

VOLUME III: CHAPTER 15

LANDFILLS

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Emission Inventory Improvement Program

DISCLAIMER

As the Environmental Protection Agency has indicated in Emission Inventory Improvement Program (EIIP) documents, the choice of methods to be used to estimate emissions depends on how the estimates will be used and the degree of accuracy required. Methods using site-specific data are preferred over other methods. These documents are non-binding guidance and not rules. EPA, the States, and others retain the discretion to employ or to require other approaches that meet the requirements of the applicable statutory or regulatory requirements in individual circumstances.

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CONTENTS

| Section | | Page |
|----------------|--|-------------|
| 1 | Introduction | 15.1-1 |
| 2 | Source Category Description | 15.2-1 |
| | 2.1 Emission Sources | 15.2-1 |
| | 2.2 Factors Influencing Emissions | 15.2-2 |
| | 2.2.1 Process Operating Factors | 15.2-2 |
| | 2.2.2 Regulatory Issues | 15.2-3 |
| 3 | Overview of Available Methods | 15.3-1 |
| | 3.1 Emission Estimation Methodologies | 15.3-1 |
| | 3.2 Available Methodologies | 15.3-1 |
| | 3.3 Data Needs | 15.3-5 |
| | 3.3.1 Data Elements | 15.3-5 |
| | 3.3.2 Application of Controls | 15.3-5 |
| | 3.3.3 Spatial Allocation | 15.3-7 |
| | 3.3.4 Temporal Resolution | 15.3-7 |
| | 3.3.5 Projecting Emissions | 15.3-7 |
| 4 | Preferred Method for Estimating Emissions | 15.4-1 |
| | 4.1 Data Collection | 15.4-1 |
| | 4.2 Landfill Gas Emission Calculation (EPA, 1995) | 15.4-2 |
| | 4.3 VOC and Hazardous Air Pollutant Emission Calculation | 15.4-3 |

CONTENTS (CONTINUED)

| Section | Page |
|----------------|--|
| 5 | Alternative Methods for Estimating Emissions 15.5-1 |
| 5.1 | Alternative One: Guidelines for Using Assumptions with Landfill Data .. 15.5-1 |
| 5.2 | Alternative Two: Regression Model 15.5-3 |
| 5.3 | Alternative Three: Population-based Waste Generation Factor 15.5-5 |
| 6 | Quality Assurance/Quality Control 15.6-1 |
| 6.1 | Emission Estimate Quality Indicators 15.6-1 |
| 6.1.1 | Data Attribute Rating System (DARS) Scores 15.6-2 |
| 6.1.2 | Sources of Uncertainty 15.6-5 |
| 7 | Data Coding Procedures 15.7-1 |
| 7.1 | Necessary Data Elements 15.7-1 |
| 8 | References 15.8-1 |
| Appendix A | |

TABLES

| | | Page |
|--------|--|-------------|
| 15.2-1 | Applicability of the NSPS and EG to MSW Landfills | 15.2-5 |
| 15.4-1 | Uncontrolled Landfill Gas Constituents | 15.4-5 |
| 15.6-1 | Preferred Method DARS Scores: Survey of All Landfills in the Inventory Region | 15.6-2 |
| 15.6-2 | Alternative Method 1 DARS Scores: Survey Using Assumptions | 15.6-3 |
| 15.6-3 | Alternative Method 2 DARS Scores: Regression Model | 15.6-3 |
| 15.6-4 | Alternative Method 3 DARS Scores: Population-based Waste Factor | 15.6-4 |
| 15.6-5 | Composite DARS Scores: Summary for All Methods | 15.6-4 |
| 15.7-1 | Area and Mobile Source Category Codes for Municipal Solid Waste Landfills | 15.7-2 |

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1

INTRODUCTION

This chapter is one of a series of documents developed to provide cost-effective, reliable and consistent approaches to estimating emissions for area source inventories. Multiple methods are provided in the chapters to accommodate needs of state agencies with different levels of available resources and skills; and different levels of needs for accuracy and reliability of their estimates. More information about the EIIP program can be found in Volume 1 of the EIIP series, *Introduction and Use of EIIP Guidance for Emissions Inventory Development*.

Throughout this chapter and other EIIP area source methods chapters, we stress that area source categories should be prioritized by the inventory planners so that resources can be spent on the source categories that are the largest emitters, most likely to be subject to regulations or are already subject to regulations, or require special effort because of some policy reason. Prioritization is particularly important for area source inventories, because in some cases, a difficult to characterize source category may contribute very little to overall emissions and attempting a high quality estimate for that source category may not be cost effective.

EIIP chapters are written for the state and local air pollution agencies, with their input and review. EIIP is a response to EPA's understanding that state and local agency personnel have more knowledge about their inventory area's activities, processes, emissions, and availability of information; and require flexible inventory methods to best use their sometimes limited resources. These EIIP area source chapters are written as a set of options presented to inventory professionals capable of using their own experience and judgement to apply the method that best fits their overall needs and constraints.

Landfills are significant sources of methane (CH₄) and carbon dioxide (CO₂). In addition to CH₄ and CO₂, small amounts of nonmethane organic compounds (NMOCs) are produced. NMOCs include reactive volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). Unlike other area sources that may be small sources individually but numerous within the inventory area, only a few landfills may be found within a multi-county area. However, each landfill may emit significant amounts of pollutants. Landfills differ from sources typically categorized as point or major sources in that pollutants are emitted over the area of the landfill, not at a specific point or points. For these reasons, landfills have been treated as area sources in the past. Recently, air operating permits have been required for landfills, so that inventory preparers have begun to address them as point sources. The preferred method described in this chapter is very close to a point source inventory method, and, if site-specific test data are available, those data may be used to develop emissions estimates.

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This chapter describes the procedures and recommended approaches for estimating emissions from landfills. Section 2 of this chapter contains a general description of the landfills category, and an overview of available control techniques. Section 3 of this chapter provides an overview of available emission estimation methods. Section 4 presents the preferred emission estimation method for landfills, and Section 5 presents alternative emission estimation techniques. Quality assurance/quality control (QA/QC) are discussed in Section 6. Data coding procedures are discussed in Section 7, and Section 8 is the reference section.

Throughout this chapter and other EIIP area source methods chapters, we stress that area source categories should be prioritized by the inventory planners so that resources can be spent on the source categories that are the largest emitters, most likely to be subject to regulations or are already subject to regulations, or require special effort because of some policy reason. Prioritization is particularly important for area source inventories, because in some cases, a difficult to characterize source category may contribute very little to overall emissions and attempting a high quality estimate for that source category may not be cost effective.

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2

SOURCE CATEGORY DESCRIPTION

The following description of landfills and discussion of landfill emission sources have been drawn from the *AP-42* section on landfills and the U.S. Environmental Protection Agency's (EPA's) Office of Policy Planning and Evaluation's (OPPE) report on anthropogenic methane emissions for 1990 (EPA, 1998a; EPA, 1994a).

A municipal solid waste (MSW) 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. An MSW landfill unit may also receive other types of wastes, such as commercial solid waste, nonhazardous sludge, and industrial solid waste (EPA, 1998a).

Landfills that accept hazardous waste should be classified as treatment, storage, and disposal facilities (TSDFs). Open dumps should not be categorized as landfills, because the waste types are variable and are not necessarily MSW. Also, the waste is not compacted and covered as waste is in a sanitary landfill, so the anaerobic decomposition process that is the source of the landfill gas may not take place. The emission estimation methods presented in this chapter are not suitable for TSDFs or open dumps.

2.1 EMISSION SOURCES

Methane and CO₂ are the primary constituents of landfill gas, and are produced during anaerobic decomposition of cellulose and proteins in the landfilled waste. Anaerobic decomposition takes place in the absence of oxygen. Although particulate emissions are generated by landfill operations, only landfill gas emissions are addressed in this chapter. In addition to CH₄ and CO₂, NMOCs are produced as a small fraction of the landfill gas emissions. NMOCs include hazardous air pollutants and reactive VOCs. 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. Uncontrolled dumps, where waste is exposed to air, result in aerobic decomposition (EPA, 1994a). Aerobic decomposition results mainly in CO₂ and water.

2.2 FACTORS INFLUENCING EMISSIONS

2.2.1 PROCESS OPERATING FACTORS

The number of landfills in the United States is declining, yet the amount of waste generated is increasing. Surveys of U.S. landfills have shown a steady decline in the estimated number of landfills taking MSW with 6,034 landfills in 1986, 3,558 landfills in 1994 and 2,216 in 1999 (EPA, 1988; Steuteville, 2000). In 1986, the average landfill capacity, based on survey data, was 2.65 million cubic yards, but the median landfill capacity of the same survey data set was 0.39 million cubic yards, showing that it is the less numerous larger landfills that handle most of the waste. A decreasing proportion of the total waste is being sent to U.S. landfills as well. In 1989, an estimated 80 percent of MSW was landfilled, and in 1994, 67 percent was sent to landfills, with recycling and incineration being the alternative form of treatment as reported in the April 1995 issue of *BioCycle* (Steuteville, 1995).

Because of stricter regulations affecting landfills, many of the smaller landfills have closed, and the larger, more technologically advanced landfills remain. Nearly one-third of MSW landfills were estimated to be privately owned in 1996, and the remainder were owned by federal, state, county, or other government entities. In the same year, an estimated 91 percent of the MSW landfills have permits, usually from the state (EPA, 1988).

Description (EPA, 1998a)

Landfill design and operation normally uses 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 meters (m) [10 to 12 feet (ft)] is reached. A daily soil cover is spread on the top and sides of the compacted waste. The soil cover can come from other parts of the landfill or be imported from outside 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.

The basic landfill unit is common to all landfilling methods, and is usually designed to accept a day's waste, after which it is closed, compacted, and covered with soil at the day's end. Generally, the height of a landfill unit is less than 2.4 m (8 ft), and the working face of the unit can extend to the facility boundaries. Waste densities generally range from 1,100 to 1,400 pounds per cubic yard after the waste has been compacted, and range from 1,700 to 1,900 pounds per cubic yard after waste degradation and settling. If site-specific data are not available, a density of 1,160 pounds per cubic yard is recommended.

Modern landfill design often incorporates liners constructed of soil such as recompacted clay, synthetics such as high-density polyethylene, or both to provide an impermeable barrier to leachate (water that has passed through the landfill) and gas migration from the landfill. Soil liners can reduce permeability to between 7 to 10 centimeters (cm) per second, and synthetic liners to between 10 to 13 cm per second.

Bioreactors within landfills are an emerging technology. Anaerobic bioreactors increase the rate of methane generation, which can then be collected and used for energy recovery, whereas aerobic bioreactors foster aerobic instead of anaerobic decomposition, reducing methane generation. These are not widely used to present. The emission estimation procedures recommended in this chapter do not reflect landfills that are being operated as a bioreactor under enhanced conditions where leachate is added.

Control Techniques

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 of this chapter.

2.2.2 REGULATORY ISSUES

Air quality standards and regulations that affect municipal solid waste landfill facility operations are New Source Performance Standards (NSPS), and Emissions Guidelines. The Standards of Performance for New Municipal Solid Waste Landfills, 40 Code of Federal Regulations (CFR) part 60, Subpart WWW are federal regulations affecting air emissions for new landfills or landfills that began construction, modification, or reconstruction on or after May 30, 1991. The Emission Guidelines required States to develop State plans to regulate existing landfills that began construction before May 30, 1991 and that have accepted waste since November 8, 1987, or have capacity to accept additional waste.

The Emission Guidelines are contained in 40 CFR part 60 Subpart Cc. As of December 1999, existing landfills throughout the U.S. were covered by either approved State plans that

implement and enforce the Emission Guidelines, or by the Federal plan in 40 CFR part 62, Subpart GGG (see 40 CFR part 62 for a list of approved State plans).

In late 2000, EPA expects to propose national emission standards for hazardous air pollutants from landfills. The proposed rule contains the same requirements as the Emission Guidelines and NSPS. The collection and control requirements of the Emission Guidelines and NSPS are the best control technology available for hazardous air pollutant emissions from landfills. Under the proposed rule, in addition to the requirements in the Emission Guidelines and NSPS, landfills that have installed controls would be subject to additional recordkeeping and reporting requirements, such as documentation of startup, shutdown, and malfunction reports.

The NSPS and the State and Federal plans that implement the Emission Guidelines require owners or operators of new and existing landfills to file a design capacity report. Landfills equal to or larger than 2.5 million megagrams (Mg) and 2.5 million cubic meters (m³) must provide periodic estimates of annual NMOCs, either through calculation using standard assumed values or based on on-site measurements (Table 15.2-1). One exception to the annual reporting requirement is that if the landfill has an estimated NMOC emission rate of less than 50 Mg/yr for the next five years, the owner or operator may elect to submit an estimate of the NMOC emission rate for the next five years rather than an annual report.

