National Pollutant Inventory

Emission Estimation Technique Manual

for

Municipal Solid Waste (MSW) Landfills
Version 1.1

Environment Australia

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Erratum for Municipal Solid Waste Landfills EET Manual (Version 1.1 – 7 January 2002) – Previous version issued November 1999.

- The revised version (1.1) has had the changes outlined below made.

Specific changes are:

Page	Outline of alteration
throughout manual	Corrected reference to NPI substance 1,1,1,2 – Tetrachloroethane. The substance was previously listed incorrectly as 1,1,2,2 - Tetrachloroethane.

EMISSION ESTIMATION TECHNIQUES
FOR
MUNICIPAL SOLID WASTE LANDFILLS

TABLE OF CONTENTS

MUNICIPAL SOLID WASTE LANDFILLS

LIST OF TABLES AND EXAMPLES

1.0 Introduction

The purpose of all Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from municipal solid waste (MSW) landfills, including those handling some hazardous wastes. It will also be relevant to landfills containing wastes of a similar composition to municipal solid waste, however, will not be applicable to some landfills accepting specific industrial or hazardous wastes such as waste rock or spoil dumps for mining.

EET MANUAL:	Municipal Solid Waste Landfills
HANDBOOK:	Waste Disposal Services: Landfills
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This Manual was drafted by the NPI Unit of the Queensland Department of Environment and Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

Context and use of this manual

This NPI manual provides a "how to" guide for the application of various methods to estimate emissions as required by the NPI. It is recognised that the data that is generated in this process will have varying degrees of accuracy with respect to the actual emissions from landfill operations. In some cases there will necessarily be a large potential error due to inherent assumptions in the various emissions estimation techniques (EETs) and/or a lack of available information of chemical processes.

EETs should be considered as 'points of reference'

The EETs and generic emission factors presented in this manual should be seen as 'points of reference' for guidance purposes only. Each has associated error bands that are potentially quite large (eg. based on generic emission factors only), uncertainties of 100% are considered likely. The general reliability associated with the various methods is discussed in the manual. The potential errors associated with the different EET options should be considered on a case-by-case basis as to their suitability for a particular facility. Facilities may use EETs that are not outlined in this document. They must, however, seek the consent of their relevant environmental authority to determine whether any 'in house' EETs are suitable for meeting their NPI reporting requirements.

Hierarchical approach recommended in applying EETs

This manual presents a number of different EETs, each of which could be applied to the estimation of NPI substances. The range of available methods should be viewed as a hierarchy of available techniques in terms of the error associated with the estimate. Each substance needs to be considered in terms of the level of error that is acceptable or appropriate with the use of the various estimation techniques. Also the availability of pre-existing data and the effort required to decrease the error associated with the estimate will need to be considered. For example, if emissions of a substance are clearly very small no matter which EET is applied, then there would be little gained by applying an EET which required significant additional sampling.

The steps in meeting the reporting requirements of the NPI can be summarised as follows:

- for Category 1 and 1a substances identify which reportable NPI substances are used (or handled by way of their incidental presence in ore or materials, or exceeds the bulk storage capacity for 1a), and determine whether the amounts used or handled are above the "threshold" values and therefore trigger reporting requirements;
- for Category 2a and 2b substances determine the amount and rate of fuel (or waste) burnt each year, the annual power consumption and the maximum potential power consumption, and assess whether the threshold limits are exceeded;
- for Category 3 substances determine the annual emissions to water and assess whether the threshold limits are exceeded; and
- for those substances above the threshold values, examine the available range of EETs and determine emission estimates using the most appropriate EET.

Generally it will be appropriate to consider various EETs as alternative options whose suitability should be evaluated in terms of:

- the associated reliability or error bands; and
- the cost/benefit of using a more reliable method.

NPI emissions in the environmental context

It should be noted that the NPI reporting process generates emission estimates only. It does not attempt to relate emissions to potential environmental impacts, bioavailability of emissions, natural background levels etc.

Facilities may undertake 'Ancillary Activities'; such as the production substances, either as a process input or through processing of waste steams. When estimating emissions a facility should ensure that emissions are not 'double counted' and process maps should be used to minimise the potential for this.

This manual is structured to allow facilities to work through the manual and address issues in a structured and coherent manner. Likely emissions from facilities are discussed as are approaches to emissions estimation and those elements of the environment where emissions may result.

2.0 Processes and Emissions

The following section presents a brief description of landfills and identifies likely sources of emissions.

2.1 Process Description

Landfills are the physical facilities used for the disposal of residual solid wastes in the surface soils of the earth. A sanitary landfill refers to an engineered facility for the disposal of municipal solid waste (MSW) designed and operated to minimise public health and environmental impacts. Secure landfills are those designed for the disposal of hazardous waste (Tchobanoglous, et al; 1993). A municipal solid waste landfill unit is a discrete area of land or an excavation that receives household waste and that is not a land application unit, surface impoundment, injection well, or waste pile. A land application unit relates to the application of substances to the land surface, such as irrigation of effluent. A waste pile is an exposed pile of unwanted, usually non-biodegradable material, generally stored above ground. Surface impoundments comprise of waters and contaminated surface water run-off contained in pits and/or built structures such as tailings and environmental dams. An injection well relates to the disposal of waste deep underground. The estimation of emissions from a land application unit, surface impoundment, injection well, and waste pile are not considered in this manual as the techniques relate mainly to the degradation of municipal solid waste containing organic waste. These techniques are not likely to be representative of these methods of disposal due to differing waste streams, chemical and physical processes likely to be occurring. An MSW landfill may also receive other types of wastes, such as commercial solid waste, non-hazardous sludge, and industrial solid waste.

The number of landfills in Australia is declining due to stricter environmental regulations although the amount of waste generated by Australians continues to grow. Most of the landfills closing are the smaller landfills with the larger and more technologically advanced landfills remaining in operation.

Landfill design and operation normally use one or a combination of three fill methods. These are the area, trench, and ramp methods, all of which use a three-step process consisting of spreading the waste, compacting the waste, and covering the waste with soil. The trench and ramp methods are not commonly used, and are not the preferred methods when liners and leachate collection systems are used.

The area fill method entails placing waste on the ground surface or landfill liner, spreading it in a layer, and compacting it with heavy equipment. Successive layers are added until a depth of 3 to 4 metres is reached. The cover is commonly deposited daily, and is used to control the blowing of waste materials across and off site, to prevent flies, rodents, birds, and other disease vectors from reaching the waste, to control odour, and to control water entry into the landfill. The trench method entails excavating daily trenches designed to receive a day's worth of waste. Successive parallel trenches are excavated and filled, with the soil from the excavation being used for cover material and wind breaks. The ramp method is typically employed on sloping land, where waste is spread and compacted in a manner similar to the area method; however, the cover material is generally obtained from the front of the working face of the filling operation.

Landfills can vary significantly in design depending on management practices. Some are unlined and permit the general public direct access to the site. Others may be fully lined, with a leachate collection system, allowing public access only to transfer stations, and support a landfill gas collection system where the gas is converted to electricity.

2.2 Emission Sources and Control Technologies

Landfills are significant sources of methane (CH_4) and carbon dioxide (CO_2). In addition to CH_4 and CO_2, amounts of non-methane organic compounds (NMOC) are also produced. NMOCs include a number of NPI-listed reactive volatile organic compounds (VOCs) and speciated organic compounds.

2.2.1 Emissions to Air

CH_4 and CO_2 are the primary constituents of landfill gas, and are produced during anaerobic decomposition of cellulose and proteins in the landfilled wastes. Although neither of these substances are NPI-listed, estimating emissions of these gases is important as they are indicators for emissions of other listed pollutants.

The decomposition is a complex process and requires certain environmental conditions. Environmental factors that affect the decomposition include moisture content of the waste, nutrient concentration, the presence and distribution of microorganisms, the particle size of the waste, water flux, pH, and temperature. Because of the complex set of conditions that must occur before landfill gas is generated, waste may be in place for a year or more before anaerobic decomposition begins and landfill gas is generated. Refuse in a landfill may produce landfill gas for 20 to 30 years, with an average of 25 years. On the other hand, aerobic decomposition results in CO_2 and water. Uncontrolled dumps, where waste is exposed to air, may be subject to aerobic decomposition, which results in generation of carbon dioxide and water.

Some emissions may also occur during the operation of the landfill site. Excavation and heavy machinery may be significant sources of emissions through both the combustion of fuel and the compaction of waste. Please refer to the *Combustion Engines EET Manual* for guidance on estimating emissions from vehicles.

Some of the landfill emissions are collected through either active or passive collection systems. Disposal or treatment of the collected gases can be accomplished by the combustion or purification of the landfill gas. Landfill gas collection and treatment methods and efficiencies are discussed in more detail in Section 3.0 of this Manual.

2.2.2 Emissions to Water and Land

Leachate is generally considered to be water that has entered a landfill site and become contaminated after diffusion through the waste or liquids within the waste. Leachate is likely to contain a number of NPI-listed substances. Its composition will vary from site-to-site, depending on many factors including; the nature of the waste in the landfill, the filling method, the level of compaction, the engineering design of the landfill, the rainfall of the region, and the stage of decomposition of the waste.

Emissions to land and waters from a landfill generally come from diffusion of leachate to the groundwater (emission to land), leaks to surface waters (emission to water), or run-off from the flow of water across the landfill site. The volume of leachate produced within a landfill will depend mainly on the rainfall of the area, how well the landfill is sealed and capped, and the original water content of the waste deposited.

