of sea salt, wind-blown soil dust and some secondary organic particulate matter. The chemical composition of PM varies in accordance with these different emission sources. One can distinguish carbonaceous PM (elemental carbon (EC) and organic particulate matter (OC)), secondary PM (ammonium salts of nitrates and sulphates), also known as SIA (Secondary Inorganic Aerosols), and natural PM (sea salt, crustal material, sulphate, nitrate and secondary organic particulate matter from natural emissions of precursors). The generic term SOA (Secondary Organic Aerosol) may comprise aerosols formed from natural as well as man-made emissions. Elemental carbon and ammonium salts are chemically well-defined, while organic PM, sea salt and crustal material consist of mixtures of chlorides, oxides of metals and silicates, and a wide range of organic compounds. Heterogeneous atmospheric reactions of ambient PM with gases can in the right circumstances result in highly reactive products like nitrous acid, which in turn is a source of the reactive hydroxyl radical (OH). Owing to their high reactivity, these components are hard to measure. These considerations need to be taken into account when crude particle measures like concentrations of PM_{10} or $PM_{2.5}$ are compared with health effects.

Road traffic is a major source of PM in urban areas. Road traffic emissions are the result of car exhaust, wear on tyres and brake linings and, indirectly, the re-suspension of road dust, crustal and organic. In general, these PM emissions are characterised by their mass and size (PM_{10} and $PM_{2.5}$), by the number of particles or by chemical composition. Most research on PM emitted by road traffic has been related to PM_{10} and $PM_{2.5}$. Recently, more research has also focused on the number of particles, the largest numbers of which are smaller than $0.1 \mu m$, the so-called 'ultrafine' particles (UF). Research has also been directed at the chemical composition of PM, with the emphasis on heavy metals, elemental carbon (EC) – which causes the 'blackness' of PM or black smoke (BS) – and primary organic compounds (OC) such as polycyclic aromatic hydrocarbons (PAH). This interest in various characteristics of PM is linked to the search for toxicological evidence to explain the epidemiologically found associations of PM in ambient air with health effects."

Recent work in Queensland, Netherlands and United Kingdom has shown that:

- For major roads, there is a strong decrease of mass and number concentration of very fine particulates with distance from the roadway.
- Street canyons (and probably tunnels) that cause enclosure of air pollution result in relatively high concentrations of coarse (PM₁₀ - PM_{2.5}) material, mainly as a result of the resuspension of road dust. These resuspended particles are of a coarser fraction than direct exhaust emissions (Aben et al 2002).
- Measurements in European tunnels show that the size distribution of emitted particulates depends strongly on traffic volume (and time of day), and agglomeration in the tunnel results in particle size increasing from 30-40 nm to 80-100 nm – this is not found in ambient air.
- Emissions of PM₁ from diesel vehicles are especially important and can vary considerably between different operating modes and how vehicles are maintained.

European and American studies currently underway (see Appendix 1) are investigating the influence of ultrafines (including very short-term exposures of 2-4 hours) on the health of laboratory volunteers and people living near roadways. The importance of ultrafine particles in causing health impacts has been reviewed in a forthcoming report for Environment Australia (Morawska, Moore and Ristovski, 2003), where the traditional use of PM weight measures for evaluation of the likely biological affects of ultrafine particles is strongly criticised. Some recent work (e.g. Pekkanen et al, 2002) has suggested that ultrafine particles can have independent effects from PM_{2.5} on cardiovascular morbidity in susceptible subjects.

3. Evaluation of ventilation tunnel impacts on PM₁₀

The prediction of ventilation tunnel impacts on air quality relies critically on:

- (a) The choice and use of emission factors for the vehicles using the tunnel. Particulate emissions can occur via the vehicle exhausts or by the resuspension of material previously deposited on the roadway (“road dust”). The emission factors for a given particulate size range will vary with vehicle type, age, conditions, road speed and slope.
- (b) A road traffic and ventilation stack dispersion model that takes the emission rates of the given sources together with the local meteorology and terrain and calculates the dilution of the plume, allowing for the atmospheric processes, the physical and chemical transformations in the plume and the interception of the plume by buildings, terrain and vegetation.
- (c) A methodology for determining the particulate contributions due to:
 - Ventilation stack.
 - Local transport sources.
 - Background air quality.