New and existing landfills that have estimated annual emissions of NMOCs greater than the 50 Mg threshold must reduce emissions under either the NSPS (for new landfills) or the applicable State and Federal Plan for existing landfills. The EPA's final rule provides a tier system under which the landfill owner or operator can determine if controls are required. The tier system allows owners and operators to conduct testing for more site-specific values to prove that emissions are below the 50 Mg/yr emission threshold. If landfill emissions exceed 50 Mg/yr, emissions must be reduced by installing gas collection systems and routing the gas to a suitable energy recovery system or combustion device that is capable of reducing NMOC emissions by 98 weight-percent or to 20 parts per million by volume dry (ppmvd) as hexane. The collection system must be operated so that the methane concentration is less than 500 parts per million (ppm) above background at the surface of the landfill (EPA, 1999). Monitoring of surface concentration and other collection system and control device operating parameters is also required.

TABLE 15.2-1

APPLICABILITY OF THE NSPS AND EG TO MSW LANDFILLS (EPA, 1999)

| Landfill Maximum Design Capacity | Constructed, Reconstructed, Modified, or Began Accepting MSW on or after 5/30/91 | Constructed, Reconstructed, or Modified before 5/30/91. Accepted Waste after 11/8/87 or Has Additional Capacity |
|---|---|--|
| <2.5 million Mg or 2.5 million m ³ | Must report design capacity. No further requirements. | Must report design capacity. No further requirements. |
| ≥ 2.5 million Mg and 2.5 million m ³ | Must comply with the requirements of the NSPS. | Must comply with the requirements of the EG. |

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3

OVERVIEW OF AVAILABLE METHODS

3.1 EMISSION ESTIMATION METHODOLOGIES

The recommended method for calculating emission estimates from landfills is to use the equation in the section addressing landfills in *AP-42* (EPA, 1998a). The Landfill Gas Emissions Model (LandGEM) uses the *AP-42* equation and eases the calculation burden for estimating emissions for individual landfills (EPA, 1998b). However, several methods are available for collecting the data needed to use the emission estimation calculation for landfills. Determining the best method to use depends upon the degree of accuracy required in the estimate, the available data, and the available inventory resources. Refer to EIIIP Volume VI, *Quality Assurance Procedures*, Sections 2.1 and 2.4.

Selection of the appropriate estimation method depends on the relative significance of emissions from this source in the inventory area and the data quality objectives (DQOs) of the inventory plan. Refer to EIIIP Volume VI, *Quality Assurance Procedures*, Sections 2.1 and 2.4 for discussions of inventory categories and DQOs.

This section discusses the methods available for collecting landfill data and identifies the preferred data collection method. A discussion of the data elements needed for each method is provided. The preferred and first two alternative methods also take into account control technologies.

3.2 AVAILABLE METHODOLOGIES

The methods are as follows:

- Preferred Method: Required reporting;
- Alternative Method One: Guidelines for using assumptions with landfill data;
- Alternative Method Two: Regression model; and
- Alternative Method Three: Population-based waste generation factor.

Before choosing any of these methods, inventory preparers should investigate how many landfills are in the inventory area. Some counties send all of their waste to landfills in other counties or even other states. If there are no landfills that have accepted waste in the past 25 years in a county, then it may not be necessary to estimate emissions from this source category for that county. Before investing resources in collecting detailed information about landfills that closed before 1987, setting a cutoff level for landfill size and age could be worthwhile. Because of RCRA rules and the Emission Guidelines, States should have lists of landfills that accepted waste since 1987.

Preferred Method

Emission estimates for all landfill emission methods are calculated using either the LandGEM or the equations from the AP-42 section on landfills. The AP-42 landfills section was updated in November 1998. Check the EPA Technology Transfer Network (TTN) Web for the most current version of the AP-42 section when preparing landfill emission estimates for an inventory. The EPA updates AP-42 as new information becomes available. The LandGEM is a personal computer-based model that uses the same equation as that in AP-42, but provides the advantages of an automated calculation and utilities. Appendix A of this chapter contains an overview of the LandGEM, with example model runs for the program. The LandGEM and the landfill section of AP-42 can be accessed from the EPA's Web site.¹ Please refer to Chapter 1 of this volume, *Introduction to Area Source Emission Inventory Development*, for more information about accessing the TTN Web site.

Total landfill gas, methane, carbon dioxide, and NMOC concentration can be calculated using the equations in AP-42 and LandGEM. The AP-42 section and the LandGEM use three equations to calculate (1) methane generation rate; (2) NMOCs or other pollutants expressed as cubic meters per year, and (3) convert the volume estimate of each pollutant to a mass estimate (kilograms per year). Reactive VOCs and air toxics can be calculated using default concentration values that are also provided. Reductions in emissions resulting from the use of controls can be calculated from control efficiency factors listed in the AP-42 section. The emissions calculations for landfill gas require several steps and a combination of site-specific information and default values. The following site-specific information is required:

- The design capacity of the landfill;
- The years the landfill has been in operation;
- Controls in place in the landfill (if available); and

¹ For Internet access to the EPA TTN Web, use <http://www.epa.gov/ttn>.

- Whether the landfill has been used for disposal of hazardous waste (codisposal)

In addition, the following default values are available in LandGEM and AP-42:

- The methane generation rate (k);
- The potential methane generation capacity (L_0);
- The concentration of NMOCs found in the landfill gas;
- The concentration of toxic air pollutants found in the landfill gas (if air toxic pollutants are to be calculated); and
- The concentration of reactive VOCs found in the landfill gas.

The AP-42 section and the LandGEM provide default factors for the parameters k , L_0 , and NMOC concentration that are needed to calculate total landfill gas, methane, carbon dioxide, and NMOC concentration. In all cases, landfill-specific values are preferred over the use of default values.

The LandGEM provides two sets of default values for k , L_0 , and NMOCs. One set is based on the requirements of the NSPS and Emission Guidelines. This set of default values produces conservative emission estimates and should be used to determine whether the landfill is subject to the control requirements of the NSPS and Emission Guidelines. The other set of default values is the same as those in AP-42 and produces more representative emission values that can be used to produce typical emission estimates in the absence of site-specific test data. The default values presently in the model may be revised in future updates of the model based on new information collected by the EPA. Unlike the AP-42 equation, the LandGEM allows the user to enter annual waste acceptance amounts into the emission model. Reductions from controls are not included in the LandGEM. The model also provides utilities for estimating values for k and landfill waste in place. Calculations are performed automatically after the necessary information has been collected and entered (EPA, 1998b).

Alternative Method One: Guidelines for Using Assumptions with Landfill Data

The first alternative method is a set of guidelines for making the best possible estimates of the values needed to calculate emissions from landfills when actual values are not directly available. Possible sources of information are given in the discussion of the method. This method supplements the approach of the preferred method, in case detailed information for every landfill in an inventory area cannot be located or budget constraints limit the level of effort for the source category.

Alternative Method Two: Regression Model

The second alternative method uses a regression model to develop waste-in-place factors for landfills in a large inventory area or modeling domain from a subset of area landfills. This method requires a survey of a subset of landfills in the inventory area. The survey covers all of the landfills in counties that can be deemed typical for the larger area. The information collected should include waste-in-place and age of the landfill, or reliable local estimates of those factors. A factor is developed that can be used to estimate the waste in place and landfill age for the remaining counties using a surrogate for activity such as population or population density.

This method should provide more specific emission estimates than Alternative Method One in most cases but, unlike Alternative Method One, still requires a considerable amount of data collection. This method can be used when the inventory area is large (greater than 10 counties), time and budget constraints are such that collection of specific data for the preferred method is not practical, yet there is still a need for region-specific information. This method is not suitable for smaller areas, where the sample size may not be adequate for good results.

The agency should have the resources to collect complete information from several counties in the inventory area or region. Personnel should be available that can interpret the statistics to judge the validity of the regression model results and set a statistically valid sample size for the survey. Although survey planning and interpretation of results require statistical training, data collection and preparation for the model require only inventory and spreadsheet skills. Most spreadsheet packages provide regression analysis tools. Regression analysis provides a mathematical model that relates two or more sets of variables to one another. In this case, the surrogate factor(s), such as population density, property values, or education level, for the survey counties are related to the amount of waste in place in landfills in those counties.

Alternative Method Three: Population-based Waste Generation Factor

This method uses a population-based waste generation factor and population by county to estimate the waste-in-place value that is used in the *AP-42* equation. The advantage of this method is that it requires no specialized information and can be completed with very little effort. Disadvantages are that solid waste disposal methods other than landfills, waste reduction programs, or transport of the waste to other areas will not be taken into account. Controls in place in individual landfills also will not be taken into account.

3.3 DATA NEEDS

3.3.1 DATA ELEMENTS

The data elements used to calculate emission estimates for landfills will depend on the methodology used for the estimation and the level of detail required in the inventory. For all methods, the minimum information for using the *AP-42* equation or LandGEM is waste in place and the open and close dates for the landfills in the area. The alternative methods can use assumptions about the opening and closure dates. Knowledge of state and local regulations and average annual rainfall also are needed.

The data elements required for the preferred method are listed in Section 3.2 under the discussion of the *AP-42* landfill section and the LandGEM.

The first alternative method can use the same data elements as those listed for the preferred method, but does not require the same detailed information. When the detailed information is not available, other information is collected to substitute. Acreage of the landfills and local practices for landfill depth can be substituted for waste-in-place. Assumptions are used for open and close dates, when actual dates are not available.

The data elements needed to calculate emissions for this category when using Alternative Method Two, the regression model, are:

- The estimated number of landfills in the entire inventory area;
- Information about each landfill in the selected survey counties (see the data elements needed for the preferred and the first alternative method); and
- Surrogate activity information for all of the inventory counties.

3.3.2 APPLICATION OF CONTROLS

Larger and newer landfills are very likely to have landfill gas collection systems in place to control air emissions. The discussion of landfill gas collection systems in the *AP-42* landfill section should be consulted for information about landfill gas controls. In that section, average control efficiencies for landfill gas constituents and emission rates for secondary compounds are given for typical landfill gas control devices.

Emissions from landfills are typically controlled by installing a gas collection system and destroying the collected gas through the use of internal combustion engines, flares, or turbines.

Gas collection systems are not 100 percent efficient in collecting landfill gas, so emissions of CH₄ and NMOCs at a landfill with a gas recovery system still occur. To estimate controlled emissions of CH₄, NMOCs, and other constituents in landfill gas, the collection efficiency of the system must first be estimated. Reported collection efficiencies typically range from 60 to 85 percent, with an assumed average of 75 percent. If site-specific collection efficiencies are available, they should be used instead of the 75 percent average.

Controlled emission estimates also need to take into account the efficiency of the control device. Control efficiencies for CH₄ and NMOCs with different control devices are presented in the AP-42 section. Emissions from control devices, also available in AP-42, need to be added to the uncollected emissions to estimate total controlled emissions. Equation 15.3-2 shows how to estimate total controlled emissions of pollutant P from a specific landfill:

$$\text{Controlled Landfill Emissions} = P \left(1 - \frac{\text{Percent Collection Efficiency}}{100} \right) + P \left(\frac{\text{Percent Collection Efficiency}}{100} \right) * \left(1 - \frac{\text{Percent Control Efficiency}}{100} \right) \quad (15.3-2)$$

Example 3-1 shows how emissions for a landfill with controls are calculated.

Example 3-1:

VOC emissions from Landfill A are estimated to be 3,197 cubic meters per year. Average collection efficiency of the landfill gas recovery system is not known at Landfill A, so a 75-percent collection efficiency rate is assumed. The collected landfill gas is controlled by a flare, which has a control efficiency for NMOCs of 83.16 percent.

$$\begin{aligned} \text{Controlled NMOC Emissions} &= 3,197 \text{ m}^3 * [1 - 0.75] + 3,197 \text{ m}^3 * [0.75] * [1 - 0.8316] \\ &= 799.25 \text{ m}^3 + 3,197 \text{ m}^3 * 0.1263 \\ &= 799.25 \text{ m}^3 + 403.78 \text{ m}^3 \\ &= 1,203 \text{ m}^3 \end{aligned}$$

When emissions have been calculated using the alternative methods, less specific information will be available about controls. However, if information is available, it should be used.

Emission factors and procedures for estimating secondary compounds (CO₂, CO, NO_x, SO₂, and HCl) from landfill gas combustion control devices are also included in AP-42.

Point Source Corrections

Some landfills in the inventory area may be counted as point sources in the point source inventory. Area source estimates for landfills should be corrected for these emissions. There are two ways to correct for the point source contribution depending on the area source estimation method used.