Most modern landfills tend to be capped by a layer of low-permeability material such as clay, to limit the amount of water entering the landfill. They also tend to be lined by a geomembrane or layer of compacted clay that operates to contain the leachate. However, these methods of leachate control are not 100% efficient, therefore it is likely that some emissions to ground or surface waters may still occur.

Leachate collected can be either recirculated through the landfill to accelerate the decomposition process, or treated and removed from the site. Leachate treatment can involve a range of physical and biological processes to produce a waste suitable for discharge to a municipal sewage system or to surface waters.

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, and the use of chemicals to control various elements of the environment (such as pesticides and dust suppressants) where these emissions contain listed substances. These emission sources can be broadly categorised as;

- surface impoundments of liquids and slurries;
- application farming;
- unintentional leaks and spills; and
- emissions of leachate to land/groundwater.

Waste disposed into a landfill is not considered as an emission to land, only emissions from the landfill.

2.2.3 Thresholds for Reporting Landfill Emissions

The NPI Guide at the front of this Handbook contains details of the list of reportable substances and thresholds associated with these substances. For the purposes of determining whether a landfill exceeds a threshold, the following factors need to be considered:

- does the landfill accept or coincidentally produce any of the listed substances in excess of 10 tonnes during the reporting period;
- does the landfill burn more than 400 tonnes of landfill gas, any other fuel or waste on-site during the reporting period; and
- does the landfill emit more than 15 tonnes of nitrogen or 3 tonnes of phosphorus to a waterway during the reporting period.

Landfill managers will need to use information available to them to estimate whether 'use' thresholds have been reached. Some waste composition studies may be necessary to assist in deciding whether thresholds have been reached.

Table 1 outlines some data on the concentration of heavy metal elements and halogenated compounds from a composition study of waste. While the threshold tests are based on compounds, it may be the case that Table 1 is the best available information.

Table 1 - Concentration of particular NPI-listed substances in MSW

NPI-Listed Substance	Household Waste[a] (mg/kg)	Waste Paper[b]		Plastic[c]	
		(mg/kg)	(%)[d]	(mg/kg)	(%)[d]
Cadmium	2.9	0.5	3.4	43.1	84.4
Chromium	76	22	5.7	28.2	2.1
Copper	31	65	41.8	78	14.4
Nickel	13	10.7	16.2	18.8	8.3
Lead	294	65.7	4.4	171.1	3.3
Zinc	310	108	6.9	402.3	7.4
Chlorine (total)	4760	1789	7.5	55012	66.1
Fluorine (organic)	71	104	29.2	14	1.1

Source: Bilitewski, et al, 1994.
[a] 30% moisture content.
[b] 8% moisture content.
[c] 6% moisture content.
[d] Percentage contribution of NPI-listed substance to entire MSW stream (eg. cadmium present in plastic makes up 84.4% of the total amount of cadmium in MSW).

3.0 Emission Estimation Techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in *The NPI Guide* at the front of this Handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility.

The four types described in *The NPI Guide* are:

- sampling or direct measurement;
- mass balance;
- fuel analysis or other engineering calculations; and
- emission factors.

Select the EET, (or mix of EETs), that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of EETs that are not outlined in this handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this handbook does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (eg. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, ie. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The **usage**[a] of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for VOCs) reporting threshold is exceeded. If the threshold is exceeded, **emissions** of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

[a]Usage is defined as meaning the handling, manufacture, import, processing, coincidental production or other uses of the substances.

3.1 Direct Measurement

You may wish to undertake direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements. However, the NPI does not require you to undertake additional sampling and measurement. For the sampling data to be adequate and able to be used for NPI reporting purposes, it would need to be collected over a period of time, and to be representative of operations for the whole year.

3.1.1 Sampling Data

Stack sampling test reports often provide emissions data in terms of kg per hour or grams per cubic metre (dry). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

3.1.2 Using Mass Balance

A mass balance identifies the quantity of substance going in and out of an entire facility, process, or piece of equipment. Emissions can be calculated as the difference between input and output of each listed substance. Accumulation or depletion of the substance within the equipment should be accounted for in your calculation.

3.1.3 Engineering Calculations

An engineering calculation is an estimation method based on physical/chemical properties (eg. vapour pressure) of the substance and mathematical relationships (eg. ideal gas law).

3.1.3.1 Fuel Analysis

Fuel analysis is an example of an engineering calculation and can be used to predict SO_2, metals, and other emissions based on application of conservation laws, if fuel rate is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements such as sulfur that may be converted into other compounds during the combustion process.

3.1.4 Emission Factors

An emission factor is a tool used to estimate emissions to the environment. In this Manual, it relates the quantity of substances emitted from a source, to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted, divided by the unit weight, volume, distance, or duration of the activity emitting the substance (eg. kilograms of sulfur dioxide emitted per tonne fuel burned).

3.2 Available Emission Estimation Techniques

The use of direct measurement data to determine emissions from landfills is recommended, where possible, over other estimation techniques, as considerable variation may occur between emission estimates and actual emissions due to variations in geography, waste composition and landfill metabolic stage. If no site-specific data exists, any of the numerous landfill emission estimation models available may be used; including those detailed within this handbook.

The techniques outlined in this manual for estimating emissions from landfills are predominantly the basis for the attached Landfill Area-Based Spreadsheet (LABS), which is an Excel spreadsheet set up to automatically calculate emissions of some NPI-listed substances from landfills.

The air emission estimation techniques used in the spreadsheet are based on a theoretical first-order kinetic model of methane production developed by the USEPA. Section 3.2 outlines the equations used as the basis of the LABS air emissions estimates.

A water emission estimation technique has been included in LABS. One method is based on assumptions and emission factors published by White, Franke and Hindle (1995). Very little information is required for this estimation technique, however, its accuracy may be limited due to some broad assumptions made. Appendix 1 outlines the use of the LABS and Section 3.3 covers the water emission estimation technique.

This section outlines the information required for estimating emissions from landfills. These are necessary for using the landfill emission estimation equations presented in Sections 3.2 and 3.3 or the LABS spreadsheet.

The first step in estimating emissions from landfills is to determine the number and location of all landfills operated by your business, both operating and closed. The minimum amount of information required to estimate emissions from each of these landfills using the equations set out in Section 3.2 or in LABS is:

- the capacity of the landfill;
- the depth and area of the landfill;
- the annual rainfall of the area;
- the density of the waste;
- the year the landfill began operation;
- the year the landfill ceased operation (if closed);
- the annual waste acceptance rate or the proposed closure date for the landfill;
- whether the landfill has accepted hazardous waste;
- whether the landfill has a gas collection system;
- whether the landfill is lined;
- the type of gas control technology used if gas is collected (eg. flare, internal combustion engine, boiler, etc); and
- the flow rate of the gas before the control technology if gas is collected.

Local governments should be able to define reasonable depths and areas for landfills and State and Territory health departments may also have information about older landfills.

Other parameters that are or can be utilised in the equations or in LABS are:

- the methane generation rate constant “k”;
- the methane generation capacity “L_o”;
- the concentration of methane within the landfill gas;
- the concentration of carbon dioxide within the landfill gas;
- the concentration of volatile organic compounds (VOCs);
- the concentration and molecular weights of NPI-listed substances within the landfill gas;
- the monthly rainfall for the region;
- the monthly temperature for the region;
- the latitude (degrees) of the landfill;
- the type of cover material (if applicable);
- the slope of the landfill cover;
- an indication as to whether any vegetation is present on the cover material;
- the concentration of specific listed substances within the leachate;
- the collection efficiency of any gas collection system;
- the control efficiency of any gas control technology (eg. flare, turbine, boiler, etc);
- the collection efficiency of the landfill liner;
- the temperature of the landfill gas;
- the concentration of oxides of nitrogen (NO_x), carbon monoxide (CO), and particulate matter (PM_{10}) in the gas after a control technology (eg. flare, turbine, boiler, etc);
- the concentration of sulfur within the landfill gas; and
- the concentration of chloride ion within the landfill gas.

Default values or estimates are available for a number of the above parameters. These will be discussed in more detail in later sections of this Manual.

3.3 Estimating Emissions to Air

3.3.1 Uncontrolled Emissions of Landfills

To estimate uncontrolled emissions of the various compounds present in landfill gas, total landfill gas emissions must first be estimated. Uncontrolled methane emissions may be estimated for individual landfills by using a theoretical first-order kinetic model of methane production (USEPA, 1997):

Equation 1

$$Q_{CH4} = L_0 * R * (e^{-kc} - e^{-kt})$$

where:

Q_{CH4} = methane generation rate at time t, m^3/yr
L_0 = methane generation potential, m^3 CH_4/tonne of refuse
R = average annual refuse acceptance rate during active life, tonne/yr
e = base log, no units
k = methane generation rate constant, yr^{-1}
c = time since landfill closure, years (c = 0 for active landfills)
t = time since the initial refuse placement, yr

Although methane is not an NPI-listed substance, estimating emissions of methane is important as an indicator and basis for calculating emissions of other listed substances.

It should be noted that the model outlined in Equation 1 was designed to estimate landfill gas generation and not landfill gas emissions to the atmosphere. Other fates may exist for the gas generated in a landfill, including the capture and subsequent microbial degradation within the landfill's surface layer. Currently, there is no data that adequately address this fate. It is generally accepted that the bulk of the gas generated will be emitted through cracks or other openings in the landfill surface and, for NPI reporting purposes, all gas generated is assumed to be emitted to atmosphere.