- (d) An evaluation method for relating the risk of health impacts to sensitive people from the predicted particulate concentrations over a representative year of operations and meteorology.

For (a), the emission estimation in the Lane Cove EIS (Appendix E) used the MAQS (1997) emission factors for particulate emissions coming from exhaust emission plus airborne brake wear and airborne tyre wear. The latter was taken as PM₁₀ only, the former a substantial fraction (64 – 100%) being PM₁₀. Allowances have been made for the influences of road slope, but not traffic speed. The MAQS inventory factors may not be very applicable to future scenarios, as they were for a particular past year (1992) and emission factors for newer vehicles may be quite different.

The particulate emission rate for non-exhaust components was assumed to be 0.009 g/km/veh and does not include any component due to resuspended dust. Recent Australasian emission inventories have used 0.013 g/km/veh for cars and 0.016 g/km/veh for heavy commercial vehicle (Joynt et al 2002) for non-exhaust components. This is 40-75% larger than the EIS values. Most Australian inventories do not normally include road dust. Recent American and European work suggests values in the range 0.03 – 0.3 g/km/vehicle for road dust for freeway conditions. In a tunnel environment that is more isolated from external sources, but with potential deposition and re-entrainment from tunnel walls as well as roadways (Gidhagen et al, 2003), it is not evident what value in this wide range is appropriate.

The emission factors are shown in Table 1.

Table 1: PM₁₀ emission factors (g/km/vehicle) for freeflow traffic mode, as given in HAS (2001)

Vehicle type	2006	2016
LDPV	0.021	0.021
HDDV	1.150	1.150
HDPV	0.081	0.081
Brake and tyre	0.009	0.009
Road dust ¹	0 (0.06 – 0.13)	0 (0.06 – 0.13)

Notes: ¹ Value in brackets gives very recent literature values, based on direct measurements (Fitz and Bufalino 2002).

LDPV = light duty petrol vehicle; HDDV = heavy duty diesel vehicle; HDPV = heavy duty petrol vehicle

For peak hours in the tunnel, with 8000 vehicles/hour and 300 – 400 HDV, the emission factors of PM₁₀ based on Table 1 will be of the order:

0.05 g/s/km for LDPV
 0.13 g/s/km for HDDV
 0.02 g/s/km from brake and tyre
 (0.14 – 0.3 g/km road dust)

giving a total emission rate for 3.4 km of tunnel of 0.68 g/s for MAQS estimates (and 1.16 – 1.7 g/s including road dust). Recent monitoring of PM₁₀ levels in the M5 East tunnel could be readily utilised to determine the suitability or otherwise of the above emission rates.

Particulate emission rates could therefore have an error of up to 70% if road dust is included. The other key uncertainties are the proportion of HDDV using the tunnel and the speed dependence of each type of particulate emission.

For item (b), the EIS has used relatively standard methods that may tend to underestimate concentrations on nearby buildings (and perhaps elevated terrain).

For item (c), the key areas in determining the total particulate concentrations are:

- Selection of appropriate background monitoring station.
- Correction of measurements to that of an ideal PM₁₀ monitoring device, allowing for the presence of secondary aerosols.
- Production of a suitable hourly or daily background PM₁₀ concentration.
- Prediction of the influence of the surface road network (sub-regional).
- Add on the influence of emissions directly from the ventilation stack and any other significant local sources.

For item (d), the evaluation can proceed by comparing total concentrations to available guidelines (if these are assumed to have a built-in safety factor) or else the increment due to tunnel operation can be used with available dose-response relationships for the various subgroups of the local population. Much of the available information is open to dispute and complicated by the varying nature of aerosols in those cities where dose-response relationships have been determined.

The final section of this report estimates the likely errors in some of the above factors to give an idea of the degree of confidence to be placed in the EIS assessments.

4. Use of TEOM samplers for background PM₁₀ assessments

The HAS reports use both HVAS measurements at two locations for the year 2000 – 2001 and the TEOM measurements from Lindfield for 1997. In the EIS correction factors have not been applied to the Lindfield TEOM information and various assumptions have been made as to what is a suitable background for use in the tunnel impact assessment.