The first approach is to remove the point source landfills from the area source emission calculations. This approach can be used if emissions are being calculated from specific information, as in the preferred and first alternative methods. If the second or third alternative methods are used, estimated emissions from the point source landfills can be subtracted from the inventory area total estimate.

3.3.3 SPATIAL ALLOCATION

Spatial allocation may be needed during inventory preparation to allocate the emission estimates calculated using Alternative Methods Two or Three to smaller areas, such as modeling grid cells, or to allocate the surrogate activity factor(s) used in Alternative Method Three to a smaller area. The preferred method and the first alternative method do not require any spatial allocation because these methods collect data for individual landfills, and emissions are assigned according to the landfills' locations.

3.3.4 TEMPORAL RESOLUTION

Seasonal Apportioning/Daily Resolution

Emissions from this source category are expected to remain constant from season to season, and they are not expected to vary on a day-to-day basis. The seasonal activity factor that should be used for this source category is 1.0.

3.3.5 PROJECTING EMISSIONS

Unlike typical sources, landfill emissions increase each year as more waste is added to the landfill. Landfill emissions peak shortly after the landfill closes, then gradually decrease over time. For projecting future emissions, projected variables such as time since initial waste

placement, amount of waste in place, and average waste acceptance rate for the particular year of interest should be used, rather than using the current values.

Emissions projections for landfill emissions need to take into account changes in emissions due to any increase or decrease in waste generation, the age of the waste in place, and any potential changes in landfill controls. Factors that may affect the amount of waste in place in landfills in the inventory area are changes in waste generation or how the waste is handled: incineration, recycling, or transport in or out of the inventory area. Emissions may change because of added controls. The preferred approach to defining these changes is to collect information from planning departments and solid waste departments about projected changes in the amount of waste in place for the projection year, the status of landfill openings or closures, and future controls.

An alternative method is to use population to scale current emission estimates to the projection year, but the effects of factors like recycling programs or additional controls at landfills will not be included.

The EIIP Projections Committee has developed a series of guidance documents containing information on options for forecasting future emissions. You can refer to these documents at <http://www.epa.gov/ttn/chief/eiip/project.htm>. Tools for the development and use of growth factors are discussed in Chapter 1 of this volume, *Introduction to Area Source Emission Inventory Development*.

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

The preferred method for this source category uses information that has been compiled as part of a permit or reporting requirement such as for NSPS or RCRA. State and local solid waste management agencies and the federal EPA Office of Solid Waste can be contacted for RCRA information. State and local air agencies or EPA Regional Offices will also have information from air permits, the NSPS, or the State or Federal plan implementing the Emission Guidelines. In fact, as part of their State plans, states were required to develop inventories and emission estimates for existing landfills that commenced construction before May 30, 1991 and accepted waste since November 8, 1987. In many cases, the information will already be compiled into a spreadsheet or database. The equations in Section 2.4, Landfills, of *AP-42* or the LandGEM are used to calculate emissions.

The Standards of Performance for New Municipal Solid Waste Landfills (NSPS), 40 CFR 60, Subpart WWW, and the Emission Guidelines for Control of Existing Municipal Solid Waste Landfills (EG), 40 CFR 60, Subpart Cc, are briefly summarized in Section 2.2.2 of this chapter. The significance of these rules for inventory preparers is that owners or operators of any new or existing MSW landfill (as defined by the NSPS and the EG) need to report design capacity, and if the landfill has a design capacity at or above 2.5 million Mg and 2.5 million m³, then periodic estimates of NMOC emissions must be reported. New and existing landfills that have estimated annual emissions of NMOCs greater than the 50 Mg limit must either reduce emissions through collection and control, or must conduct testing to prove that emissions are below the emission threshold. Landfill operators may use sampling and gas flow testing to determine more specific values for NMOC concentration and k when estimating emissions (EPA, 1995).

4.1 DATA COLLECTION

Permits can be used to collect the information needed to calculate landfill emissions. The information needed is discussed in Section 3.2, but at a minimum, landfill opening and closure year and the current amount of waste-in-place is necessary for the calculation.

Additional information that can be used, if it is available, is the amount of waste brought in annually, landfill-specific information for calculating k and L₀, and measured concentration

values for CH₄, CO₂, NMOCs, and other pollutants in the landfill gas. If the amount of waste is reported as a volume measurement, the following conversion factors can be used (EPA, 1995):

- 1,100 to 1,400 pounds per cubic yard of compacted waste;
- 1,700 to 1,900 pounds per cubic yard of waste after degradation and settling; and
- 1,160 pounds per cubic yard of waste (if unknown if waste was compacted).

In some cases, emission estimates from permits can be used, but only if those estimates have been calculated using landfill-specific data for *k* or the AP-42 defaults. If emissions have been calculated using the more conservative *k* and *L*₀ values required under the NSPS and Emission Guidelines, then emission estimates should be recalculated using AP-42 default values for *k* and *L*₀. The AP-42 default for *L*₀ should be used.

4.2 LANDFILL GAS EMISSION CALCULATION (EPA, 1995)

The emission estimation equation used to calculate landfill gas emissions is a theoretical first-order kinetic model of methane production developed by the EPA (EPA, 1991). This is the equation used in AP-42 and in the LandGEM. The equation is as follows:

$$Q_{\text{CH}_4} = L_0 R (e^{-kc} - e^{-kt}) \quad (15.4-1)$$

where:

- Q*_{CH₄} = Methane generation rate at time *t*, m³/yr;
- L*₀ = Methane generation potential, m³ CH₄/Mg refuse;
- R* = Average annual refuse acceptance rate during active life, Mg/yr;
- e* = Base log, unitless;
- k* = Methane generation rate constant, yr⁻¹;
- c* = Time since landfill closure, years (*c* = 0 for active landfills); and
- t* = Time since the initial refuse placement, years.

The average annual refuse acceptance rate (*R*) is calculated by dividing the current amount of fill by the number of years that the landfill has been accepting waste. If the landfill has a measured

value for k , then that value should be used; otherwise, the value recommended in *AP-42* should be used. Estimation of the methane generation constant, k , is a function of a variety of factors, including moisture, pH, and temperature, other environmental factors, and landfill operating conditions. Specific CH_4 generation constants (k) can be computed by use of the EPA Method 2E. L_0 is generally treated as a function of the moisture and organic content of the refuse, and the *AP-42* default value should be used.

If the computer model LandGEM is used, the measured values of k , L_0 , and NMOC concentration are preferred. Site-specific NMOC concentration can be measured using EPA Method 25C and the sampling procedures described in the NSPS. Otherwise, use the recommended values from *AP-42* for k , L_0 , and NMOC concentration. Note that *AP-42* provides separate default k values for arid areas (less than 25 inches of rain per year) and non-acid areas.

4.3 VOC AND HAZARDOUS AIR POLLUTANT EMISSION CALCULATION

When gas generation reaches steady state conditions, landfill gas consists of approximately 40 percent by volume CO_2 , 55 percent CH_4 , 5 percent N_2 and trace amounts of NMOCs when gas generation reaches steady state conditions. Therefore, the estimate derived for CH_4 generation using the method above can also be used to represent CO_2 generation. Addition of the CH_4 and CO_2 emissions will yield an estimate of total landfill gas emissions. If site-specific information is available to suggest that the CH_4 content of landfill gas is not 55 percent, then the site-specific information should be used, and the CO_2 emission estimate should be adjusted accordingly. LandGEM uses 50% of CH_4 and 50% CO_2 as the default landfill gas composition, however, these defaults can be overridden.

Emissions of pollutants other than CO_2 and CH_4 from landfills result from either their being contained in the landfilled waste or from their creation from biological processes and chemical reactions within the landfill cell. There is a wide range of values for various VOC species and air toxics in landfill emissions. For inventory purposes, it is preferable that site-specific information about landfill gas constituents be used to calculate VOC and air toxic emissions.

The emissions of reactive VOCs and toxic air pollutants must be calculated individually from the estimated emissions of total landfill gas. When using the LandGEM, enter any site-specific concentrations available for that landfill and run the model. Emissions for individual VOCs from the model results can be summed to get total VOC emissions. If the *AP-42* equations are used, use the most recent list of landfill gas constituents from *AP-42* and calculate emission estimates for each of those constituents that are defined as reactive VOCs using the equations in the *AP-42* landfill section. The *AP-42* section for landfills has default concentrations for 43 landfill gas constituents, of which 30 are currently defined as reactive VOCs and 24 are listed as hazardous air pollutants (HAPs). These landfill gas constituents are listed in Table 15.4-1.

AP-42 also contains equations and procedures for calculating controlled emissions of CH₄, NMOC, and speciated organics. It also contains procedures for calculating secondary emissions from landfills gas combustor devices (NO_x, CO, CO₂, SO₂, HCl).

TABLE 15.4-1

UNCONTROLLED LANDFILL GAS CONSTITUENTS

| Compound | VOC ^a | Hazardous Air Pollutant ^b (HAP) |
|--|------------------|--|
| 1,1,1-Trichloroethane (methyl chloroform) | N | Y |
| 1,1,2,2-Tetrachloroethane | Y | Y |
| 1,1-Dichloroethane (ethylidene dichloride) | Y | Y |
| 1,1-Dichloroethane (vinylidene chloride) | Y | Y |
| 1,2-Dichloroethane (ethylene dichloride) | N | Y |
| 1,2-Dichloropropane (propylene dichloride) | Y | Y |
| 2-Propanol (isopropyl alcohol) | Y | N |
| Acetone | N | N |
| Acrylonitrile | Y | Y |
| Bromodichloromethane | Y | N |
| Butane | Y | Y |
| Carbon disulfide | Y | Y |
| Carbon monoxide ^c | N | N |
| Carbon tetrachloride | Y | Y |
| Carbonyl sulfide | Y | Y |
| Chlorobenzene | Y | Y |
| Chlorodifluoromethane | N | N |
| Chloroethane (ethyl chloride) | Y | Y |
| Chloroform | Y | Y |
| Chloromethane | Y | N |

TABLE 15.4-1
(CONTINUED)

| Compound | VOC^a | Hazardous Air Pollutant^b (HAP) |
|---|------------------------|--|
| Dichlorobenzene ^d | Y | Y |
| Dichlorodifluoromethane | N | N |
| Dichlorofluoromethane | N | N |
| Dichloromethane (methylene chloride) | N | Y |
| Dimethyl sulfide (methyl sulfide) | Y | N |
| Ethane | N | N |
| Ethanol | Y | N |
| Ethyl mercaptan (ethanethiol) | Y | N |
| Ethylbenzene | Y | Y |
| Ethylene dibromide | Y | Y |
| Fluorotrichloromethane | N | N |
| Hexane | Y | Y |
| Hydrogen sulfide | N | N |
| Mercury ^e | N | Y |
| Methyl ethyl ketone | Y | Y |
| Methyl isobutyl ketone | Y | Y |
| Methyl mercaptan | Y | N |
| Pentane | Y | N |
| Perchloroethylene (tetrachloroethylene) | N | Y |
| Propane | Y | N |

TABLE 15.4-1
(CONTINUED)

| Compound | VOC ^a | Hazardous Air Pollutant ^b (HAP) |
|-------------------------------------|------------------|--|
| Trichloroethylene (trichloroethene) | Y | N |
| t-1,2-Dichloroethene | Y | N |
| Vinyl chloride | Y | Y |
| Xylenes | Y | Y |

NOTE: This is not an all-inclusive list of potential LFG constituents, only those for which test data were available at multiple sites (EPA 1995).

^a Reactive VOC.

^b Hazardous Air Pollutants listed in Title III of the 1990 Clean Air Amendments.

^c Carbon monoxide is not a typical constituent of LFG, but does exist in instances involving landfill (underground) combustion. Of 18 sites where CO was measured, only 2 showed detectable levels of CO.

^d Source tests did not indicate whether this compound was the para- or ortho- isomer. The para- isomer is a Title III-listed HAP.

^e No data were available to speciate total Hg into the elemental and organic forms.

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

The alternative methods to estimate the data used in the landfill equation are as follows:

- Alternative Method One: Guidelines for using assumptions with landfill data;
- Alternative Method Two: Regression model; and
- Alternative Method Three: Population-based waste generation factor.

All of the methods use the *AP-42* landfill emissions equation or LandGEM to calculate emissions. Refer to *AP-42* and Sections 3 and 4 of this chapter for information about using the equation or the model.

