Emissions Estimation Technique Manual

for

Aggregated Emissions from Domestic Lawn Mowing

November 1999

Version 1.0 - First Published 1 November 1999

EMISSIONS ESTIMATION TECHNIQUE MANUAL:
AGGREGATED EMISSIONS FROM DOMESTIC LAWN MOWING

TABLE OF CONTENTS

LIST OF TABLES

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

This manual provides guidance on the estimation of aggregated emissions from domestic lawn mowing. This activity can be a significant contributor to overall area-based emissions, particularly for lead and some VOCs.

2.1 NPI Substances

Table 1 lists the main substances in Table 2 to Annex A of the NEPM which are emitted by lawn mowers.

Table 1: NPI Substances Emitted by Domestic Lawn Mowers [a]

Benzene	Manganese and compounds
1,3-Butadiene (vinyl ethylene)	Nickel and compounds
Carbon monoxide	Oxides of nitrogen
Chromium (III) compounds	Particulate matter $\leq$ 10 μm (PM10)
Chromium (VI) compounds	Polycyclic aromatic hydrocarbons
Cobalt and compounds	Styrene
Copper and compounds	Sulphur dioxide
Cyclohexane	Toluene (methyl benzene)
Ethylbenzene	Total volatile organic compounds (VOCs)
Formaldehyde (methyl aldehyde)	Xylenes
n-Hexane	Zinc and compounds
Lead 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

There are four types of lawn mowers used in Australia: two-stroke engined mowers, four-stroke engined mowers, electric mowers and push mowers. Only the first two types emit pollutants to the atmosphere at the point of use. Power companies will report emissions from electricity generation.

Four-stroke mowers have lower emissions of VOCs, CO and PM10 than two-stroke mowers, but higher NO_x emissions. Fuel type (leaded or unleaded petrol) can also affect emissions, especially for lead and SO_2.

2.3 Emission Controls and Other Factors Affecting Emissions

Lawn mower usage can vary across a region. Important factors affecting local equipment usage include climate, land use, lot size, population demographics, and the availability of water in more arid regions (Heiken *et al*, 1997). Lawn mower usage also varies both seasonally and with day of the week. These variations do not need to be taken into account for the purposes of the NEPM, as the NPI requires reports on annual emissions, though jurisdiction may wish to gather this information for other analysis.

Changes in emission levels with increasing mower age are not specifically addressed in the emissions estimation technique (EETs). However, this factor is (at least to some extent) incorporated into the emission factors used as they are based on tests of in-use mowers.

Emissions from spills during fuel transfer can be significant. Emissions can also be affected by combustion chamber temperature and air/fuel ratio (Priest, 1996). These two issues are also not specifically addressed in the EETs.

New high pressure fuel injection two-stroke technology has been developed recently and will penetrate the Australian market in coming years. Emissions from these mowers are lower than from standard two-stroke mowers. Emission factors for this source may therefore need to be revised in the future as usage increases.

3.0 Emissions Estimation Techniques

The estimation of aggregated emissions from domestic lawn mowing requires information on the following:

- annual hours of lawn mower usage per household;
- mower type (two- or four-stroke); and
- fuel type (leaded or unleaded petrol).

Annual usage hours for different fuel types are only required for calculating emissions of lead and SO_2.

3.1 Approaches Employed

3.1.1 Determination of Annual Hours of Mower Usage

The preferred method for obtaining information on mower usage is by conducting a domestic survey. Appendix A provides guidelines for the design and conduct of these surveys. Using the domestic survey data, annual usage hours for each mower type with each fuel type can be calculated using Equation 1.

Equation 1: Calculation of annual hours of usage in an airshed for each mower and fuel type (based on domestic survey data)

$$T_{if} = [P_{if} / 100] * H_{if} * N_a$$

where

T_{if} = Total annual hours of usage of mower type i using fuel type f in airshed
P_{if} = Percentage of surveyed households using mower type i with fuel type f
H_{if} = Annual hours of mowing per household using mower type i and fuel type f
N_a = Number of households in airshed

Consideration should be given to determining usage hours on a sub-regional basis, particularly in large airsheds or where significant regional variations may occur.