The correlation of TEOM and HVAS PM₁₀ measurements has been of great concern to regulatory authorities in Australia and elsewhere. In Australia, following on work conducted by CSIRO on behalf of Environment Australia (CSIRO, 2001), the Peer Review Committee of NEPC has recommended that site-specific comparisons should be used in order to provide suitable correction factors for use in air quality evaluations. A European Community Working Group (Williams and Bruckmann 2001) have also formulated various procedures and have collated information from a variety of European and urban studies. Both groups have produced procedures against which acceptability or otherwise of the various types of measures can be judged. The criteria for Australia are summarised in Table 2.

Table 2: Criteria for acceptance of PM₁₀ samplers

Quantity	Australian criteria
Slope of regression relationship	1 ± 0.1
Intercept of regression relationship	0 ± 5 µg/m ³
Correlation coefficient (r) of reference and candidate sampler	≥ 0.97
Equivalent value of r ²	0.94

The requirement on the linear regression coefficient is quite strict and often not satisfied for the sites investigated in the CSIRO report.

The CSIRO report looked at data collected prior to 1998 for a variety of sites in Sydney and elsewhere in Australia. Taken as a whole, this national dataset suggested that suitable correction factors could be based on daily average temperature, with no correction factors being required for average temperatures above 15°C. The report noted considerable disparities between measurements undertaken at various sites. For some Sydney locations, correction factors as high as 30% appear to be required for these historical measurements.

Recent continuous monitoring by the EPA at the various Sydney sites has used newer versions of the TEOM equipment. The M5 East monitoring program has used similar equipment at two locations close to the M5 East ventilation stack. A joint RTA/RAPS program has involved a scientific committee analysing this very recent information to determine the magnitude and form of the correction factors required (if any) for this dataset. Some of these results may be of relevance to the Lane Cove location, although it is likely that a site-specific calibration study will also be required.

Recent developments in TEOM equipment include the addition of a Nafion dryer and other multi-stage processes to collect and measure the secondary aerosol. Swiss research showed that adding a Naphion dryer reduced the required correction factor from 27% to 17%. In association with various other scientific organisations, the EPA is collaborating in an Environment Australia sponsored program looking at the nature of fine particulate matter in the Sydney and other urban areas in Australia. These studies are about to commence with results likely to be available within the next two years, and will include a determination of the role of secondary aerosols in Australian urban airsheds.

The results from the M5 East and European studies can be summarised as follows:

- (a) The choice and use of equipment is important both for continuous monitoring and the traditional HVAS.
- (b) For many sites, especially those in northern European large urban areas, significant correction factors have been found and appear to have a seasonal variation. The range between different sites is large. There is, as yet, no overall consensus as to whether the correction factor is dependent on temperature or meteorological variables or the composition of the different urban aerosols.
- (c) The M5 East studies suggest that the necessary correction factors are relatively small except during the winter period. It is understood that a screening methodology is likely to be recommended whereby seasonal correction factors of less than 5% are advocated for the summer period but correction factors of up to 20% may be necessary in winter. The study found that the correlation of correction factors with temperatures was poor although the best fit linear relationship gave parameter values fairly similar to those obtained in previous CSIRO studies.
- (d) Seasonal correction factors should be based on at least 30 points of valid concurrent sampling by TEOM and HVAS methods.

- (e) Other devices that use heated inlets (such as the beta-attenuation instruments) can give similar seasonal correction factors.
- (f) Many European studies suggested TEOM correction factors of 30% for winter but 0-10% for other seasons.

5. Investigation of the 1997 Lindfield information

TEOM and HVAS 24 hour average sampling results for 1997 were obtained from the EPA and subject to similar analysis to those found useful in the M5 East scientific study. HVAS sampling occurred every 6 days whilst the TEOM operated almost continuously. The 1997 dataset gave rise to 57 days with coincident TEOM and HVAS information. We have obtained the 1997 Lindfield TEOM and HVAS information as issued in the EIS and repeated the regression analyses, both for the full year and each season separately. Table 3 shows that there is little seasonal variation except that wintertime correction factors are twice ($29 \pm 7\%$) those of the other seasons ($11 \pm 7\%$). Residual plots show no obvious dependence on average, minimum or maximum daily temperatures.