5.1 ALTERNATIVE ONE: GUIDELINES FOR USING ASSUMPTIONS WITH LANDFILL DATA

This method is a set of decision-making rules to follow for data collection of landfill waste-in-place and landfill opening and closure dates used in the *AP-42* equation or the LandGEM, and assumptions to use when local data are not available. This method should be used when the agency's budget does not allow the extensive data collection that is needed for the preferred method, or the data for all of the landfills in the inventory area are not available. If the inventory area is made up of many counties (>10), then the second alternative method may be a better approach. Although the first method is very similar to the approach used in the preferred method, a distinction is being made between the two because the use of assumptions and generalizations in the alternative method increases the uncertainty of the emission estimates.

The first step to take for this method is to identify the landfills in the inventory area. Use solid waste agency data (county, state, or EPA Regional Office) or data from air permitting groups, local planning departments, or local or state tax records. Information about closed landfills may be available from long-term employees at state, county, or local health or sanitation departments.

Second, identify landfills in the inventory area that are listed in the point source inventory. These point sources will not need to be addressed in the area source inventory. Use the

preferred method for as many landfills as possible that remain. The landfills that have been addressed at this point will probably be active, the largest, and also most likely to have controls. The final remaining landfills may make only a minor contribution to the source category emissions. Therefore, the agency preparing the inventory should decide if these smaller landfills are significant enough to warrant the effort needed to produce emission estimates from them. The effort expended for these remaining landfills may be minimized if the proportion of emissions is small.

The third step is to collect information about the acreage of the remaining landfills. Land use information from planning boards and information from tax records is best. If the acreage that is filled at the time of the inventory year is available, it will be preferable to total acreage, which may be only partly used.

If information is available about the depth of the individual landfills and landfill opening and closure dates are available, then it should be collected as well. Some states and counties have rules about landfill construction that define appropriate depths. State and county solid waste experts should be able to define a reasonable depth for area landfills. Health and sanitation departments may also have information about older landfills. Employees of long standing in these departments may provide particularly useful information.

Fourth, develop waste-in-place estimates using the following:

- Estimate the capacity for each landfill:

$$\begin{array}{r} \text{Estimated} \\ \text{Capacity} \\ \text{(Volume)} \end{array} = \begin{array}{r} \text{Landfill} \\ \text{Acreage} \end{array} * \begin{array}{r} \text{Estimated} \\ \text{Landfill} \\ \text{Depth} \end{array}$$

The LandGEM's utilities can be used to perform this calculation as well. A utility for estimating refuse in place from landfill dimensions is available in the Windows™ version of the program.

- If calculating volume is not practical from available data, determining weight and converting this to volume can be done using the following from *AP-42*:
 - 1,100 to 1,400 lb/yd³ for compacted waste;
 - 1,700 to 1,900 lb/yd³ for waste that has undergone degradation and settling; or

- Use 1,160 lb/yd³ if it is unknown whether the waste has degraded, or been compacted.

For example:

$$\begin{array}{l} \text{Estimated} \\ \text{Capacity} \\ \text{(Weight)} \end{array} = \begin{array}{l} \text{Estimated} \\ \text{Capacity} \\ \text{(Volume)} \end{array} * 1,160 \text{ lb/yd}^3$$

Another method of estimating the waste-in-place, which is needed for the emissions equation, is by using an estimate of the percentage filled. Alternatively, fill can be estimated by proportioning the estimated capacity by the years that the landfill has accepted or is expected to accept waste.

If opening and closure dates are known, then closed landfills can be assumed to have filled their capacity. Waste in place for landfills that are still accepting waste can be estimated by dividing the capacity by the number of years the landfill is accepting waste (closing year - opening year +1). Multiply the annual acceptance rate by the number of years that the landfill has been open.

If opening and closure dates for the landfills are not available, assume that the landfill is still accepting waste, and opened 25 years before the inventory year. This is a conservative assumption, and will assign most of the emissions to the inventory year. If only the closing date is known, assume that the landfill accepted waste for 10 years. This is also a conservative assumption.

Use the AP-42 defaults for L_0 and k in the equation. Calculate VOC or HAP emissions using the default concentrations and equations in AP-42.

This alternative method should allow inventory preparers the opportunity to prepare fairly reliable estimates for the largest landfills in the inventory area and more uncertain, but conservative estimates for the smaller landfills.

5.2 ALTERNATIVE TWO: REGRESSION MODEL

This method uses information gathered about a sample of the landfills in an inventory area to develop a regression model that can be used to estimate the waste in place for all of the landfills in the inventory region. Regression is used to analyze how a dependant variable is affected by the values of one or more independent variables. The dependant variable in this case is landfill

waste in place, and the independent variables are the surrogate factors that will be used to calculate waste in place estimates for other counties within the inventory area.

This method can be used as an alternative to the more detailed data collection of the preferred method when the number of counties in the inventory area is large (>10). If there are fewer than 10 counties or other geographic units in the inventory area, then this method is not suitable and the first alternative method should be used. This approach uses regression analysis to relate surrogate factors to landfill attributes. Because this method uses a survey of an inventory area subset, and the regression output includes statistical indicators of the model validity, personnel working on this method should have enough training in statistics to ensure that the results of the survey and the model are valid.

The steps taken to develop a regression model are as follows:

- Define the scope of the landfill population in the inventory area. Identify counties or other geographical units that can be efficiently surveyed and that, when combined, represent a reasonable cross section of a statistically valid size. More data points (landfills) will result in a more reliable model.
- Develop a survey approach. A mail out with written forms may be designed, a telephone survey, or a combination of the two approaches may be used. See the discussion of surveys in Chapter 1, *Introduction to Area Source Emission Inventory Development*, and in Volume I of this series.
- Define what information can be reasonably requested. The information needed can be used to develop an emissions estimate, such as the amount of waste in place (or information that allows an estimate of waste in place) and the opening and closure dates, and information that can be used to develop a surrogate, such as population, population density, rural/urban population mix, property values, and land use. The information for the emission estimation will be collected from the landfill operators or the government agency that oversees landfills for that area. The surrogate information can come from U.S. Bureau of the Census data sources, tax records, and county planners. Review the first alternative method for options when incomplete data are available.
- Distribute the survey and compile the results. If information about waste in place could not be directly collected, then use the methods discussed in the first alternative method to estimate waste in place for the surveyed landfills.
- Use the waste-in-place numbers and the surrogate values to develop a regression model of the relationship between those variables. Develop a regression model of

the relationship between the landfill age and the surrogate factors as well. Spreadsheet programs such as Lotus® 1-2-3, Quattro® Pro and Microsoft® Excel provide regression analysis as a function.

The results of the regression analysis should be reviewed for validity.

- Collect the surrogate information from the unsurveyed counties and apply the regression model factors.
- Use the *AP-42* equation or LandGEM to calculate emissions using the estimated waste in place and the estimated landfill age for each county.

5.3 ALTERNATIVE THREE: POPULATION-BASED WASTE GENERATION FACTOR

This method should be used only if there are no other means with which to calculate landfill emissions. Emissions are based on total waste in place, so waste generation must be calculated for years previous to the inventory year. Although landfills can generate emissions for many years, the greatest emissions can be assumed to be emitted from waste 25 years old or less. The steps for calculating waste in place are:

- Collect population figures for the inventory year and the 24 years previous for a total of 25 years of population data.
- Multiply the waste generation factor of 0.69 tons/person/year times the population for each year (EPA, 1996c).
- Multiply tons by 0.9072 to get megagrams (tonnes).
- Use the annual waste estimates in the LandGEM, or calculate the average annual waste estimates and use that value in the *AP-42* equation.

Because this method uses no landfill-specific information, control factors cannot be applied to these estimated emissions.

The per capita waste generation factor supplied here is from the U.S. EPA Office of Solid Waste and Emergency Response annual publication, *Characterization of Municipal Solid Waste in the United States: 1995 Update*, and represents the estimated average generation of all types of MSW in 1994. Waste types include yard trimmings, paper, glass, metals and plastics which may

be composted or recycled in some areas.² The major uncertainty of this method is that it does not account for the amount of waste shipped into or out of a county.

² The EPA Office of Solid Waste maintains a World Wide Web page at: <http://www.epa.gov/epaoswer/osw/index.htm>, can be reached by telephone through the RCRA hotline at 1-800-424-9346 or 1-800-553-7672, and by mail at: RCRA Information Center, U.S. EPA, 401 M Street, SW (5305W), Washington, DC 20460.

6

QUALITY ASSURANCE/QUALITY CONTROL

During the inventory planning process, the agency should define the data quality objectives for the inventory and set data quality goals for the emission estimates developed for this source category. QA and QC methods may vary based on the data quality objectives for the inventory. The Quality Assurance Procedures Volume (Volume VI) of the EIIP series discusses methods to be used to ensure the development of a quality inventory. QA for area source inventories is also discussed in Chapter 1 of this volume, *Introduction to Area Source Emission Inventory Development*.

When using the preferred method, the survey planning, sample design, and data handling should be planned and documented in the inventory QA/QC plan. Refer to the discussion of survey planning and survey QA/QC in Chapter 1 of this volume, and Volume VI of the EIIP series.

Data handling for the data collected using all of the methods should also be planned and documented in the inventory QA/QC plan. Other than the conversion of the waste-in-place estimates from volume to weight units, data handling does not involve any category-specific issues. However, the first and second alternative methods require decision making and assumptions in order to develop emission estimates. All of these decisions and assumptions should be clearly documented, supported in writing, and reviewed as the estimates are developed. Please consult the Emission Inventory Improvement Program (EIIP) volume on inventory QA/QC for more information about data handling and documentation.

6.1 EMISSION ESTIMATE QUALITY INDICATORS

Surveys are theoretically the most accurate approach for estimating emissions, but also are the most expensive. The advantage to using a survey is that specific information about the landfills in an area are collected in terms of the landfill fill and age, controls in place are more accurately reflected with actual data, and the local practices in waste disposal are reflected. The level of detail that is possible to collect with a survey is not available when using the alternative methods.

However, to following the preferred method does not necessarily require a survey. Information that is current and reliable may be available to state and local agencies for some landfills (especially larger landfills) from permits and reports required under RCRA, the NSPS, or the State or Federal plan that implements the Emission Guidelines.

6.1.1 DATA ATTRIBUTE RATING SYSTEM (DARS) SCORES

The Data Attribute Rating System (DARS) has been developed as a tool to rate emission inventories. A description of the system and the EIP recommendations for its use can be found in Appendix F of EIP Volume VI, Quality Assurance Procedures. The following discussion uses the DARS rating system as a way to compare the estimation approaches presented in this chapter and analyze their strengths and weaknesses.

The DARS scores for each method are presented in Tables 15.6-1 through 15.6-4. Table 15.6-5 is a summary of all of the methods' composite scores. A range of scores is given for the first and second alternative method to reflect variability in survey techniques and the validity of the assumptions that have been made in the course of data gathering. More information about DARS scoring can be found in Appendix F of EIP Volume VI.

TABLE 15.6-1

**PREFERRED METHOD DARS SCORES:
USING INFORMATION COMPILED AS PART OF A PERMIT**

| Attribute | Scores | | |
|--------------------|--------|----------|-----------|
| | Factor | Activity | Emissions |
| Measurement | 0.5 | 0.8 | 0.4 |
| Source Specificity | 0.5 | 1.0 | 0.5 |
| Spatial | 0.3 | 1.0 | 0.3 |
| Temporal | 0.8 | 1.0 | 0.8 |
| Composite Scores | 0.53 | 0.95 | 0.5 |

TABLE 15.6-2**ALTERNATIVE METHOD 1 DARS SCORES:
GUIDELINES FOR USING ASSUMPTIONS WITH LANDFILL DATA**

| Attribute | Scores | | |
|--------------------|---------------|-----------------|------------------|
| | Factor | Activity | Emissions |
| Measurement | 0.5 | 0.3 - 0.6 | 0.15 - 0.30 |
| Source Specificity | 0.5 | 0.7 - 0.9 | 0.35 - 0.45 |
| Spatial | 0.3 | 1.0 | 0.3 |
| Temporal | 0.8 | 0.8 - 1.0 | 0.64 - 0.8 |
| Composite Scores | 0.53 | 0.7 - 0.88 | 0.36 - 0.46 |

TABLE 15.6-3**ALTERNATIVE METHOD 2 DARS SCORES: REGRESSION MODEL**

| Attribute | Scores | | |
|--------------------|---------------|-----------------|------------------|
| | Factor | Activity | Emissions |
| Measurement | 0.5 | 0.5 - 0.6 | 0.25 - 0.30 |
| Source Specificity | 0.5 | 0.7 | 0.35 |
| Spatial | 0.3 | 0.7 - 0.9 | 0.21 - 0.27 |
| Temporal | 0.8 | 0.9 | 0.72 |
| Composite Scores | 0.53 | 0.7 - 0.78 | 0.38 - 0.41 |

TABLE 15.6-4**ALTERNATIVE METHOD 3 DARS SCORES: POPULATION-BASED WASTE FACTOR**

| Attribute | Scores | | |
|--------------------|--------|----------|-----------|
| | Factor | Activity | Emissions |
| Measurement | 0.5 | 0.6 | 0.30 |
| Source Specificity | 0.5 | 0.1 | 0.05 |
| Spatial | 0.3 | 0.3 | 0.09 |
| Temporal | 0.8 | 0.5 | 0.40 |
| Composite Scores | 0.53 | 0.38 | 0.21 |

TABLE 15.6-5**COMPOSITE DARS SCORES: SUMMARY FOR ALL METHODS**

| Method | Scores | | |
|----------------------|--------|------------|-------------|
| | Factor | Activity | Emissions |
| Preferred Method | 0.53 | 0.95 | 0.5 |
| Alternative Method 1 | 0.53 | 0.7 - 0.88 | 0.36 - 0.46 |
| Alternative Method 2 | 0.53 | 0.7 - 0.78 | 0.38 - 0.41 |
| Alternative Method 3 | 0.53 | 0.38 | 0.21 |

All of the DARS scores for the factor ratings are the same. This is because all of the methods use the same emission estimation method, the *AP-42* equation for landfill gas emissions. The difference between the methods is in the data collection for the variables used in the *AP-42* equation: waste in place, landfill opening and closure dates, k , L_0 , and the concentration of NMOC in the landfill gas. The data collection methods are scored as activity ratings.

