# A9 Vehicle emissions

## A9.1 Introduction

**Introduction**

This appendix gives guidance on calculating vehicle emissions such as carbon dioxide and small particulates and the impacts for the do minimum and project options.

Carbon dioxide emissions are linked to fuel consumption through vehicle operating costs, while other emissions can be calculated using the procedure provided in this appendix.

**In this appendix**

This appendix contains the following topics:

# A9.2 Vehicle emissions

**Vehicle emissions**

Vehicles with internal combustion motors emit gases and particles into the environment. These pollutants include:

- carbon dioxide ($CO_2$)
- carbon monoxide (CO)
- oxides of nitrogen (NOx)
- unburnt hydrocarbons (HC)
- lead compounds
- particles such as smoke, tyre and brake wear products.

Air pollution from vehicle emissions may be significant if one or more of the following conditions apply:

- still weather conditions, in which pollutants do not readily disperse
- bright sunlight and temperature inversion which lead to photochemical smog
- high traffic densities and stop/start operations
- confined urban streets with activities such as retail developments in close proximity.

New Zealand cities do not suffer from air pollution to the extent of some overseas cities but temperature inversion and still weather conditions can combine to cause noticeable pollution.

**Impacts of air pollution**

The effects of air pollutants vary. Some are toxic in high concentration, some aesthetically disagreeable and the persistent gaseous products gradually change atmospheric composition.

Carbon monoxide is dangerous in high doses and can be responsible for chronic effects such as loss of concentration, impairment, tiredness and headaches. However, small doses are removed from the bloodstream when the person affected moves to a cleaner environment. Photochemical oxidants, including nitrogen dioxide can be irritating to the eyes and respiratory system. Unburnt hydrocarbons, particularly benzene ring aromatic compounds that occur in diesel engine emissions, are believed to be carcinogenic. Smoke particles and odours can be offensive but of lesser health significance.

Some pollutants such as lead persist in the environment whereas others like carbon monoxide disperse and undergo chemical change.

Small particles (those less than 10 microns in diameter) from fuel, tyres, exhaust gases, dust, etc, remain airborne for up to 10 days and even in relatively calm conditions will disperse widely through a city. These particles are strongly implicated in respiratory and other infections and as a result there have been suggestions that the public health costs of this pollution are higher than most other traffic-related environmental costs in urban areas.

# A9.2 Vehicle emissions, continued

**Design guidelines**

The Ministry for the Environment (MfE) in 2002 published 'ambient air quality guidelines' which are consistent with World Health Organisation goals. A summary of the guideline values relevant to motor vehicle emissions is shown in table A9.1. The guidelines can be seen as levels, which are consistent with an 'acceptable' public health cost, but simply to meet these guidelines does not imply zero public health cost. Also regional councils may set secondary guidelines to deal with other air quality effects, such as visibility.

Note: The air quality guidelines also consider higher concentrations for shorter periods.

**Table A9.1 Guidelines for motor vehicle emissions**

| Pollutant | Period of exposure | Mean concentration mg/m$^3$ |
|---|---|---|
| Carbon monoxide (CO) | 8 hour | 10 |
| | 1 hour | 30 |
| Nitrogen oxides ($NO_x$) | 24 hour | 300 |
| | 1 hour | 100 |
| Lead | 90 days | 0.2 |
| Particulates ($PM_{10}$) | 1 year | 20 |
| | 24 hour | 50 |
| Sulphur dioxide | 1 year | 350 |
| | 24 hour | 120 |
| Ozone | 8 hour | 100 |
| | 1 hour | 150 |

# A9.2 Vehicle emissions, continued

**Mitigation of air pollution**

Pollution control is best tackled by reducing vehicle exhaust emissions. Elimination of leaded petrol in New Zealand has been completed. Therefore, long-term exposure to lead will diminish. The focus is now turning towards improved vehicle emissions standards for new vehicles and vehicle screening. Potential mitigation measures available to highway designers include increased separation distances between road and receptors, land-use controls, careful placement of intersections, and traffic management techniques aimed at maintaining free flow speeds (Highways Agency 2003).