The average annual acceptance rate is the approximate weight of waste disposed of to a landfill each year (tonne per year). If the average annual refuse acceptance rate (R) is not available for a landfill, it can be estimated by dividing the capacity of the landfill by the number of years that the landfill has accepted or is proposed to be accepting waste (closing year - opening year).

The capacity of the landfill is the total volume or weight of waste that can be accepted into the landfill. If the capacity of a landfill is unknown, it can be calculated from the volume of the landfill (area * depth) multiplied by the density (d) of the waste. If the density of the waste within a landfill is unknown, the default densities Table 2 should be used.

Table 2 - Density of Refuse in Landfills

Waste Compaction	Waste Density (kg/m^3)
Compacted waste	653 - 831 (average 742)
Significantly degraded or settling	1 009 - 1 127 (average 1 068)
Unknown if waste was compacted	688

Source: USEPA, 1997.

If opening and closure dates for the landfills are not available, and an approximation cannot be made, you should conservatively assume that the landfill opened 25 years before the current NPI reporting year if it is still accepting waste. If only the closing date is known, and an estimate of the opening year cannot be made, you should assume the landfill accepted waste for 10 years, again this is a conservative assumption.

Methane generation-rate constant k is a constant value that determines the rate of landfill gas generation (measured in yr^{-1}). The k is a function of moisture content of the refuse, availability of nutrients for methanogens, pH, and temperature. The first-order decomposition model assumes that k values before and after peak landfill gas generation are the same. Table 3 provides default values for k. If site-specific data is not available, choose the default value that is likely to best represent the location and characteristics of a particular landfill.

Methane generation capacity L_o is a constant that represents the potential capacity of a landfill to generate methane (measured in cubic metres per tonne of refuse). L_o generally depends on the amount of cellulose in the refuse. Table 3 provides default values for L_o. If site-specific data is not available, you should choose the default value that is likely to best represent the location and characteristics of a particular landfill. The Australian values presented are likely to be the most representative of Australian conditions. Specific methane generation constants (k and L_0) can be developed for a specific landfill site by the use of the EPA Method 2E (40 CFR Part 60 Appendix A (available from www.epa.gov/ttnemc01/promgate.html)).

Table 3 - Default Values for k, Lo, and VOC

VOC Concentration for Landfills	Default Values		
	Australian[a]	AP-42[b]	AP-42 Arid [b,c]
Methane generation rate constant "k"	0.058 yr^{-1}	0.04 yr^{-1}	0.02 yr^{-1}
Methane generation capacity "L_0"	79 m^3/tonne of waste	100 m^3/tonne of waste	100 m^3/tonne of waste
VOC for landfills accepting hazardous waste	-	2060 ppmv	-
VOC for landfills accepting only municipal solid waste	520 ppmv	235 ppmv	-

VOC = volatile organic compounds
[a] National Greenhouse Gas Inventory Committee, 1996; Duffy, et al, 1995.
[b] USEPA, 1998.
[c] Arid is defined as an area receiving less than 635mm of rain per year.

VOC is the fraction of landfill gas containing volatile organic compounds expressed as hexane (with the exception of methane). To estimate uncontrolled emissions of VOCs, and speciated NPI-listed substances, Equation 2 should be used to first estimate emissions in volume terms followed by Equation 3 to convert emissions to kilograms per year.

Equation 2

$$Q_i = (1 + (C_{CO2\%}/C_{CH4\%})) * Q_{CH4} * (C_i / 10^6)$$

where:

Q_i	=	emission rate of pollutant i, m^3/yr
Q_{CH4}	=	methane generation rate, m^3/yr (from Equation 1)
C_i	=	concentration of i in landfill gas, ppmv
$C_{CH4\%}$	=	the concentration of CH_4 as a percentage of the total landfill gas. If unknown, assume 55% CH_4
$C_{CO2\%}$	=	the concentration of CO_2 and other gas constituents as a percentage of the total landfill gas. If unknown, assume 45%
10^6	=	conversion from ppmv

Equation 3 calculates mass emissions (in kilograms per year) of VOC and speciated organic and inorganic compounds.

Equation 3

$$UM_i = Q_i * \left[\frac{MW_i * 1atm}{8.205 * 10^{-5} * 1000 * (273 + T)} \right]$$

where:

UM_i	=	uncontrolled mass emissions of pollutant i, kg/yr
Q_i	=	emission rate of pollutant i, m^3/yr (from Equation 2)
MW_i	=	molecular weight of i, g/gmol
T	=	temperature of landfill gas, °C
$8.205 * 10^{-5}$	=	constant to convert emissions of i to kg/yr, m^3-atm/gmol-K
1000	=	constant, g/kg
273	=	constant 0°C, Kelvin

The above equation assumes that the operating pressure of the system is approximately 101.3 kPa (1 atmosphere). If the temperature of the landfill gas is not known, an assumed temperature of 25°C is recommended for Australian conditions.

Table 4 lists the concentration and molecular weights for a number of substances found in landfill gas. Table 3 provides total VOC (as hexane) default values. If site-specific data is not available, you should choose the default value that is likely to best represent the location and characteristics of a particular landfill. The Australian values presented are likely to be the most representative of Australian conditions although the arid-zone default figures should be used for landfill estimations in most inland Australian towns and cities. ('Arid' is defined as receiving less than 635mm rainfall per year.) Site-specific concentrations of non-methane organic compounds (NMOC) in landfill gases can be determined using EPA Reference Method 25C (available from http://www.epa.gov/ttnemc01/promgate.html).

Table 4 - Uncontrolled Default Concentrations for Landfill Gas Constituents

Pollutant	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating	NPI-Listed Substance
1,1,1-Trichloroethane	133.41	0.48	B	N
1,1,1,2-Tetrachloroethane	167.85	1.11	C	N
1,1,2-Trichloroethane	133.41	0.1	E	Y
1,1-Dichloroethane	98.97	2.35	B	N
1,2-Dichloroethane	98.96	0.41	B	Y
1,1-Dichloroethene	96.94	0.2	B	N
1,2-Dichloropropane	112.99	0.18	D	N
2-Propanol	60.11	50.1	E	N
Acetone	58.08	7.01	B	Y
Acrylonitrile	53.06	6.33	D	Y
Benzene	78.11	1.91*	B*	Y
Bromodichloromethane	163.83	3.13	C	N
Butane	58.12	5.03	C	N
Carbon disulfide	76.13	0.58	C	Y
Carbon monoxide	28.01	141	E	Y
Carbon tetrachloride	153.84	0.004	B	N
Carbonyl sulfide	60.07	0.49	D	N
Chlorobenzene	112.56	0.25	C	N
Chlorodifluoromethane	86.47	1.3	C	N
Chloroethane	64.52	1.25	B	Y
Chloroform	119.39	0.03	B	Y
Chloromethane	50.49	1.21	B	N
Dichlorobenzene	147	0.21	E	N
Dichlorodifluoromethane	120.91	15.7	A	N
Dichlorofluoromethane	102.92	2.62	D	N
Dichloromethane	84.94	14.3	A	Y
Dimethyl sulfide	62.13	7.82	C	N
Ethane	30.07	889	C	N
Ethanol	46.08	27.2	E	Y
Ethylbenzene	106.17	4.61	B	Y
Ethyl mercaptan	62.13	2.28	D	N
Ethylene dibromide	187.88	0.001	E	N
Fluorotrichloromethane	137.38	0.76	B	Y
Hexane	86.18	6.57	B	Y
Hydrogen sulfide	34.08	35.5	B	Y
Mercury	200.61	2.92×10^{-4}	E	Y
Methyl ethyl ketone	72.11	7.09	A	Y
Methyl isobutyl ketone	100.16	1.87	B	Y
Methyl mercaptan	48.11	2.49	C	N
Pentane	72.15	3.29	C	N
Tetrachloroethylene	165.83	3.73	B	Y
Propane	44.09	11.1	B	N

Table 4 - Uncontrolled Default Concentrations for Landfill Gas Constituents cont'

Pollutant	Molecular Weight	Default Concentration (ppmv)	Emission Factor Rating	NPI-Listed Substance
Toluene	92.13	39.3*	A*	Y
t-1,2-Dichloroethene	96.94	2.84	B	N
Trichloroethylene	131.40	2.82	B	Y
Vinyl chloride	62.50	7.34	B	Y
Xylenes	106.16	12.1	B	Y

Source: USEPA, 1998, Table 2.4-1

* Based on no history of, or unknown, co-disposal. For benzene and toluene, where co-disposal is known, use the following data **:

Pollutant	Default Concentration (ppmv)	Emission Factor Rating
Benzene	11.1	D
Toluene	165	D

** Source USEPA, 1998, Table 2.4-2

It is important to note that the compounds listed in Table 4 are not the only compounds likely to be present in landfill gas. The listed compounds are those that were identified through a review of the available literature. The reader should be aware that additional compounds are likely to be present, such as those associated with consumer and industrial products. Given this information, extreme caution should be exercised in the use of the default concentrations provided.

The methane and carbon dioxide within the landfill gas is a product of biodegradation of refuse in landfills. When gas generation reaches steady state conditions, landfill gas consists of approximately 40% carbon dioxide, 55% methane, 5% nitrogen (and other gases) and trace amounts of NMOCs. If site-specific information on the methane and/or carbon dioxide concentration is not available, 55% should be used as a default for methane and 45% for carbon dioxide.

Example 1 illustrates the use of Equation 1 to Equation 3. The values presented Table 4 can be used as defaults for other substances expected to be present in landfill gas.

