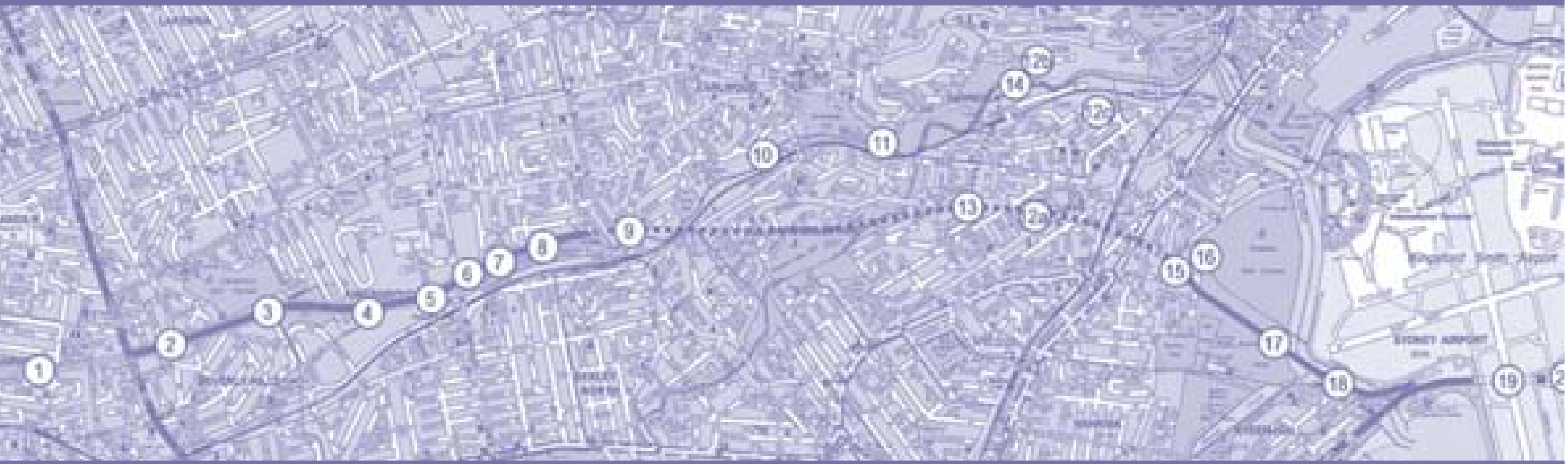
Investigation into the possible health impacts of the M5 East Motorway Stack on the Turrella Community

Reanalysis of the Phase 2 Cross Sectional Survey of symptom prevalence within the Turrella Community



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Executive summary

The M5 East motorway is a 10km long, four-lane dual carriage motorway, which links central Sydney with Sydney's southwest. In the first half of 2002, after the opening of the M5 East tunnels, NSW Health received over 80 complaints from local residents who believed their health was being adversely affected by the M5 East stack exhaust despite local air quality monitoring not demonstrating a significant change in pollutant levels following the opening of the tunnels. NSW Health developed a multi-phase study to investigate whether there was an association between emissions from the stack and symptoms reported by local residents. The first phase of this study identified symptoms that had a possible relationship with the M5 East stack. The second phase undertook a survey of the local community to determine the prevalence of these symptoms across three zones of relatively high, medium and low modelled stack emissions. Zones from modelled stack emissions were defined using emitted stack pollutant data and pollutant readings at local monitoring sites from February 2002 to January 2003. The survey asked about symptoms between September to November 2003. Although this study could not totally discount the possibility of stack emissions causing health effects it found no evidence of an association between prevalence of reported symptoms and modelled emissions from the M5 East stack.

In July 2004, NSW Health was advised that portal emissions occurred during the Phase Two study period (September to November 2003). As a result the modelled exposure zone boundaries used in the Phase 2 study may not have been good estimates of actual exposure during the study period. As a consequence, NSW Health undertook to re-analyse the data collected in the Phase 2 study.

This report details the outcomes of the re-analysis of the Phase 2 survey data using the new modelled exposure zones for the study period. The new exposure zones took into account both stack and portal emissions and were modelled by Commonwealth Scientific and Industrial Research Organisation (CSIRO) – Marine and Atmospheric Research using actual emission data collected over the study period.

We used the survey data collected from respondents in the initial Phase 2 study and assigned the respondents to the new exposure zones. We then compared the prevalence of eye, nose and throat symptoms between areas with relatively high, medium and low levels of exposure to emissions from the M5 East stack and portals.

The limitations highlighted in the original Phase 2 study still apply to the findings of this re-analysis. In addition, further limitations were also introduced by the use of different zones for sampling and analysis.

Our conclusions do not differ from those reported in April 2004, in that the study did not demonstrate an association between prevalence of reported symptoms and modelled emissions from the M5 East tunnels. The study design did not allow any conclusions to be made regarding an association between portal emissions and health effects.

With any epidemiological study, there are limits in the study's ability to detect an effect. This study was not designed to assess long-term health impacts of emissions. It does not exclude the possibility that certain sensitive individuals do experience symptoms which are related to the M5 East stack. There is no feasible scientific method to establish or disprove either of these possibilities in relation to the M5 East motorway.

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SECTION 1

Background

The M5 East Motorway is a 10 km long, four-lane dual carriage motorway, which links central Sydney with Sydney's southwest. Four kilometres of the M5 East Motorway is a tunnelled section which is ventilated via a single exhaust stack, located in Turrella. The tunnels opened to traffic in December 2001.

In the first half of 2002, after the opening of the M5 East tunnels, NSW Health received over 80 complaints from local residents who believed their health was being adversely affected by the M5 East stack exhaust. Monitoring around the stack showed that the levels of measured pollutants had not changed from before to after the tunnel opening. Following consultation with key stakeholders and experts, NSW Health developed a multi-phase study to investigate whether there was an association between emissions from the stack and symptoms reported by local residents.

The first phase of the study was conducted to identify and categorise symptoms reported by local residents. Residents were offered clinical consultations with physicians from the Royal Prince Alfred Hospital in April and May 2003.[1] This phase formed a base for the second phase of the investigation by identifying which symptom(s) had a potential relation to the M5 East stack. Symptoms of eye, nose and throat irritation were identified as those that should be asked about in the second phase of the investigation.

Phase 2[2] of the investigation was undertaken from October to November 2003. The NSW Health Computer Assisted Telephone Interview (CATI) facility interviewed residents around the M5 East stack to determine the prevalence of eye, nose and throat symptoms in the local community. All local residents were initially assigned into one of three exposure zones according to their estimated level of exposure to stack emissions. These emissions were modelled by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) – Marine and Atmospheric Research using an analysis of emitted stack pollutants and pollutant readings at local monitoring sites from February 2002 to January 2003. A random selection of residents was then interviewed with equal numbers selected from each of the three zones. Prevalence of eye nose and throat symptoms was compared across the exposure zones. The Phase Two investigation found no evidence of an association between prevalence of reported symptoms and modelled emissions from the M5 East stack. Based upon this finding and the limitations inherent to any further studies, it was concluded that there was no scientific justification to conduct further epidemiological studies into the reported health effects on the community surrounding the M5 East stack.

The ventilation system for the tunnel was designed to ventilate all emissions via the stack as far as practical and consequently the modelling used in the Phase Two study assumed that all tunnel emissions were via the stack. In July 2004 NSW Health was advised that significant amounts of portal emissions had occurred during the Phase Two study period (September to November 2003). As a result the exposure zones used to explore a potential association between emissions and health effects may have been inaccurate.
NSW Health undertook to re-analyse the data collected in Phase 2 using new exposure zones that took into account both stack and portal emissions. This report presents the findings of this re-analysis.

Ethical approval for this investigation was obtained in August and September 2003 from the Ethics Review Committees of South Eastern Sydney (Southern Section) and Central Sydney Area Health Services.

SECTION 2

Objectives

The objectives of this study were to determine:

1 the prevalence of eye, nose and throat symptoms in remodelled exposure zones using self reported data from the study period (September to November 2003)

2 whether the prevalence of symptoms is associated with the level of modelled pollutant exposure from the M5 East stack and portals.

Study methods

This re-analysis of Phase 2 of the M5 East health investigation retains the community-reported health data gathered during October and November 2003, but reallocates respondents to newly estimated tunnel emission exposure zones.

The study period is defined as September to November 2003, as the telephone survey asked adults living in the vicinity of the M5 East stack about symptoms experienced in the month before their telephone interview.

Symptoms of interest, identified in Phase 1, related to eyes (soreness, scratchiness, dryness, grittiness, burning and watering), the nose (itchiness, sneezing, dryness, runny, congestion) and throat (soreness, dryness).

Symptom prevalence is compared between new zones with relatively low, medium and high exposure to modelled M5 East stack and portal emissions during the period September to November 2003, and any exposure-response relationship explored.

3.1 Assessment of exposure in the study area

Modelling of exposure to emissions from the M5 East stack was based on in-stack hourly averaged data and portal flow data from September to November 2003. This information was supplied by the Roads and Traffic Authority (RTA) and included:

- number of fans operating
- volume flow rate
- temperature
- concentrations of fine particles with a diameter small than 10 micrometres (PM10) and oxides of nitrogen (NOx).

In the original analysis comparable annual average flow data for the 12 months between February 2002 to January 2003 was used to determine the modelled zones.

Modelling was undertaken using The Air Pollution Model (TAPM) version 3.0. As in Phase 2, modelled ground level oxides of nitrogen was used to determine the exposure zones. The average (three month), peak and second-highest one-hour ground level NOx concentrations (due to stack and portal emissions) were modelled. Appendix A contains a complete description and outputs from this modelling.

3.2 Definition of new study exposure zones

The report undertaken by CSIRO – *Marine and Atmospheric Research (Appendix A)* concluded that:

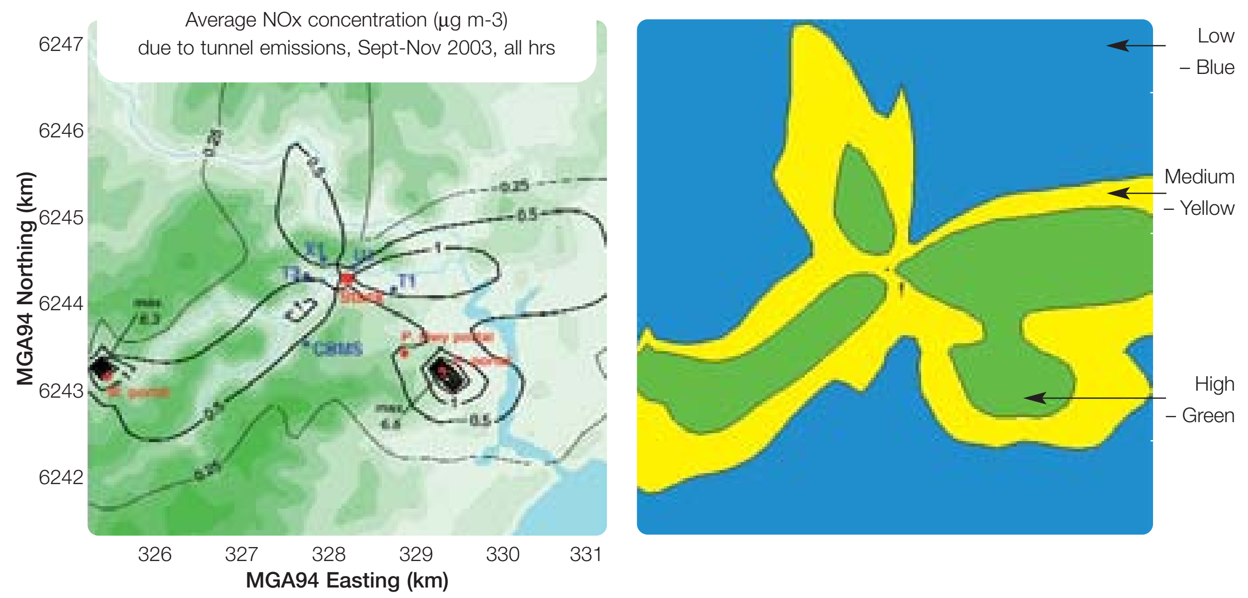
> *Exposure zones based on average ground level NOx concentrations for the September to November 2003 period modelled in this report have a very similar overall pattern to those obtained from an earlier analysis using modelling for the year from February 2002 to January 2003* (Phase 2).

We defined new exposure zone cut points to maintain the same ratio of pollutant concentrations defining the high:medium and medium:low boundaries and a similar number of residents per zone as used in the original analysis. This has resulted in different cut points values due to different predicted emission levels.

The following exposure zones were created from the modelled average NOx concentrations (September-November 2003) using ERMapper v7.1 image processing software:[3]

High exposure zone	greater than 0.54µg m^{-3} NOx
Medium exposure zone	between 0.30µg m^{-3} and 0.54µg m^{-3} NOx
Low exposure zone	less than 0.30µg m^{-3} NOx

Figure1. Modelled contours of average ground level concentrations of oxides of nitrogen from stack and portal emissions, and assigned exposure zones



The methodology of the following sections (Telephone Survey and Questionnaire), is unchanged from Phase 2 as no additional respondent data was collected for the re-analysis:

3.3 Administration of the telephone survey

Telephone interviews were conducted by the NSW Health Survey CATI facility from 1 October to 18 November 18 2003.* Telephone interviews were undertaken using the NSW Health Survey methodology.[4] As questions on the symptoms of interest related to the participants' experience in the previous four weeks, the telephone survey assessed symptomatology between September and November 2003.

3.4 Outcome assessment – Questionnaire

The data obtained from the questionnaire in Phase 2 of the investigation was re-used in this re-analysis. The questionnaire was designed to assess the primary outcome measures (symptoms) and also to measure those factors that could confound or modify any potential association between the exposure zones and these outcomes.

Principal outcome measures were eye, nose and throat symptoms. Potential confounders were age, sex, exposure to cigarette smoke, and the presence of internal garaging** and potential effect modifiers were age, general health, asthma and time spent at home.

Questions on demographics and household characteristics, general and mental health, chemical sensitivity, smoking status, environmental tobacco exposure, garaging of vehicle, home heating and asthma were taken from the NSW Health Survey.[5] By using questions that were consistent with the NSW Health Survey, comparisons between the survey area and the state could be undertaken.

Questions on eye symptoms were developed using the *McMonnies Dry Eye questionnaire*.[6] Questions on environmental worry were developed from Lipscomb et al[7] and Shusterman et al.[8] The research team developed questions on nose, throat and mouth symptoms, time usually spent at home, awareness of the study, and odour.

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* Interviews in languages other than English were undertaken until 21 December 2003. No difference was found between including or excluding these interviews from the data set.

** Internal garaging has been linked with increased levels of the motor vehicle pollutant benzene in the household (National Industrial Chemical Notification and Assessment Scheme (NICNAS) Benzene – Priority Existing Chemical Assessment Report No. 21 NICNAS 2001).

3.5 Statistical validity of the re-analysis of sampled data

Expert advice on the appropriate statistical methods to employ to re-analyse the telephone survey data was obtained. The statistical issues are explained in detail in Appendix B. In brief, the advice sought related to the most appropriate method to analyse the original survey data now that it has been reassigned to new exposure zones.

This advice concluded that :

> *'...the approach of using the new* (exposure) *zone* (September to November 2003) *variable for analysis and the old (*exposure) *zone* (February 2002 to January 2003) *variable for calculating estimation weights is considered to be the most appropriate method, and other approaches could result in biased effect estimates.'*

The full report from the statistics consultancy is located in Appendix B.

3.6 Re-analysis

As with Phase 2 the survey sample was weighted to adjust for the differences in the probabilities of selecting a particular person in a household, based on the number of eligible adults in that household. Post stratification weights were used to reduce the effect of differing non-response rates among males and females and age groups on the survey estimates. These weights were adjusted for differences between the age and sex structure of the survey sample and population estimates for each exposure zone. Further information about the general weighting process is provided elsewhere.[4] The population estimates were derived from *Australian Bureau of Statistics 2001 Census Community Profiles Series*.[9] Zone populations were estimated by the allocation of collector district populations to the zone in which collector district centroids were located.

Design-based analysis was performed to account for features of the sample design[10] and provide approximately unbiased estimates and appropriate standard errors.[11] Call and interview data were manipulated and analysed using SAS v.8.0 statistical software package.[12] The SURVEYMEANS procedure was used to calculate 95 per cent confidence intervals for descriptive analysis. Additional analysis and multivariable modelling were undertaken using SUDAAN 8.0.1 statistical software package.[13] The SURVIVAL procedure was used for multivariable modelling with Taylor series linearization methods used for variance estimation.

The association between exposure zone and symptom outcomes was examined using a generalized linear model with log link, fitted with a Cox's proportional hazards model with constant follow-up time. This approach was used since the odds ratio, a measure of effect derived from logistic regression models, is a poor estimate of the risk ratio with common outcomes (>10%).[14,15]

The independent predictor of new exposure zone was modelled as a categorical variable using the low zone as the reference category. The following covariates were included in the multivariable analysis as clinically relevant confounders: sex, age in years (continuous scale), exposure to cigarette smoke (exposed / unexposed), and exposure to emissions from garaged vehicles (exposed / unexposed). Effect modification was tested for clinically plausible effect modifiers: current asthma (yes / no), general health (excellent, very good, good / fair, poor) and age group.

The analysis comprised two major areas:

1 Profile of the new zones compared to each other and the state where possible –

Age, sex, education level, general health (rated good or above), poor mental health (if scored as high or very high psychological distress), asthma, indoor air pollution sources, smoking, home ownership and chemical sensitivity were compared between zones, and between the study area as a whole and NSW.

Environmental worry, exposure time, odour and awareness that the survey related to the M5 investigation, were compared across the three zones only.