If the concentration of toxic pollutants resulting mainly from motor vehicles exceeds the levels shown in the table A9.1, then there is a strong prima facie case for remedial action. Even where concentrations are lower than in table A9.1, there are likely to be benefits of pollution reduction. The practical application of this may mean reducing traffic volumes and stop/start conditions, or improving the ventilation of affected areas.

**Assessment of air pollution**

An indication of pollution levels can be obtained from one of several pollution prediction methods. These allow the concentration of pollutants to be estimated from traffic volume and speed, and the distance from the roadway to the point of measurement based on the characteristics of the New Zealand vehicle fleet (Ministry of Transport, 1998).

Recommendations on the most appropriate form of assessment in particular circumstances are currently being prepared (SKM, 2003) and recently good practice guidelines have been issued by the Ministry for Environment covering, the preparation of emissions inventories (MfE, 2001), atmospheric dispersion modelling (MfE 2004) and air quality monitoring (MfE, 2000). Contacting the appropriate regional council may be useful as they sometimes carry out air pollution analysis, eg, using emission inventory techniques.

# A9.3 Vehicle emissions procedure

**Calculating ambient air emission loads**

This procedure has been developed from the Ministry of Transport vehicle fleet emission model and can be used when ambient air quality emission calculations are required. It provides emission estimates for carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM10) and volatile organic compounds (VOC). Procedures for $CO_2$ emissions are provided in appendix A9.7. Follow the emission procedure below to calculate the emission loads for each road link and time period.

**Emission procedure**

<table>
<tr><th>Step</th><th>Action</th></tr>
<tr><td>1</td><td>Determine the:<br>• Traffic composition (appendix A2.2)<br>• Time period total average travel time per vehicle (appendix A3.26)</td></tr>
<tr><td>2</td><td>Convert the traffic composition vehicle classes into emission classes:
<table>
<tr><th>Emission class</th><th>Vehicle classes (appendix A2.2)</th></tr>
<tr><td>Light<br>(vehicles less than 3.5 tonnes)</td><td>Passenger Cars<br>Light Commercial Vehicles</td></tr>
<tr><td>Heavy<br>(vehicles greater than 3.5 tonnes)</td><td>Medium Commercial Vehicle (MCV)<br>Heavy Commercial Vehicle I (HCVI)<br>Heavy Commercial Vehicle II (HCVII)<br>Buses</td></tr>
</table></td></tr>
<tr><td>3</td><td>Calculate average speed on link road:<br>Speed (km/h) = 60 x length / TT<br>where:<br>length = road link length (km)<br>TT = time period total average travel time per vehicle (appendix A3.26)</td></tr>
</table>

# A9.3 Vehicle emissions procedure, continued

**Emission procedure**, continued

| Step | Action |
|---|---|
| 4 | Calculate the emission rates for light and heavy vehicle types:<br><br>Emission (g/vkt) = A x Speed$^2$ + B x Speed + C<br><br>where:<br><br>Speed = average speed on link road from step 3<br><br>A, B, C = coefficients from table below |

| Emission | Vehicle | A | B | C |
|---|---|---|---|---|
| CO | Light | $3.6 \times 10^{-3}$ | -0.545 | 25.5 |
| | Heavy | $6.47 \times 10^{-4}$ | -0.11 | 7.31 |
| NOx | Light | $2.46 \times 10^{-4}$ | -0.0287 | 1.67 |
| | Heavy | $2.04 \times 10^{-3}$ | -0.275 | 17.4 |
| PM10 | Light | $2.45 \times 10^{-5}$ | -0.00342 | 0.153 |
| | Heavy | $3.82 \times 10^{-4}$ | -0.0455 | 2.65 |
| VOC | Light | $5.53 \times 10^{-4}$ | -0.081 | 3.55 |
| | Heavy | $3.07 \times 10^{-4}$ | -0.0584 | 3.30 |

| Step | Action |
|---|---|
| 5 | Weight the calculated emission rates by vehicle flow composition (g/vkt):<br><br>= % light vehicles x light emission rate<br><br>+ % heavy vehicles x heavy emission rate |
| 6 | Multiply the weighted emission rates by the time period's total vehicle volume and the road's length to give the emission load (g). |

**Example**

For a 1 km road with 1000 vehicles travelling along it with a calculated travel time of 2.371 min/veh and a vehicle flow composition of 95% light and 5% heavy.