Example 1 - Calculation of Uncontrolled Emissions of Substances as Landfill Gas

A landfill with a capacity of 40 000 tonnes of waste began operation in 1989 and is due for closure in 2003. It accepts approximately 2860 tonnes of waste per year. Using Equation 1, the methane generation rate can be calculated for 1999 based on Australian methane generation constants from Table 3.

$$Q_{CH4} = L_0 * R * (e^{-kc} - e^{-kt})$$

where:

L_0 = 79 m^3/tonne of waste (from Table 3)
R = 2860 tonnes of waste
k = 0.058 yr^{-1} (from Table 3)
c = 0 years since landfill closure
t = 10 years since the initial refuse placement

$$Q_{CH4} = 79 * 2860 * (e^{-(0.058*0)} - e^{-(0.058*10)})$$
$$= 225\,940 * (e^{0} - e^{-0.58})$$
$$= 99\,436.6 \text{ m}^3 \text{ methane produced per year}$$

Emissions of non-methane volatile organic compounds VOC (as hexane), or any other substance within the landfill gas, can be calculated using Equation 2.

$$Q_i = (1 + (C_{CO2\%}/C_{CH4\%})) * Q_{CH4} * (C_i / 10^6)$$

where:

Q_{CH4} = 99 436.6 m^3/yr (from Equation 1)
C_i = 520 ppm_v VOC (from Table 3)
$C_{CH4\%}$ = 55%
$C_{CO2\%}$ = 45%

$$Q_i = (1 + (45/55)) * 99\,436.6 * (520/1\,000\,000)$$
$$= 1.82 * 99\,436.6 * 0.00052$$
$$= 94.1 \text{ m}^3 \text{ of VOCs per year}$$

To determine that mass of emissions of VOCs per year, apply Equation 3.

$$UM_i = Q_i * \left[\frac{MW_i * 1atm}{8.205 * 10^{-5} * 1000 * (273 + T)} \right]$$

where:

Q_i = 94.1 m^3/yr (from Equation 2)
MW_i = 86.18 g/gmol (VOC as hexane)
T = 25°C

$$UM_i = 94.1 * [(86.18 * 1)/(8.205 * 10^{-5} * 1000 * (273 + 25))]$$
$$= 331.7 \text{ kg of VOCs emitted per year.}$$

3.3.2 Using Site-Specific Data

Pollutant concentrations and methane generation constants can be determined for any specific landfill site through direct measurement. USEPA Reference Method 2E and 25C (available from http://www.epa.gov/ttnemc01/promgate.html) can be used for landfill gas testing and subsequent determination of pollutant concentrations and methane generation constants. The use of direct measurement data is recommended, where possible, over other estimation techniques, as considerable variation may occur between emission estimates and actual emissions due to variations in geography, waste composition and landfill metabolic stage.

If site-specific total pollutant concentrations are available from landfill gas testing data, they must be corrected for air infiltration that can occur by two different mechanisms: landfill gas sample dilution, and air intrusion into the landfill. These corrections require site-specific data for the landfill gas methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2) content. Concentrations for CH_4, CO_2, N_2, and O_2 can usually be found in the source test report for the particular landfill along with the total pollutant concentration data. If the ratio of N_2 to O_2 is less than or equal to 4 (approximated from 3.79, as found in ambient air), then the total pollutant concentration is adjusted for sample dilution by assuming that CO_2 and CH_4 are the primary (100%) constituents of landfill gas, and the following equation is used:

Equation 4

$$C_i = (C_s * 10^6)/(C_{CO2} + C_{CH4})$$

where:

C_i = concentration of pollutant i in landfill gas (corrected for air infiltration) (ie. VOC as hexane), ppmv

C_s = concentration of pollutant in landfill gas from source testing (not corrected for air infiltration), ppmv

C_{CO2} = CO_2 concentration in landfill gas, ppmv

C_{CH4} = CH_4 concentration in landfill gas, ppmv

10^6 = constant, to correct concentration of i to ppmv

If the ratio of N_2 to O_2 concentration is greater than 4, then the total pollutant concentration should be adjusted for air intrusion into the landfill by using Equation 4 and adding the concentration of N_2 to the denominator. This is shown by Equation 5:

Equation 5

$$C_i = (C_s * 10^6)/(C_{CO2} + C_{CH4} + C_{N2})$$

where:

C_i = concentration of pollutant i in landfill gas (corrected for air infiltration) (ie. VOC as hexane), ppmv
C_s = concentration of pollutant in landfill gas from source testing (not corrected for air infiltration), ppmv
C_{CO2} = CO_2 concentration in landfill gas, ppmv
C_{CH4} = CH_4 concentration in landfill gas, ppmv
C_{N2} = N_2 concentration in landfill gas, ppmv
10^6 = constant to correct concentration of i to ppmv

3.3.3 Estimating Emissions from Landfills with Control Technologies

Landfill emissions are often controlled by installing a gas collection system, and by burning the collected gas through the use of internal combustion engines, flares, or turbines. If a landfill has some form of gas collection and control, further information will need to be gathered to estimate emissions.

Gas collection systems are not 100 percent efficient in collecting landfill gas, so emissions of methane and other compounds at a landfill with a gas recovery system will occur. To estimate emissions of substances from landfills with a control system, the collection efficiency of the system must first be estimated. Reported collection efficiencies range from 60 to 85 percent, with an average of 75 per cent most commonly assumed (USEPA, 1998). If site-specific collection efficiencies are available, they should be used instead of the 75 per cent average.

Emission estimates also need to take into account the control efficiency of the control device. If site-specific control efficiencies are not known, some default efficiencies based on test data for the combustion of methane and other organic compounds are presented in Table 5.

Table 5 - Control Efficiencies for LFG Constituents

Control Device	Constituent [a]	Control Efficiency (%)		
		Typical	Range	Factor Rating
Boiler / Steam Turbine	VOC	98.0	96 - 99 +	D
	Halogenated Species	99.6	87 - 99 +	D
	Non-Halogenated	99.8	67 - 99 +	D
Flare [b]	VOC	99.2	90 - 99 +	B
	Halogenated Species	98.0	91 - 99 +	C
	Non-Halogenated	99.7	38 - 99 +	C
Gas Turbine	VOC	94.4	90 - 99 +	E
	Halogenated Species	99.7	98 - 99 +	E
	Non-Halogenated	98.2	97 - 99 +	E
Internal Combustion Engine	VOC	97.2	94 - 99 +	E
	Halogenated Species	93.0	90 - 99 +	E
	Non-Halogenated	86.1	25 - 99 +	E

Source: USEPA, 1998.

[a] Halogenated species are those containing atoms of chlorine, bromine, fluorine, or iodine. For any control equipment, the control efficiency for mercury should be assumed to be zero.

[b] Where information on equipment was given in the reference, test data were taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

Secondary compounds formed during the combustion of landfill gas, (eg. carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), hydrogen chloride (HCl) and particulate matter of ≤10μm (PM_{10})), can also be estimated using emission factors, mass balance and/or engineering methods if site-specific data is not available.

Emission factors for NO_x, CO and PM_{10} are given in Table 6. Note that the activity unit is expressed as "10^6 m^3 Methane". If landfill gas production data is collected (as opposed to the methane generation calculation method outlined in Equation 1) this should be multiplied by 0.55 (based on the indicative concentration of methane in landfill gas of 55% (USEPA AP-42, 1998)).

Controlled emissions of SO_2 and HCl can be estimated using site-specific landfill gas constituent concentrations and mass balance methods. If site-specific data is not available, the data in Table 4 can be used in conjunction with Equation 8 through to Equation 11.

Table 6 - Emission Factors for Secondary Compounds Exiting Control Devices

Control Device	Pollutant [a]	Emission Factor ($kg/10^6m^3$ methane)	Emission Factor Rating Code
Flare [b]	Nitrogen dioxide	650	C
	Carbon monoxide	12000	C
	Particulate matter	270	D
IC Engine	Nitrogen dioxide	4000	D
	Carbon monoxide	7500	C
	Particulate matter	770	E
Boiler/Steam Turbine [c]	Nitrogen dioxide	530	D
	Carbon monoxide	90	E
	Particulate matter	130	D
Gas Turbine	Nitrogen dioxide	1400	D
	Carbon monoxide	3600	E
	Particulate matter	350	E

Source: USEPA, 1998.

[a] No data on PM size distributions was available, however for other gas-fired combustion sources, most of the particulate matter is less than 2.5µm in diameter. Hence, this emission factor can be used to provide conservative estimates of PM_{10} emissions.

[b] Where information on equipment was given in the reference, test data was taken from enclosed flares. Control efficiencies are assumed to be equally representative of open flares.

[c] All source tests were conducted on boilers, however emission factors should also be representative of steam turbines. Emission factors are representative of boilers equipped with low-NO_x burners and flue gas recirculation. No data was available for uncontrolled NO_x emissions.

Example 2 illustrates the application of the emission factors from Table 6, using Equation 6 below.