An alternative (or default) methodology is to determine overall annual fuel consumption figures for lawn mower use in the jurisdiction, convert these to hours of use using average fuel consumption data, and adjust these estimates to obtain figures for the airshed in question (see Equations 2 and 3).

Volumetric consumption of leaded and unleaded petrols can be obtained from ABARE (1999). It is estimated that about 0.8% of the total consumption of two- and four-stroke fuels in a jurisdiction is for motor mowers DEST (1996). This figure may change over time, and the most appropriate percentage should be confirmed from later versions of the referenced document.

Using the default figures in Table 2, the amount of fuel used by each mower type can be determined. The fuel use in each mower type can then be converted to usage hours using typical fuel usage rates. ABARE figures are for States and Territories (jurisdictions) as a whole and need to be scaled down by household or population for an airshed.

Table 2: Summary of Default Assumptions for Using ABARE Data

Mower Type	Percentage of Mower Fleet [a]	Average Fuel Consumption ($L\ hr^{-1}$) [b]
2-stroke	60	1.22
4-stroke	40	0.731

[a] This ratio is likely to change towards 4-stroke mowers in future years (DEST 1996). The ratio should be confirmed from later versions of this document.
[b] Priest, M. (1996).

Equation 2: Calculation of annual hours of usage in a jurisdiction for each mower and fuel type (based on State fuel consumption figures)

$$T_{if} = V_f * (F_{if} / 100) * (P_i / 100) / C_i$$

where

T_{if} = Total annual hours of usage for mower type i using fuel type f in a jurisdiction, $hr\ yr^{-1}$
V_f = Total annual consumption of fuel type f in the jurisdiction, $L\ yr^{-1}$
F_{if} = Percentage consumption of fuel type f by mower type i in the jurisdiction
P_i = Percentage of mower type i in the overall mower fleet
C_i = Average fuel consumption rate of mower type i, $L\ hr^{-1}$

Equation 3: Conversion of annual hours of usage in a jurisdiction to annual hours of usage in an airshed

$$T_{ifa} = T_{if} * N_a / N_j$$

where

T_{ifa} = Total annual hours of usage for mower type i using fuel type f in the airshed, $hr\ yr^{-1}$
T_{if} = Total annual hours of usage for mower type I using fuel type f in the jurisdiction, $hr\ yr^{-1}$
N_a = Number of households in the airshed
N_j = Number of households in the jurisdiction

3.1.2 Calculation of Airshed Emissions of NPI Substances

Once the annual hours of usage of each type of mower and fuel in an airshed are known, the annual emission of each NPI substance from that mower and fuel type combination can be calculated using Equation 4.

Equation 4: Calculation of airshed emissions of each NPI substance for each mower and fuel type

$$E_{ifj} = T_{if} * F_{ifj} * 10^{-3}$$

where

E_{ifj} = Annual emissions of substance j from mower type i using fuel f, kg yr^{-1}
T_{if} = Annual hours of usage for mower type i using fuel type f, hr yr^{-1}
F_{ifj} = Emission factor for substance j in mower type i using fuel type f, g hr^{-1}

3.1.3 Calculation of Aggregated Emissions

The total annual emission of each NPI substance can be calculated by summing the annual emissions from each mower and fuel type combination as per Equation 5.

Equation 5: Calculation of aggregate airshed emissions for each NPI substance

$$E_j = \sum_i \sum_f E_{ifj}$$

where

E_j = Aggregate annual emissions in airshed of pollutant j, kg yr^{-1}
E_{ifj} = Annual emissions in airshed of pollutant j from mower type i using fuel type f, kg yr^{-1}

3.2 Spatial Surrogates and Spatial Allocation

Annual emissions should be spatially allocated on the basis of household distribution, giving consideration to any regional variations in use where possible.

The Australian Bureau of Statistics collects data on populations and households by Collection District (CD). These data can be allocated to grid cells using a specific program or Geographic Information System. The annual emissions of a substance from a particular grid cell can then be estimated with Equation 6.

Equation 6: Allocating emissions to a grid cell

$$E_{jk} = E_j * N_k / N_a$$

where

E_{jk} = Annual emissions of substance j in grid cell k
E_j = Aggregate annual emissions of pollutant j in the airshed
N_k = Number of households in grid cell k
N_a = Number of households in airshed

3.3 Emission Factors

Emission factors for use in determining aggregate emissions from lawn mowers are provided in Table 3. The emission factors listed for lead and sulphur dioxide are based on average Australian fuel composition. If local fuel content is known, these factors can be adjusted using Equation 7.