2 Comparison of symptoms of interest across new zones –

i **Scores were calculated from individual reports of symptoms by the following method:**

a *Calculation of eye symptom / nose symptom / throat symptom scores:* If the participant answered 'yes' to any one of the six eye symptoms they were noted as having an 'Eye Symptom'. Likewise if a participant answered 'yes' to any one of the five nasal symptoms they were noted as having a 'Nose Symptom' and if a participant answered 'yes' to any of the two throat symptoms, they were noted as having a 'Throat Symptom'.

b *Calculation of more frequent and / or severe index for eye nose and throat:* To calculate the more frequent and / or severe score, each frequency (sometimes, often, constantly) and severity response (mild, moderate, severe) was assigned a value from 1-3. The frequency and severity were then multiplied together to come up with a frequent and / or severe score. If that score was over 1 (that is if the participant had a symptom greater than sometimes of a *mild* nature) then the participant was defined as having a more frequent and/or severe eye, nose or throat symptom.

c *Dry Eye Score:* Responses to the questions from the McMonnies Dry Eye Questionnaire were scored according to standard methodology. The dry eye prevalence was determined by a score greater than 11. Dry eye prevalence was then compared across zones, and to prevalence identified in separate studies on the populations of Melbourne, Victoria[16] and Mackay, Queensland.[17]

ii. Symptom scores were compared across new exposure zones by:

a calculating crude point prevalence estimates with 95% confidence intervals across new exposure zones

b calculating crude prevalence rate ratios with 95% confidence intervals across new exposure zones. This was done for the high and medium zones using the low exposure zone as the reference category

c modelling adjusted prevalence rate ratios with 95% confidence intervals. Again this was done for the high and medium zones using the low exposure zone as the reference category.

Results

4.1 Survey participants

The data obtained from the Phase 2 investigation had 1,431 participants (59% participation rate). Assigning the 1,431 participants to the new exposure zones resulted in 410 subjects in the high exposure zone, 486 subjects in the medium exposure zone and 533 subjects in the low exposure zone.

The age, and education level of participants did not differ between the zones (Table 4.1).

The overall prevalence of certain common conditions in the study area was similar to that observed, using the same NSW Health Survey instrument, across the whole of NSW (Table 4.2).

There was a significant difference between zones in the proportion of the population that was aware the survey was related to the M5 East Stack. Awareness was lowest in the low exposure zone. Compared to the NSW population, the three zones had lower levels of internal garaging.

Table 4.1. Age, sex and total participants by new zone

		High zone (n = 410)	Medium zone (n = 486)	Low zone (n = 533)	Overall (n = 1,429)
Age	Mean (95% CI)	45 (41 - 48)	47 (44 - 49)	44 (42 - 54)	44 (43 - 46)
Sex	Female%	53.0%	46.6%	49.8%	49.3%
Education level	Year 10 (%) (95%CI)	26.2 19.3-33.1	31.0 24.4-37.7	22.9 18.4-27.3	25.2 21.7-28.7
	HSC (%) (95%CI)	24.9 17.3-32.5	21.5 15.2-27.8	23.2 18.4-28.1	22.9 19.3-26.5
	TAFE (%) (95%CI)	21.3 15.6-26.9	21.7 16.1-27.2	23.1 18.7-27.6	22.7 19.4-25.9
	University (%) (95%CI)	27.7 20.3-35.1	25.8 20.3-31.4	30.8 25.7-35.9	29.2 25.5-33.0

Table 4.2. Respondent characteristics by new zone

	High zone % (95% CI)	Medium zone % (95% CI)	Low zone % (95% CI)	Overall % (95% CI)	State* % (95%CI)
General health[i]	84.7 (80.5-89.0)	76.7 (70.7-82.7)	81.5 (77.8-85.2)	80.5 (77.6-83.4)	80.7 (79.7-81.7)
Mental health[ii]	9.2 (5.8-12.7)	15.2 (9.6-20.7)	13.2 (9.7-16.7)	13.3 (10.6-16.1)	12.2 (11.4-13.1)
Diagnosed asthma[iii]	6.8 (4.0-9.7)	9.9 (4.8-15.0)	11.6 (8.1-15.1)	10.8 (8.1-13.4)	10.6 (9.8-11.3)
Environmental worry[iv]	15.8 (11.1-20.4)	13.7 (9.8-17.7)	11.8 (8.4-15.2)	12.6 (10.1-15.1)	N/A
Exposure time[v]	49.1 (41.2-57.0)	51.5 (44.5-58.5)	49.6 (44.3-54.9)	50.1 (46.1-54.1)	N/A
Odour detection[vi]	29.2 (21.6-36.9)	24.2 (17.7-30.7)	23.4 (19.2-27.7)	24.1 (20.8-27.4)	N/A
Awareness of survey link to M5 stack[vii]	12.6 (8.8-16.5)	10.8 (7.4-14.2)	2.2 (1.0-3.3)	5.2 (4.0-6.4)	N/A
Indoor heating pollution[viii]	27.1 (20.3-33.9)	25.9 (19.7-32.0)	28.4 (23.4-33.4)	27.6 (23.9-31.3)	22.6 (20.6-24.7)
Home ownership[ix]	63.5 (55.2-71.8)	66.7 (59.7-73.7)	58.7 (53.3-64.1)	61.1 (57.0-65.1)	N/A
Personal smoking[x]	17.9 (12.2-23.7)	24.8 (18.5-31.1)	26.6 (21.9-31.3)	25.4 (21.9-28.9)	21.4 (20.3-22.4)
Smoke free households[xi]	82.0 (76.3-87.8)	85.5 (80.5-90.4)	78.9 (74.5-83.3)	80.8 (77.6-84.0)	81.0 (80.0-82.0)
Internal garaging[xii]	11.3 (6.1-16.5)	8.4 (5.0-11.8)	11.8 (8.2-15.3)	10.9 (8.4-13.5)	22.2 (20.0-24.3)
Chemical sensitivity[xiii]	1.4 (0.3-2.6)	3.6 (0.4-6.8)	2.4 (0.7-4.0)	2.6 (1.2-4.0)	2.9 (2.5-3.4)
Teeth and gums symptoms[xiv]	18.5 (12.5-24.5)	20.1 (14.8-25.4)	19.0 (14.6-23.5)	19.2 (16.0-22.5)	N/A

* Values reported only where there are State-wide data

i General health rated as excellent, very good or good.

ii Kessler 6 scored at high or very high psychological distress.

iii Been told by a doctor or at a hospital that they had asthma AND had symptoms of asthma or taken treatment for asthma in the past 12 months.

iv Prevalence of the very worried category.

v Most of time spent at this address.

vi Foreign odours detected everyday or few days per week.

vii Participant aware that survey was about the M5 East stack.

viii Unflued gas heater, slow burning combustion heater, open fire place or kerosene heater being the usual way to heat areas in the home.

ix Home owner, mortgagee, life tenure or rent / buy scheme.

x Participant smoked daily or occasionally.

xi Household is smoke free.

xii Garage is attached to house and has internal access.

xiii Participant has been diagnosed with chemical sensitivity.

xiv Soreness of teeth or gums constantly, often or sometimes.

4.2 Symptoms by zone

4.2.1 Eye symptoms

4.2.1.1 Prevalence and crude rate ratios

Overall, 50% of people reported any occurrence of one or more of the six eye symptoms and 17.2% reported one or more 'More Frequent and/or Severe Eye Symptoms'. Table 4.3 presents the prevalence of eye symptoms by exposure zone.

Table 4.3. Eye symptoms, frequency and severity by new zone

	Any eye symptom		More frequent and/or severe eye symptoms	
	%	(95% CI)	%	(95%CI)
High zone	51.6	(43.8-59.5)	15.0	(10.2-19.7)
Medium zone	57.3	(50.6-64.1)	21.3	(15.4-27.1)
Low zone	47.1	(41.8-52.4)	16.0	(12.2-19.8)
Overall	50.0	(46.0-54.0)	17.2	(14.2-20.1)

The prevalence of dry eye, classified according to the modified McMonnies Dry Eye Questionnaire, was 6.6% (Table 4.4). This is within the range observed in two previous general population surveys in Melbourne, Victoria and Mackay, Queensland (1.5-16.3%).

Table 4.4. McMonnies dry eye prevalence by new zone

	%	(95% CI)
High zone	7.1	(3.8-10.5)
Medium zone	7.5	(3.4-11.5)
Low zone	6.3	(3.9-8.7)
Overall	6.6	(4.7-8.6)

The crude prevalence rate ratios of 'Eye Symptoms' differed between zones. The rate of eye symptoms in the medium exposure zone was significantly higher than the rate in the low exposure zone. Rates of eye symptoms were not significantly elevated in the high exposure zone. The crude prevalence rate ratios of 'More Frequent and/or Severe Eye Symptoms' did not differ between the high and low exposure zones or between the medium and low exposure zones (Table 4.5).

4.2.1.2 Modelling

The higher rate of eye symptoms in the medium zone compared to the low zone persisted after adjustment for potential confounders of age, sex, exposure to cigarette smoke and internal garaging (Table 4.5).

Table 4.5. Crude and adjusted prevalence rate ratios for eyes

	Any eye symptom		More frequent and/or severe eye symptoms	
	Crude prevalence rate ratio (95% CI)	Adjusted prevalence rate ratio (95% CI)	Crude prevalence rate ratio (95% CI)	Adjusted prevalence rate ratio (95% CI)
High zone	1.10 (0.91-1.32)	1.11 (0.92-1.34)	0.94 (0.63-1.39)	0.95 (0.64-1.40)
Medium zone	1.22 (1.03-1.43)	1.23 (1.05-1.45)	1.33 (0.92-1.91)	1.28 (0.89-1.83)
Low zone	1.00 (REF)	1.00 (REF)	1.00 (REF)	1.00 (REF)

Prevalence rate ratio adjusted for age, sex, exposure to cigarette smoke and internal garaging. Crude prevalence rate ratios of these confounders may be found in Appendix C.

4.2.2 Nose symptoms

4.2.2.1 Prevalence and crude rate ratios

Overall, 66.6% of people reported any occurrence of one or more of the five nose symptoms and 32.9% reported one or more 'More Frequent and/or Severe Nose Symptoms'. Table 4.6 presents prevalence of nose symptoms by exposure zone.

Table 4.6. Nose symptoms, frequency and severity by new zone

	Any nose symptoms		More frequent and/or severe nose symptoms	
	%	(95%CI)	%	(95%CI)
High zone	60.3	(52.4-68.2)	30.8	(24.0-37.7)
Medium zone	67.4	(61.0-73.9)	38.2	(31.4-45.0)
Low zone	67.2	(62.2-72.2)	31.2	(26.5-36.0)
Overall	66.6	(62.9-70.4)	32.9	(29.2-36.6)

The crude prevalence rate ratios of 'Nose Symptoms' and 'More Frequent and/or Severe Nose Symptoms' did not differ between the high and low exposure zones or between the medium and low exposure zones (Table 4.7).

4.2.2.2 Modelling

After adjusting for the potential confounders of age, sex, exposure to cigarette smoke and internal garaging there was still no evidence of an association between zones and symptoms (Table 4.7).

Table 4.7. Crude and adjusted prevalence rate ratios for nose

	Any nose symptom		More frequent and/or severe nose symptoms	
	Crude prevalence rate ratio (95% CI)	Adjusted prevalence rate ratio (95% CI)	Crude prevalence rate ratio (95% CI)	Adjusted prevalence rate ratio (95% CI)
High zone	0.90 (0.77-1.04)	0.90 (0.77-1.04)	0.99 (0.76-1.29)	1.00 (4.76-1.31)
Medium zone	1.00 (0.89-1.13)	1.01 (0.89-1.14)	1.22 (0.97-1.55)	1.20 (0.96-1.52)
Low zone	1.00 (REF)	1.00 (REF)	1.00 (REF)	1.00 (REF)

Prevalence rate ratio adjusted for age, sex, exposure to cigarette smoke and internal garaging. Crude prevalence rate ratios of these confounders may be found in Appendix C.

4.2.3 Throat symptoms

4.2.3.1 Prevalence and crude rate ratios

Overall, 33.1% of people reported any occurrence of one or more of the two throat symptoms and 14.9% reported one or more 'More Frequent and/or Severe Throat Symptoms'. Table 4.8 presents prevalence of throat symptoms by exposure zone.

Table 4.8. Throat symptoms, frequency and severity by new zone

	Any throat symptom		More frequent and/or severe throat symptoms	
	%	(95% CI)	%	(95%CI)
High zone	31.0	(23.4-38.6)	13.7	(9.0-18.4)
Medium zone	32.9	(26.5-39.3)	15.7	(10.7-20.6)
Low zone	33.5	(28.4-38.6)	14.8	(11.1-18.5)
Overall	33.1	(29.3-36.9)	14.9	(12.1-17.7)

The crude prevalence rate ratios of 'Throat Symptoms' and 'More Frequent and/or Severe Throat Symptoms' did not differ between the high and low exposure zones or between the medium and low exposure zones (Table 4.9).

4.2.3.2 Modelling

When adjusting the crude prevalence rate ratios for the potential confounders of age, sex, exposure to cigarette smoke and internal garaging there was still no evidence of an association between zones and symptoms (Table 4.9).

Table 4.9. Crude and adjusted prevalence rate ratios for throat

	Any nose symptom		More frequent and/or severe nose symptoms	
	Crude prevalence rate ratio (95% CI)	Adjusted prevalence rate ratio (95% CI)	Crude prevalence rate ratio (95% CI)	Adjusted prevalence rate ratio (95% CI)
High zone	0.93 (0.69-1.24)	0.96 (0.73-1.28)	0.92 (0.60-1.41)	0.97 (0.63-1.49)
Medium zone	0.98 (0.77-1.26)	1.01 (0.79-1.30)	1.06 (0.71-1.58)	1.07 (0.72-1.59)
Low zone	1.00 (REF)	1.00 (REF)	1.00 (REF)	1.00 (REF)

Prevalence rate ratio adjusted for age, sex, exposure to cigarette smoke and internal garaging. Crude prevalence rate ratios of these confounders may be found in Appendix C.

Discussion

A previous discussion of this study has been provided in the Phase 2 report and should be read in conjunction with this document.

This re-analysis of the M5 East health investigation has not demonstrated an association between the emissions from the M5 East tunnels and reports of eye, nose or throat symptoms. The analysis has found a higher proportion of residents from the medium zone compared to the low zone reporting eye symptoms but this finding is not replicated when comparing residents from the high zone to those from the low zone. These results were unchanged when adjusted for potential confounders (age, sex, exposure to cigarette smoke and internal garaging).

The relevance of the isolated finding of a higher prevalence of eye symptoms in the medium exposure zone to the M5 East tunnels emissions is uncertain. The use of 95% confidence intervals to determine significance means that one in 20 comparisons will be significant due to chance alone. In this study we have undertaken 14 comparisons, so it is reasonably likely that one significant association could be reported by chance. An important criterion to indicate causation in epidemiology is demonstration of dose-response effect. That is, the observed effect should increase as the dose (i.e. exposure) increases. If the detected association was due to M5 tunnel emissions then one would expect to see a similar or larger effect in the high exposure zone and that was not demonstrated in this case.

5.1 Study power

The ability of the study to establish a 'true' association between exposure and health effects (study power) is determined by the number of individuals surveyed, the prevalence of the symptom and the minimum effect size to be detected. Re-analysis of the Phase 2 data using exposure zones modelled from September to November 2003 slightly reduced the power of the study. It was however noted in the independent review undertaken by the University of Wollongong Centre for Statistical and Survey Methodology that analysis undertaken in this manner was the most appropriate method and that other approaches could result in biased effect estimates.

5.2 Modelled exposure zones

With the release of the Phase 2 Investigation report came community concern as to the representativeness of the exposure zones. It was argued that modelling annual averages for pollutants from February 2002 to January 2003 would not represent the actual exposure experienced by participants during the survey period (September to November 2003). While the exposure zones (February 2002 to January 2003 & September to November 2003) are similar, the modelling and analysis using the new exposure zones (September to November 2003) provides a more valid estimate of potential exposure during the study period.

5.3 Portal emissions

The Phase 2 study was designed to examine whether there were population health effects associated with the M5 East stack emissions. It was not designed (nor did it sample) to determine whether there were any population health effects from portal emissions. This re-analysis therefore cannot be used to infer or discount any possible health effects to people around the portals from portal emissions. An insufficient number of people living near the portals were sampled to allow a separate analysis of the prevalence of health effects for this group.

5.4 Validity of exposure measure

As with the original Phase 2 analysis, allocation of respondents to exposure to M5 East tunnel emissions is based on modelled exposure. We used a modelled estimate of exposure as the contribution of the M5 East tunnels to community air pollution is expected to be too small to measure and is not distinguishable from background pollutants. As a consequence exposure estimates cannot be directly validated. However as accurate records of tunnel usage, air flows and pollutant concentrations were available to combine with recorded weather data the estimation of exposure to emissions during the study period is likely to be fairly robust.

In undertaking this analysis we have again based the exposure assessment on the estimated average exposure to oxides of nitrogen only.

The modelling undertaken by CSIRO Marine and Atmospheric Research for the Phase 2 Investigation modelled NOx, PM_{10} and Non Methane Volatile Organic Compound pollutant levels. Exposure patterns from all three pollutants were similar. Therefore NOx levels are likely to be a good proxy measurement of overall pollutant exposure, and are commonly used in studies of the health effects of traffic emissions.

There is also some debate about whether peak or average exposure is the more important with respect to the potential for health effects. There is no consensus on this matter. However, there is considerable similarity between the areas of highest peak and average impact, so the choice of either is unlikely to substantially alter the findings.

In summary, the new exposure zones are likely to be the most representative estimates available of actual tunnel emissions exposure during the study period.

Other aspects of the study design and interpretation are as discussed in the April 2004 Phase 2 report.

5.5 Limitations

The limitations highlighted in the original Phase 2 study still apply to the findings of this re-analysis and should be read in conjunction with this report. In addition, further limitations were introduced by the use of different zones for sampling and analysis.