Equation 6

$$CM_{kpy,,i} = EF_i * ((Q_{CH4}/1000000) * (LE/100))$$

where:

$CM_{kpy,,i}$ = controlled landfill emissions of pollutant i, kg/yr
EF_i = emission factor for pollutant i, $kg/10^6m^3$ methane
Q_{CH4} = methane generation rate at time t, m^3/yr (from Equation 1)
LE = efficiency of the landfill gas collection system, %

Example 2 - Calculating Emissions Using Emission Factors

A landfill has an internal combustion engine operating continuously throughout a reporting year to control landfill gas emissions. Using Equation 6, emission factors presented in Table 6, the methane generation rate calculated in Example 1 using Equation 1, and a gas collection efficiency of 75%, emissions of nitrogen dioxide can be estimated.

$$CM_{kpy,NO2} = EF_{NO2} * ((Q_{CH4}/1000000) * (LE/100))$$

where:

EF_{NO2} = 4000 kg/$10^6 m^3$ methane
Q_{CH4} = 99 436.6 m^3/yr (from example 1)
LE = 75%

$$CM_{kpy,NO2} = 4000 * ((99\ 436.6/1000000) * (75/100))$$
$$= 298 \text{ kg } NO_2\text{/yr}$$

It is assumed that the landfill gas collection and control system operates constantly and that minor durations of system downtime associated with routine maintenance and repair will not appreciably effect emission estimates. Emissions from the control devices need to be added to the uncollected emissions to estimate total controlled emissions. This can be calculated for specific substances and total VOCs by application of Equation 7.

Equation 7

$$CM_i = [UM_i * (1 - LE/100)] + [UM_i * (LE/100) * (1 - CE/100)]$$

where:

CM_i = controlled landfill emissions of pollutant i, kg/yr
UM_i = uncontrolled mass emissions of pollutant i, kg/yr (from Equation 3)
LE = efficiency of the landfill gas collection system, %
CE = efficiency of the landfill gas control device, %

Example 3 - Calculating Controlled Emissions of Gases from a Landfill

Using the results from Example 1, the emissions of volatile organic compounds (VOCs) from a landfill with a gas turbine used as a control system can be calculated using Equation 7.

$$CM_i = [UM_i * (1 - LE/100)] + [UM_i * (LE/100) * (1 - CE/100)]$$

where:

UM_i = 331.7 kg/yr (from Example 1)
LE = 75 % gas collection efficiency
CE = 94.4 % VOC removal efficiency for gas turbine

$$\begin{aligned} CM_i &= [331.7 * (1 - (75/100)] + [331.7 * (75/100) * (1 - (94.4/100))] \\ &= 82.9 + 13.9 \\ &= 96.9 \text{ kg of VOCs emitted per year.} \end{aligned}$$

Emission factors are available for CO, NO_x, and SO_2 in Table 6 in units of kilograms per hour per flow rate before the control device (dry cubic metres per minute).

To calculate emissions of CO, NO_x, and SO_2 using the emission factors, you should multiply the emission factor for the relevant control technology from Table 6, by the flow rate of the gas before the control technology, to obtain an actual emission rate (in kilograms per hour). Yearly estimates are obtained by multiplying this figure by the hours that the control device operates over a year. Controlled emissions of SO_2 and HCl can be estimated using site-specific landfill gas constituent concentrations and mass balance methods. If site-specific data is not available, the data in Table 4 and Table 5 can be used in conjunction with Equation 8 to Equation 11.

To prepare estimates of SO_2 emissions, data on the concentration of reduced sulfur compounds within the landfill gas are needed. The best way to prepare this estimate is with site-specific information on the total reduced sulfur content of the landfill gas expressed in parts per million by volume. Equation 2 and Equation 3 can then be used to estimate the uncontrolled emissions of reduced sulfur compounds. Equation 8 can then be used to estimate SO_2 emissions from controlled sources with the assumption that all sulfur is converted to SO_2.

Equation 8

$$CM_{kpy,\ SO2} = UM_{kpy,S} * (LE/100) * 2$$

where:

CM_{SO2}	=	controlled mass emissions of SO_2, kg/yr
UM_S	=	uncontrolled mass emissions of reduced sulfur compounds (from Equation 3), kg/yr
LE	=	efficiency of the landfill gas collection system, %
2	=	ratio of the molecular weight of SO_2 to the elemental weight of S

If site-specific data for total reduced sulfur compounds as sulfur is not available, site-specific concentrations for speciated reduced sulfur compounds can be used for C_p in Equation 9. To convert the individual sulfur compound concentrations to the total concentration of reduced sulfur compounds, use Equation 8. After the total reduced sulfur concentration has been calculated, use Equation 2, Equation 3, and Equation 9 as before to derive SO_2 emissions.

Equation 9

$$C_S = \sum_{i=1}^{n} C_p * S_p$$

where:

C_S	=	concentration of total reduced sulfur compounds, ppmv as S (for use in Equation 2)
C_p	=	concentration of each reduced sulfur compound, ppmv
S_p	=	number of moles of S produced from the combustion of each reduced sulfur compound (ie. 1 for sulfides, 2 for disulfides, etc)
n	=	number of reduced sulfur compounds available for summation

If no site-specific data is available, a value of 46.9 ppmv can be assumed for C_s, based on the default concentrations presented in Table 4.

Example 4 - Calculating Sulfur Dioxide (SO_2) Emissions

Using information from the Example 1 in this manual, this example demonstrates how to calculate SO_2 emissions from landfills with a landfill gas collection and control system. As no data exists for the concentration of sulfur in the landfill gas, the concentration of reduced sulfur compounds is assumed to be the default concentration of 46.9ppm. Apply Equation 2 and Equation 3 to calculate uncontrolled mass emissions of reduced sulfur compounds:

$$Q_i = (1 + (C_{CO2\%}/C_{CH4\%})) * Q_{CH4} * (C_i / 10^6)$$

where:

Q_{CH4} = 99436.6 m^3/yr (from Equation 1 and Example 1)
C_i = 46.9 ppmv
$C_{CH4\%}$ = 55%
$C_{CO2\%}$ = 45%

Q_i = (1 + (45/55)) * 99436.6 * (46.9/1000000)
= 8.5 m^3 of reduced sulfur compounds emitted per year

Using Equation 3:

$$UM_i = Q_i * \left[\frac{MW_i * 1atm}{8.205 * 10^{-5} * 1000 * (273 + T)}\right]$$

where:

Q_i = 8.5 m^3/yr (from Equation 2)
MW_i = 32.06 g/gmol for sulfur
T = 25°C
UM_i = 8.5 * [(32.06 * 1)/(8.205 * 10^{-5} * 1000 * (273 + 25))]
= 11 kg of reduced sulfur compounds as S emitted per year

To determine emissions of sulfur dioxide (SO_2) use Equation 8:

$$CM_{SO2} = UM_S * (LE/100) * 2$$

where:

UM_i = 11 kg/yr (from Equation 3)
LE = 75 %
CM_{SO2} = 10 * (75/100) * 2
= 16.7 kg of SO_2 per year emitted from a landfill burning landfill gas

Hydrogen chloride (hydrochloric acid (HCl)) emissions are formed when chlorinated compounds in landfill gas are combusted in control equipment. The best method of estimating HCl emissions, if site-specific data is not available, is a procedure similar to that previously discussed for estimating SO_2, ie, assume all chlorine is converted to hydrogen chloride. If site-specific data on HCl emissions is not available, data on the total chloride concentration can be used (expressed as ppmv as the chloride ion (Cl^-)) along with Equation 10. If data on site-specific individual chlorinated compounds is not available, then a default concentration of 42 ppmv can be used for C_{Cl} based on compounds listed in Table 4 and Equation 10.

Equation 10

$$C_{Cl} = \sum_{i=1}^{n} Cp * Clp$$

where

C_{Cl} = concentration of total chloride, ppmv as Cl^- (for use in Equation 2)
Cp = concentration of each chlorinated compound, ppmv
Clp = number of moles of Cl^- produced from the combustion of each chlorinated compound (ie. 3 for 1,1,1-trichloroethane, etc)
n = number of chlorinated compounds available for summation.

After the total chloride concentration (C_{Cl}) has been estimated, Equation 2 and Equation 3 should be used to determine the total uncontrolled mass emission rate of chlorinated compounds as chloride ion (UM_{Cl}). This value is then used in Equation 11 to calculate HCl emissions.

Equation 11

$$CM_{HCl} = UM_{Cl} * (LE/100) * 1.03 * (1 - (CE/100))$$

where:

CM_{HCl} = controlled mass emissions of HCl, kg/yr
UM_{Cl} = uncontrolled mass emissions of chlorinated compounds as chloride, kg/yr (from Equation 2 and Equation 3)
LE = efficiency of the gas collection system, %
1.03 = ratio of the molecular weight of HCl to the molecular weight of Cl^-
CE = control efficiency of the landfill gas control device, %

3.3.4 Estimating Emissions for Open Burning of Municipal Waste

Ground-level open burning emissions are affected by many variables, including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase emissions of particulate matter, carbon monoxide, and hydrocarbons and suppress emissions of nitrogen oxides. Emissions of sulfur oxides are a direct function of the sulfur content of the refuse (USEPA, 1992). Open burning of municipal waste is generally not practiced or illegal in most states of Australia.

Table 7 - Emission Factors for Open Burning of Municipal Refuse

Substance	Emission Factor (kg/tonne)	Emission Factor Rating
Total particulate matter[a]	8	D
Sulfur oxides	0.5	D
Carbon monoxide	42	D
Volatile organic compounds	15	D
Oxides of nitrogen	3	D

Source: USEPA, 1992

[a] Particulate emissions represent total emissions of particulate matter. To determine the fraction of less than 10 micrometers, a characterisation of the size may be necessary.

The USEPA has released a report on the open burning of household waste in barrels. This report can be found at: http://ftp.epa.gov/ttn/catc/dir1/barlbrn1.pdf. Table 4.1 of this report can be used to estimate trace emissions from open burning.

3.4 Estimating Emissions to Water and Land

Emissions of NPI-listed substances to water will generally come from leachate emissions to ground and surface waters, and overland flow during rain events. As with landfill gas, it is difficult to provide typical figures for the generation and composition of leachate from landfilled wastes. Both the amount and composition of leachate will depend on many factors, such as the nature of the waste landfilled, the landfilling method, the level of waste compaction, the design of the landfill and the annual rainfall and evapotranspiration of the region.