Speed = 1 x 60 / 2.371 = 25.3 km/hr

Light CO = $3.6 \times 10^{-3} \times (25.3)^2 - 0.545 \times (25.3) + 25.5$

= 14.0 g/vkt

Heavy CO = $6.47 \times 10^{-4} \times (25.3)^2 - 0.11 \times (25.3) + 7.31$

= 4.9 g/vkt

Weighted CO emission rate = 95% x 14.0 + 5% x 4.9

= 13.5 g/vkt

CO emission load = weighted CO emission rate x vkt

= 13.5 x (1 km x 1000 vehicles) = 13500 g

# A9.4 Valuation of emissions

**Valuation of emissions**

Mortality costs have been estimated as a 0.101% increase in daily death rates for a 1 microgram per $m^3$ increase in PM10. Based on UK costs (assuming similar death rates and adjusting for New Zealand costs of life), the annual mortality costs in New Zealand are $30 per person exposed per year per microgram/$m^3$ increase in PM10. This figure can be increased by 30% (based on US and French contingent valuation studies) to take account of poorer health amongst those who do not die, to give a total annual cost of $40 per person per year per microgram/$m^3$. By contrast, health costs of ground level ozone are believed to be an order of magnitude less.

There are major problems in assessing the meaning and usefulness of these values in the New Zealand environment. Firstly, the death rates to not increase linearly with pollution, and most parts of New Zealand are likely to have far lower rates of pollution than Europe. Secondly, the impacts will be highly site-specific.

Figures for New Zealand need to be based on specific locations. The cost shall be calculated as:

0.001 × ΔPM10 concentration × population exposed × normal death rate × value of life.

Where: ΔPM10 concentration is the change in average concentration for the period analysed.

Other research (Bein) suggests that a light vehicle travelling at 40 km/h has particulate costs of approximately NZ1.0 cents per km (C$0.006 mortality + morbidity costs). A heavy vehicle has costs of approximately NZ20 cents per km (C$0.14 + morbidity). Note that the high heavy vehicles cost is for diesel engines and petrol engines impose only 20 percent of the cost. These per km costs should be used in assessing the negative effects of generated traffic in urban areas. In particular they should be used for studies of major changes to urban traffic networks which increase traffic into urban areas or which reduce traffic by increasing public transport.

Particulate effects are likely to be of most significance in comparing alternative urban transport proposals, and in modelling the effects of motorways where these increase traffic (and hence fuel use) in urban areas.

# A9.5 Emissions reporting

**Reporting of emissions**

Expected effects of projects on air pollution shall be reported. These effects may take the form of reductions in air pollution on confined urban streets or major urban arterial as a result, for example, of a new by-pass, or increases in air pollution in the vicinity, for example, of a new arterial route.

If the effects of the project on air pollution are significant, predictions of air pollution shall be reported against the design guidelines in table A9.1 and where the project includes measures to mitigate air pollution, the incremental costs and benefits of these measures shall also be reported.

In evaluating and reporting expected effects of air pollution, it is important to refer to regional and local authority planning documents. These may provide guidance to the assessment methodology appropriate to the area in question. Also, the *Resource Management Act* does allow regional and territorial authorities to set regionally specific air quality guidelines and standards. Where these exist, predictions should be reported against those criteria rather than the design guidelines in table A9.1. It is also important to recognise other potential sources of air pollution in the vicinity of any proposed development and incorporate these effects into the overall assessment (eg, domestic fires in high density urban areas). The design guidelines in table A9.1 are intended to be applied to the cumulative effects of all activities.

# A9.6 Carbon dioxide emissions

**Carbon dioxide emissions**

The greenhouse effect is the trapping of heat in the lower atmosphere by greenhouse gases, particularly carbon dioxide and water vapour. These gases let energy from the sun travel down to the earth relatively freely, but then trap some of the heat radiated by the earth.

**Impacts of carbon dioxide**

While carbon dioxide occurs naturally, in the last 200 years the concentration of carbon dioxide in the Earth's atmosphere has increased by 25 percent. As these extra amounts of carbon dioxide are added to the atmosphere they trap more heat causing the Earth to warm. This extra warming is called the enhanced greenhouse effect and is predicted to significantly change the Earth's climate.