Scores for all methods are limited by the fact that emissions from this source category depend on a number of variables that cannot be adequately modeled in a single, fairly simple equation. The most significant limitation to the emission equation is that without detailed understanding of the

types of wastes being landfilled (expressed as the generation potential, L_0) and the impact of climate on landfills (expressed as the methane generation constant, k), local variables are not reflected in the calculation. It is difficult to generalize landfill emissions from region to region because local waste management will determine how much of the waste is recycled and what types of wastes are landfilled, and local rules will determine landfill construction and the use of controls.

Activity data, if it is understood to be the waste in place, landfill age, and control information, can be collected with a satisfactory amount of detail. The preferred method collects data for each landfill for the time period of the inventory. All scores assume that adequate QA/QC measures are performed and that no significant deviations from the prescribed methods have been made. If these assumptions are not met, new DARS scores should be developed according to the guidance in Appendix F of the EIIP QA Procedures volume.

DARS scores vary for Alternative Method One depending on how many of the landfills must have assumptions made about their capacity or age, and how significant their emissions are compared to those for which the detailed information is available. The scores for Alternative Method Two will vary based on how many counties the survey portion of the study can cover, and how closely the surveyed counties represent the estimated counties. Alternative Method Three has the lowest scores of all of the methods because using a per capita estimate of waste generation as a surrogate for waste in place will not reflect the local variables of waste reduction and recycling, incineration, or shipping the waste out of or into the area. Also, population can be a poor surrogate because it will not include waste generated by people that live outside of the area but work in the area. This method also will not include the effect of controls.

6.1.2 SOURCES OF UNCERTAINTY

Estimates generated using any of these methods 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. Even with repeated testing, it is still necessary to predict future emissions using AP-42 equations and the site-specific measured methane generation rate constant (k), and NMOC or and HAP concentrations. This is because mass emission rates from landfills change from year to year as additional waste is added, and as the initial waste gets older.

The preferred method gives higher-quality estimates than any of the alternative methods but requires more effort. The level of effort required to calculate emissions using the preferred method will vary depending on the availability of information from permitting agencies and the

form in which it can be retrieved. Readers are reminded that the goal of the inventory is to locate and estimate the largest share of landfill emissions possible within the budget for this source category. Small landfills that closed before 1987 (for Emission Guidelines and RCRA States should have a list of landfills that accepted waste since 1987) may require more time and effort than their proportionate contribution to the source category emissions total. It is possible to estimate a range of error that results from not including those landfills in the inventory. 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 characterized as accurately as those for other source categories may be.

The first alternative method is similar to the preferred method, but uses assumptions that introduce uncertainty to the estimates. This uncertainty cannot be quantified. Statistics describing the error and the uncertainty of the activity for the second alternative method are calculated with the regression model. This second method will require a similar amount of effort to collect and compile the survey information from the selected counties as that needed for the preferred method, but the remaining portion of the inventory area requires much less effort. The uncertainty of the emission estimates and the activity information developed through the preferred and second alternative methods may be quantified (see QA Procedures volume, Chapter 4). However, the statistics needed to quantify the uncertainty of the first and third alternative methods are incomplete. Activity for the third alternative method is based on the use of population as a surrogate, which does not take into account local waste management practices or possible controls being used in the inventory area.

7

DATA CODING PROCEDURES

The inventory preparer should check the EPA website (<http://www.epa.gov/ttn/chief/>) for the latest information (codes) available to characterize emission estimates from landfills. A complete list of Source Classification Codes (SCC) can be retrieved at <http://www.epa.gov/ttn/chief/codes/>. Table 15.7-1 lists the applicable SCCs for landfills.

Available codes and process definitions influence and help guide the preparation of emission estimates for this category. Data transfer formats should be taken into account when an inventory preparer plans for data collection, calculation, and inventory presentation. Consistent categorization and coding will result in greater continuity between emission inventories for use in regional and national scale analyses.

7.1 NECESSARY DATA ELEMENTS

If the category emissions data will be transferred to EPA for incorporation into the national criteria and toxics air pollutant inventory, specific data transfer formats are acceptable. The acceptable data transfer format(s) are described and available for download at <http://www.epa.gov/ttn/chief/net/>. The acceptable data transfer formats contain the data elements necessary to complete the data set for use in regional or national air quality and human exposure modeling. The inventory preparer should review the area source portion of the acceptable file format(s) to understand the necessary data elements. The EPA describes its use and processing of the data for purposes of completing the national inventory, in its Data Incorporation Plan, also located at <http://www.epa.gov/ttn/chief/net/>.

TABLE 15.7-1

**AREA AND MOBILE SOURCE CATEGORY CODES FOR
MUNICIPAL SOLID WASTE LANDFILLS**

| Process Description | Source Category Code |
|-------------------------------------|-----------------------------|
| Landfills: All Categories | 26-20-000-000 |
| Landfills: Industrial | 26-20-010-000 |
| Landfills: Commercial/Institutional | 26-20-020-000 |
| Landfills: Municipal | 26-20-030-000 |

8

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APPENDIX A

Landfill Gas Emissions Model

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APPENDIX A

This appendix is organized into the following sections:

- 15.A-1 Abstract
- 15.A-2 Introduction
- 15.A-3 System Utilities
- 15.A-4 Examples: Steps for Running a Study Using the Model
- 15.A-5 Potential Operational Errors

Attachments

15.A-1 ABSTRACT

This document is an abridged user's guide for a computer model, the Landfill Gas Emissions Model (LandGEM), for estimating air pollutant emissions from municipal solid waste (MSW) landfills. The model was developed by the Control Technology Center. This manual provides step-by-step guidance for using this model. The Landfill Gas Emissions Model can be used to estimate emission rates for methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from landfills for emission inventories. The program can also be used by landfill owners and operators to determine if a landfill is subject to the control requirements of the federal New Source Performance Standard (NSPS) for new MSW landfills (40 CFR 60 subpart WWW) or the Emission Guidelines for existing MSW landfills (40 CFR 60 Subpart Cc).

The model is based on a first order decay equation. The model can be run using site-specific data for the parameters needed to estimate emissions or, if no site-specific data are available, using default values. There are two sets of default values. One set is based on the requirements of the NSPS and Emission Guidelines. This set of default values produces conservative emission estimates and can be used to determine whether the landfill is subject to the control requirements of the NSPS and Emission Guidelines. The other set of default values is based on emission factors in the U.S. Environmental Protection Agency's (EPA's) *Compilation of Air Pollutant Emission Factors, AP-42* (EPA, 1998a). This set of default values produces more representative emission values and can be used to produce typical emission estimates to be used in emission inventories. The default values presently in the model are the parameter values recommended by the NSPS and *AP-42* as of September 1997. However, these parameter values may be revised in future updates of the model based on new information collected by the EPA.

15.A-2 INTRODUCTION

The Landfill Gas Emissions Model (LandGEM) provides an automated estimation tool for quantifying air emissions from municipal solid waste (MSW) landfills. This document provides an introduction to the model and step-by-step instructions for using it. The model was developed by the Control Technology Center (CTC) of the U.S. Environmental Protection Agency and can be obtained by downloading from the TTN Web (<http://www.epa.gov/ttn/catc/>). A glossary of terms is available as Attachment 15.A-1.

Air emissions from landfills come from landfill gas, generated by the decomposition of refuse in the landfill. Landfill gas is assumed by this model to be roughly half methane and half carbon dioxide, with additional, relatively low concentrations of other air pollutants. The following information is needed to estimate emissions from a landfill:

- The design capacity of the landfill,

- The amount of refuse in place in the landfill, or the annual refuse acceptance rate for the landfill,
- The methane generation rate (k),
- The potential methane generation capacity (L_o),
- The concentration of total nonmethane organic compounds (NMOC) and speciated NMOC found in the landfill gas,
- The years the landfill has been in operation, and
- Whether the landfill has been used for disposal of hazardous waste (codisposal).

Default values are available for k , L_o , NMOC concentration, and toxic air pollutant concentrations.

The estimation method used by the model is a simple first-order decay equation. Because the data available for landfills, such as data on the quantity, age, and composition of the refuse in the landfill are limited, using a more sophisticated calculation method was not justified. The Landfill Gas Emissions Model estimates emissions of methane, carbon dioxide, nonmethane organic compounds, and selected air pollutants. A list of the air pollutants for which the model will calculate emissions is included as Attachment 15.A-2.

Information on the assumptions used in the model can be found in the background information document (NTIS-PB91-197061) written to support the Standards of Performance for New Stationary Sources (40 CFR 60 Subpart WWW) and Emission Guidelines for Control of Existing Sources (40 CFR 60 Subpart Cc) and in the public docket (Docket A-88-09).

The Landfill Gas Emissions Model can be used with site-specific data for all the information needed to generate emission estimates, or it can be used with two different sets of default values. One set of default values (the CAA defaults) is for estimating emissions to determine the applicability of the Clean Air Act (CAA) regulations for MSW landfill emissions, specifically the New Source Performance Standards (NSPS) for new MSW landfills and the Emission Guidelines for existing MSW landfills. The CAA default values in the model provide emission estimates that would reflect the expected maximum emissions and generally would be used only for determining the applicability of the regulations to a landfill. To estimate emissions for an air emissions inventory in the absence of site-specific data, a second set of default values (the AP-42 defaults) is provided in the model. The AP-42 default values in the model are based on emission factors from the U.S. Environmental Protection Agency's *Compilation of Emission Factors, AP-42* (EPA, 1998a). The AP-42 default values provide emission estimates that should reflect typical landfill emissions and are the values suggested for use in developing estimates for state inventories.

15.A-3 SYSTEM UTILITIES

The landfill model is designed as a tool to estimate landfill emissions. To aid in estimation, the landfill model has been equipped with Help screens to describe and explain features of the model and its functions. In addition, the model has been equipped with utility functions to assist the user. Like Help screens, the utilities for this program are available when any of the model windows (i.e., the Operating Parameters window or a Report window) is being used. There are three utilities: a Unit Conversion utility, a Refuse Estimator utility, and an Autocalc function. These utility functions are described in the succeeding sections.

15.A-3.1 The Unit Conversion Utility

This program uses metric units (such as megagrams of refuse) rather than English units (such as tons of refuse), because metric units are used by the federal government and for the CAA regulations for MSW landfills. However, users of the model who prefer to use English units can use the conversion utility to convert English units to metric units, or vice versa.

To use the Unit Conversion utility:

1. Choose Unit Conversions from the Utilities menu.
2. Type the units to be converted in the “To convert from” text box. The units should be in a format specified by the program. This format is explained in the Help for the Unit Conversion utility. Select [Help], then choose Unit Formulas in the topics list on the main Help screen. For example, use the symbol ^ to indicate an exponent, * to indicate multiplication, and / to indicate division. The following are several examples of units in formats that will be accepted by the system: kg/m³; 1.25 kg/m/s; 1.25 kg(m*s)².
3. Type the units to convert to in the “to” text box.
4. Select [Convert] and the units will be converted. If the units you typed in were units only, with no value, the result of conversion will be a factor by which to multiply the value. If the units you typed in were accompanied by a value (e.g., 35,000 tons) the result will be a converted value (e.g., 31,751 Mg).
5. [Update] will update the units conversion database by adding new units or editing units already included in the conversion database. See below.
6. To exit the Unit Conversion utility, select [Cancel] or double click on the close button in the upper right corner of the Utility window.