Table 3: Emission Factors for Domestic Lawn Mowing

NPI Substance	Emission Factor ($g\ hr^{-1}$)[a]			
	2-Stroke Engine		4-Stroke Engine	
	Leaded	Unleaded	Leaded	Unleaded
Benzene[a]	17.0	17.0	2.30	2.30
1,3-Butadiene[a]	2.16	2.16	0.292	0.292
Carbon monoxide[b]	731	731	489	489
Chromium (III) compounds[c,d]	0.00332	0.00332	0.000219	0.000219
Chromium (VI) compounds[c,d]	0.00138	0.00138	0.000091	0.000091
Cobalt and compounds[c]	0.0047	0.0047	0.00031	0.00031
Copper and compounds[c]	0.0047	0.0047	0.00031	0.00031
Cyclohexane[a]	0.517	0.517	0.070	0.070
Ethylbenzene[a]	3.96	3.96	0.534	0.534
Formaldehyde[e]	2.8	2.8	0.68	0.68
n-Hexane[a]	0.548	0.548	0.740	0.740
Lead and compounds[f]	0.110	0.002	0.066	0.001
Manganese and compounds[c]	0.0047	0.0047	0.00031	0.00031
Nickel and compounds[c]	0.0047	0.0047	0.00031	0.00031
Oxides of nitrogen[b]	1.45	1.45	4.85	4.85
PM10[e,g]	7.80	7.80	0.515	0.515
Polycyclic aromatic hydrocarbons[h]	0.895	0.895	0.121	0.121
Styrene[I]	0.304	0.304	0.041	0.041
Sulphur dioxide[e,j]	1.02	0.300	0.701	0.206

Toluene[a]	28.6	28.6	3.87	3.87
Total VOCs[b, k]	304	304	41.1	41.1
Xylenes[a]	21.0	21.0	2.83	2.83
Zinc and compounds[c]	0.0047	0.0047	0.00031	0.00031

[a] EPAV (1999).
[b] Priest (1996).
[c] CARB (1991).
[d] Assuming the same fraction of chromium(VI) (29.3%) as that emitted from fuel oil combustion (USEPA 1998).
[e] USEPA (1985).
[f] Emission factor based on Australian average lead content of 2.10 mg L^{-1} for unleaded petrol and 150 mg L^{-1} for leaded petrol (Challenger, B., AIP, July 1997, pers. comm.) and 77 % of lead being emitted to air (Biggins and Harrison 1979). This value should be adjusted if local fuel content is available (see Equation 7).
[g] EPAV (1995).
[h] Kahlili et al (1995).
[i] % weight in petrol liquid (Weir, P., Western Power; Bowman, D., Shell 1995, pers. comm.).
[j] Emission factor based on Australian average sulphur content of 0.017 % by mass for unleaded petrol and 0.058 % by mass for leaded petrol (Challenger, B., AIP, July 1997, pers. comm.). This value should be adjusted if local fuel content is available (see Equation 7).
[k] EPAV (1996).

Equation 7: Adjusting emission factors for local fuel content

$$F_{jl} = F_{ja} * C_{jl} / C_{ja}$$

where

F_{jl} = Emission factor for pollutant j for local fuel
F_{ja} = Emission factor for pollutant j for average Australian fuel
C_{jl} = Fuel Content of pollutant j (%) for local fuel
C_{ja} = Fuel Content of pollutant j (%) for average Australian fuel

3.4 Sample Calculations

The sample domestic survey results in Table 4 will be used in the sample calculations.

Table 4: Sample Domestic Survey Results Summary

	Two-Stroke Engine		Four-Stroke Engine		Electric Mower	Push Mower	No Lawn
	Leaded	Unleaded	Leaded	Unleaded			
% of households	22	27	18	26	2	3	2
Mowing time (hr yr^{-1} $household^{-1}$)	17	16	18	15	20	30	nil

In addition, it will be assumed that the number of households in the airshed is 200,000, and the number of households surveyed was 2,000.