Table 3: TEOM-HVAS regression analyses for the available Lindfield information (TEOM = a HVAS + b)

Period	Regression	Slope	Intercept	R ²	N
1994-99	RMA	0.84	0.6		172
1994-99	Linear	0.75	2.2	0.81	172
1997	Linear	0.87	0	0.86	57
Summer 97	Linear	0.90	0	0.73	14
Autumn 97	Linear	0.88	0	0.96	15
Winter 97	Linear	0.78	0	0.91	14
Spring 97	Linear	0.90	0	0.90	14

It is noted that the number of data points per season is probably too small to have great confidence in the use of seasonal factors.

Figure 1 shows the time series of concurrent TEOM and HVAS information, including the corrected TEOM values utilising the recommended seasonal correction factors. For the nine HVAS measurements with 24 hour average PM₁₀ over 30 µg/m³, the corrected TEOM values were much lower than the HVAS measurements on three occasions, and significantly higher on one occasion (mid-December). The latter event (HVAS = 39 µg/m³, TEOM = 48 µg/m³, corrected TEOM = 53 µg/m³) deserves further scrutiny.

The HVAS measurements were only for 1 in 6 days. Figure 2 shows the 24 hour averages for the complete 1997 TEOM dataset, both for uncorrected and corrected values. The corrections lead to three events of over 50 µg/m³ and the number of events over 40 µg/m³ increasing from 2 to 6.

Figures 1 and 2 have used the mean seasonal correction factors. A more conservative approach of using the 95% confidence limits would have given significantly more exceedances of 50 µg/m³.

6. Historical TEOM data for Lindfield and other Sydney sites

The CSIRO report (2001) gives the available results for Lindfield and various other Sydney monitoring sites, for the period 1994-1999. The CSIRO analysis for Lindfield used 172 data points, with missing data for the middle and end of this period. Like most of the NSW sites, there was little temperature dependence on the TEOM correction factor, with 12-25% underprediction for the temperature range 8-20°C.

Table 4 compares the various factors from available Sydney sites from the CSIRO and recent Earlwood information. There is considerable variability between the various sites but overall correction factors of the order 15-18% appear appropriate for several of the northern Sydney suburbs.

Table 4: Comparative values for TEOM correction factors

Site	Regression	Slope	Intercept	N
Lindfield 94-99	RMA	0.84	0.6	172
Lindfield 97	Linear	0.87	0	57
Earlwood 94-99	RMA	0.78	0.07	113
Earlwood 00-01	Linear	0.80	0	
Blacktown 94-97	RMA	0.95	-0.6	196
Warrawong 94-97	RMA	0.80	0.8	194
Beresford 94-98	RMA	1.09	0	149
Richmond 94-98	RMA	0.85	0.00	166

From Table 3 we recommend a mean correction factor of 11% for all seasons except winter (29%) for the 1997 Lindfield data, based on the slope of the regression line. Any TEOM value of, say, 35 $\mu\text{g}/\text{m}^3$ in winter should be corrected to 45 $\mu\text{g}/\text{m}^3$ equivalent HVAS (see Table 5 and Table 6). There will be some events for which this correction factor is an underestimate. Taking the errors in the slope into account, more conservative values would be 36% in winter, 18% otherwise.

Table 5: Sensitivity of adjusted TEOM concentrations ($\mu\text{g}/\text{m}^3$) to chosen correction factors.

TEOM	Corrected value range ¹	Recommended value ²
25	29.5	32.2
30	35.4	38.6
35	41.3	45.1
40	47.2	51.5
45	53.1	58.0

¹ Range given by assuming 18-30% correction factor as a very conservative approach.

² Values based on 29% correction factor.

Table 6: Effect of using different seasonal (as given in Table 3) factors for Lindfield 1997 data (values given in $\mu\text{g}/\text{m}^3$).