Table 8 provides emission factors for an average municipal solid waste landfill, however site or region-specific emission factors should be used instead where available.

A number of landfill leachate generation models have been developed, the most commonly used being The Hydrologic Evaluation of Landfill Performance (HELP) Model. Unfortunately, a considerable amount of site-specific information is necessary to estimate emissions, which is unlikely to be available for many smaller facilities. If a more accurate model can be utilised, or site-specific monitoring data is available, it is recommended that this be used as an alternative to estimation techniques presented in this manual. However, you must seek approval from your relevant administering authority to use estimation techniques not covered by this handbook.

A very simplistic technique for estimating leachate generation and water emissions have been included in this manual. In addition, any direct measurement data or water balance can be used as an alternative to emissions estimation.

The method presented is based on the annual rainfall for the area and is the basis of leachate estimation techniques presented in the waste generation spreadsheet "Integrated Solid Waste Management - A Lifecycle Inventory" (White, Franke and Hindle, 1995). This method is based on an estimation that 13% of the rainfall on a landfill site emerges as leachate.

3.4.1 The "Lifecycle Inventory" Method

It has been estimated that approximately 13% of the rainfall on a landfill site emerges as leachate (White, Franke and Hindle, 1995). From this, an annual estimation of the amount of leachate generated in a landfill without a cap or liner can be made. This estimate is represented by Equation 12.

If the landfill is lined and/or capped, or has a leachate collection system, the efficiency of such control technologies should be estimated and figured into the calculation of leachate emitted. In the absence of more reliable data, you should assume that a landfill liner and collection system will be 70% efficient over the active life of a landfill, and that the active period for leachate production is around 30 years.

Equation 12

$$E_{leachate} = Q * \left[\frac{[R*(P/100)]}{[H*(D/1000)]}\right]*[1-(CE/100)]$$

where:

$E_{leachate}$ = leachate generation rate, L/yr
Q = total amount of waste in place, tonne
H = depth of the landfill, m
P = percentage of rainfall to the site emerging as leachate (assume 13% if more site-specific data is not available), %
D = density of the waste, kg/m^3 (see Table 2)
1000 = conversion from kilograms to tonnes of waste, kg/tonne
CE = control efficiency of landfill liner, cap and/or leachate collection system, %
R = annual average rainfall to the site or area, mm/yr (equivalent to $L/m^2.yr$ when conversion from mm/yr to volume of water entering landfill $[(mm/m^2.yr)*(m/1000mm)*(m^2)*(1000L/m^3)]$)

The concentration of specific NPI-listed substances in the leachate can then be used to estimate annual emissions of these substances to water using Equation 13. This method for estimating emissions of NPI-listed substances to waters has been incorporated into the landfill area-based spreadsheet (LABS) accompanying this document and outlined in Appendix 1.

Equation 13

$$E_{kpy,i} = (E_{leachate} * EF_i)/10^6$$

where:

$E_{kpy,i}$ = annual emission of substance i, kg/yr
$E_{leachate}$ = annual emission of leachate containing substance i, L/yr
EF_i = emission factor for substance i, mg/L
10^6 = conversion of mg to kg, mg/kg

Example 5 - Calculating Emissions from Leachate

Emissions from leachate from a landfill site can be calculated using Equation 12 and the following information. 40 000 tonnes of waste is placed in a landfill which receives an annual average rainfall of 1120 mm/yr. Approximately 13% of the rainfall to the site emerges as leachate from the landfill which is 20m deep. The density of waste in the landfill has been approximated to 740 kg/m^3. The landfill's liner and collection system has a control efficiency of about 70%.

$$E_{leachate} = Q * \left[\frac{[R * (P/100)]}{[H * (D/1000)]} \right] * [1 - (CE/100)]$$

where:

Q	=	40 000 tonnes
R	=	1120mm/yr
H	=	20m
P	=	13%
D	=	740 kg/m^3
CE	=	70%

$E_{leachate}$ = 40 000 * [(1120 * (13/100))/(20 * (740/1000)] * [1 - (70/100)]
= 40 000 * 9.84 * 0.3
= 118 054 litres of leachate per year

Annual emissions of lead can be calculated using Equation 13 and the emission factor for lead from Table 8.

$E_{leachate}$	=	118 054 L/yr
EF_{Lead}	=	$6.3 * 10^{-2}$ mg/L
10^6	=	10^6 mg/kg

$E_{kpy, Lead}$ = $(E_{leachate} * EF_{Lead})/ 10^6$
$E_{kpy,Lead}$ = $(118\ 054 * 6.3 * 10^{-2})/10^6$
= 0.007437 kg Lead/yr

Table 8 - Uncontrolled Default Concentrations of Substances in Leachate from Municipal Solid Waste Landfills

Substance	Emission Factor [a] (mg/L)	Emission Factor Rating
Ammonium	210 (30)[c]	U
Antimony	6.6 E-02	U
Arsenic	1.4 E-02	U
Beryllium	4.8 E-03	U
Cadmium	1.4 E-02	U
Chlorine	590	U
Chromium	6 E-02	U
Copper	5.4 E-02	U
Fluorine	0.39	U
Lead	6.3 E-02	U
Mercury	6 E-04	U
Nickel	0.17	U
Zinc	0.68	U
1,2-Dichloroethane	0.01	U
Benzo(a)pyrene	2.5 E-04	U
Benzene	3.7 E-02	U
Chloroform	2.9 E-02	U
Chlorophenol	5.1 E-04	U
Dichloromethane	0.44	U
Ethylbenzene	5.8 E-02	U
Total Nitrogen [b]	425 (137.5)[c]	U
Phenol	0.38	U
Total Phosphorus [b]	30 (7.5)[c]	U
Toluene	0.41	U
Vinyl chloride	0.04	U

Source: White, Franke and Hindle (1995)

[a] Emission factors represent a typical municipal solid waste landfill. These factors are not likely to be representative of landfill sites accepting hazardous waste.

[b] Tchobanoglous, et al (1993) Total nitrogen emission factor developed from the addition of the typical concentrations of organic nitrogen, ammonia nitrogen and nitrate. Ranges for these substances are:
10-800mg/L for organic nitrogen, 10-800 mg/L for ammonia nitrogen, and 5-40 mg/L for nitrate. These typical values will vary with the metabolic state of the landfill.

[c] Emission factors in brackets relate to emissions from mature landfills (>10 years).

3.4.2 Water Balance Method

An alternative, and possibly more accurate, method of estimating leachate emissions for high rainfall and tropical areas is to use a water balance. Essentially, a water balance is a type of mass balance which involves summing the amounts of water entering the landfill site, and subtracting the amounts of water lost through evaporation, transpiration, runoff, chemical reactions and leaving the site as water vapour within landfill gas. Water balance methods vary in their degree of complexity and the method used will predominantly depend on the amount of site-specific information available.

A number of references cover methods of conducting a water balance for a landfill site. For example, McBean, et al, 1995 and Tchobanoglous, et al, 1993. Also, computer software based on models such as the Hydrologic Evaluation of Landfill Performance (HELP) Model (Schroeder, et al, 1984) is available. If you wish to utilise a water balance for estimating emissions from your facility, it is recommended that you consult these references for further information.

4.0 Emission Estimation Techniques: Acceptable Reliability and Uncertainty

Emission estimates generated for landfills using the LABS model, or the equations outlined in this Workbook, are relatively uncertain. A variety of chemical, biological, and physical factors affect the rate of landfill emissions. The only reliable way to determine emissions is by direct, continuous measurement. Source testing can provide a snapshot of emissions at a given time period, but landfill emissions can fluctuate over time. Therefore, source-testing results are not always a reliable estimator of average or future emissions without a large number of repeated samples.

The use of site-specific data gives higher quality estimates than the use of the defaults and assumptions provided in the tables, but requires more effort. The goal in estimating landfill emissions is to locate and estimate the largest share of landfill emissions possible within the budget for this source. Small landfills that have been closed for a decade or more may require more time and effort than their proportionate contribution to the total landfill emissions. It is possible to estimate a range of error that results from not including those landfills in the NPI. Landfill emissions depend on a complex combination of variables and, even with the most accurate data for waste in place and the landfill age, emissions cannot be characterised as accurately as those for other area-based categories may be.

Where emission factors are used, every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A	-	Excellent
B	-	Above Average
C	-	Average
D	-	Below Average
E	-	Poor
U	-	Unrated

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APPENDIX 1

LANDFILL AREA-BASED SPREADSHEET (LABS)

This Appendix is organised into the following sections:

1.0 Introduction

The Landfill Area Based Spreadsheet (LABS) is an *Excel* spreadsheet program to calculate emissions of NPI-listed substances to air and water. The model is based on a first-order kinetic model of methane production developed by the USEPA. The LABS is designed to calculate emissions of a number of NPI-listed substances for any number of landfill sites simultaneously in a NPI-region.

The equations and details of the data to be collected for estimating emissions from landfills within a reporting region is covered in the main body of this Manual. This appendix is designed to provide a guide to the practical use of the LAB spreadsheet.

2.0 Data Needs

The minimum information required for each landfill to estimate emissions using the LABS is:

- the capacity of the landfill;
- the depth and area of the landfill;
- the annual rainfall of the region;
- the density of the waste;
- the year the landfill began operation;
- the year the landfill ceased operation (if closed);
- the annual waste acceptance rate or the proposed closure date for the landfill;
- whether the landfill has accepted hazardous waste;
- whether the landfill has a gas collection system;
- whether the landfill is lined or has some other form of leachate control;
- the type of gas control technology used if gas is collected (eg. flare, internal combustion engine, boiler, etc); and
- the flow rate of the gas before the control technology if gas is collected.