Example 1: Calculation of annual hours of usage in an airshed for each mower and fuel type (based on domestic survey data)

Using Equation 1

$$T_{if} = [P_{if} / 100] * H_{if} * N_a$$

the annual mowing time for two-stroke engines using leaded fuel

$$T_{2\text{-stroke, leaded}} = (22 / 100) * 17 * 2 * 10^5$$
$$= 7.48 * 10^5 \text{ hr yr}^{-1}$$

For the default method, in addition to the default data in Table 2, it is assumed that data from ABARE indicate total leaded petrol usage in the jurisdiction is 10^9 L yr^{-1}.

Example 2: Calculation of annual hours of usage for each mower and fuel type (based on State fuel consumption figures)

Using Equation 2

$$T_{if} = V_f * (F_{if} / 100) * (P_i / 100) / C_i$$

the annual mowing time in the jurisdiction for two-stroke engines using leaded fuel is

$$T_{2\text{-stroke, leaded}} = 10^9 * (0.8 / 100) * (60 / 100) / 1.22$$
$$= 3.93 * 10^6 \text{ L yr}^{-1}$$

This figure would then need to be scaled down by relative household or population numbers to give total annual hours in the airshed.

Example 3: Calculation of aggregate airshed emissions of PM10 (using the results from Example 1)

Using Equation 4

$$E_{ifj} = T_{if} * F_{ifj} / 10^3$$

and Table 3 data for PM10, annual airshed emissions of PM10 from 2-stroke mowers using leaded fuel are

$$E_{2\text{-stroke, leaded, PM10}} = T_{2\text{-stroke, leaded}} * F_{2\text{-stroke, leaded, PM10}}$$
$$= 7.48 * 10^5 * 7.80 / 10^3$$
$$= 5.83 * 10^3 \text{ kg yr}^{-1}$$

then, using Equation 5

$$E_j = \sum_i \sum_f E_{ifj}$$

aggregate PM10 emissions for the airshed for all mower and fuel types can be calculated from

$$E_{PM10} = E_{2\text{-stroke,leaded, PM10}} + E_{2\text{-stroke, unleaded, PM10}} + E_{4\text{-stroke, leaded, PM10}} + E_{4\text{-stroke, unleaded, PM10}}$$

4.0 Uncertainty Analysis

4.1 Data Reliability

Data from domestic surveys are highly reliable, provided appropriate consideration has been given to survey design and conduct (see Appendix A). Calculation of hours of usage and emissions from overall fuel consumption data for a jurisdiction (the default method) will have low to moderate reliability because of uncertainties about lawn mowing's share of overall consumption and the scaling of usage to airsheds.

4.2 Reliability of Emission Factors

The emission factors for CO, NO_x and total VOCs are from Priest (1996) and are based on testing of 29 in-use mowers in Australia. Since the emission factors are derived locally, the reliability of these emission factors is high. The emission factor for lead is based on lead content and consumption rate of petrol. Since the emission factor is derived using mass balance, its reliability is also considered to be high.

Emission factors for SO_2, PM10 and formaldehyde are obtained from the USEPA (1985). Since these emission factors are not derived locally, their reliability is considered to be medium.

Factors for many of the other substances rely on speciation profiles derived from petrol-engined motor vehicles, the reliability of which is felt to be low to medium.

4.3 Problems and Issues Encountered

This EET does not include lawn mowing for open space maintenance (e.g. golf courses, municipal areas and roadsides). The 1996 Port Phillip Region Inventory (EPAV 1998) found that, while domestic lawn mowing contributed the majority of CO and VOC emissions (75% and 84% respectively of total mower emissions), the reverse was true for PM10 and NO_x (only 38% and 6% respectively of total mower emissions), the remainder coming from open space maintenance. Not including open space mower emissions in the NPI will therefore underestimate the impact of this source.

The EET also does not include emissions from other petrol-engined garden appliances such as chainsaws, brush cutters and the like, or emissions from spills and leaks during fuel transfer.

4.4 Recommendations for Further Work

The effects of mower age on emissions could be further investigated and factored into EETs. Given the overall contribution of lawn mower emissions, significant further work may not be warranted, but additional testing of a range of in-use mowers of varying ages would enable more representative emission factors to be developed for the mower fleet.

