Emissions Estimation Technique Manual

for

Aggregated Emissions from Railways

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EMISSIONS ESTIMATION TECHNIQUE MANUAL:
AGGREGATED EMISSIONS FROM RAILWAYS

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1.0 Introduction

1.1 The NPI

The National Pollutant Inventory (NPI) was established under a National Environment Protection Measure (NEPM) made by the National Environment Protection Council (NEPC) under Commonwealth, State and Territory legislation on 27 February 1998. This Measure is to be implemented progressively through the laws and administrative arrangements of each of these participating jurisdictions (i.e. State and Territory Governments).

The NEPM and an associated Memorandum of Understanding for the NPI, which have been published as a single document by the NEPC, provide more details on the purpose and structure of the NPI, and the arrangements for implementation of the NEPM that have been agreed by the jurisdictions. Users of this Manual should read this publication if they are unfamiliar with the NEPM or the NPI.

1.2 Purpose and Scope of the Manual

The NPI will be developed as an internet database designed to provide information on the types and amounts of certain chemical substances being emitted to the air, land and water environments. If the NPI is to achieve its aim of communicating useful and reliable information to the community, industry and governments on pollutants present in our environment, the emissions estimation techniques (EETs) used to generate inputs to the NPI need to be consistent, and the process for developing these techniques needs to be transparent. This Manual has been developed, reviewed and finalised in this context.

The NEPM contains a list of substances for which emissions will be reported on an annual basis to the Commonwealth Government, which will then compile and publish the NPI. The aggregated emissions manuals, of which this is one, have been prepared to assist State and Territory Governments in preparing these submissions, and to facilitate consistent reporting between these jurisdictions.

State and Territory Governments will also be compiling and submitting emissions data based on annual inputs from reporting facilities. These facilities are primarily industrial enterprises which use (or handle, manufacture or process) more than specified amounts of certain polluting substances, burn more than specified amounts of fuel, or consume more than certain amounts of energy. These amounts or “thresholds” (which are clearly defined in the NEPM) govern whether an industrial facility is required to report and what substances it is required to report on, and industry handbooks are being developed to help industries to prepare the information for these reports.

The aggregated emissions manuals complement these handbooks, and are intended to enable Governments to estimate emissions from non-industrial activities (e.g. transportation, domestic and commercial activities) and

emissions from industry which are not reported because the relevant thresholds are not exceeded or are exempt from reporting.

Annual submissions are also to be prepared and submitted in conformance with the NPI Data Model and Data Transfer Protocol. For emissions to the air environment, this Protocol only requires jurisdictions to submit data on emissions into the particular airsheds that are listed in the Protocol, and not to the rest of each jurisdictional area. For example, under the 1998 to 2000 Memorandum of Understanding, in Victoria, emissions data are only required for the Port Phillip and Latrobe Valley Regions. In addition, emissions data are required to be submitted on a gridded basis, with each jurisdiction determining a grid domain and grid cell size necessary to meet its obligations under Section 7 of the NEPM.

Therefore, in addition to recommending and providing details and examples of appropriate emissions estimation techniques (EETs) for the relevant NPI substances, this Manual provides guidance on the spatial allocation of emissions and the use of area-based surrogates for accurately distributing the activities or sources in question.

1.3 Application of the Manual

Each of the aggregated emissions manuals provides details of:

- the NPI substances that are expected to be emitted from the relevant aggregated source type;
- the origins or sources of the emissions, and the processes that may generate them;
- the impacts of any control equipment or procedures on those emissions;
- the broad approaches that may be employed in the estimation and spatial allocation of emissions;
- details of emission factors to be used in the estimation of emissions; and
- a series of illustrative sample calculations for each estimation technique.

Each of the manuals also contains a section on “Uncertainty Analysis”, which provides information and guidance to users on the reliability of the various estimation techniques, problems and issues associated with their development and application, and recommendations for their improvement. In preparing the aggregated emissions manuals it has been recognised that some jurisdictions already undertake detailed emissions inventories on a regular basis, based on relatively sophisticated methodologies. For these jurisdictions the manuals offer techniques which represent commonly available best practice for emissions estimation in Australia (i.e. techniques of high quality which can be employed by larger or more experienced jurisdictions with an acceptable expenditure of time and effort). The most recent developments in inventory methodology in Australia and overseas have been considered in selecting and documenting these techniques.