TEOM	Spring	Summer	Autumn	Winter
20	27.8	27.8	28.5	32.2
30	33.3	33.3	34.2	38.6
35	38.9	38.9	39.9	45.1
40	44.4	44.4	45.6	51.5
45	50.0	50.0	51.3	58.0

7. The importance of secondary aerosols

Secondary aerosols consist of organic compounds, sulphates and nitrates, and are virtually all contained in the PM_{2.5} and PM₁₀ size fractions. There are few ongoing measurements of aerosol composition for sites in Sydney. Measurements at Mascot conducted by ANSTO (1999) for a 7 year period show that:

- Mascot PM₁₀ mass concentrations are typically 2.74 times those of PM_{2.5}.
- PM_{2.5} consists of organics (27%), elemental carbon (30%), ammonium sulphate (20%), soil (6%), seasalt (9%), lead (1.8%), and trace elements including nitrate (below 1%).
- The organic component of the PM_{2.5} is highest in winter (31-36%), lowest in summer (2-6%), the sulphate levels highest in summer (29-36%), for 2000-01 data.
- Measured nitrate levels are very low.

Separate consideration is often given to the secondary inorganic and organic components. For the main inorganic components, ammonium sulphate is not very volatile whilst organic compounds and ammonium nitrate are sufficiently volatile for nearly all material to be lost by heating to 50°C as in the TEOM. CSIRO noted that even PM₁₀ measured by a HVAS may underestimate values by 3% or more if sample heating occurs in the transition from outside to laboratory temperatures.

The most recent American work on the semi-volatile nature of secondary organic aerosols (Eatough et al 2003) has shown the following:

- Secondary organic aerosols are essentially all semi-volatile organic material.
- Secondary organic aerosols are not retained on the heated filter of a TEOM monitor and hence are not detected by this sampling technique.
- Essentially all of the organic material lost from the heated filter of a TEOM sampler is secondary organic aerosols. In addition, secondary ammonium nitrate is also lost.
- Some secondary organic aerosols are also lost during sampling from single filter samplers such as the Federal Reference Method (FRM) PM_{2.5} sampler and equivalent techniques.
- The amount of secondary organic aerosols lost from single filter samplers can vary from less than 1/3 during cold winter conditions to essentially all during warm summer aerosol collection periods.
- Secondary organic aerosol can only be reliably collected using an appropriate denuder sampler.

Ammonium nitrate and semi-volatile organic compounds are significant components of fine particles in many urban atmospheres. These components, however, are not properly identified with current EPA accepted methods such as the FRM PM_{2.5} or other single filter samplers due to a large loss of semi-volatile material from the filter during sampling. Continuous PM_{2.5} mass measurements using methods such as the TEOM monitor heats the sample to remove particle-bound water which also results in evaporation of significant amounts of semi-volatile material.

If organic and nitrate compounds comprise say 35% by weight of PM_{2.5} in winter and if PM₁₀ = 2 PM_{2.5}, in winter, the TEOM correction factor by loss of organics and nitrate would be of the order of 17%, not too dissimilar to the values found above for Lindfield and other Sydney sites.

The Lane Cove Tunnel Action Group response to the EIS notes the use of a constant correction factor of 9.5 µg/m³ for missing secondary aerosol concentrations in European modelling of regional PM₁₀. More recent Dutch work looks at the alternative ways of using TEOM data, modelling of primary and emissions and estimation of secondary components. Aben et al (2002) show that either correcting the TEOM data or modelling the various components give similar values. For Sydney, this conclusion is likely to be valid but the modelling of the more important secondary organic material is likely to be more difficult. However, it is safe to conclude that using corrected TEOM and adding a secondary component would lead to significant overestimation of total PM₁₀.

8. Re-evaluation of the impact of the tunnel development, using corrected background and error estimates for different components

8.1 Emission estimation

Of all the criteria pollutants, PM₁₀ is the one for which the least experimental work on vehicle emissions has been conducted in Australia. No Australian emissions inventory currently includes estimates of the contribution of road dust. European and American studies suggest that this may lead to a 5-50% underestimate of total vehicle emissions and that road dust is likely to be increasingly important as the vehicle usage increases in future (i.e. there are no likely controls for road dust that will keep pace with increasing VKT, in contrast to the situation for exhaust emissions).