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
CO	Carbon monoxide
EET	Emissions estimation technique
EF	Emission factor
EPAV	Environment Protection Authority of Victoria
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NO_x	Oxides of nitrogen
NPI	National Pollutant Inventory
PM10	Particulate matter less than or equal to 10 μm
SO_2	Sulphur dioxide
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound

6.0 References

ABARE (1999). *Australian Energy: Market developments and projections to 2014-15*, ABARE Research Report 99.4, Australian Bureau of Agricultural and Resource Economics, Canberra.

Biggins, P.D.E. and Harrison, R.M. (1979). "Atmospheric Chemistry of Automotive Lead", *Environ. Sci. Technol*., vol 13, pp 558-565.

CARB (1991). *Identification of Particulate Matter Species Profiles - ARB Speciation Manual,* 2nd edn, vol 2, California Air Resources Board, California, USA.

DEST (1996). *Energy: Workbook for Transport (Mobile Sources)*, National Greenhouse Gas Inventory Committee, Department of the Environment, Sport and Territories, Canberra.

EPAV (1995). *South East Queensland Air Emissions Inventory Consultancy*, Environment Protection Authority of Queensland, Brisbane.

EPAV (1996). *Technical report on the Air Emission Trials for the National Pollution Inventory, vol 2*, AGPS, Canberra.

EPAV (1998). *Air Emission Inventory: Port Phillip Region*, Publication no 632.

EPAV (1999). *Measurement of motor vehicle pollutants and fleet average emission factors in Melbourne*, Publication no 652.

Heiken, J. G., Pollack, A. K., Ruhl, E. (1997). "Guidance for Estimating Lawn And Garden Equipment Activity Levels", chapter in EIIP Document Series, vol. III, United States Environment Protection Agency, Research Triangle Park, North Carolina, USA.

Kahlili, N. R., Scheff, A. P. and Holsen, T. M. (1995). "PAH source fingerprints for coke ovens, diesel and gasoline engines, highway tunnels, and wood combustion emissions", *Atmos. Environ.*, vol 29, no 4, pp 533-542.

Priest, M. (1996). *Lawnmower Use and Emissions in Australia*, University of Newcastle, Newcastle.

USEPA (1985) *Compilation of Air Pollutant Emission Factors, Vol II, Mobile Sources,* AP-42, 5th edn, United States Environment Protection Agency, Research Triangle Park, North Carolina, USA.

USEPA (1998). *Compilation of Air Pollution Emission Factors, vol I, Stationary Point and Area Sources,* AP-42, 5th edn, Supplement E, United States Environmental Protection Agency, Research Triangle Park, North Carolina, USA.

7.0 Appendices

APPENDIX A: GUIDELINES FOR CONDUCT OF DOMESTIC SURVEYS

APPENDIX A
GUIDELINES FOR CONDUCT OF DOMESTIC SURVEYS

1 Background

Manuals for estimating aggregated emissions are required to assist State and Territory Governments in preparing annual inputs to the Commonwealth for the National Pollutant Inventory (NPI). The aggregated emissions manuals complement the industry 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 NEPM thresholds are not exceeded.

For emissions from domestic sources the estimation techniques are generally based on estimates of overall household activity levels, such as the combustion of fuel, consumption of materials, and usage of equipment and appliances. Information on some of these activities can be derived to an acceptable accuracy with a survey questionnaire distributed to a representative number of households in a particular airshed.

For other activities accurate data may be available from other sources (e.g. usage of surface coatings and aerosols) and so a survey will not be required. Also, although the usual estimation technique may be relatively crude (e.g. for domestic and commercial solvents the estimate is based on a US EPA per capita emission factor), it is unlikely that a survey would be particularly useful because of the large number of products involved.

In summary, a survey should be used where sufficiently accurate data are not available from other sources, where a survey is appropriate and practicable, and where it offers the prospect of better data than other approaches.

2 Development of Survey Technique

Surveys of this type have been successfully undertaken as part of NPI Trials in Dandenong, Launceston, Newcastle and Port Pirie in 1995 and 1996, and for the Port Phillip Region emissions inventory in 1997. These surveys in turn evolved from earlier exercises undertaken for the Brisbane, Sydney and Auckland regions in the early 1990s.