Where a more simplified methodology for emissions estimation of acceptable quality is available, it is recommended in the manual for the use of those jurisdictions which may, for the time being at least, lack the data, resources or

expertise to employ a more sophisticated approach, or not see the need for highly reliable estimates in that particular part of the inventory.

2.0 Emissions Covered by the Manual

2.1 NPI Substances

Table 1 lists the main NPI substances that are emitted from railway locomotives.

Table 1: NPI Substances Emitted from Locomotives [a]

Acetaldehyde	Manganese and compounds
Antimony and compounds	Mercury and compounds
Arsenic and compounds	n-Hexane
Benzene	Nickel and compounds
Cadmium and compounds	Oxides of nitrogen
Carbon monoxide	Particulate matter ≤ 10 μm (PM10)
Chromium (III) compounds	Polycyclic aromatic hydrocarbons
Chromium (VI) compounds	Selenium and compounds
Cobalt and compounds	Sulphur dioxide
Copper and compounds	Toluene
Ethylbenzene	Total volatile organic compounds (VOCs)
Formaldehyde	Xylenes
Lead and compounds	Zinc and compounds

[a] Paragraph 2 (e) of Schedule A to the NEPM requires that, for the purposes of emissions estimation, a substance listed in Tables 1 and 2 of that Schedule as " (a metal) and a compound" refers only to the amount of metal that may be emitted. The EETs described in this manual have been prepared accordingly. Thus, the emission factors for metals and their compounds relate only to the amount of the metal itself that may be emitted as a part of these compounds.

2.2 Emission Sources and Related Processes

Railway locomotives used in Australia are primarily of two types: electric and diesel-electric. Electric locomotives are powered by electricity generated at stationary power plants and emissions are produced only at the electrical generation plant, which is considered a point source and therefore not considered in this manual. Diesel-electric locomotives, on the other hand, use a diesel engine and an alternator or generator to produce the electricity required to power its traction motors. Emissions produced by these diesel engines are covered in this manual.

A third type, the steam locomotive, is used in very localised operations, primarily as tourist attractions. Emissions from these locomotives are insignificant and no emission factors have been developed for them. In addition, the particulates emitted from operating steam locomotives are so large that nearly all particles fall to the surface within 50 metres.

Other sources of emissions from railroad operations include small gasoline and diesel engines used on refrigerated and heated rail cars. These engines are thermostatically controlled, working independently of train motive power, and will not be covered in this manual. Brake dust from trains can also be a source of PM10. However, no emission factor is available for it.

Locomotives can perform two different types of operations: line haul and yard (or switch). Line haul locomotives, which perform the line haul operations, generally travel between distant locations, such as from one city or town to another. In this manual, line haul operations include intermodal freight services, mixed freight services, and passenger services. Yard locomotives, which perform yard operations, are primarily responsible for moving railcars within a particular railway yard. Note that the industry handbook "Railway Yard Operations" also cover emissions from yard operations. If emissions from railway yards are reported as facility emissions, they should be excluded in the aggregated emission estimation.

2.3 Emission Controls

There are usually no specific emission control devices or equipment fitted to railway locomotive engines.

3.0 Emissions Estimation Techniques

3.1 Approaches Employed

The methods described in this manual enable the preparation of annual inventories based on yearly activity data. These methods are based on a national locomotive fleet mix and average fuel consumption figures developed by USEPA (1992).

For line haul or yard locomotives, emissions are calculated by multiplying the amount of fuel consumed by line haul or yard locomotives in the inventory area (or NPI airshed) by the appropriate emission factors for NPI substances.

Equation 1: Estimating locomotive emissions

Airshed Emissions = Fuel Consumption in Airshed × Emission Factors

Fuel consumption data for line haul locomotives can usually be provided by railway companies or transport authorities. If fuel consumption figures are only available for the jurisdiction (State or Territory) as a whole, an estimate of fuel consumption in the NPI airshed can be obtained by using the ratio of traffic density (expressed in gross tonne kilometre or GTK) in the airshed to that of the jurisdiction. If traffic density data are not available, the lengths of the railway system in the airshed and the jurisdiction can be used as an alternative method of estimating airshed fuel consumption.