Some emissions studies rely on PM₁₀ measurements that have not been corrected for loss of semi-volatiles and these may lead to underestimation of vehicle exhaust emissions.

It is not clear whether the Australian vehicle emissions inventories properly include the influence of speed and slope for PM₁₀ emissions. The EIS uses no speed dependence and a gradient dependence only for road slopes over 5%. The slope enhancement is calculated as 4% for westbound traffic and 0% for eastbound traffic. The EIS also assumes that the traffic in the tunnel operates in free-flow travel mode (and hence that no congestion – expected for travel speeds less than 20 kph – will occur). The EIS has the same PM₁₀ emission factors for 2006 and 2016.

Recent European work shows that modern (direct-injecting) petrol cars emit far more particles than conventional petrol cars (and almost as much as diesel cars). Newer diesel vehicles will have particulate traps – petrol cars do not.

These examples suggest that the emission factors for PM₁₀ deserve further attention. It is of interest that the M5-East Freeway Sub-Regional Air Quality Management Plan (SKM, April 2002) used recent unpublished work by Xu (2001) of the NSW EPA who has produced revised emission factors for the MVEPS Improvement Program. These factors are shown in Table 7 for 2002 for freeway (lowest values) and congested arterial (worst case) roads, together with the equivalent values for the 1997 MAQS study where available.

Table 7: Comparison of PM₁₀ vehicle emission factor

Vehicle type	Expected proportion ¹ (%)	Xu (2002)		MAQS (1992)	
		Freeway	Congested arterial	Freeway	Congested arterial
Passenger Petrol	73.3	0.017	0.055	0.021	
Passenger Diesel	2.0	0.327	0.391		
Light Commercial Petrol	10.3	0.014	0.047		
Light Commercial Diesel	2.8	0.451	0.354		
Heavy Duty Petrol	0.7	0.077	0.253	0.081	
Rigid Truck Diesel	3.2	0.418	0.523	1.15	
Articulated Truck Diesel	3.9	0.463	0.804		
Bus Diesel	0.3	0.471	0.697		

Note¹ Average values for Sydney fleet – 8% HGV, 13.1% LGV, 76.3% passenger.

The EIS uses 0.021 g/km/veh for light duty petrol vehicles (passenger and light commercial), 0.081 g/km/veh for heavy duty petrol vehicles and 1.15 g/km/veh for heavy duty diesel vehicles (trucks and buses), together with 0.009 g/km/veh for brake wear and tear. This suggests that the EIS emission rates are reasonable if the tunnel operates in freeway mode (average speed 70 kph) and road dust resuspension can be neglected. If the traffic is at a speed where traffic management measures are needed, emission rates may be underestimated by 5%. If road dust is included (at 0.06 g/km/veh, a low estimate from recent American studies) and if the tunnel traffic is congested, the maximum error would increase to 60%.

For present purposes, it is reasonable to take the error in traffic PM₁₀ emission rates for the tunnel as ± 50%.

8.2 Dispersion modelling

HAS modelling shows that the worst-affected receptors at ground can expect an additional 24 hour PM₁₀ concentration of up to 3 µg/m³ due to ventilation stack emissions, with values over 1 µg/m³ for 5% of the days. Some ridge-top receptors could receive up to 1 µg/m³. For the worst-affected receptor, values over 1 µg/m³ can be expected in most months of the year (information provided by HAS in a letter to NSW Department of Health).

Depending on the final stack configuration and temperature of the stack exhaust, it is possible that elevated receptors close to the ventilation stack could receive 24 hour average stack contribution of up to 16 µg/m³ (the EIS gives values of 7.8 µg/m³ for distant apartment blocks). The doubling of the EIS estimate may occur if the stack height and plume momentum buoyancy are inadequate to ensure clearance of nearby buildings

8.3 Selection of background concentrations

Previous sections have shown that Lindfield TEOM results should be increased by 29% in winter and 11% for other seasons (these are average correction factors – on some occasions, greater values are necessary).

8.4 Error analysis for worst-case 24 hour average PM₁₀ exposure

The above values can be used to estimate the worst-case exposures for the most-affected receptors – more detailed modelling is required to look at the community exposure.

The resulting concentrations are shown in Table 8.