For the NPI trials project, assistance was obtained from ABS in refining previous surveys and sampling processes, and a market firm was engaged for the PPR survey to further refine survey techniques. Best practice in survey design and execution is now considered to provide highly reliable data for emission estimation purposes.

These techniques are now sufficiently trialled that pilot surveys are not considered necessary, although minor adaptations for each survey region are usually required.

3 The Survey Process

A typical domestic survey can be completed within about three months. The process can be summarised as follows:

- The jurisdiction engages a market research or similar firm to assist with survey design and execution.
- The jurisdiction and firm jointly design the questionnaire.
- The firm designs a sampling plan.
- The firm prints the questionnaire and, with input from the jurisdiction, prepares covering letters and envelopes using the latter's letterhead, and reply-paid envelopes addressed to the jurisdiction.
- The population is sampled by the firm with a mail-out questionnaire.
- The jurisdiction receives the completed returns and provides an initial technical check.
- The returns are passed to the firm for data entry.
- The firm sends a second mail-out to increase return rate.
- Again, the second round of returns is checked by the jurisdiction, and the additional data is entered by the firm.
- The full data set analysed by the jurisdiction and/or firm.
- The jurisdiction uses the survey data to generate emissions data.

One of the key tasks of the assisting firm is to design the sample, ensuring that the sample size leads to an overall return which keeps sampling error to an acceptable level, and that the sample obtained is genuinely representative of the population within the Region.

It is possible to divide the survey region into sub-regions to improve the spatial accuracy of the data obtained. However, unless there are good reasons for believing that there are distinct differences in activity levels between these sub-regions, this approach is not recommended as it effectively amounts to treating each sub-region as a discrete area for survey, each requiring a similar level of sampling. This would obviously result in a significant increase in survey costs. Also, given the uncertainties in the survey process and emissions estimation, the resulting improvements in spatial accuracy may be difficult to justify.

4 Design of Questionnaire

The survey questions should be developed by the jurisdiction, and discussed and refined with the firm. Questionnaires and covering letters used in other jurisdictions (as described above) provide a useful starting point, as they are the product of a series of lessons learnt over the last decade about domestic activity surveys.

It is recommended that the temptation to ask for data that is unlikely to be used should be resisted, including information on attitudes and opinions, as the shorter and simpler the questionnaire, the better the response rate is likely to be.

It should also be recognised that if relevant aggregated data is already available (e.g. data on overall domestic gas consumption may be available from gas retailers), there is little point in asking households for this information, as its accuracy would almost certainly be reduced.

5 Use of Mail Surveys

The nature of the data required for emissions inventories lends itself very well to a mail survey, as potential respondents may need to spend a little time in developing accurate responses (e.g. by discussing questions with other household members, checking equipment details, etc). Allowing surveys to be completed over a few days is therefore likely to produce more accurate responses.

While telephone or door-to-door survey methods produce quicker results, it is difficult to achieve response rates comparable with mail surveys without repeated call-backs to households, and hence comparatively high costs. Also, mail surveys are considered to be more suited to the gathering of factual information, whereas phone or door-to-door methods are usually better for gathering information on opinions and attitudes.

6 Use of Stationery of Jurisdiction

The use of Government stationery (preferable signed by a Government official) is considered to be a significant factor in obtaining good response rates.

7 Response Rates

For mail surveys of this type response rates are generally 50 to 55%, with the initial mail-out generating around 30% of returns and the follow-up a further 20%.

With these types of response rates, a sample size of 600 (i.e. about 300 returns) results in a sampling error of only about 5.6% at 95% probability. Increasing the sample size to 1000 only reduces the error to 4.4%.

Questionnaires could be numbered, allowing identification of households which have submitted returns and elimination of them from the second mail-out. However, this reduces confidentiality and may discourage reporting of activities which may not be strictly legal or acceptable (e.g. waste incineration). It is therefore considered preferable for the second mail-out to include the full initial sample. The initial covering letter should therefore make it clear that this process is being followed to ensure confidentiality, and apologise in advance to people who return their questionnaires quickly.

8 Checking of Returns

Returns should be forwarded in the first instance to the jurisdiction, as there are benefits in an initial technical check of returns prior to data entry. This increases data quality, and allows obviously conflicting, inaccurate or incomplete responses to be removed. This can be done progressively as returns are received, thereby not delaying the overall process.