Railway length or traffic density data are also usually obtainable from the railway companies or transport authorities. The length of railways can often be obtained from a map or GIS maintained by the relevant Government.

Fuel consumption data for yard locomotives can also be obtained from railway companies or transport authorities. If the fuel consumption is provided for the jurisdiction as a whole, it needs to be proportioned according to the ratio of yard locomotives in the NPI airshed and the jurisdiction respectively. If the fuel consumption is not provided separately for yard locomotives, it can be estimated by the following equation:

Equation 2: Estimating yard locomotive fuel consumption

Inventory Fuel Consumption = Number of Yard Locomotives × Average Fuel Consumption per Day × Number of Days of Operation

The number of yard locomotives can be obtained from railway companies or transport authorities. A value of 863 litres can be used for the average fuel

consumption per day (USEPA 1992) if the data is not available. The number of days of operation is usually 365.

If data for the number of yard locomotives cannot be obtained, the emissions inventory can be approximated by assuming that all fuel is consumed by line haul locomotives.

ABARE (1999) also publishes fuel consumption figures for rail transport for Australia, which need to be scaled down for a jurisdiction based on the total automotive diesel oil consumed in the jurisdiction and Australia. However, figures from ABARE should only be used if data are otherwise unavailable.

3.2 Spatial Surrogates and Spatial Allocation

Emissions from line haul locomotives are assigned to the railway lines, and the emissions in each grid cell are calculated from the fraction of total airshed GTK in the grid cell, or fraction of total rail length if GTK data are not available (see Equation 3).

Equation 3: Estimating emissions in a grid cell

Emissions in a grid cell are estimated by the following equation:

$$E_i = E \times L_i / \sum_i L_i$$

where

E_i = emissions in grid cell i
E = emissions in airshed
L_i = GTK or length of railway in grid cell i

Emissions from yard locomotives should be assigned to the railway yards and made proportional to the number of yard locomotives. If such data are not available, the emissions can be assigned to the railway lines according to GTK or length of railway.

3.3 Emission Factors

Once fuel consumption figures have been calculated or estimated, NPI airshed emissions are determined by multiplying that value by the fleet average emission factors for each pollutant (expressed in grams per litre of fuel burned (g L^{-1}). The emission factors recommended for all line haul and yard locomotives are shown in Table 2.

The emission factors for sulphur dioxide are based on an average Australian diesel sulphur content of 0.15 percent sulphur by weight (Challenger, B., AIP March 1997, pers. comm.). If the diesel sulphur content is given for a

jurisdiction, Equation 4 can be used to adjust the sulphur dioxide emission factors.

Table 2: Locomotive Emission Factors

Substance	Line Haul Locomotive Emission Factor[a] ($g\ L^{-1}$)	Yard Locomotive Emission Factor[a] ($g\ L^{-1}$)
Acetaldehyde	0.0755	0.181
Antimony and compounds	1.92×10^{-4}	2.28×10^{-4}
Arsenic and compounds	4.17×10^{-6}	4.96×10^{-6}
Benzene	0.0440	0.105
1,3-Butadiene[b]	0.0401	0.0963
Cadmium and compounds	9.31×10^{-5}	1.11×10^{-4}
Carbon Monoxide	7.50	10.7
Chromium (III) compounds[c]	8.84×10^{-6}	1.05×10^{-5}
Chromium (VI) compounds[c]	3.67×10^{-6}	4.37×10^{-6}
Cobalt and compounds	8.34×10^{-6}	9.92×10^{-6}
Copper and compounds	4.17×10^{-5}	4.96×10^{-5}
Ethylbenzene	0.00152	0.00366
Formaldehyde	0.223	0.536
Lead and compounds	4.17×10^{-5}	4.96×10^{-5}
Manganese and compounds	3.20×10^{-5}	3.80×10^{-5}
Mercury and compounds	3.47×10^{-5}	4.13×10^{-5}
n-Hexane	0.0358	0.0859
Nickel and compounds	2.08×10^{-5}	2.48×10^{-5}
Oxides of Nitrogen	59.1	60.4
Particulate Matter ≤10.0 µm[d]	1.39	1.65
Polycyclic Aromatic Hydrocarbons[e]	0.0188	0.107
Selenium and compounds	5.56×10^{-6}	6.61×10^{-6}
Sulphur Dioxide[f]	2.59	2.59
Toluene	0.0445	0.107
Total Volatile Organic Compounds[g]	2.54	6.09
Xylenes	0.00711	0.0171
Zinc and compounds	5.56×10^{-4}	6.61×10^{-4}