SECTION 6

Conclusions

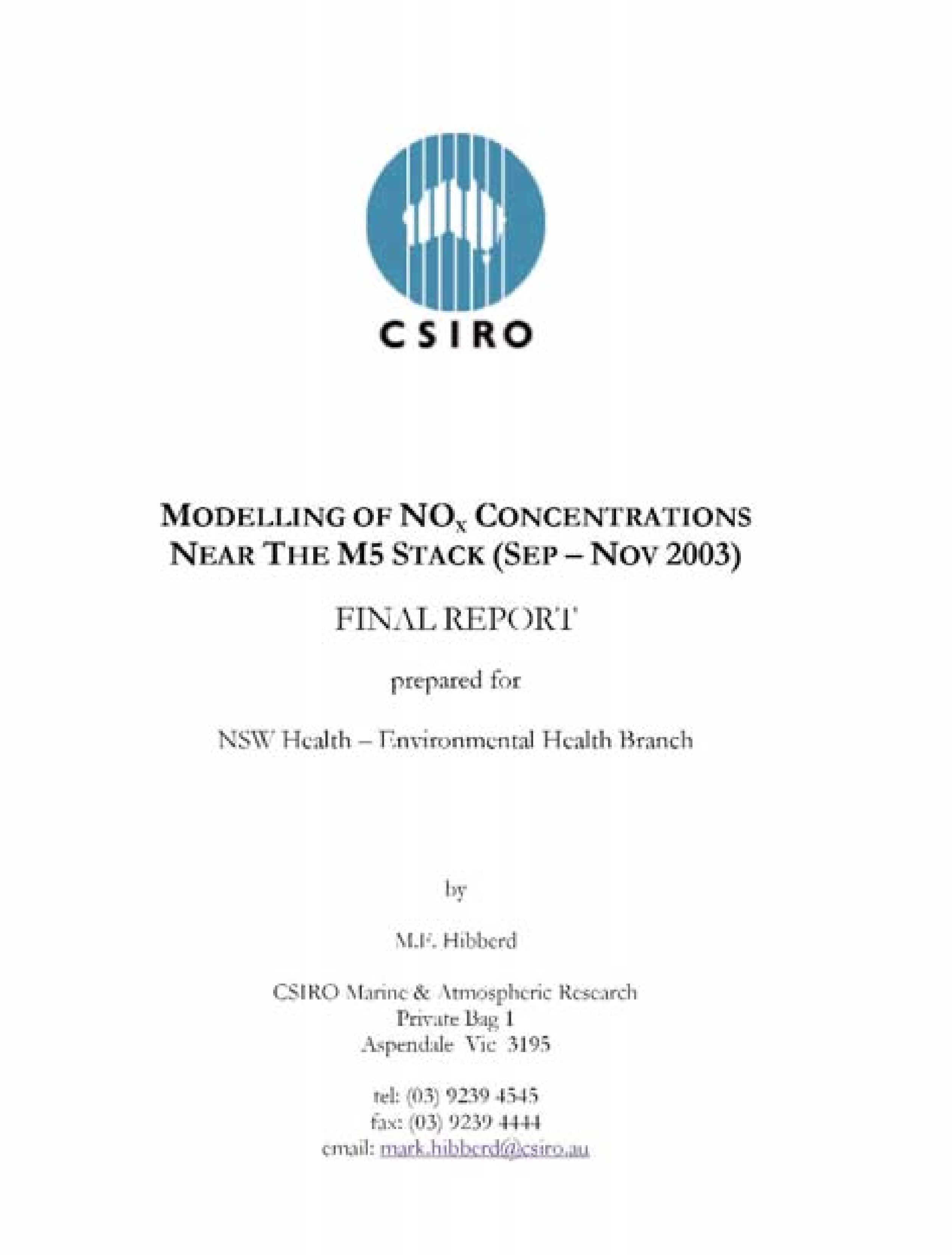
This report describes the re-analysis of the second phase of an investigation to determine if community health complaints are related to emissions from the M5 East tunnels. The re-analysis was conducted following information that portal emissions may have substantially changed the pattern of exposure assumed in the original analysis. Our conclusions do not differ from those reported in April 2004, in that the study did not demonstrate an association between prevalence of reported symptoms and modelled emissions from the M5 East tunnels. The study design does not allow any conclusions to be made regarding an association between portal emissions and health effects.

The methodology used represents the best possible epidemiological approach to determining if there were population health effects from the M5 East stack emissions. However, as with any epidemiological study, there are limits in its ability to detect an effect. In particular, this study was not designed to assess long-term health impacts of emissions. Furthermore, it does not exclude the possibility that certain highly sensitive individuals do experience symptoms that are related to the M5 East stack. There is no feasible scientific method to establish or disprove either of these possibilities.

The study found a potential for higher exposure to air pollutants around the tunnel portals during periods of portal emissions. However as the study respondents were not selected to investigate the effect of portal emissions we are unable to determine if there were any health effects associated with portal emissions.

APPENDIX A

CSIRO Report



CSIRO

MODELLING OF NO_x CONCENTRATIONS NEAR THE M5 STACK (SEP – NOV 2003)

FINAL REPORT

prepared for

NSW Health – Environmental Health Branch

by

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Executive Summary

A modelling study was undertaken using The Air Pollution Model (TAPM) to predict the impact of NO_x emissions from the M5-East tunnel (both stack and portal emissions) on a 6 x 6 km region surrounding the stack for the period from September to November 2003. Because exposure levels depend on both the concentration and the time spent in the area and many people spend significant daytime periods outside the area, the concentration statistics were reported both as all-hour statistics and excluding weekdays hours from 08:00 to 18:00 hours.

The main results are:

- The greatest impact of the tunnel emissions occurs near the portals due to portal emissions. This is because of the significant portal emissions (up to 2.6 g s^{-1} NO_x) compared to stack emissions of up to 14 g s^{-1} NO_x. The portal emissions occur at ground level whereas the stack emissions are released well above the ground and are subject to much greater mixing and dilution before reaching the ground.
- The greatest difference when weekday data from 08:00 to 18:00 hours are excluded is lower NO_x concentrations to the north of the stack.
- Overall, there is reasonable agreement between the shapes of the concentration zones for the three concentration statistics – maximum 1-hour average, second highest 1-hour average, and average concentrations.
- Given this reasonable agreement and the nature of the health symptoms survey, it is considered to be most appropriate to use the average concentrations for determining the exposure zones in analysis of the survey data.
- Exposure zones based on average ground-level NO_x concentrations for the September to November 2003 period modelled in this report have a very similar overall pattern to those obtained from an earlier analysis using modelling for the year from February 2002 to January 2003.

Table of Contents

1 Introduction

The M5 motorway in southern Sydney includes a 4 km long tunnel that is ventilated through a single exhaust stack located in Turella, about 10 km south-west of the Sydney CBD. The M5 East stack is designed to remove all motor vehicle exhaust emissions from the tunnel but it has been found that emissions from the portals occur on some occasions.

In late 2003, NSW Health conducted a cross-sectional survey of health symptom prevalence in the local population surrounding the M5 East exhaust stack. In the survey, respondents were asked about symptoms occurring in the four weeks preceding the interview date.

In an earlier analysis of these survey data, NSW Health used exposure zones based on the annual average NO_x concentration modelled in a previous report by CSIRO (Hibberd, 2003) using TAPM for the year from February 2002 to January 2003. NSW Health plans to reanalyse the survey data using exposure zones based on NO_x concentration fields obtained from TAPM modelling for the survey period with the impact of portal emissions included.

Figure 1 is a site map showing the location of the stack and surrounding monitoring sites. Table 1 lists the coordinates of the stacks, monitoring sites and tunnel portals using the 1994 Map Grid of Australia (MGA) coordinate system.

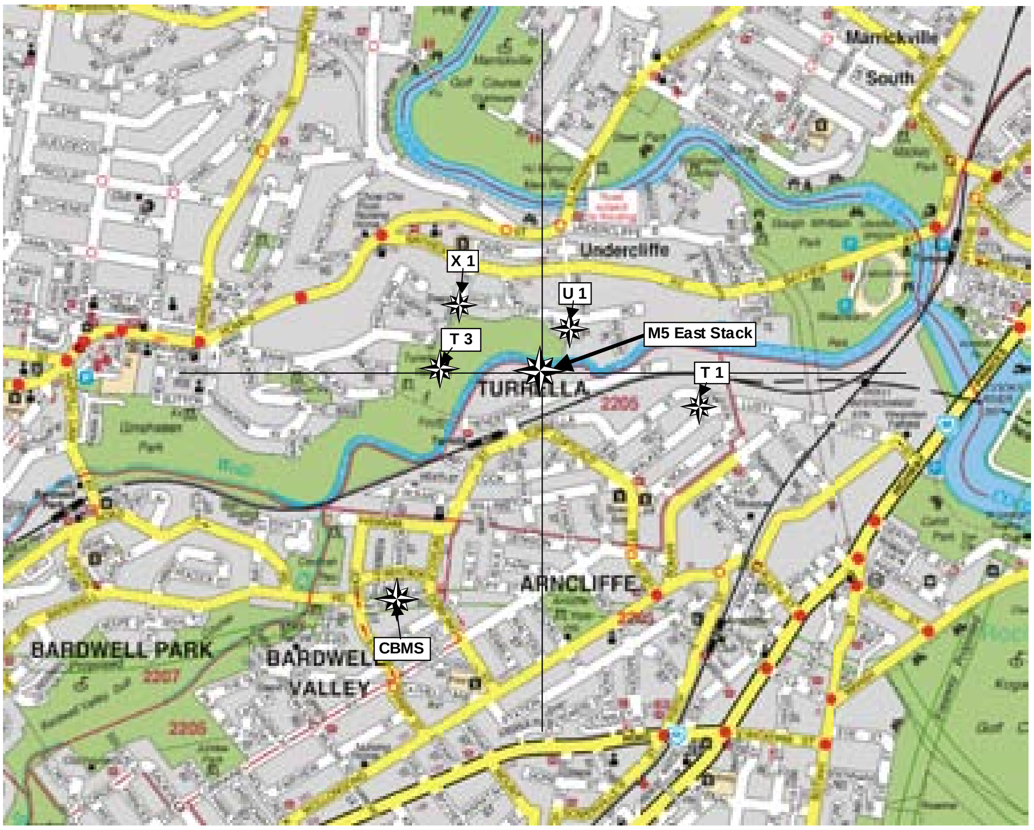

Figure 1. Location map showing a 3.2 km by 2.5 km region with the M5 East stack near the centre and the surrounding monitoring stations. T1 at the corner of Walker and Thompson Streets, Turrella; U1 at the corner of Jackson Place and Highcliff Road, Undercliffe; X1 at the corner of Wavell Parade and David Street, Earlwood; and CBMS (community based monitoring station) at Gipps Street Lookout, Bardwell Valley.

Table 1. MGA94 coordinates of the M5-East stack, M5 monitoring sites, and M5 tunnel portals (with anemometer code in brackets).

Site	**MGA94 Coordinates**	
	Easting (km)	**Northing (km)**
M5 Stack	328.206	6244.291
Monitoring Sites		
T1 Cnr Walker & Thompson Sts	328.741	6244.169
U1 Cnr Jackson Pl & Highcliff Rd	328.280	6244.421
X1 Cnr Wavell Pde & David St	327.930	6244.512
CBMS (Community Based Monitoring Station) Gipps St Lookout	327.731	6243.531
Tunnel Portal Locations		
Western End near Bexley Rd		
Mainline West entry (ASS101)	325.430	6243.350
Mainline West exit (ASS210)	325.450	6243.320
Eastern End near Marsh St		
Mainline East entry (ASS207)	329.360	6243.130
Mainline East exit (ASS104)	329.380	6243.150
Marsh St entry (ASS611)	329.270	6243.200
Marsh St entry (ASS706)	329.290	6243.250
Princess Highway exit (ASS505)	328.865	6243.430

2 Scope of Work

The scope of work outlined in the project brief is as follows:

1. Quality control the supplied stack emissions data and set up stack emission file for the modelling.

2. Estimate the portal NO_x emissions and set up the portal emissions files for the modelling. Compute the hourly emissions from each portal based on portal air flow volumes, vehicle traffic flows, supply fan inflow volumes, and NO_x emission factors appropriate for the M5 tunnel.

3. Run the CSIRO air pollution model TAPM (Version 3.0) for the period September 2003 to November 2003 for a region of 6 x 6 km centred on the M5 stack with a meteorological grid spacing of 300 m and pollution grid spacing of 150 m. The pollutant sources in the modelling will be stack and portal emissions of NO_x.

4. Validate the wind data from the TAPM meteorological module by comparing against observations from the ambient air quality monitoring sites U1 and CBMS. Evaluate the sensitivity of the modelled ground-level concentrations to the use of the wind data assimilation option in TAPM.

5. Use the model output to generate contour plots of average, peak, and second-highest 1-hour NO_x ground-level concentrations due to the impact of the stack and portal emissions for emissions from 3 September to 18 November 2003.

6. Prepare separate exposure maps (appropriate for those who work or study outside the area) by excluding weekday data from 08:00 to 18:00 hours. This can be used with survey question 49, which provides data to distinguish between respondents who spend most of their time in the area and those who work or study elsewhere.

7. Compare and comment on differences between the exposure patterns given by the average, peak and second-highest concentrations, and recommend the most appropriate maps for determining exposure when re-analysing the cross-sectional survey data.

3 Stack Emission Data

The M5 stack is 35 m high with a 6.7 x 6.7 m square cross-section opening at the top. For modelling purposes, this is equivalent to a circular cross-section with a diameter of 7.6 m. The stack's location is listed in Table 1.

Hourly averaged data were supplied by the RTA from in-stack monitoring equipment. Data for each day were supplied in separate comma-delimited files with the following data reported:

- Date
- Time (start of hour)
- Number of fans operating
- Volume flow rate (actual $m^3 s^{-1}$)
- Temperature (°C)
- NO, NO2 and NO_x concentration (ppm)
- PM10 concentration ($\mu g\ m^{-3}$).

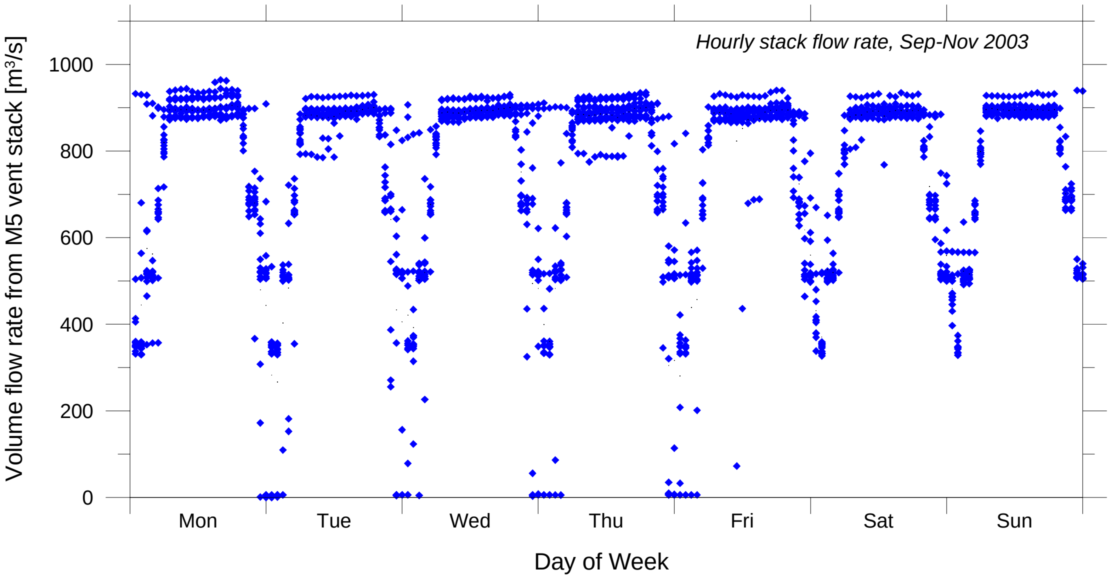

Figure 2. Weekly pattern of hourly-average volume flow rates from the stack using all data from the period September to November 2003.

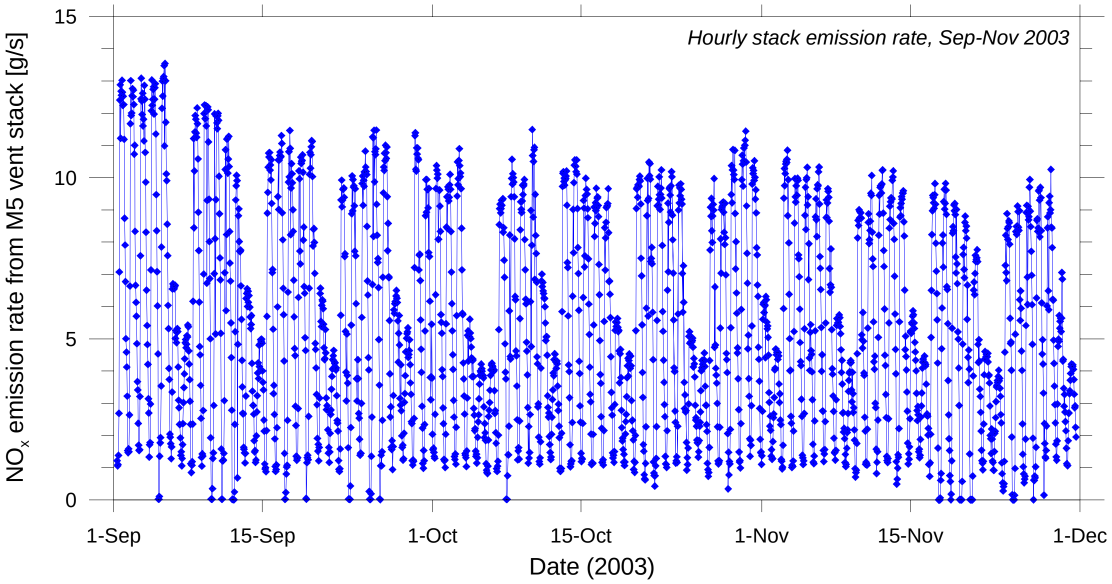

Figure 3. Times series of hourly-average NO_x emission rate from the stack for the period September to November 2003.

The data from 1 September to 30 November 2003 were combined into a single emission file. The final file was checked for consistency and missing data. Small negative airflows at midnight on 17 November were set to zero. Figure 2 shows the volume flow rate plotted against the time of the week. This indicates that daytime stack flow rates are about 900 $m^3\ s^{-1}$ with reduced flow rates at night and occasional zero flow in the middle of the night.