Other parameters that are or can be used in LABS are:

- the methane generation rate constant k;
- the methane generation capacity L_o;
- the concentration of methane within the landfill gas;
- the concentration of carbon dioxide within the landfill gas;
- the concentration of volatile organic compounds (VOCs);
- the concentration and molecular weights of NPI-listed substances within the landfill gas;
- the concentration of NPI-listed substances within the leachate;
- the collection efficiency of any gas collection system;
- the control efficiency of any gas control technology (eg. flare, turbine, boiler, etc);
- the collection efficiency of any landfill liner or leachate control system;
- the temperature of the landfill gas;
- the concentration of oxides of nitrogen (NO_x), carbon monoxide (CO) and particulate matter (PM_{10}) in the gas after a control technology (eg. flare, turbine, boiler, etc);
- the concentration of sulfur within the landfill gas; and
- the concentration of chloride ions within the landfill gas.

Default values or estimates are available for a number of the above parameters. These defaults and further information is provided in the main body of this document, and tend to be incorporated into LABS.

3.0 Operating the Landfill Area Based Spreadsheet (LABS)

3.1 Inputting Data

The spreadsheet is separated into a number of separate worksheets, however, it is likely that you would only need to access the worksheets for **Input**, **Air Emissions**, and **Water Emissions**. All data to be provided will be typed on the **Input** worksheet. The spreadsheet is colour-coded as a guide to what data needs to be provided, and what data is automatically calculated. If the colour of the column is:

white -	some data input is required;
light grey -	data may not be needed in some circumstances or a number of options are available for input of data;
dark grey -	only site-specific values are required (where available); and
green -	no data input needed.

This section will provide a general outline of data required and the purpose of each column on the **Input** worksheet.

Column A Landfill: This column requires that some identifying name be provided for each landfill. This is to identify each landfill for inclusion on the NPI database or for reference.

Column B Address: The address of the landfill site.

Column C Postcode: This is the postcode of the landfill site.

Column D Latitude and Longitude or AMG Coordinates: The latitude and longitude or Australian Map Grid (AMG) Coordinates are to be indicated here. AMG co-ordinates may be found in recent versions of the local street directory, AUSLIG maps, or from land title information.

Column E Capacity: This is the total capacity or amount of waste (in tonnes) that the landfill can accept. This value may be projected for landfills that are still operating and expected to operate for a number of years. If the capacity of the landfill is unknown, it may be estimated from the volume (area multiplied by depth) of the landfill and the density of waste. This is calculated by completing columns F through to L on the spreadsheet, and leaving column E blank. Any data placed in column E will be displayed as the final landfill capacity in column M.

Column F Depth: Indicate the depth of the landfill (in metres) if the total capacity of the landfill is unknown (column E). This will be used to calculate the total capacity of the landfill, and may be used to calculate the leachate generation rate.

Column G Area: Indicate the area of the landfill (in square metres) if the total capacity of the landfill is unknown (column E). This figure is used to calculate the total capacity of the landfill, and may be used to calculate the leachate generation rate.

Column H Compacted: This provides a default value for the density of compacted waste (742 kg/m^3). This is used to calculate the capacity of the landfill if not indicated in column E. Place a "x" in this column if the landfill practices include compacting their waste. Do not check any of the other columns I, J or K. The default density will be displayed in column L.

Column I Settled: This provides a default value for the density of waste that has settled or significantly degraded (1 067.88 kg/m^3). This value will be the most appropriate for landfills that have been closed for some time. The density of the waste is used to calculate the capacity of the landfill if it has not been indicated in column E. Place an "x" in this column if the landfill waste can be considered to have settled. Do not check any of the other columns H, J, or K. The default density will be displayed in column L.

Column J Unknown: This provides a default value for the density of waste if it is unknown whether waste has been compacted (688 kg/m^3). This figure is used to calculate the capacity of the landfill if not indicated in column E. Place an "x" in this column if it is unknown whether the landfill practices include compacting waste. Do not check any of the other columns H, I, or K. The default density will be displayed in column L.

Column K Other: Check this column if the density of waste at a particular site is known and the capacity of the landfill was not indicated in column E. If you check column K, column L will display "?". You must indicate a density in column L if you choose this option (kg/m^3). Do not check any of the other columns H, I or J.

Column L Density of Waste: This is the density of the waste that will be used to calculate the total capacity of the landfill (column M) if this had not been indicated in column E, as well as the leachate generation rate. The value displayed here will depend on which column from H to K was checked. The only time a value will need to be typed into this column is if column K was checked (ie a site-specific waste density is available).

Column M Capacity: This is the total capacity of the landfill, calculated from the actual capacity inputted into column E, or from values inputted into columns F to L. No data should be typed into this column.

Column N Approx. Opening Year: Indicate the year that the landfill began accepting waste.

Column O Approx. Closure Year: Indicate the year that the landfill ceased accepting waste. If the landfill is still operational, indicate the proposed closure year for the landfill.

Column P Current Year: Indicate the current year.

Column Q Time Since Landfill Closure: No data will need to be typed into this column. This calculates the number of years the landfill has been closed based on information provided in column O. If the landfill is still operating, the value should display a zero. This value is used in calculating the methane generation rate.

Column R Time Since Refuse Placed: No data will need to be typed into this column. This calculates the number of years since the landfill began operation based on data provided in column N. This value is to be used in calculations of the methane generation rate.

Column S CH_4 Conc.: Indicate the percentage of methane in the landfill gas. If this is not known for a specific site, 55% should be assumed.

Column T CO_2 + Other Constituents Conc.: Indicate the percentage of carbon dioxide and other trace constituents in the landfill gas. If this is unknown for a particular site, 45% should be assumed.

Column U Australian Methane Generation Rate Constant: The methane generation rate constant is a value that determines the rate of landfill gas generation (measured in yr^{-1}). An Australian default value of 0.058 yr^{-1} will be used for this constant if this column is checked with an "x". Do not check any of the other columns V to Y if this default is used. The value will be indicated in column Y.

Column V AP-42 Methane Generation Rate Constant: The methane generation rate constant is a value that determines the rate of landfill gas generation (measured in yr^{-1}). An AP-42 default value of 0.04 yr^{-1} will be used for this constant if this column is checked with an "x". Do not check any of the other columns U, W or X if this default is used. The value will be indicated in column Y.

Column W Arid Methane Generation Rate Constant: The methane generation rate constant is a value that determines the rate of landfill gas generation (measured in yr^{-1}). An AP-42 default value of 0.02 yr^{-1} for arid areas will be used for this constant if this column is checked with an "x". Arid areas are those that receive less than 635mm of rain per year. Do not check any of the other columns U, V or X if this default is used. The value will be indicated in column Y.

Column X Other Methane Generation Rate Constant: The methane generation rate constant is a value that determines the rate of landfill gas generation (measured in yr^{-1}). If this column is checked with an "x", you will be required to input a site-specific value for this constant. This value should be typed into column Y which will be displaying a "?". Do not check any of the other columns U, V, or W if this default is used.

Column Y Methane Generation Rate Constant k: The methane generation rate constant is a value that determines the rate of landfill gas generation (measured in yr^{-1}). The value displayed in this column will depend on the default value checked (columns U to X). The only time this column will need to be changed is if column X had been checked, and a site-specific value is available.

Column Z Australian Methane Generation Potential: The methane generation potential represents the potential capacity of a landfill to generate methane (measured in cubic metres per tonne of refuse). An Australian default value of 79 m^3 per tonne will be used for this constant if this column is checked with an "x". Do not check any of the other columns AA to AC if this default is used. The value will be indicated in column AD.

Column AA AP-42 Methane Generation Potential: The methane generation potential represents the potential capacity of a landfill to generate methane (measured in cubic metres per tonne of refuse). An AP-42 default value of 100 m^3 per tonne will be used for this constant if this column is checked with an "x". Do not check any of the other columns Z, AB or AC if this default is used. The value will be indicated in column AD.

Column AB Arid Methane Generation Potential: The methane generation potential represents the potential capacity of a landfill to generate methane (measured in cubic meters per tonne of refuse). An AP-42 default value of 100 m^3 per tonne for arid areas will be used for this constant if this column is checked with an "x". Arid areas are considered those that receive less than 635mm of rain per year. Adelaide receives 455mm of rainfall annually and is the only capital city located within the arid zone. Do not check any of the other columns Z, AA or AC if this default is used. The value will be indicated in column AD.

Column AC Other Methane Generation Potential: The methane generation potential represents the potential capacity of a landfill to generate methane (measured in cubic meters per tonne of refuse). If this column is checked with an "x", you will be required to input a site-specific value for this constant. This value should be typed into column AD which will be displaying a "?". Do not check any of the other columns Z, AA or AB if this default is used.

Column AD Methane Generation Potential L_o: The methane generation potential represents the potential capacity of a landfill to generate methane (measured in cubic meters per tonne of refuse). The value displayed in this column will depend on the default value checked (columns Z to AC). The only time this column will need to be changed is if column AC has been checked, and a site-specific value is available.

Column AE Annual Acceptance Rate: This is the approximate number of tonnes of waste disposed to the landfill each year of operation (tonne per year). This value must be indicated. If the annual acceptance rate is unknown, it can be estimated by dividing the capacity of the landfill by the number of years it has or is proposed to operate.