[a] Emission factors obtained from USEPA (1991) and speciated using data from CARB (1991a) and CARB (1991b).
[b] Fraction in total volatile organic compounds assumed to be the same as that of diesel trucks (USEPA 1993).
[c] Assuming the same fraction of chromium(VI) (29.3%) as that emitted from fuel oil combustion (USEPA 1998).
[d] Particulate fraction assumed to be the same as that of diesel trucks (EPAV 1995).
[e] Data obtained from diesel engine (Kahlili et al 1995).
[f] Based on a fuel sulphur content of 0.15 percent by weight.
[g] Converted from those of total hydrocarbons (USEPA 1992).

Equation 4: Adjusting sulphur dioxide emission factors

Adjusted Sulphur Dioxide Emission Factor = (Sulphur Content of Diesel Fuel in NPI Airshed / 0.15) × Sulphur Dioxide Emission Factor (from Table 2

USEPA (1985) has also published emission factors for supercharged and turbocharged locomotives. However, these emission factors are quite old and not recommended for use.

3.4 Sample Calculations

Example 1: Estimating carbon monoxide emissions from locomotives in the Port Phillip Region

Fuel consumption by diesel locomotives in Victoria is 35.7×10^6 L yr^{-1}.

No data are provided for fuel consumption by yard locomotives or the number of yard locomotives, so it is assumed that all fuel is consumed by line haul locomotives.

No data are provided for GTK in the Port Phillip Region, and fuel consumption in the Port Phillip Region airshed is obtained by proportioning State-wide data according to railway length.

The proportion of Victoria's total rail length which is in the Port Phillip Region is 0.207.

Hence fuel consumption in the Port Phillip Region

$= 0.207 \times 35.7 \times 10^6$

$= 7.38 \times 10^6$ L yr^{-1}

Then, using Equation 1, the emissions of carbon monoxide are

$= 7.38 \times 10^6 \times 7.50$ g yr^{-1}

$= 55.4$ tonne yr^{-1}

4.0 Uncertainty Analysis

In the following discussion the reliability of data and other estimates is classified into 3 levels of confidence: high (uncertainty of 20% or less), medium (uncertainty of between 20% and 80%) and low (uncertainty of greater than 80%).

4.1 Data Reliability

Railway companies or transport authorities usually keep good records of fuel consumption and GTK, and the reliability of these data is high. Data from ABARE needs to be scaled down for a jurisdiction and the reliability of such data is considered to be medium.

4.2 Reliability of Emission Factors

Emission factors for carbon monoxide, oxides of nitrogen, particulate matter of 10 µm or less, sulphur dioxide and total volatile organic compounds are derived from the US national locomotive fleet and the application of such factors to Australian fleet reduces their reliability to medium.

Emission factors for other substances are obtained from the emission factors of total volatile organic compounds and particulate matter, and speciation profiles for these substances. The speciation factors are measured from diesel trucks or engines and the application of such factors to diesel locomotives reduces their reliability. The reliability of these emission factors is therefore considered to be low.

4.3 Recommendations for Further Work

To improve the accuracy of these techniques, it would be necessary to measure emissions from diesel locomotives operating in Australia. Research is also required for determining an accurate speciation profile of volatile organic compounds and particulate emissions.

5.0 Glossary of Terms and Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
AE	Aggregated Emissions
AIP	Australian Institute of Petroleum
CARB	California Air Resources Board
EPAV	Environment Protection Authority of Victoria
GIS	Geographic information system
GTK	Gross tonne kilometre
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NPI	National Pollutant Inventory
PM10	Particulate matter less than or equal to 10 μm
USEPA	United States Environmental Protection Agency

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