The NO_x data in ppm are reported at 0°C and were converted to $\mu g\ m^{-3}$ by multiplying by 2050 (to adjust to 20°C), multiplying by 10^{-6} to obtain $g\ m^{-3}$, and multiplying by the stack volume flow rate to obtain a NO_x emission rate in $g\ s^{-1}$. Figure 3 shows the time series of hourly-average NO_x emission rates for the study period. There is a steady decline in the peak weekday emission rates from about 13 $g\ s^{-1}$ at the start of

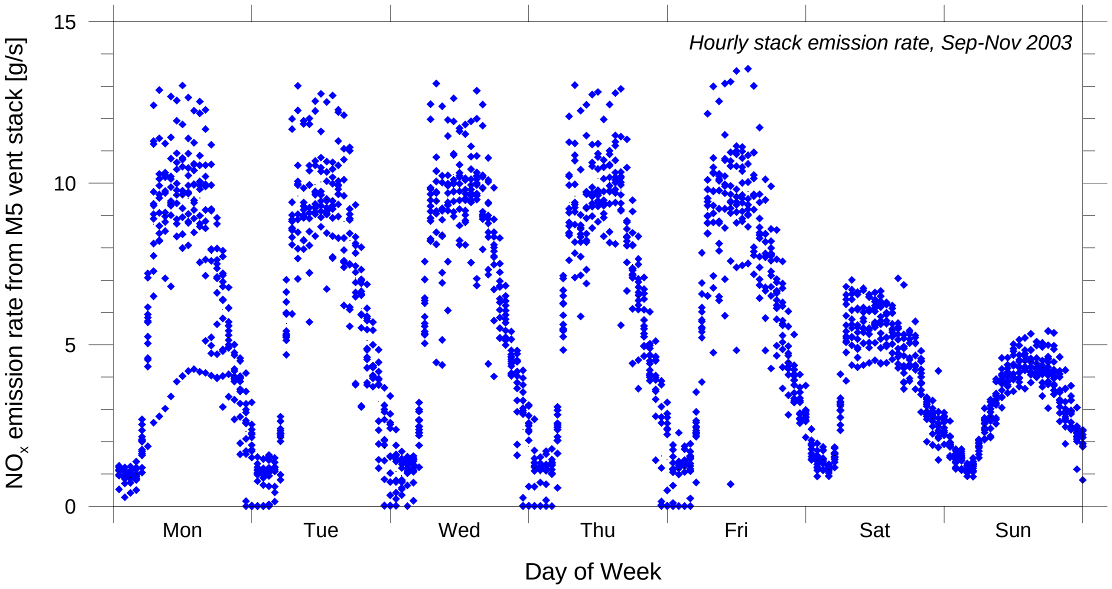

Figure 4. Weekly pattern of hourly-average NO_x emission rate from the stack using all data from the period September to November 2003.

the study period to 9–10 g s^{-1} at the end of the study period. This is unusual and may indicate a calibration drift, but it is not significant for the overall conclusions from the modelling in this study.

Figure 4 shows the same data plotted to show the daily and weekly variation in NO_x emission rates. One Monday in the study period (6 October) was a public holiday and this is clearly distinguishable in the figure from the other Monday data as having peak emission rates of about 4 g s^{-1} rather than about 10 g s^{-1}. In the later analysis where weekday data from 08:00 to 18:00 hours are excluded, this day (6 October) is treated as a weekend day.

4 Portal emission data

In addition to emissions from the stack, there are occasions when emissions occur from the portals. Anemometers (wind measuring devices) are located at each of the tunnel portals as part of the tunnel monitoring system for control of the ventilation fans. There are a total of seven tunnel portals, one at each end of the two main traffic tubes (total four), two at the Marsh Street portals and one at the exit onto the Princess Highway. The locations of the portals are listed in Table 1. The data from these anemometers (converted to volume flows in m^3 s^{-1}) were provided as 15-minute averages and averaged to produce one-hour averages. The sign convention (i.e. positive or negative readings) used with the flow measurements provided by the tunnel operator is that flow in the direction of the traffic is positive. This means that for entry portals positive airflow readings equate to inflow at the portal, whereas for exit portals negative readings equate to inflow at the portal. The sign convention adopted in this report for the portal flows is that positive values correspond to inflows and negative values to emissions from the portals.

Because of the high variability in the portal flows, we also obtained data on the volume flows recorded at the two main supply fans (used to feed each of the traffic tubes) and the volume flows recorded at the two main exhaust fans (exhausting air from each of the tubes) in order to check the mass balance of tunnel flows, i.e. the total flow into the tunnel should equal the total flow out of the tunnel.

Figure 5 shows the time series of the hourly balance of portal, supply and exhaust flows through the study period. The overall average of -10 m^3 s^{-1} (about 1% of the normal supply and exhaust flows) provides confidence in the overall accuracy of the portal flow measurements, while the standard deviation of 50 m^3 s^{-1} is a measure of the uncertainty in the individual hourly flow measurements.

One unexpected feature was discovered in the analysis, namely that the sum of the exhaust flow reported for the eastbound and westbound tubes was on average about 80 m^3 s^{-1} greater than the measured stack flow, as shown in Figure 6. Greater reliance was placed on the sum of the exhaust flows from the two tubes than the stack flow, because of the good balance achieved in Figure 5. The reason for the discrepancy in Figure 6 is not known.

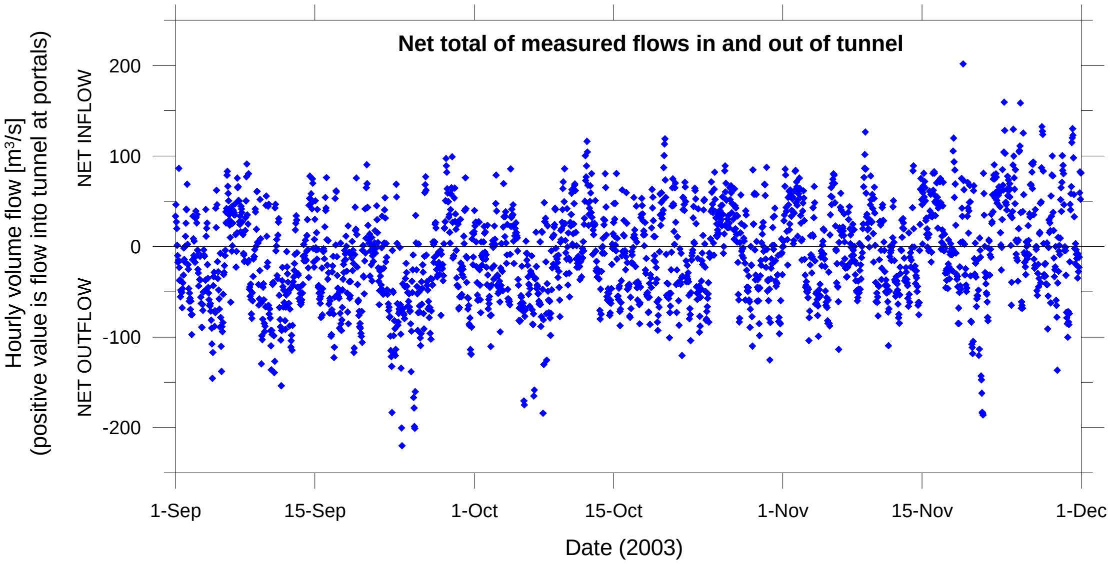

Figure 5. Time series of the net flow balance computed using the measured portal, supply and exhaust fan volumes. The overall average is a net outflow of 10 $m^3 s^{-1}$, with a standard deviation of 50 $m^3 s^{-1}$.

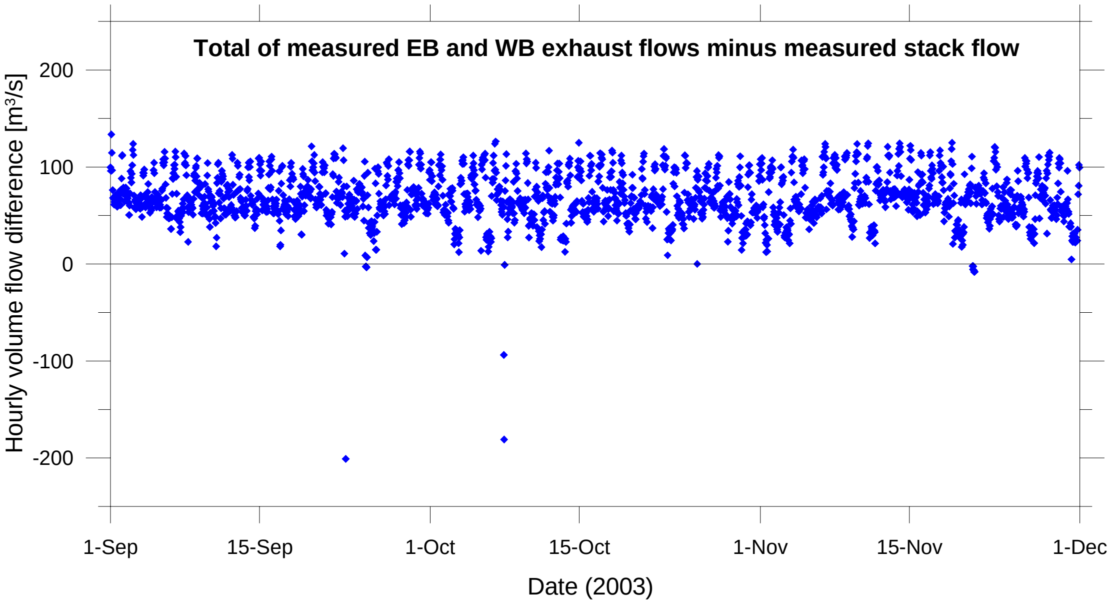

Figure 6. Time series of the total exhaust fan flows from the eastbound and eastbound traffic flows minus the measured stack flow. The average discrepancy is 80 $m^3 s^{-1}$.

In order to compute the NOx emission rates from the portals it is necessary to know the NOx concentration in the portal emissions as well as the portal volume flows. In the modelling carried out here, the NOx concentration measured in the stack was used as representative of the NOx concentrations in the portal emissions. This is supported by the data in Figure 7, which shows the correlation between tunnel inflow/outflow and the hourly traffic numbers. The red trend line highlights that most portal flows occur with higher traffic numbers, which suggests that the stack NOx concentrations recorded on these occasions should provide a reasonable estimate of the NOx concentration in the portal emissions.

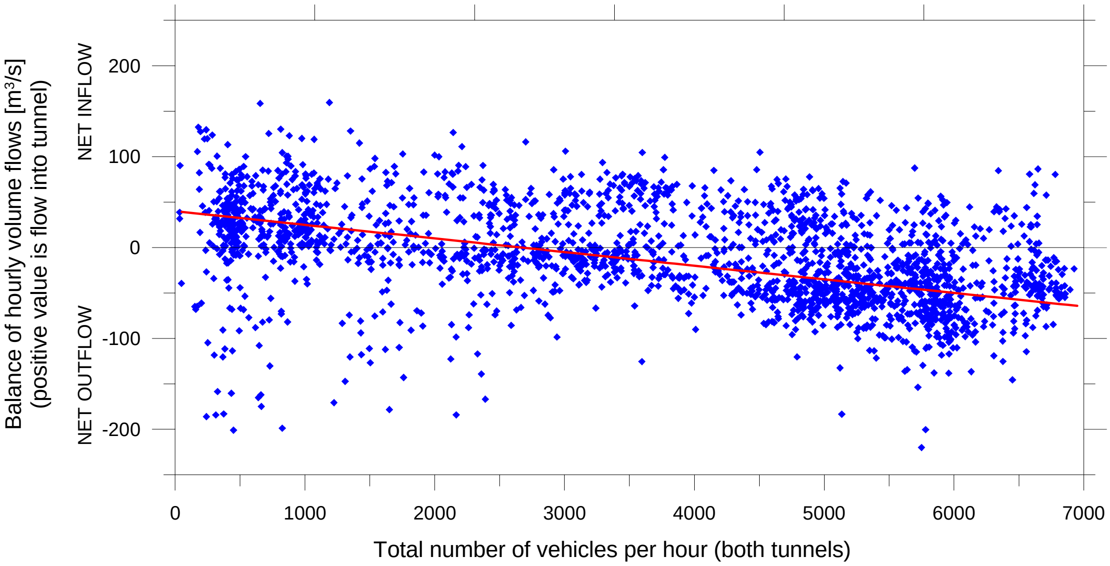

Figure 7. Net inflow/outflow of the tunnel as a function of the hourly traffic numbers in the tunnel. The red trend line highlights that most of the portal outflows occur with high traffic numbers.

This may not always be the case and so several other methods were examined to derive portal NO_x emission rates. One used the difference between the measured stack emission rate and the NO_x emission rate derived from total traffic volumes and the NO_x emission factors derived by Hibberd (2005) from M5-East tunnel data. These data showed reasonable agreement with the method of using stack NO_x concentrations but with a large scatter of about ±2 g s^{-1}. An attempt was made to estimate the number of vehicles that had contributed NO_x to the air emitted from each portal but the absence of information on the cross flow between the vehicle tubes near the tunnel portals meant that this was not possible. Thus the original estimate of portal NO_x concentrations based on stack NO_x concentrations was used in the modelling.

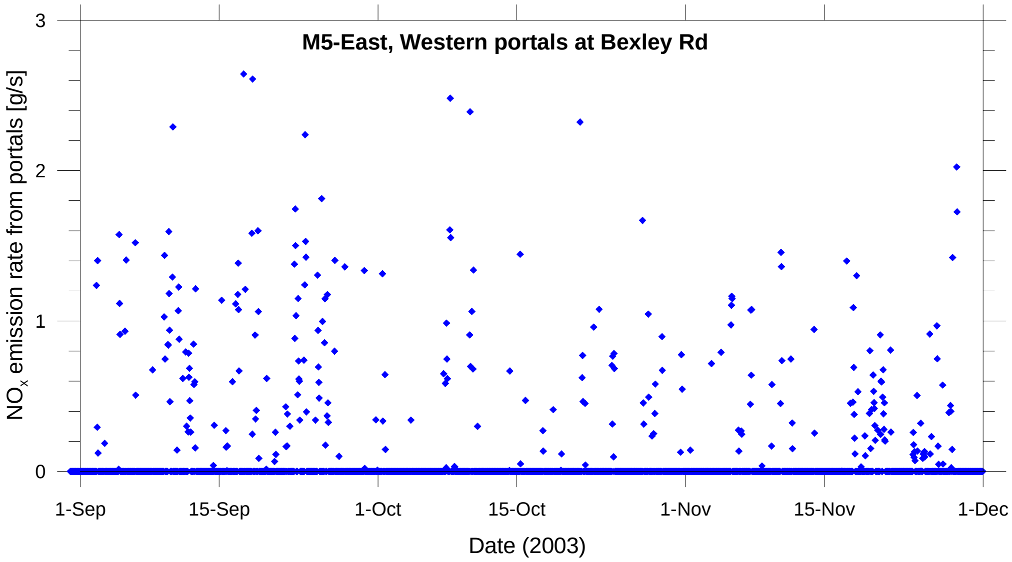

Figure 8. Time series of hourly-average NO_x emission rates (g s^{-1}) from the western portals at Bexley Road. Emissions were detected for 278 hours (13% of all hours).

Figure 8 to Figure 11 show the time series of NO_x emissions from the four groups of portals – one group at the western end of the tunnel near Marsh Street, one at the eastern end of the tunnel on the freeway, one at the Marsh Street portals, and one at the Princess Highway portal. The highest emissions (above 2 g s^{-1}) occur from the eastern portals on the freeway (Figure 8) whereas portal emissions are most frequent from the Marsh Street portals (42% of all hours).

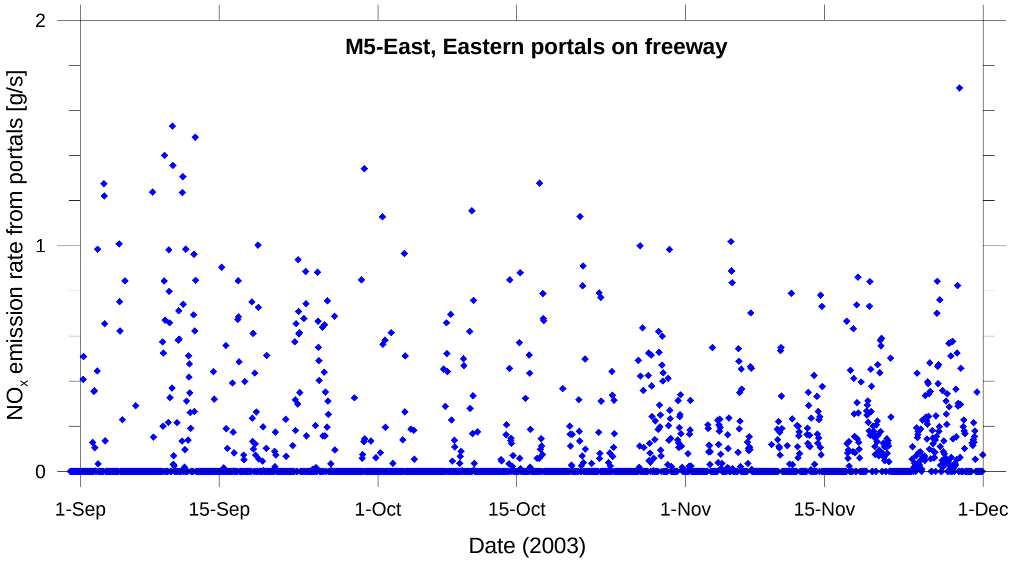

Figure 9. Time series of hourly-average NO_x emission rates (g s^{-1}) from the eastern portals on the freeway. Emissions were detected for 611 hours (28% of all hours).