You can add new units and delete or edit existing unit conversion factors in the Unit Conversion utility with the Unit Database Maintenance facility.

To update the Unit Conversion Utility:

1. Choose Unit Conversions from the Utilities menu.

2. In the Unit Conversions screen, select [Update]. A Unit Database Maintenance dialog box will come up.
3. Type the unit to add to the unit conversion database in the "Unit" text box.
4. Specify whether the unit is case dependent. Metric units, for example, are generally case dependent; mg and Mg are different units. English units are generally not case dependent; ton and Ton are the same unit.
5. Select [Locate] to locate a unit in the database, to be sure the unit is not already there.
6. Type the conversion factor for the unit in the "Factor" text box.
7. Type the metric unit into which the English unit will be converted in the "Base Unit" text box. The base units should be base units in the metric system, if possible (that is, you would use g rather than Mg as a base unit). The base units of the metric system are listed in Help. To access, select [Help]. Choose Search Method in the topics list on the main Help screen and "base quantity" highlighted in the Help text. A list of the metric base units and abbreviations for them will appear.
8. Select [Add] or [Delete] to add a unit to or delete it from the conversion database.
9. Updating the conversion database is explained in the Help for the Unit Conversion Utility. To access help for updating the conversion database, select Help. Choose Adding Units or Database Maintenance from the topics list on the main Help screen.

15.A-3.2 The Refuse Estimator Utility

This program requires refuse in place or refuse acceptance rates, and calculates emissions using refuse in place. The Refuse Estimator utility allows a user to estimate emissions using this program even if no refuse in place data are available other than the dimensions of the landfill.

To use the refuse estimator:

1. Select Refuse Estimator from the Utilities menu.
2. In the Refuse Estimator dialog box, select the Landfill Size (Acres) text box. If you do not have the size of the landfill in acres, use the Unit Conversion utility to convert to acres.
3. Enter the acreage of the landfill.
4. Select the Landfill Depth (Feet) text box. Enter the depth of the landfill in feet. Use the Unit Conversion utility if necessary to convert the depth to feet.
5. Select [Estimate]. The estimator will estimate the refuse in place in Mg and the value will appear in the Estimated Refuse in Place (Mg) text box.
6. Select [OK] to exit the Refuse Estimator.

15.A-3.3 The Autocalc Function

The Autocalc function is located under the Edit menu. This function can be used to assist the user in calculating either waste acceptance rates or refuse in place for the years of operation of the model. The Autocalc function is easy to use and allows the user either to enter an average acceptance rate for a period of operation or to linearly interpolate refuse data between two years (e.g., year 1 and year 10 of a given period of uniform or linearly increasing or decreasing waste acceptance). Examples of how to use the Autocalc function are available in Attachment 15.A-3.

The user should take caution: The Autocalc function does not recognize the landfill capacity as the upper limit which the refuse in place cannot exceed. It is possible to use the Autocalc function to calculate values for the acceptance rates or the refuse in place that cause the final values for the accumulated refuse to exceed the landfill capacity. If accumulated refuse exceeds the landfill capacity, the data must be erased or adjusted before a report can be generated.

15.A-4 EXAMPLES: STEPS FOR RUNNING A STUDY USING THE MODEL

This section outlines a step-by-step example of how to operate the emission estimation model for a standard case. Section 4.1 of this document describe the basic operation of the model. The methodology for modifying the parameters to run specific scenarios are described in section 4.3.

The following steps need to be followed to run a model:

- Open or Create a New Landfill Study,
- Select Model Parameters for Calculating Emissions,
- Define the Operating Parameters of the Landfill,
- Adapt the Model for a Specific Scenario,
- Generate a Report, and
- Save the Landfill Study.

The following *Model Parameters* are needed to estimate emissions from a landfill:

- The methane generation rate (k),
- The potential methane generation capacity (L_o),
- The estimated percentage composition of methane and carbon dioxide in the landfill gas (the default value is a 50/50 split),
- The concentration of nonmethane organic compounds (NMOC) and speciated NMOC found in the landfill gas,
- The concentrations of toxic air pollutants found in the landfill gas, and
- Whether the landfill has been used for disposal of hazardous waste (codisposal).

The following *Operating Parameters* are needed to estimate emissions from a landfill:

- The years the landfill has been in operation (including the Closure Year),
- The design capacity of the landfill, and
- The amount of refuse in place in the landfill, or the annual refuse acceptance rate for the landfill.

The following data entry pattern is recommended when entering operating parameters into the computer model:

- Select the Year Opened;
- Select the final year for which information is available (Current Year);
- Make any changes to the Closure Year that are needed;
- Enter the Landfill Capacity; and
- Enter the Acceptance Rate or Refuse In Place data.

With the exception of the requirement that the landfill capacity must be entered before any waste data, this recommended order of entry is not required.

15.A-4.1 An Example User Session

This section describes a step-by-step procedure for estimating landfill emissions using the model, which can be operated in Windows 3.1, Window 3.11, or Windows 95. The data provided below are for a generic landfill and a generic study.

Landfill Scenario Model Parameter Data:

| | |
|---|--|
| Methane Generation Rate (k): | AP-42 default |
| Methane Generation Potential (L_0): | AP-42 default |
| Percentage Composition of CO ₂ and CH ₄ : | 50%/50% |
| Concentration of NMOC: | AP-42 default |
| Selected Air Pollutant: | add <i>Ethyl Mercaptan</i> (MW = 62.13; concentration = 0.86) |
| Landfill Type: | Codisposal |

Landfill Scenario Operating Parameter Data:

| | |
|---------------------------|--------------|
| Year Opened: | 1975 |
| Current Year: | 1995 |
| Landfill Design Capacity: | 3,000,000 Mg |

| | |
|--------------------------------|-------------------------------------|
| Refuse in Place in 1980: | 330,500 tons |
| Annual Refuse Acceptance Rate: | 109,890 ton/yr from 1980 to 1994 |
| Autocalc: | (Refuse in place from 1975 to 1979) |
| Closure Year: | 2001 |

Steps

I. Open or Create a New Landfill Study

1. Launch the program (either by double-clicking on the program icon or selecting landwin.exe from the Program Manager).
2. The Landfill Gas Emissions Model will open with an abbreviated set of menus. From the File menu, select [New] or [Open] to run a landfill study. A landfill study window (the Operating Parameters window) will open. A new landfill study is assigned the default name *landfill.000*. This name will be replaced by a user-supplied name when the landfill study is saved and named.

II. Select Model Parameters for Calculating Emissions

A. Methane Generation Rate (k) and Methane Generation Potential (L_0)

1. To set the default values for k, L_0 , and NMOC concentration used to calculate emissions, select the Defaults menu.
2. To set the system for estimating emissions for emission inventories for municipal solid waste landfills, select AP-42.

B. Percentage Composition of CO_2 and CH_4

1. From the Parameters menu, select Air Pollutants. An Air Pollutant Compound Parameters dialog box will appear.
2. Methane and carbon dioxide are assumed to make up 50 percent each of the landfill gas. Leave these percentages as they are.

C. Concentration of NMOC

1. From the Parameters menu, select Air Pollutants. An Air Pollutant Compound Parameters dialog box will appear.
2. Because the AP-42 defaults were selected from the Defaults menu (see step A.2.) the NMOC concentration has already been set as the AP-42 default; the other options (i.e., CAA defaults and User Specific defaults) are dimmed and cannot be

selected. Only when the User Specific option is selected from the Defaults menu can the value for the NMOC concentration be changed.

D. Concentrations of Toxic Air Pollutants

1. A total of 47 air pollutants expected to be emitted from landfills is included in the program. Air pollutants that are designated as HAP and/or VOC are indicated as so in parentheses. Additional air pollutants can be added or inappropriate ones can be deleted. To edit the list of toxic air pollutants for which emissions will be estimated, select Air Pollutants from the Parameters menu. In the Air Pollutant Compound Parameters dialog box that opens, select [Edit Air Pollutants]. A Selected Air Pollutants dialog box will open.
2. To add an additional entry for Ethyl Mercaptan, type over the existing data that appear for a pollutant in the box. Start by selecting the name of the chemical in the text box. Delete this information and type in *Ethyl Mercaptan*.
3. Select the molecular weight text box. Delete the information in the box and type in *62.13*.
4. Select the Concentration, Codisposal, text box. Delete the information in the box and type in *0.86*. Repeat this step for the concentration, no codisposal, text box.
5. Choose [Append] to add the record for Ethyl Mercaptan.
6. Select [OK] to accept these data and to add Ethyl Mercaptan to the list of air pollutants for which emissions will be estimated. In the Air Pollutants Parameters dialog box, select [OK] to accept the set values for pollutant concentrations.

E. Landfill Type

1. Select Parameters from the Main Menu.
2. Select Landfill type.
3. Select Codisposal. This option should be used when the landfill has been used to dispose of hazardous waste.

III. Define the Operating Parameters of the Landfill

A. Enter Year Opened and Design Capacity

1. Select the Year Opened text box in the data entry box. The year opened defaults to 10 years before the current year (determined from the computer's clock).
2. Delete the default Year Opened. Enter 1975.
3. Delete the default Current Year. Enter 1995.
4. Select the Capacity text box and type in 3.0E+06 for 3,000,000 Mg refuse capacity. Press Enter to accept this value.

B. Enter Refuse In Place for the First Year of Accepting Refuse

1. Because the refuse in place in 1980 and annual refuse acceptance rate values for this landfill are recorded in tons and the program calls for megagrams, the units of measure need to be converted.
 - 1(a). From the Main Menu, select Utilities.
 - 1(b). Select Unit Conversions to bring up the dialog box for the unit conversion utility.
 - 1(c). Select the "To convert from" text box. Type in the refuse in place value, including the units: *330,500 tons*.
 - 1(d). Select the "to" text box. Type in the units to which you want to convert: *Mg*.
 - 1(e). Select [Convert].
 - 1(f). The box with the result (the "multiply quantity in source unit by" text box) will give the value of the refuse in place in Mg. This value rounds to 300,000 Mg. Record this value to use later.
 - 1(g). To convert the annual acceptance rate to Mg, select the "To convert from" text box. Delete the value in it and type in *109,890 tons*.
 - 1(h). Select the "to" box and type in *Mg*.
 - 1(I). Select [Convert]. The annual acceptance rate in Mg rounds to 100,000 Mg. Record this value to use later.
 - 1(j). To exit the unit conversion utility, Select [Cancel] or double-click on the close box in the upper right corner of the conversion utility dialog box.
2. In the Operating Parameters table, select the year 1980. The cells in the Acceptance Rate/Refuse in Place column for 1980 will be highlighted by a bold box around them.
3. Select the button in the data entry box for Refuse in Place.
4. Select the Waste Value text box.
5. Type in 3.0E+05 (300,000) for the refuse in place in 1980. Press Enter to accept the value. The program will enter 3.0E+04 as the refuse in place for all following years up to the current year until you enter specific values for specific years. The table represents refuse in place, which is cumulative.
6. Highlight the Refuse in Place cells from 1975 through 1980. Choose the Autocalc function from the Edit menu. By using the Autocalc function, you will assume that waste has been received at a uniform rate of 60,000 Mg/yr since the landfill opened. You will see this change reflected in the refuse acceptance rates from 1975 through 1979.

C. Enter Refuse Acceptance Rates for Following Years

1. Enter a refuse acceptance rate for 1980 of 100,000 Mg. Do this by selecting the Acceptance Rate (Mg) cell in the row for 1980. This selection will select the Acceptance Rate (Mg/yr) check box on the toolbar. Highlight the entry in the Waste Value box on the toolbar and type 100,000. Press Enter to accept this value. [Note: Refuse in place values in this model are calculated at the beginning of the year. That is, the refuse in place for a landfill is a total of the previous year's refuse in place and the previous year's refuse acceptance rate. By entering a value of 100,000 Mg received in 1980, you will not have altered the Refuse in Place value for that year (i.e., the value will remain 300,000 Mg). However, the Refuse in Place value for 1981 will be changed to 400,000 Mg.]
2. The refuse acceptance rate remains constant from 1980 through 1994. Using the Autocalc function will help to speed the data entry rather than repeating step 1 for each year from 1980 to 1994. To do this, repeat step C.1 for the year 1994 (i.e., enter a refuse acceptance rate for 1994 of 100,000 Mg). Highlight the refuse acceptance rate cells from 1980 through 1994. Then select the Autocalc function from the Edit menu. This action will change the refuse acceptance rates for these years from their default values to 100,000 Mg/yr. Consequently, the refuse in place values will increase by 100,000 Mg each year from 1981 through 1995. The refuse in place in 1995 should total 1,800,000 Mg.