Table 8: Error estimates for worst-case PM₁₀ exposure due to ventilation stack emissions

Quantity	Estimated error (%)
Emission rates	± 50
Dispersion modelling	Up to 100
Background	11-29

Hence:

- Worst-case background concentrations (stated as 39.5 µg/m³) should be increased to 51 µg/m³.
- Stack contribution of 3 µg/m³ for ground-level and 8 µg/m³ for elevated level receptors should be increased to 5 µg/m³ and 24 µg/m³ respectively, for worst-case emission factors and dispersion estimates.
- Should these occur at the same time as high backgrounds, there will be additional exceedances of the NSW goal of 50 µg/m³.
- The frequency of such high events does depend on traffic and stack characteristics as well as pertaining meteorological conditions.

8.5 Increase in health risks

The health risk evaluation in the EIS used a largest maximal increase of 3.0 µg/m³ for 24 hour average PM₁₀ concentration (and disregarded the exposure of people in nearby buildings). It used relative risk factors for mortality and some morbidity measure based on pre-1997 epidemiological studies. There has been considerable work conducted in the past 10 years that give an idea of seasonal risk factors for different sections of the community.

In many ways, the value of a background concentration being in the range 30-50 $\mu\text{g}/\text{m}^3$ is only needed to justify the use of risk factors from other cities since, if the exposure-effect relationship is linear, the exact value does not matter much. The above considerations suggest that an increment of over 10 $\mu\text{g}/\text{m}^3$ for a 24 hour PM_{10} concentration is quite possible for receptors near to the stack. Recent Australian work on hospital admissions for asthmatics would imply that this may lead to a significant risk for nearby sensitive people, especially if background values of PM_{10} exceed 40 $\mu\text{g}/\text{m}^3$. A better definition of the make-up of these local communities is required to give an assessment of the likely risks caused by such exposures.

9. Utility of further PM_{10} modelling

Further detailed modelling of expected PM_{10} exposures will be worthwhile once better information on tunnel design and characteristics becomes available from the preferred or chosen tunnel construction contractor. The tunnel usage may be quite different to that given in the EIS, as found in the M5-East first year of operation where the traffic flows were some 40% greater than expectations. The PM_{10} concentrations inside the M5-East tunnel and ventilation stack are still under investigation, and may lead to some useful resolutions of the outstanding uncertainties

Further modelling is not advised until there is more confidence in the emission factors used for PM_{10} and until there is a fuller evaluation of the importance of road dust for a tunnel environment.

Better evaluation of background concentrations could be obtained by seeking TEOM correction factors for several nearby Sydney locations for recent years. The information collected by ANSTO on organic and other secondary aerosols would be useful to seek better correction factors (i.e. construct a mathematical model to predict the daily correction factor based on recent air quality and meteorological information).

Finally, the proper evaluation of health impacts of tunnel operation should look at several measures:

- 24 hour values of PM_{10} , $\text{PM}_{2.5}$, $\text{PM}_{10-2.5}$ and PM_1 .
- Short-term (say 2-4 hour) concentrations of the above.
- Changes in particle number concentration, using available results on the effects of traffic ultrafines.

Whilst Katestone Environmental is able to assist in the dispersion modelling, it is worthwhile contacting particular researchers in several fields:

- Professor Bart Brunekreef (University of Utrecht) who is a leading world expert in the health impacts of traffic emissions. He would be able to advise on recent work on PM_1 and road dust health impacts and the relevant risk factors.
- Associate Professor Lydia Morawska (QUT) who is now completing a study for Environment Australia on ultrafines and traffic, and has recently published work on the modelling of road traffic ultrafines (Gromotnev et al 2003)

- Dr Gavin Fisher (NIWA and President of Clean Air Society of Australia and New Zealand) who can advise on relevant New Zealand studies and on the importance of road dust.