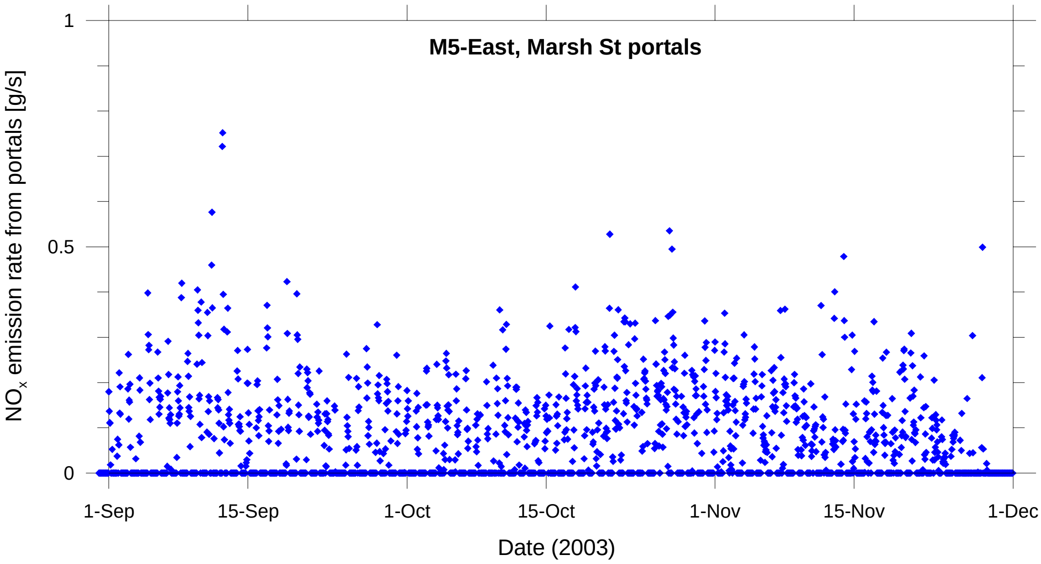

Figure 10. Time series of hourly-average NO_x emission rates (g s^{-1}) from the Marsh Street portals (entry and exit). Emissions were detected for 923 hours (42% of all hours).

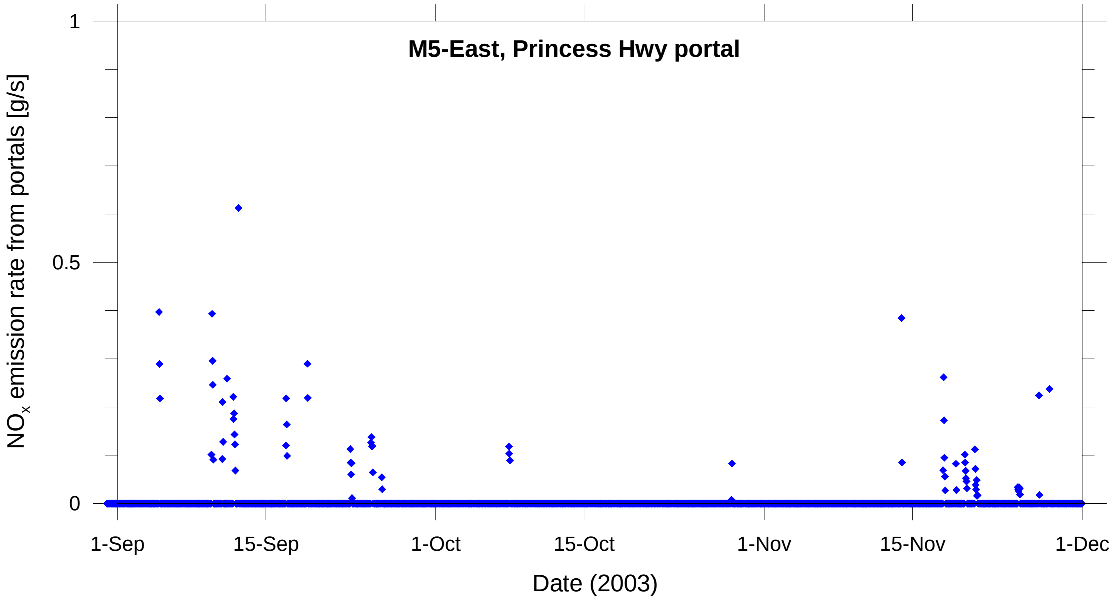

Figure 11. Time series of hourly-average NO_x emission rates (g s^{-1}) from the Princess Highway exit portal. Emissions were detected for 74 hours (3% of all hours).

5 Modelling

The modelling was undertaken using The Air Pollution Model (TAPM) version 3.0 (Hurley, 2005). This model, developed at CSIRO Atmospheric Research, consists of prognostic meteorological and air pollution modules that can be run for multiple nested domains.

The meteorological simulations were carried out on five nested grids (each 27 × 27 horizontal grid points and 30 vertical levels) with grid spacings of 30, 10, 3, 1, and 0.3 km. The grid spacings for the corresponding pollution simulations (45 × 45 × 30 grid points) over slightly smaller domains were 15, 5, 1.5, 0.5, 0.15 km. All grids were centred at 33º 55.5´ S, 151º 8.5´ E near the M5 stack and corresponding to (328.225, 6244.605) km in MGA (Map Grid Australia) 1994 coordinates.

Terrain elevation was obtained from AUSLIG data (250-m resolution) and from a dataset with 100 m horizontal resolution developed for the original stack modelling by Hyder (2000). The land-use classification was obtained from the dataset accompanying the TAPM modelling package. The deep soil moisture was assigned the default value of 0.15. An hourly-varying NO_x emissions data file for the stack was produced in the required format from the in-stack monitoring data. The portal NO_x emissions were modelled as near ground level volume sources with a length of 50 m, width of 10 m and height of 10 m. These dimensions were chosen to represent the plume from the tunnel portal, which is initially well mixed by the traffic as it leaves the portal and is spread out along the length of the roadway. Further detail was not warranted given the 150 m resolution on the inner pollution grid of the model. The pollutants were modelled in tracer mode with the near-source Lagrangian option turned on.

The three-month simulation was split into one-month runs and executed on a PC cluster with a total CPU processing time of 100 hours.

5.1 Comparison between observed and modelled winds

The good agreement between the modelled and observed wind directions is shown in Figure 12, which compares the relative probability of wind directions at the monitoring sites U1 and CBMS. In each case there are peaks for east-north-easterly, southerly and westerly winds with very similar frequencies of occurrence. The model results for CBMS show somewhat more westerlies and fewer north-westerlies than the observations but overall the agreement is good. Hour-by-hour comparisons of modelled and observed wind directions (not shown here) also show close agreement, indicating that the model predicts the correct wind directions at the correct times.

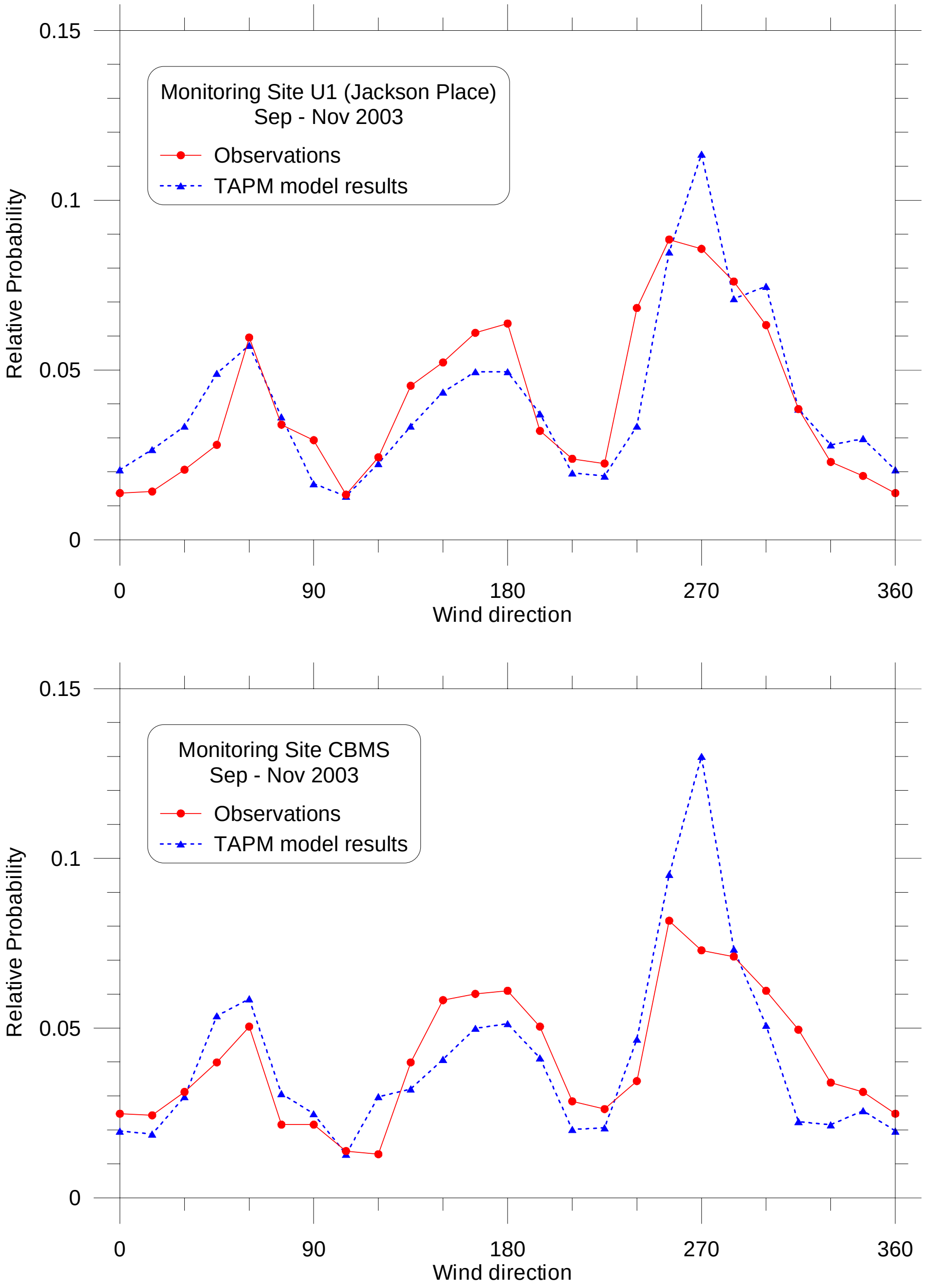

Figure 12. Comparison of observed and modelled probability densities of wind direction at monitoring sites U1 and CBMS for the period September – November 2003.

Comparison of the modelled and observed wind speeds (not shown here) indicated that at both U1 and CBMS, the model somewhat overpredicted the frequency of winds speeds in the 2–5 m/s range and underpredicted the frequency of the higher speed winds, although these higher speeds occur relatively infrequently. The effect of these differences was found to have little effect on the modelled ground-level concentrations, as discussed in Section 6.1.

6 Results

The TAPM output was analysed to generate average, peak and second-highest ground-level NO_x concentration contours (due to stack and portal emissions) in the 6 x 6 km region surrounding the stack.

The predicted concentration fields are shown in Figure 13 to Figure 18 overlaid on the topography of the region. The first three figures include concentrations from all hours during the modelled period, whereas the next three figures exclude weekday data during the period from 08:00 to 18:00 hours to represent the exposure of residents who work or study outside the region.

The most significant feature of the figures compared to results from the earlier study (Hibberd, 2003) is the high ground-level concentrations near the tunnel portals. These are typically ten times larger than any of the ground-level concentrations due to stack emissions. Although portal emissions of NO_x (at most 2.6 g s^{-1}) are about five times smaller than stack emissions (up to 14 g s^{-1}), the stack emissions are released well above the ground and are subject to much greater mixing and dilution before reaching the ground. In contrast, the portal emissions occur at ground level. This explains why the portal emissions have an impact on ground-level concentrations that is up to 50 times greater than if the same emissions occurred from the stack. Indeed this demonstrates the reason for using stacks to disperse emissions — the ground-level impact is greatly reduced.

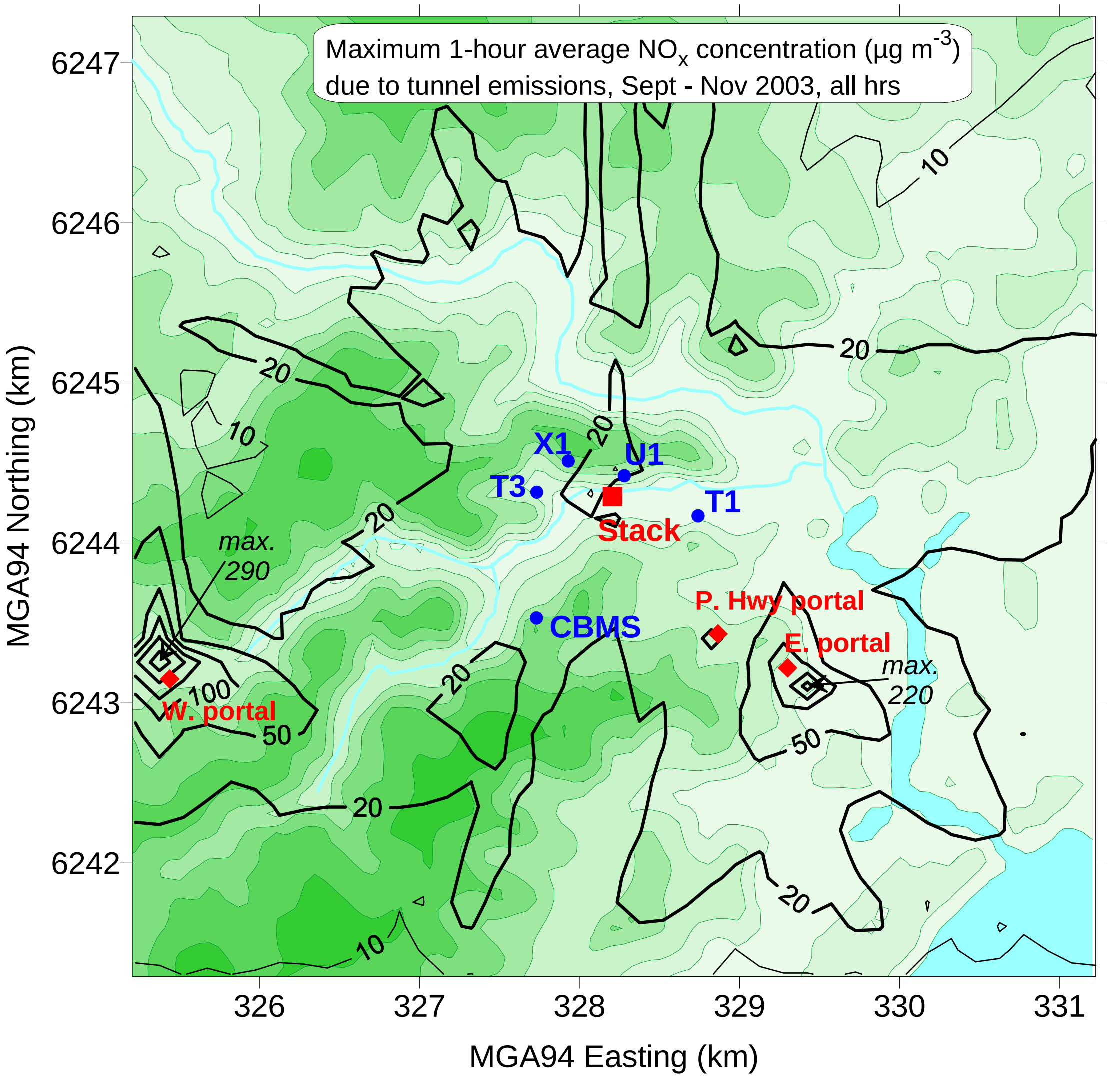

Figure 13. Contours of the impact of the stack emissions on maximum 1-hour average NO_x ground-level concentrations in the 6 x 6 km regions surrounding the M5 East stack modelled using TAPM for the period September – November 2003 (all hours).

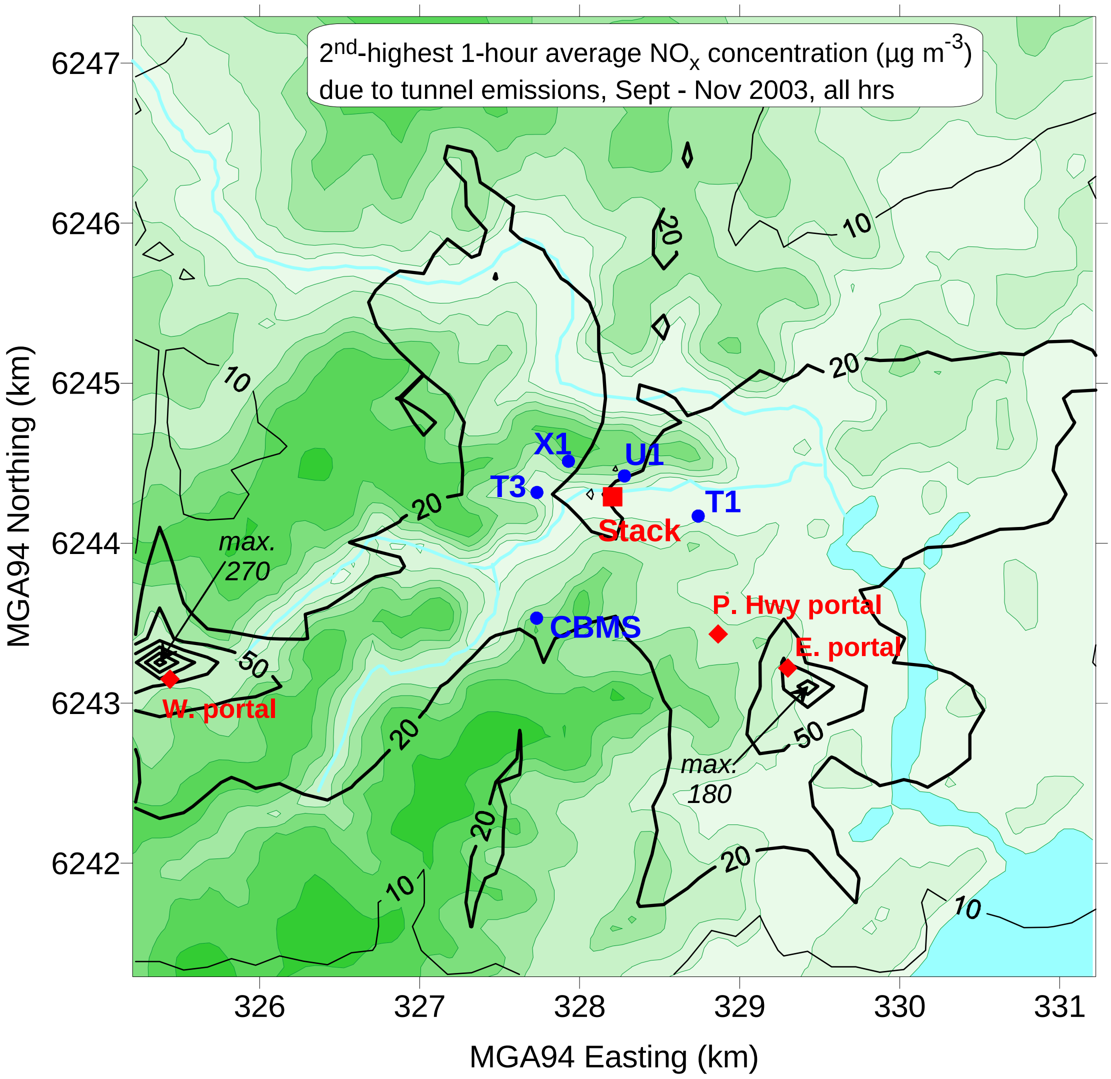

Figure 14. Contours of the impact of the stack emissions on second-highest 1-hour average NO_x ground-level concentrations in the 6 x 6 km regions surrounding the M5 East stack modelled using TAPM for the period September – November 2003 (all hours).