Column AF Accepted Hazardous Waste: If the landfill has ever accepted hazardous waste, type "y" or "yes" in this column. If not, leave this column blank (note: LABS only recognises the presence or absence of data in this column, not the actual figure or letter/s typed in. Therefore, it is irrelevant what letter, number or group of figures is typed in, only that the cell either contains data or is blank).

Column AG Australian VOC: Type an "x" in this column to use the Australian default concentration of VOC in the landfill gas (520 ppmv). This will be used to calculate the total emissions (in kilograms per year) of total VOCs from the landfill. Do not check columns AH or AI if you wish to use this Australian default. The VOC value should be displayed in column AJ.

Column AH AP-42 VOC: Type an "x" in this column to use the AP-42 default concentration of VOC in the landfill gas that will be used to calculate the total emissions (in kilograms per year) of VOCs from the landfill. This value will be displayed in column AJ, and will vary depending on whether column AF has been marked (ie. the landfill has accepted hazardous waste). For landfills that have not accepted hazardous wastes, a VOC concentration of 595 ppmv is used. For landfills that have accepted hazardous wastes, a concentration of 2 420 ppmv is used. Do not check columns AG or AI if you wish to use this AP-42 default.

Column AI Site-specific VOC: Type an "x" in this column to use a site-specific default concentration of VOCs in the landfill gas. If you check this column, you will need to type the value into column AJ (parts per million by volume). This will be used to calculate the total emissions (in kilograms per year) of total VOCs from the landfill. Do not check columns AG or AH if you wish to use a site-specific value.

Column AJ VOC conc.: The VOC concentration displayed in this column will be used to calculate the total emissions of VOCs (in kilograms per year). The value displayed in this column will depend on which default was checked in columns AG, AH or AI. The only time any data will need to be typed in this column is when column AI was checked and a site-specific VOC concentration is available. This concentration should be in parts per million by volume.

Column AK Temperature of Landfill Gas: The temperature of the landfill gas (degrees Celsius) must be indicated., However, if this is unknown, a value of 25°C should be assumed.

Column AL Is the Landfill Lined?: Mark this box with a "y" or "yes" only if the landfill is lined, capped, or has some other mechanism for the control of leachate emissions. If the landfill has no leachate control, leave this column blank. (Note: LABS only recognises the presence or absence of data in this column, not the actual figure or letter/s typed in. Therefore, it is irrelevant what letter, number or group of figures is typed in, only that the cell either contains data or is blank)

Column AM Site-Specific Control Efficiency?: If a landfill has some form of leachate control and the efficiency for the site is known, it should be indicated in this column (%). This value will then be displayed in column AN. If a site-specific efficiency is not known, leave this column blank.

Column AN Efficiency of Leachate Collection: This column indicates the control efficiency of any leachate control system. If a value has been typed into column AM, it will be displayed in this column. However, no data should be typed into this column.

Column AO Site-Specific Leachate Generation Rate: If data is available on the leachate production rate (litres per year) for a specific site or area, indicate a value in this column. If not, leave this column blank.

Column AP Annual Rainfall: Indicate the annual average rainfall (mm) for a particular area. This value will be used to estimate the leachate production rate if site-specific data is not available.

Column AQ Leachate generation: The leachate generated by the landfill (litres per tonne of waste) will be displayed in this column. The value displayed will be calculated from data provided in columns AP (annual rainfall), F (depth of landfill) and L (density of waste).

Column AR Gas Collection and Control System?: Type a "y" or "yes" in this column only if the landfill has a gas collection and control system. If the landfill does not, leave this column blank and do not complete any of the columns AS to BF. (Note: LABS only recognises the presence or absence of data in this column, not the actual figure or letter/s typed in. Therefore, it is irrelevant what letter, number or group of figures is typed in, only that the cell either contains data or is blank)

Column AS Site-Specific Collection Efficiency: If the efficiency of the gas collection system for a particular landfill is known, type this value (%) in this column. This value will be displayed in column AT. If the collection efficiency is unknown, type nothing and an efficiency of 75% will be assumed.

Column AT Efficiency of Collection System: As gas collection systems are not 100 percent efficient in collecting landfill gas, emissions of substances at a landfill with a gas recovery system still occur. To estimate emissions of substances from landfills with a control system, the collection efficiency of the system must first be estimated. If a site-specific value was indicated in column AS, this will be displayed here. If it was not, a value of 75% will be displayed. No data will need to be typed into this column.

Column AU Flow Rate Before Control: Indicate the flow rate of the landfill gas before it enters the control device. This flow rate should be in dry cubic metres per minute.

Column AV Methane Flow Rate: This is the flow rate of methane in the landfill gas before the control technology (in dry cubic metres per minute). This is calculated from the value indicated in column AU (ie. the landfill gas flow rate) multiplied by the fraction of gas that is methane (calculated from column S8). This value is necessary to estimate the emissions of oxides of nitrogen, carbon monoxide, and particulate matter from the control technology.

Column AU Boiler/Steam Turbine: Type an “x” in this column if the landfill gas control technology is a boiler or steam turbine. Do not mark columns AV, AW or AX if this column has been indicated.

Column AV Flare: Type an “x” in this column if the landfill gas control technology is a flare. Do not mark columns AU, AW or AX if this column has been indicated.

Column AW Gas Turbine: Type an “x” in this column if the landfill gas control technology is a gas turbine. Do not mark columns AU, AV, or AX if this column has been indicated.

Column AX IC Engine: Type an “x” in this column if the landfill gas control technology is an internal combustion engine. Do not mark columns AU, AV, or AW if this column has been indicated.

Column AY Site-Specific Control Efficiency: Type an “x” in this column if you wish to input site-specific values for the control efficiency of the control technology at a particular landfill. If you choose this option, leave column AZ blank, and type the control efficiencies (%) in columns BA to BD for the compounds specified: VOCs, halogenated species (those containing chlorine or bromine), non-halogenated species, and mercury.

Column AZ Assumed Control Efficiency: Type an “x” in this column if you wish to used the default efficiencies (%) for the control technology chosen in columns AU to AX. If you check this column, leave column AY blank.

Column BA VOC Control Efficiency: The efficiency displayed in this column will depend on whether the default efficiencies were chosen (column AZ was marked) and the type of control technology chosen from columns AU to AX. If column AY was checked and a site-specific efficiency is available, type this value in this column (%). The efficiency indicated in this column relates only to VOCs.

Column BB Halogenated Species Control Efficiency: The efficiency displayed in this column will depend on whether the default efficiencies were chosen (whether column AZ was marked) and the type of control technology chosen from columns AU to AX. If column AY was checked and a site-specific efficiency is available, type this value in this column (%). The efficiency indicated in this column relates only to halogenated compounds, which are those containing chlorine, bromine, fluorine or iodine (for example, trichloromethane).

Column BC Non-Halogenated Species Control Efficiency: The efficiency displayed in this column will depend on whether the default efficiencies were chosen (whether column AZ was marked) and the type of control technology chosen from columns AU to AX. If column AY was checked and a site-specific efficiency is available, type this value in this column (%). The efficiency indicated in this column relates only to non-halogenated compounds, such as hydrogen sulfide.

Column BD Mercury Control Efficiency: The efficiency displayed in this column will depend on whether the default efficiencies were chosen (whether column AZ was marked) and the type of control technology chosen from columns AU to AX. If column AY was checked and a site-specific efficiency is available, type this value in this column (%). The efficiency indicated in this column relates only to mercury.

Column BE Sulfur Conc. in Gas: If a site-specific concentration is known for reduced sulfur compounds (in parts per million by volume), it should be indicated in this column. If it is unknown, leave this column blank and the concentration will be estimated from default concentrations for sulfur-containing substances. This value will be used to estimate sulfur dioxide emissions from the control device.

Column BF Chloride Conc. in Gas: If a site-specific concentration is known for the total chloride concentration in the landfill gas (parts per million by volume), it should be indicated in this column. If it is unknown, leave this column blank and the concentration will be estimated from default concentrations of chlorinated compounds. This value will be used to estimate hydrogen chloride emissions from the control device.

3.2 Air Emissions

Emissions to the atmosphere of various NPI-listed substances can be viewed in the **Air Emissions** worksheet. It is unlikely that any data will need to be altered on this worksheet, although if site-specific concentrations for individual NPI-listed substances emitted to air are available, they can be altered on this worksheet. The first four columns on the **Air Emissions** sheet will be copied from the **Input** sheet. The rest of the columns present the emissions of substances in kilograms per year. If the landfill had a control technology, use the results from the *Controlled Emissions* columns. If the landfill had no gas collection and control device, use the results from the *Uncontrolled Emissions* columns. For landfills without any gas control technology, the secondary products of combustion such as sulfur dioxide, nitrogen dioxide, hydrogen chloride, and particulate matter will not be displayed as they are formed during the combustion of landfill gas.

3.3 Water Emissions

Emissions to water of various NPI-listed substances can be viewed in the **Water Emissions** worksheet. It is unlikely that any data will need to be altered on this worksheet. The first four columns of the **Water Emissions** worksheet are copied from the **Input** worksheet. The rest of the columns display emissions of substances in kilograms per year.

3.4 Emission Factors

The worksheet titled **Emission Factors** contains all water and some air emission factors/concentrations used to calculate emissions of specific substances. If site-specific NPI-listed substance concentrations are available, they may be typed into the appropriate column in this worksheet. For some individual substances emitted to air, any alterations to the concentration may be done in the **Air Emissions** worksheet in rows 5 or 6 (whichever may be appropriate).