10. Conclusions and recommendations

1. Lindfield TEOM data used for evaluating background PM₁₀ concentrations will underestimate by at least 10% (and up to 40%), dependent on air quality and meteorological conditions.
2. The correction factor is unlikely to be solely dependent on temperature and the CSIRO default recommendations are poor descriptors of conditions at Lindfield.
3. Available information suggests that the presence of secondary organic compounds is likely to cause most of the underestimation. TEOMs tend to volatilise a substantial part of the organic and nitrate components. Organic aerosols are more important in Sydney especially in winter (when TEOM correction factors are largest).
4. These corrections to background are important in determining the likely number of exceedances per year of the NSW air quality goal for PM₁₀ exposures. It is of less importance in conducting a health risk assessment where the increment in concentrations is more relevant.
5. Secondary aerosols are potentially important and even existing HVAS sampling results may underestimate their contribution. Secondary nitrates appear to be less important in the Sydney airshed than in European cities where the addition of a component for secondary aerosols has been recommended. If TEOM correction factors are used in Sydney, the role of secondary aerosols will have already been partially catered for.
6. Errors in emission estimates and the dispersion modelling near buildings are also quite significant. PM₁₀ emissions from vehicles, brake and tyre wear and the resuspension of road dust are more poorly known than other conventional traffic pollutants.
7. Further advice should be sought on PM₁₀ emission factors and their dependence on slope and vehicle speed. Approaches could be made to the EPA/RTA to allow a better quantification of the errors and to determine the relevant emission factors from M5 East tunnel measurements.
8. Further advice should be sought on the health impacts of traffic emissions, with particular emphasis on recent European and American studies of traffic hot spots and recent field and laboratory studies on PM₁ and ultrafines.
9. Further dispersion modelling would be worthwhile once better information is available on:
 - Traffic flows expected (in the light of M5-East underestimates and the figures finally used by Lane Cove Tunnel tenderers).

- Emission estimates of PM₁₀ based on recent information and full consideration of changes in vehicle fleet, slope and speed effects and the importance of resuspended dust.
- Better information on final stack characteristics and the presence of sensitive people in buildings close to the two ventilation stacks.

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Figure 1: Time series of TEOM and high-volume sampler results compared to the corrected TEOM values for Lindfield, for 1997 concurrent measurements.

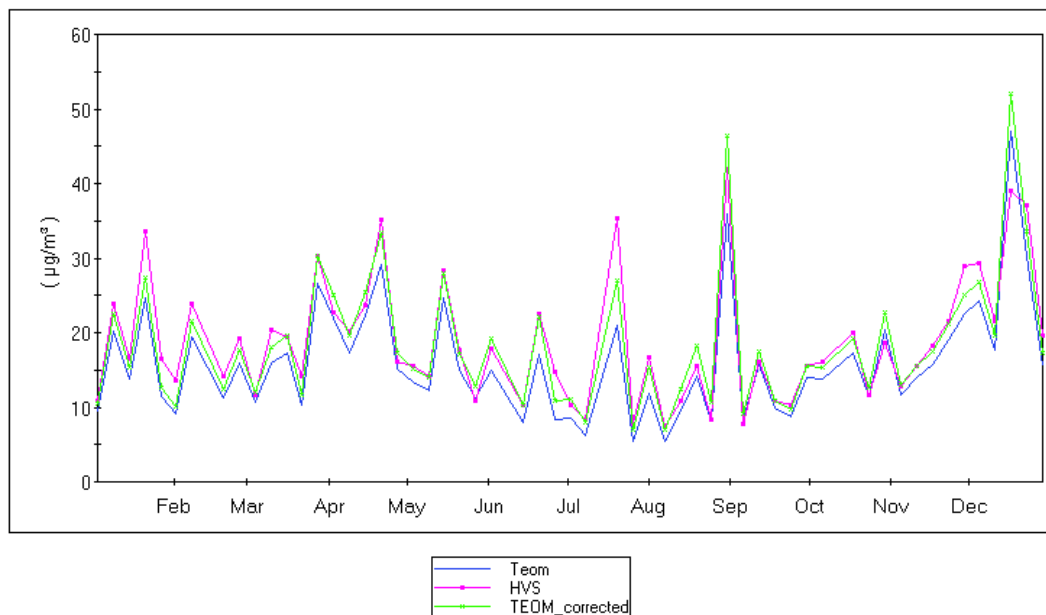


Figure 2: Time series of TEOM and corrected TEOM values for the entire dataset for Lindfield for 1997.