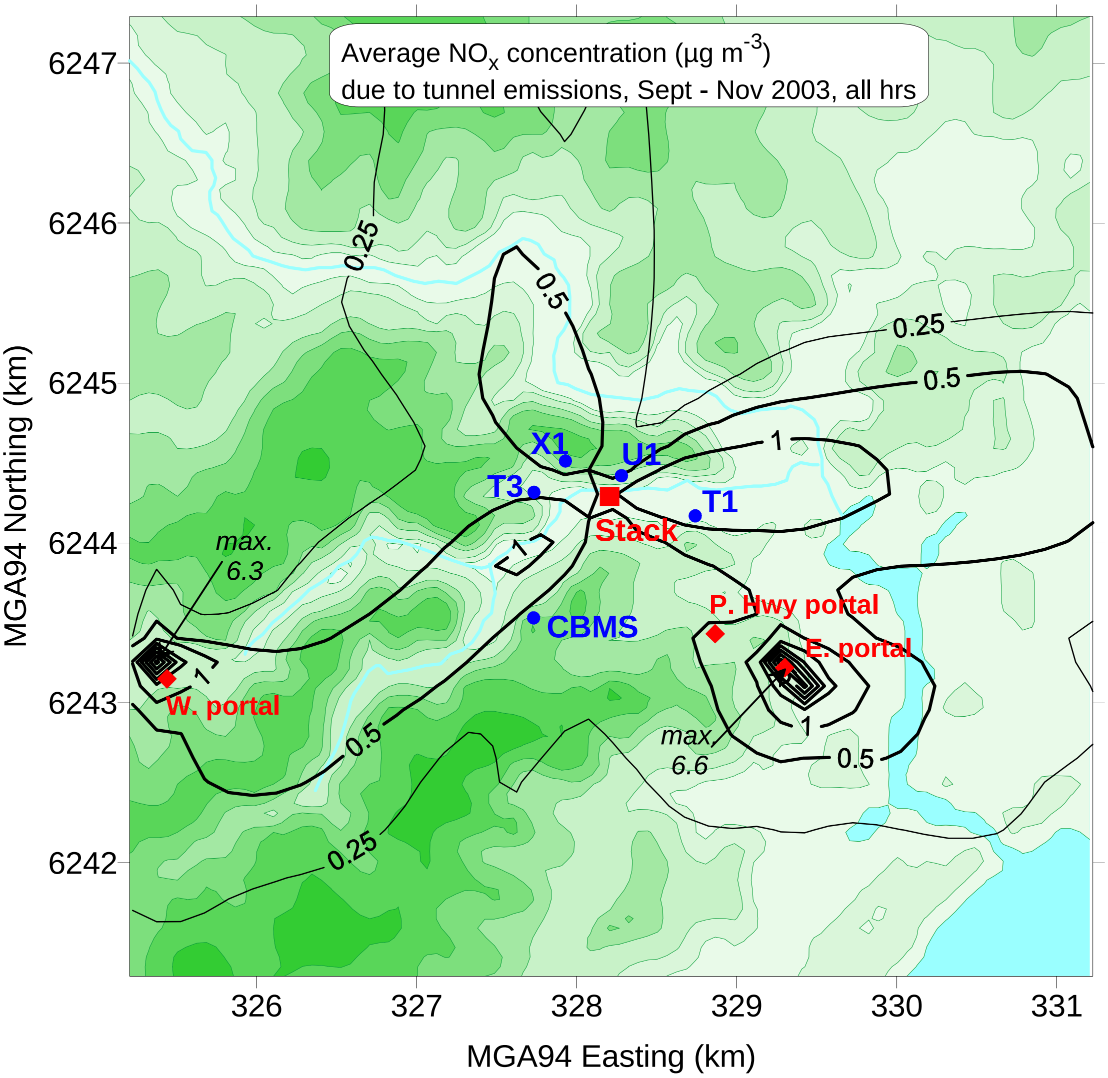

Figure 15. Contours of the impact of the stack emissions on average NO_x ground-level concentrations in the 6 x 6 km regions surrounding the M5 East stack modelled using TAPM for the period September – November 2003 (all hours).

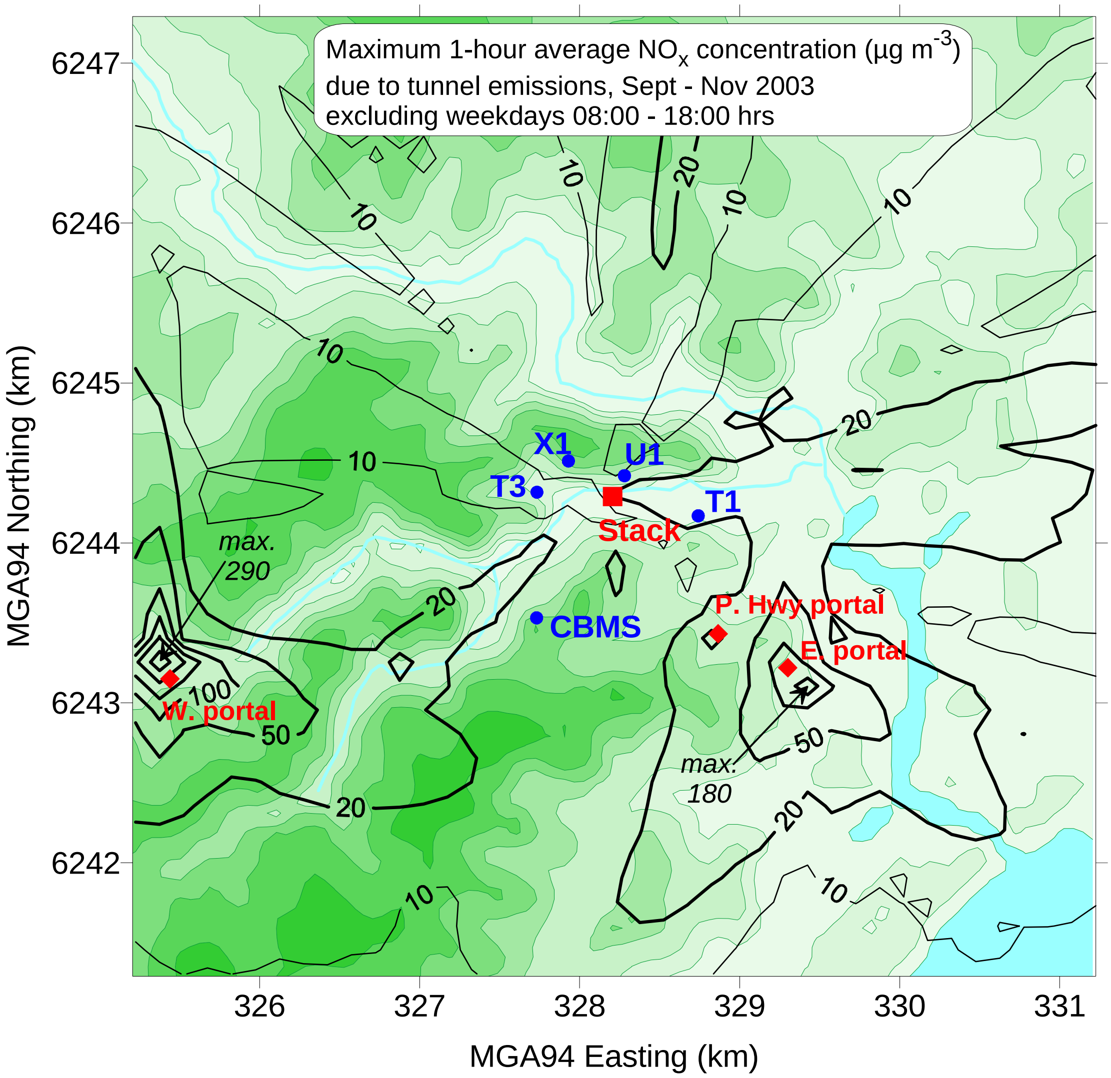

Figure 16. Contours of the impact of the stack emissions on maximum 1-hour average NO_x ground-level concentrations in the 6 x 6 km regions surrounding the M5 East stack modelled using TAPM for the period September – November 2003, excluding weekday data from 08:00 to 18:00 hours.

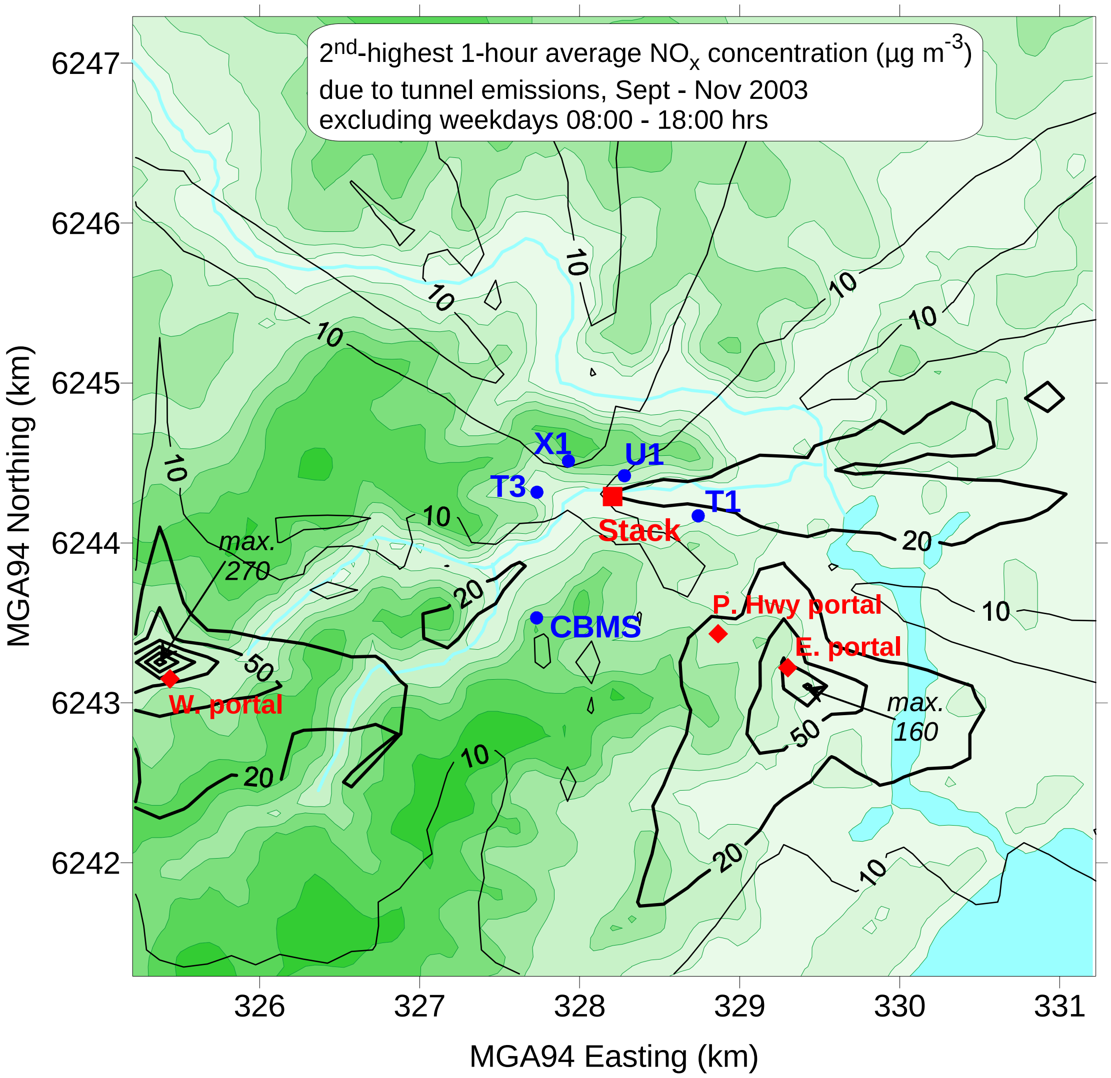

Figure 17. Contours of the impact of the stack emissions on second-highest 1-hour average NO_x ground-level concentrations in the 6 x 6 km regions surrounding the M5 East stack modelled using TAPM for the period September – November 2003, excluding weekday data from 08:00 to 18:00 hours.

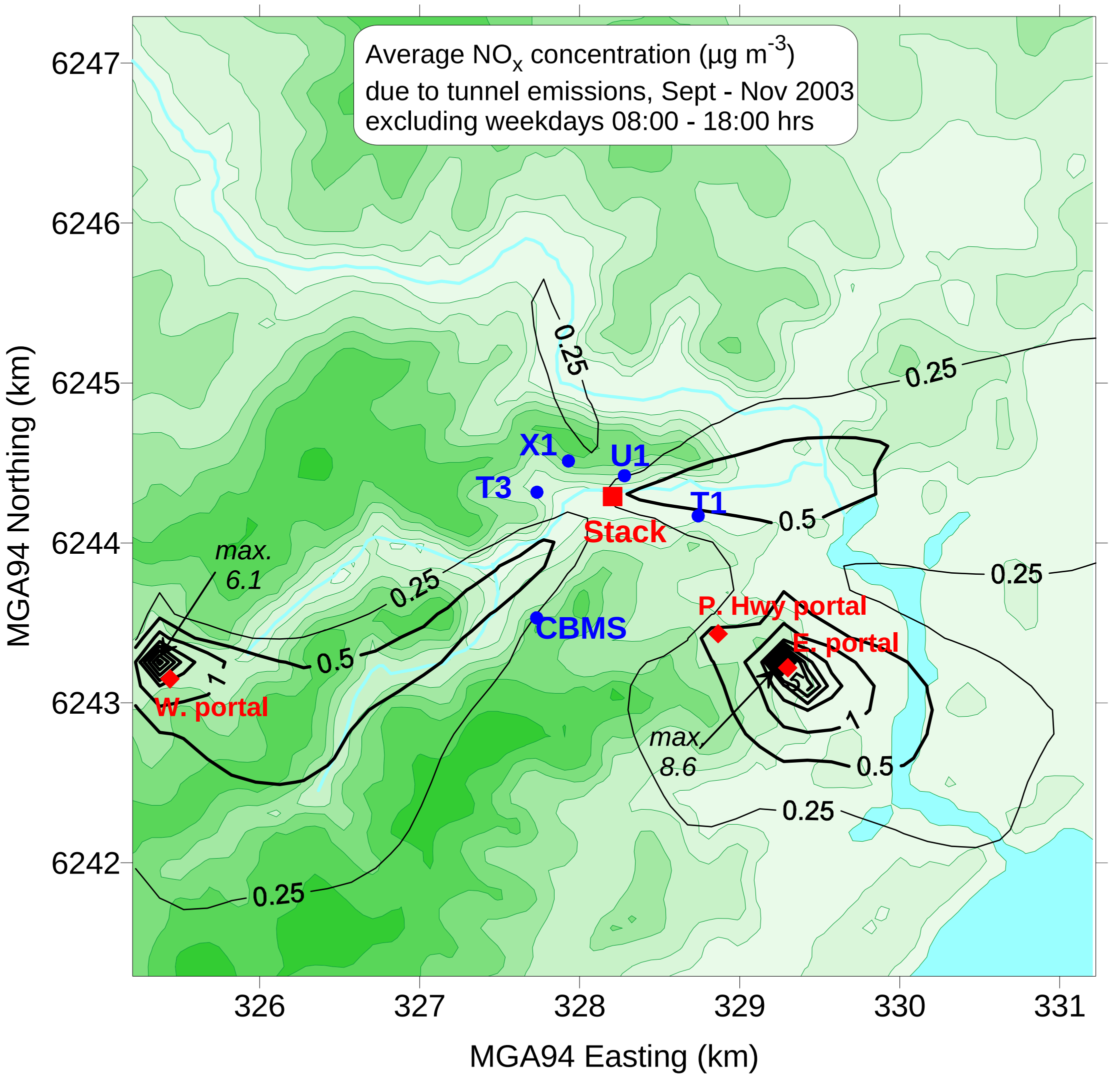

Figure 18. Contours of the impact of the stack emissions on average NO$_x$ ground-level concentrations in the 6 x 6 km regions surrounding the M5 East stack modelled using TAPM for the period September – November 2003, excluding weekday data from 08:00 to 18:00 hours.

6.1 Effect of data assimilation on model results

In results presented above, TAPM was run in its normal mode without any assimilation of observed meteorological data. That is, the prognostic meteorological component of TAPM used only the large-scale weather information obtained from the Bureau of Meteorology LAPS (Limited Area Prediction System) or GASP (Global Analysis and Prediction) analyses at a horizontal grid spacing of about 100 km at 6-hourly intervals as boundary conditions for the model outer grid.

It is also possible to run TAPM in a data assimilation mode in which wind speed and direction observations are used to nudge the predicted meteorology towards the observations. However, some care is needed when using data assimilation in the model. For example, data measured in a valley, where winds are usually aligned along the valley axis, should not unduly influence the model results outside the valley. In addition, winds can change significantly with height, particularly in the lowest 100 m of the atmosphere, so that observed near-surface winds (such as from a 10 m tower) should not unduly influence winds higher up.