Carbon dioxide makes up about half of the extra greenhouse gases and a significant proportion of this extra carbon dioxide is emitted by motor vehicles.

**Valuation of carbon dioxide emissions**

There has been considerable debate as to the cost of carbon dioxide emissions and proposed values cover a wide range. The variation reflects uncertainty about the levels and timing of damage as well as an appropriate discount rate. The *Land Transport Pricing Study (1996)* determined an average cost of carbon dioxide emissions of $30 per tonne, which is updated to $40 per tonne (2004 values) and which equates to 12 cents per litre of fuel. Carbon emissions are approximately valued at 7.5 per cent of total vehicle operating costs for default traffic composition. These values shall be used in project evaluations. Light and heavy vehicle carbon emissions can be individually determined in A9.7.

The monetary value adopted to reflect the damage costs of carbon dioxide emissions in project evaluations has no relationship to the level of carbon tax that the government might consider as a policy instrument to restrain carbon dioxide emissions.

# A9.7 Assessment of carbon dioxide emissions

| | |
|---|---|
| **Assessment of carbon dioxide emissions** | There is a direct relationship between carbon dioxide emissions and fuel consumption and emissions can be calculated using different procedures for road inks and for intersections. |
| **Emission classes** | The emissions classes defined in step 2 of section 9.3 are applicable to the assessment of carbon dioxide emissions. |
| **Road links** | For road links vehicle operating costs (VOC) are calculated by summing running costs and roughness costs. The fuel cost component of running costs is in the range 20-40%, depending on speed and gradient, while for roughness costs the fuel cost component is negligible. The following formulae can be used to determine carbon dioxide emissions:<br><br>Light $CO_2$ (in tonnes) = VOC($) x 0.0015<br><br>Heavy $CO_2$ (in tonnes) = VOC($) x 0.0028<br><br>Where VOC includes values due to speed and gradient (Tables A5.1 – A5.11) and congestion (Tables A5.16 – A5.23), i.e. VOC due to roughness is excluded (Tables A 5.12 – A5.15)<br><br>For shape correction projects the VOC benefits are due mainly to reduced roughness costs and no change in carbon dioxide emissions shall be reported. |
| **Intersections** | Where computer-based models, such as SIDRA, INTANAL and SCATES, are used to analyse intersection improvements, then fuel consumption, which is an output of these models, can be used to determine carbon dioxide emissions by applying the following formula:<br><br>Light $CO_2$ (in tonnes) = Fuel consumption (in litres) x 0.0022<br><br>Heavy $CO_2$ (in tonnes) = Fuel consumption (in litres) x 0.0025<br><br>These formula can also be used for projects evaluated using computer models. |
| **Generated traffic** | For generated traffic, the total VOC or carbon dioxide generated by the additional trips shall be estimated, and the resulting values calculated. |
| **Reporting of carbon dioxide emissions** | The predicted value change in carbon dioxide emissions shall be calculated as $40 per tonne of carbon dioxide or five percent of the VOC changes, and shall be included in the BCR. Carbon dioxide impacts shall also be quantified in tonnes and reported in the project summary sheet. |

# A9.8 References

**References**


1. Ministry for the Environment, *Good-practice guide for air quality monitoring and data management,* Wellington, 2000. http://www.mfe.govt.nz/publications/
2. Ministry for the Environment, *Good practice guide for preparing emission inventories,* Wellington, 2001. http://www.mfe.govt.nz/publications/
3. Ministry for the Environment, *Ambient air quality guidelines,* Wellington, 2002. http://www.mfe.govt.nz/publications/
4. Ministry for the Environment, *Good practice guide for atmospheric dispersion modelling,* Wellington, 2004. http://www.mfe.govt.nz/publications/
5. Ministry of Transport, *Vehicle fleet emissions model: New Zealand vehicle fleet database and model development,* Wellington, December 1998
6. Sinclair Knight Merz, *Guidelines for assessing the effects of discharges to air from Land Transport (draft),* report for Auckland Regional Council, 2003.