D. Closure Year

1. To set the closure year of the landfill, select the Closure Year item from the Parameters menu.
2. Click on the check box User Specified to permit entry of a certain closure year.
3. Type in *2001*. Select [OK]. [Note: When a report is generated the program will calculate, based on this selection, the difference (1,200,000 Mg) between the landfill design capacity (3,000,000 Mg) and the refuse in place (1,800,000 Mg) for the last year for which information has been entered (i.e., 1995). The program will divide this value by the number of years (6) between the current year (1995) and the closure year (2001). When a report is generated, the quotient (200,000 Mg/yr) will be entered as the acceptance rates for the years in which no data have been entered.]

IV. Adapt the Model for a Specific Scenario

Models can be adapted to specific scenarios to account for non-biodegradable waste or areas of the landfill for which the emissions are collected and controlled. For this study it was assumed that none of the waste in the landfill is non-biodegradable and that none of the

emissions from the landfill are collected and controlled. These topics are discussed in more detail in section 4.3.

V. Generating a Report, Saving a Study, and Exiting the Program

A. Generate a Textual Report of Emissions

1. To see the emissions generated based on the operating parameters, program defaults, and pollutant concentrations selected, select Reports from the Main Menu. To generate a textual report of emissions, select Text. A dialog box titled *Select an Emitted Substance* will appear.
2. Select *Ethyl Mercaptan* as the pollutant to report. Select [OK] to generate the emission report for all the years the landfill is open, plus 200 years past closure. A report will appear in the landfill study window.
3. To print the report, select Print from the File menu. A Print dialog box will come up, with a list of variable printers.
4. Select a printer. Select [Print].
(A copy of the text report is included as Attachment 15.A-4).

B. Generate a Graphical Report of Emissions

1. To generate a graphical report of emissions, select Graphics from the Reports menu.
2. Select *Ethyl Mercaptan*. Select [OK].
3. Select Print from the File menu. Select [Print].
(A copy of the graphical report is included as Attachment 15.A-5.)

C. Save the Landfill Study

1. To save the landfill study and assign a filename, select Save As from the File menu. A dialog box for Save As Landfill Study will appear, with a list of the landfill study files, if there are any (landfill study files are assigned a .PRM file extension), in the working directory for the program. The landfill study will be filed in the working directory of the program unless you specify another directory.
2. Select the File Name text box. Type *test*. The program will add the .PRM extension to the filename. This study will be saved in the working directory for the program as test.PRM. Select [OK].

D. Exit the Program

1. Select Exit from the File menu.

15.A-4.2 Adapting the Model for a Specific Scenario

Whenever possible, actual landfill data should be used to run the emissions estimation model. However, sometimes landfill data may be incomplete or unavailable, or a landfill owner or operator may wish to estimate the emissions for a landfill that has not yet opened. In such cases, the model can be used to forecast landfill emissions.

15.A-4.2.1 Forecasting Landfill Emissions

When forecasting emissions, it is best to use any actual data that are available. Even if a complete set of data is not available, any partial data sets should be put into the model. In cases where data are not available, the model can be used to give reasonable estimates of the landfill waste to forecast emissions.

Using the model to forecast emissions is similar to calculating past waste acceptance rates and refuse in place. The same general methodology described in the previous sections is used: select the model parameters, identify the length of operation of the landfill, enter the refuse in place or the acceptance rates of refuse, and run a report.

The principal difference between modeling emissions for existing landfill wastes and forecasting emissions for future landfill wastes is that, instead of actual data, estimates are needed for the length of operation, landfill capacity, and landfill waste when forecasting emissions. The following paragraphs describe the modified approach to use when forecasting emissions.

Length of Operation: Specifying the length of operation of the landfill can be more complicated when forecasting emissions. If precise years of operation (e.g., 1950, 1990, 1991) are known, they can be entered for the time variables (e.g., Year Opened, the Current Year, and the Closure Year), and the model functions normally. However, when precise dates are not known, the length of operation of the landfill can be specified with generic year numbers, such as 0001 (Year Opened), 0015 (Current Year), and 0016 (Closure Year).

Begin entering the length of time in which the landfill operates by entering a value for the Year Opened. Then choose a value for the Current Year that allows you to input refuse data for as many years past opening as you desire. The current year is the last year for which you will be able to input refuse data into the model. If the landfill will be open and accepting waste after the current year, then the user can choose a value for the Closure Year, or the computer model will automatically calculate it. However, if the

current year is the year in which the landfill will reach its capacity, the user should either allow the computer to automatically calculate the closure year or specify a closure year value that is one year in the future of the current year.

Landfill Capacity: The model algorithms and validation procedures require that a design capacity be entered prior to entering yearly refuse data. That is, even for a landfill not yet in operation, the total landfill capacity must be specified before any other information about the refuse in the landfill can be entered. If necessary, the user may use the Refuse Estimator to determine the landfill capacity from estimated landfill dimensions.

Landfill Waste: For each year of operation, the amount of landfill refuse must either be entered as a refuse in place or an acceptance rate. If data are available for either refuse parameter, they should be entered into the model. For years in which no such data are available, estimates must be provided. The Autocalc Function can assist the user in entering estimates for years in between those in which refuse acceptance rate or the amount of refuse in place is known.

15.A-4.2.2 Compensating for Non-biodegradable Debris, Areas with Emission Controls, and Areas Outside the Radius of Influence of Emission Controls

In certain cases, there are sections of a landfill that contain largely non-biodegradable debris (e.g., concrete, rocks, asphalt or other demolition debris) and do not produce emissions that other landfill refuse does. If records are available documenting such a quantity of waste and the regulatory agency is in agreement with this judgement, this amount of waste can be subtracted from the accumulated waste and the landfill capacity.

Similarly, when an area of the landfill is operated with a gas collection system and emission controls, this area of the landfill and the subsequent landfill waste will not release emissions at the same rate as an uncontrolled area of the landfill. In the case of a landfill with such emission controls, the user must estimate the quantity of the waste for which gas is collected and controlled. The controlled and uncontrolled portions of the landfill can then be modeled separately. Application of controls are discussed in Section 3.3.2 of this chapter.

15.A-5 POTENTIAL OPERATIONAL ERRORS

Some inputs can cause problems in the operation of the program. The following sections describe how to avoid them.

15.A-5.1 The Autocalc Function

The Autocalc function is located under the Edit menu and assists the user in calculating waste acceptance rates or refuse in place for the years of operation of the model. The Autocalc function will not recognize the landfill capacity as the upper limit for the accumulated refuse. When this occurs, calculated values for accumulated refuse will exceed the landfill capacity.

The user should compare the amount of accumulated refuse as calculated by the Autocalc function to the landfill capacity value prior to entering the data into the model to be certain that the refuse in place does not exceed the landfill capacity. If the calculated accumulated refuse amounts do exceed landfill capacity, then the user should adjust the acceptance rate data in the Autocalc function to reduce the calculated accumulated refuse amount. Please note that the program will continue to run if the entered value for landfill capacity has been exceeded.

15.A-5.2 The Closure Year

The Closure Year function is located under the Parameters menu and allows the user either to calculate the closure year automatically or to specify an actual closure date for the landfill. In either case, the closure year is the year in which the landfill waste accumulated reaches the capacity of the landfill. The default option is for the model to calculate the closure year automatically. The following is a brief description of the two options and an explanation of how the closure variable choice affects operation of the model.

System Calculated Closure Year: The computer model will project the closure based on the last non-zero acceptance rate and the capacity of the landfill. The model will project waste acceptance at the last non-zero acceptance rate until the year in which the accumulated refuse in place reaches the landfill capacity. This year becomes the closure year.

User-specified Closure Year: If the user does not know the refuse acceptance rates for the final years of the landfill's operation, the user may specify the closure year for the landfill and allow the computer to calculate the acceptance rates until closure. The model will calculate the acceptance rates for the final years of operation by dividing the remaining capacity of the landfill by the number of years between the current year and the user-specified closure year.

The user must take caution when specifying the closure year because of the model's method of calculation. If a closure year is chosen that is the same as the current year, the model's calculation routine will not be able to estimate emissions correctly. To avoid this problem, the user should always specify a closure year that is at least one year beyond the current year even if the current year is the year in which the refuse in place reaches the capacity of the landfill (i.e., a case in which the current year is, by definition, the closure year). If the current year is the

closure year, we recommend allowing the model to automatically calculate the closure year (i.e., use the default System Calculated Closure Year).

15.A-5.3 Cut, Copy, and Paste

The Cut, Copy, and Paste commands, which function similarly as in other Windows software programs, are designed to be implemented in the following way: highlight the contents of the origin cell (i.e., drag the cursor across the cell with the primary mouse button depressed); select the Cut or Copy command; highlight the contents of the destination cell; and then select the Paste command.

**ATTACHMENT 15.A-1
GLOSSARY OF TERMS**

| Term | Definition |
|---|--|
| Codisposal | Disposal of hazardous waste as well as other kinds of waste in a landfill. |
| Landfill Capacity | The total amount of refuse that can be disposed of in the landfill. |
| Landfill Gas | Landfill gas is a product of biodegradation of refuse in landfills and consists of primarily methane and carbon dioxide, with trace amounts of NMOC and air pollutants. |
| Methane Generation Rate Constant (k) | k is a constant that determines the rate of landfill gas generation. The first-order decomposition model assumes that k values before and after peak landfill gas generation are the same. k is a function of moisture content in the landfill refuse, availability of nutrients for methanogens, pH, and temperature. |
| Nonmethane Organic Compounds (NMOC) | NMOC are specified in this program as the fraction of landfill gas containing nonmethane organic compounds, expressed as hexane. NMOC include air pollutants and volatile organic compounds. NMOC concentration can be measured using guidance provided by the proposed EPA Method 25C. |
| Potential Methane Generation Capacity (L_o) | L_o is a constant that represents the potential capacity of a landfill to generate methane (a primary constituent of landfill gas). L_o depends on the amount of cellulose in the refuse. |
| Air Pollutants | Compounds found in landfill gas or emitted with landfill gas, some of which are listed as air pollutants under section 112 of the Clean Air Act. A total of 47 air pollutants emitted from landfills are included in the model. |
| Closure Year | The year in which the landfill ceases, or is expected to cease, accepting waste. |

ATTACHMENT 15.A-2. POLLUTANTS INCLUDED IN THE LANDFILL GAS EMISSIONS MODEL

| Chemical | Molecular Weight | Concentration (ppmv) | |
|--|------------------|----------------------|---------------|
| | | Codisposal | No Codisposal |
| 1,1,1-Trichloroethane (HAP) | 133.41 | 0.48 | 0.48 |
| 1,1,1,2-Tetrachloroethane (HAP/VOC) | 167.85 | 1.11 | 1.11 |
| 1,1,2-Trichloroethane (HAP/VOC) | 133.41 | 0.1 | 0.1 |
| 1,1-Dichloroethane (HAP/VOC) | 98.96 | 2.35 | 2.35 |
| 1,1-Dichloroethene (HAP/VOC) | 96.94 | 0.2 | 0.2 |
| 1,2-Dichloroethane (HAP/VOC) | 98.96 | 0.41 | 0.41 |
| 1,2-Dichloropropane (HAP/VOC) | 112.99 | 0.18 | 0.18 |
| 2-Propanol (VOC) | 60.11 | 50.1 | 50.1 |
| Acetone | 58.08 | 7.01 | 7.01 |
| Acrylonitrile (HAP/VOC) | 53.06 | 6.33 | 6.33 |
| Benzene (HAP/VOC) | 78.12 | 11.1 | 1.91 |
| Bromodichloromethane (VOC) | 163.83 | 3.13 | 3.13 |
| Butane (VOC) | 58.12 | 5.03 | 5.03 |
| Carbon Disulfide (HAP/VOC) | 76.14 | 0.58 | 0.58 |
| Carbon Monoxide | 28.01 | 141 | 141 |
| Carbon Tetrachloride (HAP/VOC) | 153.84 | 0.004 | 0.004 |
| Carbonyl Sulfide (HAP/VOC) | 60.07 | 0.49 | 0.49 |
| Chlorobenzene (HAP/VOC) | 112.56 | 0.25 | 0.25 |
| Chlorodifluoromethane (VOC) | 86.47 | 1.3 | 1.3 |
| Chloroethane (HAP/VOC) | 64.52 | 1.25 | 1.25 |
| Chloroform (HAP/VOC) | 119.38 | 0.024 | 0.024 |
| Chloromethane (HAP/VOC) | 50.49 | 1.21 | 1.21 |
| Dichlorobenzene (VOC/HAP for 1,4 isomer) | 147 | 0.21 | 0.21 |
| Dichlorodifluoromethane (VOC) | 120.91 | 15.7 | 15.7 |
| Dichlorofluoromethane (VOC) | 102.92 | 2.62 | 2.62 |
| Dichloromethane (HAP) | 84.93 | 14.3 | 14.3 |
| Dimethyl Sulfide (VOC) | 62.13 | 7.82 | 7.82 |
| Ethane | 30.07 | 889 | 889 |
| Ethanol (VOC) | 46.08 | 27.2 | 27.2 |
| Ethylbenzene (HAP/VOC) | 106.17 | 4.61 | 4.61 |
| Ethyl Mercaptan (VOC) | 62.13 | 1.25 | 1.25 |
| Ethylene Dibromide (HAP/VOC) | 187.88 | 0.001 | 0.001 |
| Fluorotrichloromethane (VOC) | 137.37 | 0.76 | 0.76 |
| Hexane (HAP/VOC) | 86.18 | 6.57 | 6.57 |
| Hydrogen Sulfide | 34.08 | 35.5 | 35.5 |
| Mercury (HAP) | 200.61 | 0.000253 | 0.000253 |
| Methyl Ethyl Ketone (HAP/VOC) | 72.11 | 7.09 | 7.09 |
| Methyl Isobutyl Ketone (HAP/VOC) | 100.16 | 1.87 | 1.87 |
| Methyl Mercaptan (VOC) | 48.11 | 2.49 | 2.49 |
| Pentane (VOC) | 72.15 | 3.29 | 3.29 |
| Perchloroethylene (HAP/VOC) | 165.83 | 3.73 | 3.73 |
| Propane (VOC) | 44.1 | 11.1 | 11.1 |
| Toluene (HAP/VOC) | 92.14 | 165 | 39.3 |
| Trichloroethene (HAP/VOC) | 131.38 | 2.82 | 2.82 |
| t-1,2-Dichloroethene | 96.94 | 2.84 | 2.84 |
| Vinyl Chloride (HAP/VOC) | 62.5 | 7.34 | 7.34 |
| Xylene (HAP/VOC) | 106.17 | 12.1 | 12.1 |