The sensitivity of the model results to data assimilation of wind observations from U1 and CBMS was tested by incorporating hourly averaged wind data from U1 and CBMS. It was found that average NO_x concentrations at any given location were changed by less than 20% from the model results without data assimilation; there were increases at some locations and decreases at other locations. This close agreement is consistent with the good agreement between modelled and measured winds discussed in Section 5.1.

6.2 Exposure zones

The results from this modelling will be used by NSW Health to define exposure zones for analysis of the data from the cross-sectional health survey. In their earlier analysis, Capon *et al.* (2004) generated a map of exposure zones based on annual average concentrations modelled for the year February 2002 to January 2003. They defined three exposure zones – low, medium, and high – with the coverage shown in the left-hand panel of Figure 19. The zones corresponded to the following annual average ground level concentrations of NO_x:

- High exposure zone – greater than 0.36 µg m^{-3}
- Medium exposure zone – between 0.20 µg m^{-3} and 0.36 µg m^{-3}
- Low exposure zone – less than 0.20 µg m^{-3}

The right-hand panel of the figure indicates the pattern of exposure zones that would be obtained using the average ground-level NO_x concentrations for the September to November 2003 period modelled in this report. Apart from the inclusion of regions near the portals in the high exposure zones and a slight extension to the east of the eastern lobe, there is remarkable similarity in the overall pattern of the exposure zones. In drawing the new zones, the ratio of 1.8 between the concentrations defining the high and medium zones has been maintained at the same level as in the earlier study but the absolute levels have been adjusted to obtain similar coverage areas for the low and medium exposure zones (the medium exposure zone includes average NO_x concentrations between 0.30 µg m^{-3} and 0.54 µg m^{-3}. It should be noted that the high concentrations near the portals are restricted to a region within a couple of hundred metres of the portals. The selection of the appropriate concentrations to be

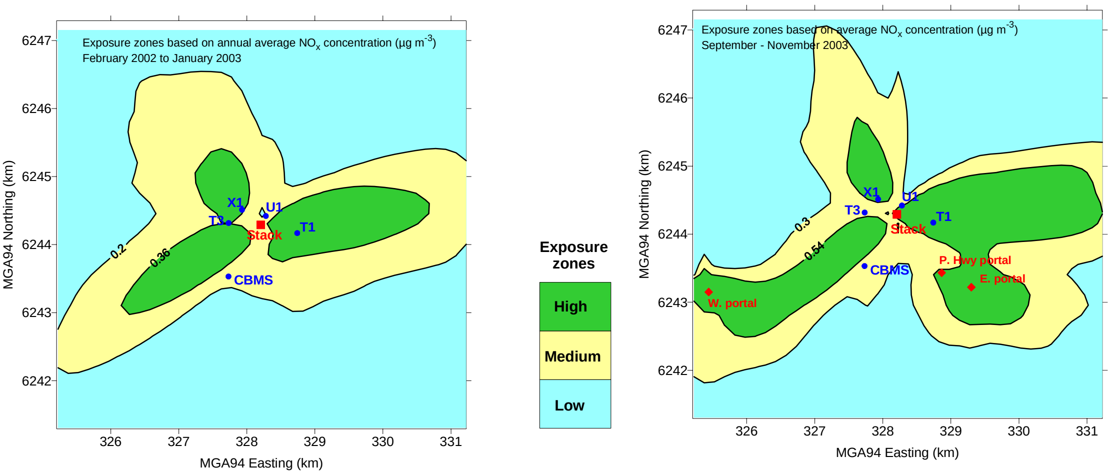

Figure 19. Comparison of exposure zone assigned by Capon *et al.* (2004) based on the earlier CSIRO report (Hibberd, 2003) in the left-hand pane with exposure zones based on results from the current modelling in the right-hand pane.

used for defining the exposure zones depends on the requirements of the data analysis to be undertaken by NSW Health.

Figure 20 compares exposure zones obtained using indicative concentration levels based on the data in Figure 13 to Figure 18 for the three different concentrations statistics and the two exposure periods (all hours and excluding weekday data from 08:00 to 18:00 hours). The influence on the extent of the zones of the concentration values selected for defining the zones needs to be taken into account when comparing the zones shown in the figures. Overall, there is reasonable agreement between the shapes of the exposure zones for the three concentration statistics – maximum 1-hour average, second highest 1-hour average, and average concentrations. In all cases, the highest exposures are near the portals and there are lower concentrations to the north of the stack when the weekday daytime hours are excluded. These are the most salient features when comparing the plots.

The NSW Health survey of health symptom prevalence was carried out over a three month period with respondents asked about symptoms occurring in the four weeks preceding the interview date. By definition, the maximum 1-hour average NO_x concentrations only occurred once during the study period and the second-highest concentrations was only equalled or exceeded twice during the study period. Thus, it can be concluded that it is most appropriate to use the average concentrations for determining the exposure zones.

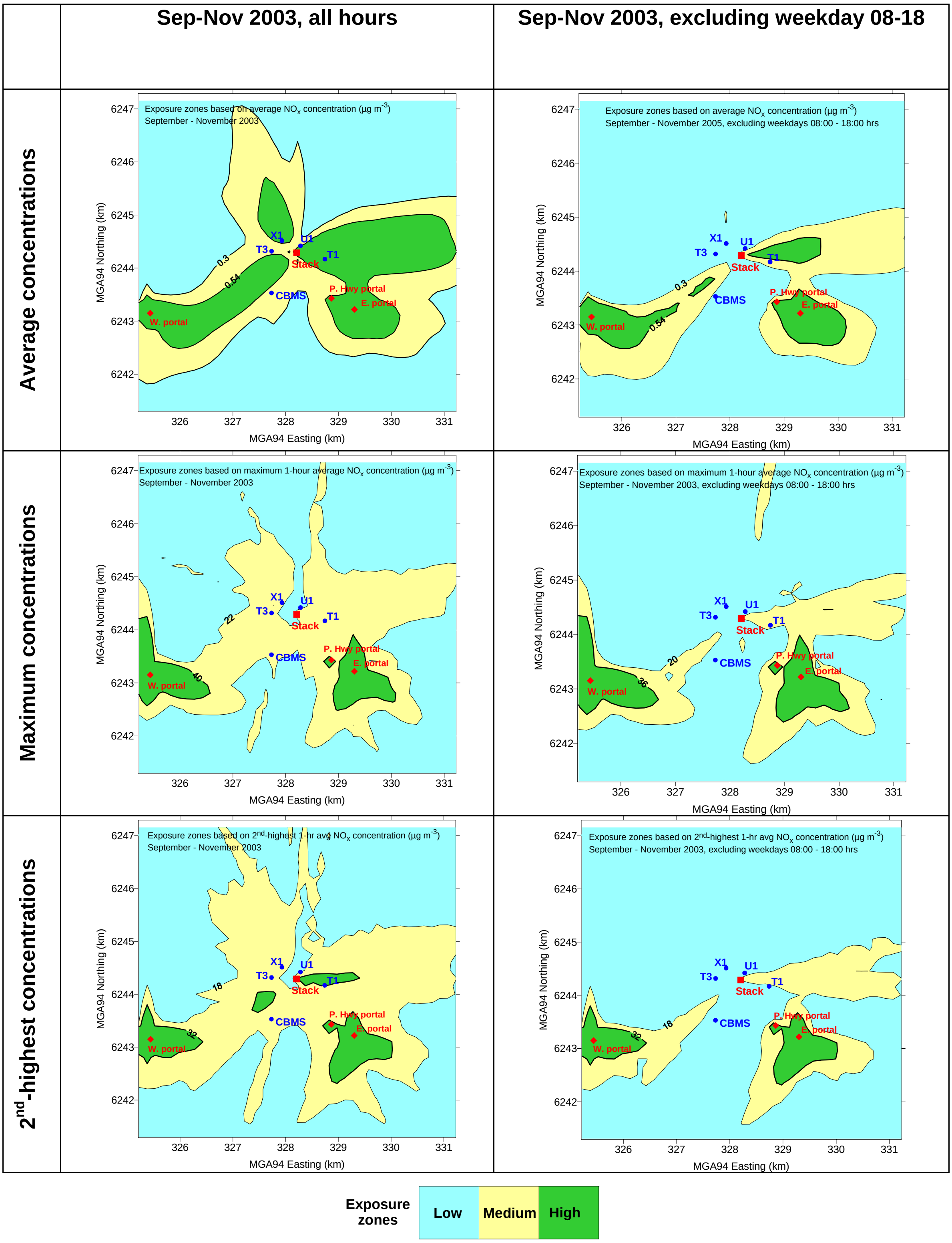

Figure 20. Comparison of "exposure zones" for different concentration statistics (average, maximum or 2nd-highest) and exposure periods (all hours or non-working hours). The upper left-hand pane shows the exposure zones from Figure 19. The concentrations at the cross-over points between the zones are 0.3 and 0.54 µg m^{-3} for the average concentrations, 22 and 40 µg m^{-3} for the maximum concentrations, and 18 and 32 µg m^{-3} for the 2nd-highest concentrations.

7 Conclusions

A modelling study was undertaken using The Air Pollution Model (TAPM) to predict the impact of NO_x emissions from the M5-East tunnel (both stack and portal emissions) on a 6 x 6 km region surrounding the stack for the period from September to November 2003. Because exposure levels depend on both the concentration and the time spent in the area and many people spend significant daytime periods outside the area, the concentration statistics were reported both as all-hour statistics and excluding weekdays hours from 08:00 to 18:00 hours.

The main findings were:

- The greatest impact of the tunnel emissions occurs near the portals due to portal emissions. This is because of the significant portal emissions (up to 2.6 g s^{-1} NO_x) compared to stack emissions of up to 14 g s^{-1} NO_x. The portal emissions occur at ground level whereas the stack emissions are released well above the ground and are subject to much greater mixing and dilution before reaching the ground.
- The greatest difference when weekday data from 08:00 to 18:00 hours are excluded is lower NO_x concentrations to the north of the stack.
- Overall, there is reasonable agreement between the shapes of the concentration zones for the three concentration statistics – maximum 1-hour average, second highest 1-hour average, and average concentrations.
- Given this reasonable agreement and the nature of the health symptoms survey, it is considered to be most appropriate to use the average concentrations for determining the exposure zones in analysis of the survey data.
- Exposure zones based on average ground-level NO_x concentrations for the September to November 2003 period modelled in this report have a very similar overall pattern to those obtained from an earlier analysis using modelling for the year from February 2002 to January 2003.

8 References

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APPENDIX B

University of Wollongong report

Recalculation of adjusted prevalence rate ratios based on revised risk zoning in the M5 health investigation

Centre for Statistical and Survey Methodology
University of Wollongong
October 2006

1 Summary of findings

The Phase 2 Report contains estimates of relative risk by Zone, which were calculated using the Cox Proportional Hazards model, allowing for unequal probability sampling. This report contains new estimates of parameters from this model using a new Zone variable. The new Zone variable has been created to reflect possible emissions from the ends of the M5 tunnel. Zone is significant for one of the six new models. The confidence intervals for the zone effect are fairly wide, and these give the best indication of what level of zone effects could exist but not be detected by this study.

The new relative risks have higher standard errors than those published in the Phase 2 report. This is because the disproportionate sampling by the original zones leads to higher standard errors for estimates by the new zones. This means that the power of the study is somewhat less than originally intended. For example, if two zones had prevalences of 6% and 12%, the study was designed to have a power of 80% for detecting the difference between the zones. This power drops to about 60% when the new zones are used in the analysis.

Disproportionate sampling did not have this effect on the original analysis using old zone, because the zone definition used in the design was the same as the zone definition used in the analysis. Nevertheless the approach of using the new zone variable for analysis and the old zone variable for calculating estimation weights is considered to be the most appropriate method, and other approaches could result in biased effect estimates.

The applicability of the Cox Proportional Hazards for point in time cross-sectional can be justified as a computational tool to fit a more natural model, the generalized linear model with log link. The Appendix contains details.

2 Outline

Study design

The M5 Health Investigation involved collection of data from 1,431 respondents. The scope of the survey was people aged 17 years and over living in a 6km by 6km area centred on the M5 East Stack. Information on eye, nose, throat and mouth symptoms was collected as well as risk factors including smoking, age and sex. Respondents were also classified to one of three 'exposure zones': low, medium and high. This referred to the exposure to possible risks related to the M5 East Stack. The main aim of the data collection and analysis is to determine whether exposure zone is related to incidence of medical symptoms, after controlling for other covariates.

The survey was conducted by telephone interviewing. The sample was selected by stratified simple random sampling of telephone numbers from the electronic white pages, where strata were exposure zones. One person was selected at random from each selected household. The sample was designed to include 524 people in each exposure zone giving 1,531 people in total. This design was adopted to give a power of 80% to detect a difference between two exposure zones where the true prevalences in the two zones are 6% and 12%. The participation rate for the survey was 59% (calculated by the number of successful interviews divided by the number of eligible households).
The achieved counts were

Low exposure zone	492
Medium exposure zone	481
High exposure zone	456
Exposure zone missing	2
Total.	**1,431**

Estimation weights were calculated allowing for:

- sampling fractions applied to electronic white page numbers in the three strata;
- probability of selection within households (equal to one divided by the number of eligible people in the household);
- adjustment for non-response based on population counts by age group and sex in each zone.

The final adjustment was based on 2001 Census data. Collector districts (CDs) were assigned to the three zones based on where their centroid was located.

The Phase 2 report considered the following six main dependent variables:

1 any eye symptom
2 more frequent and/or severe eye symptoms;
3 any nose symptom
4 more frequent and/or severe nose symptoms;
5 any throat symptom
6 more frequent and/or severe throat symptoms.

The data was initially analysed using the Cox Proportional Hazards (PH) model, allowing for the sample design which had unequal selection probabilities due to unequal household sizes and stratification by zone. The SUDAAN package was used.

Outline of this Report

In the initial Cox PH regression, weighting was based on the sample selection process, where strata were Zone, and weights depended on Zone, household size, age and sex. The variable Zone was also an explanatory variable in the regression. Subsequent to the data collection and Phase 2 report, it was decided that the definition of exposure zone could be changed to reflect M5 emissions from the tunnel ends. The new variable (called New_Zone) was fairly similar to Zone but not identical. The University of Wollongong was asked to advise on how the analysis could accommodate this change.

Section 3 of this report will describe how the new zone variable can easily be accommodated into the Cox PH model. Section 4 shows the effect estimates for the new models, and compares the standard errors and design effects for the new model and the model based on the old zone variable. The use of the new zone variable results in the power of the study being less than the design objective.

The use of the Cox PH procedure can be justified as a computational tool for fitting a generalized linear model with a log link, which is a reasonable model for the M5 data. The approach used in the Phase 2 report is sensible, but the model used should not be referred to as the Cox PH model. This is explained in Appendix 1.

Appendix 2 contains a detailed table of model estimates for the new models.

3. Use of zone variable in Cox Proportional Hazards Analysis of M5 Study

Summary of analysis method used in Phase 2 Report

Each dependent variable was analysed using the Cox proportional hazard model. In this model, each person is assumed to have been exposed to risk factors for a given exposure time (E). The hazard, or instantaneous risk, of developing a condition (eg any eye symptom) at time is given by the 'hazard function':

> h(t) = (Probability that person develops condition between exposure time t and t+k, given that they did not have condition at time t) / k

where k is a small number. The hazard function h(t) can be interpreted as the probability that a person will develop the condition in one unit of time, given that they do not have the condition at time t.

The Cox PH model is usually applied to observations of:

- an indicator of whether each person had the condition when the study was terminated
- the 'survival time' which is the time taken for each person to develop the condition (if at all).

In the M5 study, all that was measured was whether or not each person had each condition at a single point in time. To fit the Cox PH model, it was required to assume that each person has equal exposure time, and further assumptions about when people with symptoms developed those symptoms are presumably also needed. This approach gives rise to a large number of tied 'survival' times which were handled using the Breslow method (eg Kalbfleisch and Prentice, 2002).

The M5 data was collected from a survey where different respondents had different weight depending on which zone they lived in, the number of people in their household, and the non-response adjustment by age and sex. The Cox proportional hazards model was fitted using these weights with the SUDAAN package.

Revising the zoning in the Proportional Hazards Model

In the Cox regression in the Phase 2 report, weighting was based on the sample selection process, where strata were Zone, and weights depended on Zone, household size, age and sex. The variable Zone was also an explanatory variable in the regression.

Subsequent to the data collection and Phase 2 report, it was decided that the definition of exposure zone could be improved to better reflect M5 emissions from the tunnel ends. The new variable (called New_Zone) was fairly similar to Zone but not identical. This raised the question of how this change should be reflected in the analysis method.

Sampling weights are intended to reflect the sample selection (& survey response) process. The sample design was not affected by the creation of the New_Zone variable, since the survey had already been conducted. The sample was selected based on Zone, and therefore weighting should be calculated based on Zone, to reflect the probabilities of selection of the survey as it was conducted. Similarly, when stratification variables are specified in SUDAAN, the strata should be defined to be Zone, not New_Zone, as this reflects how the sample was actually selected.

The New_Zone variable would replace Zone as one of the explanatory variables. In the initial analysis described in the Phase 2 report, the zone variable used in calculating the weights was identical to the zone variable used as an explanatory variable. This will no longer be the case when New_Zone is used as an explanatory variable. This does not invalidate the analysis - there is no theoretical or practical requirement for the weighting variables to be the same as the analysis variables. Often they are the same (as in the initial analysis of the M5 study), but this should not stop the data analyst changing an explanatory variable if an improved measure is available.

Other options which may be considered but are not appropriate include:

- using the analysis based on the old zone variable. This would not reflect the possible impact of the emissions from the tunnel ends
- using both Zone and New_Zone in the model. This is not recommended as the two variables are the same for most subjects. As a result, the covariates associated with the two zones would be highly correlated and parameter estimates would be unstable with high standard errors
- recalculating estimation weights based on new Zone. This could result in biased estimates because the probabilities of selection depend on the old zone.

Models using the new zone variable

Table 1 shows the parameter estimates and relative risks for the new Zone factor, from a binary model with a log link, fitted using the working Poisson model, using survey weights. Other covariates were also used; the table in Appendix 2 shows the full model. The model was fitted using the SUDAAN package using a modification of the program used to calculate the results in the Phase 2 Report. The standard errors and confidence intervals have been calculated accounting for the survey weights.