Note: Technical support information for the above pollutant data is located in the *Compilation of Air Pollutant Emission Factors, AP-42, Volume 1: Stationary Point and Area Sources* (EPA, 1998a) which can be obtained from the TTN website (<http://www.epa.gov/ttn/chief/ap42back.html>) or from the National Technical Information Service.

ATTACHMENT 15.A-3 EXAMPLES OF THE AUTOCALC FUNCTION

Example 1: Using the Autocalc Function When Only Partial Data Are Available

If refuse information is available for only certain years of landfill operation and assumptions can be made about acceptance rates in the years for which there is no information, the Autocalc function can be useful to estimate and enter acceptance rate data. In this example, the user will have two periods of acceptance rates for which the Autocalc function will be used: one in which the user will assume that the acceptance rate increases linearly over time and one in which the acceptance rate is constant for a number of years. In this example, the landfill will open in 1971, and the current year will be 1986.

To input an increasing refuse acceptance rate, an acceptance rate must be entered for the beginning and ending points. Assume that the landfill capacity is 2,000,000 Mg, the refuse acceptance rate in the first year (1971) is 10,000 Mg/yr, and the refuse acceptance rate in the tenth year (1980) is 100,000 Mg/yr. To use the Autocalc function to interpolate between the two rates, select the waste acceptance rate for the year 1971. Click and drag the mouse until all the cells from years 1971 through 1980 are highlighted. Then, from the Edit menu, select the Autocalc function. The computer model will linearly interpolate the acceptance rate for the years between 1971 and 1980. In this case, the rate increases from 10,000 Mg/yr to 100,000 Mg/yr in 10,000 Mg/yr increments.

To enter a constant refuse acceptance rate, the same value for the acceptance rate must be entered for the beginning and end points of the period throughout which refuse is received at a uniform rate. In this case, assume that the acceptance rate remains constant at 100,000 Mg/yr from 1980 through 1985. Start by entering 100,000 Mg/yr in the acceptance rate cell for the year 1985. (A value of 100,000 Mg/yr should have already been entered for 1980 based on the directions in the previous paragraph). Then highlight all the cells from years 1980 through 1985. From the Edit menu choose the Autocalc function. The computer model will enter the acceptance rate of 100,000 Mg/yr for each year between 1980 and 1985. Note that, in both cases, entering acceptance rate values with the Autocalc function caused the estimates for the refuse in place to change accordingly.

Example 2: Using the Autocalc Function With No Data for Early Periods of Operation

This example will begin with a new study. Assume that a landfill with a of capacity 5,000,000 Mg opens in the year 1971 and the current year is 1980. For the last two years (i.e., 1979 and 1980) the amount of refuse in place has been recorded. In 1979 the refuse in place

totaled 2,000,000 Mg, and in 1980 it was 2,350,000 Mg. However, there are no records to indicate what the refuse in place was for 1971 through 1978.

The Autocalc function can be used to estimate the refuse in place for the years between 1971 (the year the landfill opened) and 1978. The refuse in place in 1971 must be zero because 1971 is the year the landfill opened. Assuming that refuse acceptance rates were constant between 1971 to 1978, the Autocalc function can be used to linearly interpolate backwards to produce estimates of the refuse between 1971 and 1978. As in the previous example, begin by selecting the cell with the earlier date (i.e., move the active cell to the refuse in place for 1971). Click and drag the mouse until all the cells between 1971 and 1979 are highlighted. Then choose the Autocalc function from the Edit menu. The values in both the refuse acceptance rate and refuse in place column will be calculated. The refuse acceptance rate for years 1971 through 1978 will be 250,000 Mg/yr, and the refuse acceptance rate for 1979 will be 350,000 Mg/yr. The refuse in place estimates will be adjusted accordingly from 1971 (0 Mg in place) to 1979 (2,000,000 Mg in place).

ATTACHMENT 15.A-4
A COPY OF THE TEXT REPORT FROM THE EXAMPLE STUDY IN SECTION 4.1

Source: C:\LANDFILL\TEST.PRM

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Model Parameters

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Lo: 100.00 m³ / Mg
k : 0.0400 1/yr
NMOC : 2420.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume
Air Pollutant : Ethyl Mercaptan
Molecular Wt = 62.13 Concentration = 0.860000 ppmV

=====

Landfill Parameters

=====

Landfill type : Co-Disposal
Year Opened : 1975 Current Year : 1995 Closure Year: 2001
Capacity : 3000000 Mg
Average Acceptance Rate Required from
Current Year to Closure Year : 200000.00 Mg/year

=====

Model Results

=====

| Year | Refuse In Place (Mg) | Ethyl Mercaptan Emission Rate (Mg/yr) | (Cubic m/yr) |
|------|----------------------|--|--------------|
| 1976 | 6.000E+04 | 1.067E-03 | 4.128E-01 |
| 1977 | 1.200E+05 | 2.092E-03 | 8.094E-01 |
| 1978 | 1.800E+05 | 3.076E-03 | 1.190E+00 |
| 1979 | 2.400E+05 | 4.022E-03 | 1.557E+00 |
| 1980 | 3.000E+05 | 4.932E-03 | 1.908E+00 |
| 1981 | 4.000E+05 | 6.516E-03 | 2.522E+00 |
| 1982 | 5.000E+05 | 8.038E-03 | 3.111E+00 |
| 1983 | 6.000E+05 | 9.501E-03 | 3.677E+00 |
| 1984 | 7.000E+05 | 1.091E-02 | 4.221E+00 |
| 1985 | 8.000E+05 | 1.226E-02 | 4.743E+00 |
| 1986 | 9.000E+05 | 1.355E-02 | 5.245E+00 |
| 1987 | 1.000E+06 | 1.480E-02 | 5.727E+00 |
| 1988 | 1.100E+06 | 1.600E-02 | 6.191E+00 |
| 1989 | 1.200E+06 | 1.715E-02 | 6.636E+00 |
| 1990 | 1.300E+06 | 1.825E-02 | 7.064E+00 |
| 1991 | 1.400E+06 | 1.932E-02 | 7.475E+00 |
| 1992 | 1.500E+06 | 2.034E-02 | 7.870E+00 |
| 1993 | 1.600E+06 | 2.132E-02 | 8.249E+00 |

| | | | |
|------|-----------|-----------|-----------|
| 1994 | 1.700E+06 | 2.226E-02 | 8.614E+00 |
| 1995 | 1.800E+06 | 2.316E-02 | 8.964E+00 |
| 1996 | 2.000E+06 | 2.581E-02 | 9.989E+00 |
| 1997 | 2.200E+06 | 2.836E-02 | 1.097E+01 |
| 1998 | 2.400E+06 | 3.080E-02 | 1.192E+01 |
| 1999 | 2.600E+06 | 3.315E-02 | 1.283E+01 |
| 2000 | 2.800E+06 | 3.540E-02 | 1.370E+01 |
| 2001 | 3.000E+06 | 3.757E-02 | 1.454E+01 |
| 2002 | 3.000E+06 | 3.610E-02 | 1.397E+01 |
| 2003 | 3.000E+06 | 3.468E-02 | 1.342E+01 |
| 2004 | 3.000E+06 | 3.332E-02 | 1.290E+01 |
| 2005 | 3.000E+06 | 3.202E-02 | 1.239E+01 |
| 2006 | 3.000E+06 | 3.076E-02 | 1.190E+01 |
| 2007 | 3.000E+06 | 2.955E-02 | 1.144E+01 |
| 2008 | 3.000E+06 | 2.840E-02 | 1.099E+01 |
| 2009 | 3.000E+06 | 2.728E-02 | 1.056E+01 |
| 2010 | 3.000E+06 | 2.621E-02 | 1.014E+01 |
| 2011 | 3.000E+06 | 2.518E-02 | 9.746E+00 |
| 2012 | 3.000E+06 | 2.420E-02 | 9.364E+00 |
| 2013 | 3.000E+06 | 2.325E-02 | 8.997E+00 |
| 2014 | 3.000E+06 | 2.234E-02 | 8.644E+00 |
| 2015 | 3.000E+06 | 2.146E-02 | 8.305E+00 |
| 2016 | 3.000E+06 | 2.062E-02 | 7.979E+00 |
| 2017 | 3.000E+06 | 1.981E-02 | 7.666E+00 |
| 2018 | 3.000E+06 | 1.903E-02 | 7.366E+00 |
| 2019 | 3.000E+06 | 1.829E-02 | 7.077E+00 |
| 2020 | 3.000E+06 | 1.757E-02 | 6.799E+00 |
| 2021 | 3.000E+06 | 1.688E-02 | 6.533E+00 |
| 2022 | 3.000E+06 | 1.622E-02 | 6.277E+00 |
| 2023 | 3.000E+06 | 1.558E-02 | 6.031E+00 |
| 2024 | 3.000E+06 | 1.497E-02 | 5.794E+00 |
| 2025 | 3.000E+06 | 1.439E-02 | 5.567E+00 |
| 2026 | 3.000E+06 | 1.382E-02 | 5.349E+00 |
| 2027 | 3.000E+06 | 1.328E-02 | 5.139E+00 |
| 2028 | 3.000E+06 | 1.276E-02 | 4.937E+00 |
| 2029 | 3.000E+06 | 1.226E-02 | 4.744E+00 |
| 2030 | 3.000E+06 | 1.178E-02 | 4.558E+00 |
| 2031 | 3.000E+06 | 1.132E-02 | 4.379E+00 |
| 2032 | 3.000E+06 | 1.087E-02 | 4.207E+00 |
| 2033 | 3.000E+06 | 1.045E-02 | 4.042E+00 |
| 2034 | 3.000E+06 | 1.004E-02 | 3.884E+00 |
| 2035 | 3.000E+06 | 9.643E-03 | 3.732E+00 |

| | | | |
|------|-----------|-----------|-----------|
| 2036 | 3.000E+06 | 9.265E-03 | 3.585E+00 |
| 2037 | 3.000E+06 | 8.902E-03 | 3.445E+00 |
| 2038 | 3.000E+06 | 8.553E-03 | 3.310E+00 |
| 2039 | 3.000E+06 | 8.217E-03 | 3.180E+00 |
| ... | ... | ... | ... |
| 2198 | 3.000E+06 | 1.421E-05 | 5.499E-03 |
| 2199 | 3.000E+06 | 1.365E-05 | 5.284E-03 |
| 2200 | 3.000E+06 | 1.312E-05 | 5.076E-03 |

ATTACHMENT 15.A-5 A COPY OF THE GRAPHICAL REPORT FROM THE EXAMPLE STUDY IN SECTION 4.1

Projected Ethyl Mercaptan Emissions