Table B.1. Relative risks of new zone variable (estimated using a binary model with log link and survey weights)

Dependent variable	Coefficient (P-Value)		Relative risk (95% CI)	
	High Zone	Medium Zone	High Zone	Medium Zone
Any eye symptom	0.103 (0.287)	0.208 (0.012)	1.109 (0.917,1.341)	1.232 (1.047,1.449)
Frequent and/or severe eye symptoms	-0.049 (0.500)	0.245 (0.181)	0.952 (0.645,1.405)	1.278 (0.893,1.829)
Any nose symptom	-0.107 (0.162)	0.008 (0.898)	0.898 (0.773,1.044)	1.008 (0.893,1.138)
Frequent and/or severe nose symptoms	-0.002 (0.989)	0.187 (0.113)	0.998 (0.761,1.310)	1.205 (0.957,1.517)
Any throat symptom	-0.037 (0.796)	0.013 (0.919)	0.963 (0.727,1.277)	1.013 (0.792,1.295)
Frequent and/or severe throat symptoms	-0.033 (0.881)	0.064 (0.755)	0.968 (0.630,1.486)	1.066 (0.715,1.587)

4. Effect of weighting and rezoning on standard errors on zone coefficients

Table 2 shows the estimated design effects for the new models. The standard errors are also shown. The design effect is the variance of an estimator calculated from a complex sampling scheme divided by the variance of the same estimator calculated using a simple random sample of the same size. (The variance of an estimator is the standard error squared.) Thus it is a measure of the effect of the sample design and the weighting method on the precision of an estimator. The SUDAAN default method of calculating design effects was used.

There are a number of alternative definitions of the design effects, for example the design effect can be defined to be the effect of weighting but not stratification on the variance, or the effect of using weighting on the estimated variance relative to using an unweighted estimator.

The design effects for the new model were between 0.4 and 0.7. Even though the survey was stratified using the old zoning while the model is based on the new zone, the design effects are still less than one. This indicates that the design still gave better results than an unstratified sample, presumably because the new and old zones were related to some extent. Even better precision could have been achieved if New Zone could have been used in stratification.

Table B.2. Design effects and standard errors for new zone coefficients

Dependent variable	Design effect		Standard errors of beta	
	High Zone	Medium Zone	High Zone	Medium Zone
Any eye symptom	0.525	0.945	0.097	0.083
Frequent and/or severe eye symptoms	0.658	1.664	0.198	0.183
Any nose symptom	0.393	0.662	0.077	0.062
Frequent and/or severe nose symptoms	0.656	1.270	0.139	0.117
Any throat symptom	0.716	1.321	0.144	0.125
Frequent and/or severe throat symptoms	0.730	1.621	0.219	0.203

Table 3 shows the design effects and standard errors for the models using the old Zone variable. A comparison of Table 2 and Table 3 shows that the standard errors are higher for the new models. This is because the sample design was based on the old zone, so that the design gives better precision for models based on the old zone than for models based on the new zone. The sample was designed to give approximately equal sample sizes in each of the old zones, and to have little variation in the weights in each old zone. Table 4 shows that the variation in the weights within each new zone is much higher, which is one contributing factor to the higher standard errors in the new model.

In comparing the precision of the old and new model, we have referred to the standard errors achieved by each model, not to the design effects. This is because each design effect is the ratio of the variance to the variance that would be expected for the same model estimated from a simple random sample of the same size. Thus the design effects of the two models are not directly comparable because the two design effects were calculated using different denominators.

Table B.3. Design effects for old zone coefficients

Dependent variable	Design effect		Standard errors of beta	
	High Zone	Medium Zone	High Zone	Medium Zone
Any eye symptom	0.271	0.797	0.079	0.077
Frequent and/or severe eye symptoms	0.408	1.157	0.155	0.165
Any nose symptom	0.165	0.545	0.053	0.057
Frequent and/or severe nose symptoms	0.376	1.049	0.108	0.110
Any throat symptom	0.360	1.090	0.118	0.110
Frequent and/or severe throat symptoms	0.502	1.420	0.191	0.188

Table B.4. Behaviour of weights by old and new zones

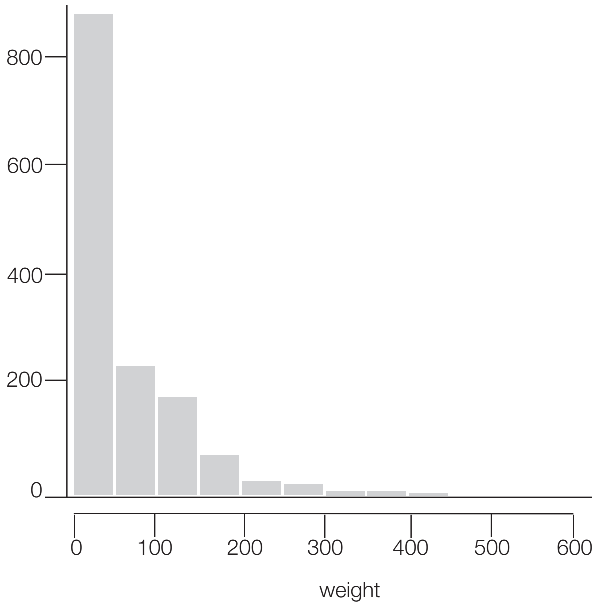
	Mean weight	Coefficient of variation (%) of Weights
Overall	59.57	116.6
Old zone = low	117.52	70.5
Old zone = medium	38.68	67.5
Old zone = high	10.60	69.8
New zone = low	105.94	75.5
New zone = medium	43.60	118.7
New zone = high	18.26	128.1

It may seem that it would be better to use the old zone in the model, as SEs are lower than in the model with new zone. In spite of the higher SEs, it is still better to use the new zone instead if this is thought to be a better representation of the potential risk from proximity to the M5. Suppose that the new zone is a risk factor, and the old zone can be assumed to be this risk factor measured with error. In this case, the regression on old zone will tend to dilute the model coefficients.

If the study could have been designed using New Zone as strata, this would have improved standard errors for the New Zone estimates. The study was designed to have a power of 80% for detecting a difference between two zones with prevalences 6% and 12%. Due to the increased standard errors, the power for detecting this change would be approximately 60%. The power would be approximately 80% for detecting a difference between two groups with prevalences 6% and 14%.

There are a number of extreme weights as shown in Figure 1. Truncating the weights would reduce standard errors to some extent, however the improvement is probably not large enough to be worth the effort in reanalysing the data. For example, if the weights were truncated at 300, the coefficient of variation of the weights would reduce from 117% to 88%, which would reduce design effects by around 10%.

Figure B.1. Distribution of estimation weights



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APPENDIX B1

Justification of the use of the Cox Proportional Hazards Model procedure

Logistic Regression Model

Define Y to be a variable equal to one for people with a condition (eg eye symptoms) and 0 for others. Let x_1, ..., X_p be explanatory variables. The logistic regression model is:

$$P[Y = 1] = \frac{e^{\alpha+\beta_1 x_1+\ldots+\beta_p x_p}}{1+e^{\alpha+\beta_1 x_1+\ldots+\beta_p x_p}}$$

where $\alpha, \beta_1, \ldots, \beta_p$ are parameters which would be estimated from a data set. The exponential of parameter β_k can be interpreted as the 'odds ratio' associated with parameter k. This is generally considered the appropriate model for binary data, because the probability is a smooth function of the covariates, and the fitted probabilities are always between 0 and 1.

The usual summary measures from logistic regressions are odds ratio. Odds ratios are a difficult to explain to a non-quantitative audience, and the relative risk is often considered to be a more useful measure for this reason. The Phase 2 report mentions the well known fact that odds ratios and relative risks are approximately equal when the prevalence of the condition being modelled is less than 10%, however this is not the case in the M5 study.

The logistic model is still valid in this case and in fact deals with large prevalences naturally. There is a danger that odds ratios can mislead in this case if they are incorrectly interpreted as relative risks (Davies 1998). This has led some authors to mistakenly conclude that logistic regression is not a valid method for prevalence values above 10 or 15% (for example, Skov 1998).

Generalized Linear Model with log link

For the M5 study, a model which provided relative risks was required. The generalized linear model with log link can provide this. The model is defined by

$$P[Y = 1] = e^{\alpha+\beta_1 x_1+\ldots+\beta_p x_p}$$

where $\alpha, \beta_1, \ldots, \beta_p$ are parameters which would be estimated from a data set. The exponential of parameter β_k can be interpreted as the relative risk associated with parameter k. Unlike the logistic regression model, it is possible for this model to give probabilities greater than one for some values of the parameters and explanatory variables.

Maximum likelihood is the usual approach to estimating parameters in generalized linear models. Generally, parameters are restricted to values such that

$$e^{\alpha+\beta_1 x_1+\ldots+\beta_p x_p} \leq 1$$

for every observation in the data. Whether this restriction is imposed or not, if there are observations in the data which have fitted probability close to one, the parameter estimates will be extremely sensitive to them (Lumley et al 2006).

Fitting the Log Link Model using a Working Poisson Model

An alternative approach to fitting the model is to use the following estimating equation:

$$e^{\alpha+\beta_1 x_1+\ldots+\beta_p x_p} \leq 1$$

where represents the vector of all explanatory variables for person i, and Y_i represents Y for person i (eg Lumley et al 2006). This is the same estimating equation as used in modelling Y as a Poisson random variable with a log link. Hence this model can be fitted using the Poisson model in standard statistical packages. This is just a device for fitting the binary model with log link and gives correct estimates of the parameters even though Y is not really a Poisson variable as this would imply that values of 2 or higher are possible.

Lumley et al (2006) comment that treating Y as Poisson means that parameter estimates are correct but that variance estimates are positively biased. This can be corrected by using a robust variance estimator such as the sandwich estimator. Robust variance estimators used in most statistical packages which incorporate the survey design, including Sudaan, R, STATA and SAS. As a result, using the Poisson routines in these packages will give valid parameter estimates and standard errors for the binary model with log link. The approach is referred to as the ‘working Poisson model’ method. The term 'working' is used, because it is not necessary to assume the Poisson model, rather Poisson model fitting procedures are used as a tool to solve (2) and thereby fit the log link model (1).

Fitting the Log Link Model using a working Proportional Hazards Model

The M5 study conducted data for (effectively) a single point in time, with six binary dependent variables which were analysed separately, and a number of explanatory variables. The Cox Proportional Hazards model was used. The Cox PH model is usually applied to observations of:

- an indicator of whether each person had the condition when the study was terminated
- the ‘survival time’ which is the time taken for each person to develop the condition (if at all).

In the M5 study, what was measured was whether or not each person had each condition at a single point in time. The estimating equation (2) can be solved by using the Cox PH model fitting procedures as follows:

- the exposure time for each person is set to a constant, say one
- each person who had the condition (eg eye symptoms) is supposed to have developed them at the very end of the exposure time
- each person who did not have the condition is supposed to have not developed the condition by the end of the exposure time
- the Breslow method for resolving tied survival times is used.

It turns out that this procedure is equivalent to obtaining the solution to (2) and hence is equivalent to fitting (1) (for example see Lumley et al 2006).

The justification for using Cox PH procedures is that they are equivalent to solving (2) and fitting (1). The Cox PH model does not directly apply to point in time data, but the procedure is appropriate as a computing tool to fit the log link model (1).

References used in Appendix B1

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APPENDIX B2

Detailed tables

Table B2.1. Relative risks with survey weights and new zone

Dependent variable	Covariate	Coefficient (Beta)	P-Value	Relative risk (RR)	Lower confidence interval for RR	Upper confidence interval for RR
Any eye symptom	Age (1yr)	-0.0014	0.5467	0.9986	0.9942	1.0031
	Sex (female)	0.0331	0.6822	1.0336	0.8821	1.2112
	Exposure to cigarette smoke	0.1550	0.0676	1.1676	0.9889	1.3787
	Internal garaging	-0.0057	0.9658	0.9943	0.7657	1.2911
	High zone (new)	0.1032	0.2874	1.1087	0.9167	1.3409
	Medium zone (new)	0.2084	0.0119	1.2317	1.0471	1.4489
Frequent and/or severe eye symptoms	Age (1yr)	0.0119	0.0074	1.0119	1.0032	1.0207
	Sex(female)	0.2639	0.1318	1.3019	0.9237	1.8351
	Exposure to cigarette smoke	0.4167	0.0180	1.5169	1.0740	2.1423
	Internal garaging	-0.2092	0.4999	0.8112	0.4415	1.4904
	High zone (new)	-0.0493	0.8038	0.9519	0.6449	1.4049
	Medium zone (new)	0.2451	0.1805	1.2778	0.8925	1.8294
Any nose symptom	Age (1yr)	-0.0015	0.3619	0.9985	0.9951	1.0018
	Sex (female)	0.0164	0.7791	1.0165	0.9067	1.1396
	Exposure to cigarette smoke	-0.0202	0.7503	0.9800	0.8654	1.1098
	Internal garaging	-0.1241	0.2451	0.8833	0.7165	1.0890
	High Zone (new)	-0.1073	0.1621	0.8983	0.7728	1.0441
	Medium Zone (new)	0.0080	0.8975	1.0080	0.8926	1.1384
Frequent and/or severe nose symptoms	Age (1yr)	0.0001	0.9764	1.0001	0.9940	1.0063
	Sex (female)	0.1910	0.0942	1.2105	0.9678	1.5141
	Exposure to cigarette smoke	-0.0682	0.5863	0.9340	0.7304	1.1944
	Internal garaging	-0.3184	0.1596	0.7273	0.4666	1.1336
	High zone (new)	-0.0020	0.9886	0.9980	0.7605	1.3098
	Medium zone (new)	0.1865	0.1126	1.2050	0.9570	1.5172

Table B2.1. Relative risks with survey weights and new zone

		Coefficient	P-Value	Relative risk	Lower confidence	Upper confidence
Any throat symptom	Age (1yr)	-0.0089	0.0099	0.9911	0.9844	0.9978
	Sex (female)	0.1693	0.1508	1.1845	0.9401	1.4923
	Exposure to cigarette smoke	0.1477	0.2194	1.1591	0.9157	1.4673
	Internal garaging	0.0991	0.5814	1.1041	0.7763	1.5705
	High zone (new)	-0.0373	0.7955	0.9634	0.7266	1.2774
	Medium zone (new)	0.0128	0.9187	1.0129	0.7921	1.2952
Frequent and/or severe throat symptoms	Age (1yr)	0.0039	0.4690	1.0040	0.9933	1.0147
	Sex (female)	0.3272	0.0960	1.3870	0.9435	2.0391
	Exposure to cigarette smoke	0.2249	0.2733	1.2521	0.8373	1.8726
	Internal garaging	-0.1444	0.6733	0.8656	0.4422	1.6942
	High zone (new)	-0.0328	0.8808	0.9677	0.6300	1.4864
	Medium zone (new)	0.0635	0.7547	1.0656	0.7153	1.5873

APPENDIX C

Crude and adjusted prevalence rate ratios of potential confounders

Table C.1. Crude prevalence rate ratios of potential confounders by eye symptoms

Confounder	Crude prevalence rate ratio (eye symptom) (CI)	Adjusted prevalence rate ratio (eye symptom) (CI)	Crude prevalence rate ratio (more frequent &/or severe eye symptoms) (CI)	Adjusted prevalence rate ratio (more frequent &/or severe eye symptoms) (CI)
Age (1 yr)	1.00 (0.99-1.00)	1.00 (0.99-1.00)	1.01 (1.00-1.02)$^{+}$	1.01 (1.00-1.02)$^{+}$
Sex (female)	1.03 (0.87-1.21)	1.03 (0.88-1.21)	1.30 (0.92-1.84)	1.30 (0.92-1.84)
Exposure to cigarette smoke	1.16 (0.99-1.37)	1.17 (0.99-1.38)	1.37 (0.96-1.96)	1.52 (1.07-2.14)$^{+}$
Internal garaging	0.98 (0.81-1.19)	0.99 (0.77-1.29)	0.79 (0.51-1.22)	0.81 (0.44-1.49)

Table C.2. Crude prevalence rate ratios of potential confounders by nose symptoms

Confounder	Crude prevalence rate ratio (nose symptom) (CI)	Adjusted prevalence rate ratio (nose symptom) (CI)	Crude prevalence rate ratio (more frequent &/or severe nose symptoms) (CI)	Adjusted prevalence rate ratio (more frequent &/or severe nose symptoms) (CI)
Age (1 yr)	1.00 (1.00-1.00)	1.00 (1.00-1.00)	1.00 (0.99-1.01)	1.00 (0.99-1.01)
Sex (female)	1.02 (0.91-1.14)	1.02 (0.91-1.14)	1.23 (0.98-1.54)	1.21 (0.97-1.51)
Exposure to cigarette smoke	0.98 (0.87-1.11)	0.98 (0.87-1.11)	0.90 (0.71-1.15)	0.93 (0.73-1.19)
Internal garaging	0.93 (0.81-1.07)	0.88 (0.72-1.09)	0.78 (0.58-1.05)	0.73 (0.47-1.13)

Table C.3. Crude prevalence rate ratios of potential confounders by throat symptoms

Confounder	Crude prevalence rate ratio (throat symptom) (CI)	Adjusted prevalence rate ratio (throat symptom) (CI)	Crude prevalence rate ratio (more frequent &/or severe throat symptoms) (CI)	Adjusted prevalence rate ratio (more frequent &/or severe throat symptoms) (CI)
Age (1 yr)	0.99 (0.98-1.00)$^{+}$	0.99 (0.98-1.00)$^{+}$	1.00 (0.99-1.01)	1.00 (0.99-1.01)
Sex (female)	1.16 (0.92-1.47)	1.18 (0.94-1.49)	1.38 (0.94-2.02)	1.39 (0.94-2.04)
Exposure to cigarette smoke	1.20 (0.94-1.52)	1.16 (0.92-1.47)	1.19 (0.81-1.76)	1.25 (0.84-1.87)
Internal garaging	1.08 (0.82-1.41)	1.10 (0.78-1.57)	0.83 (0.53-1.30)	0.87 (0.44-1.69)

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