User's Manual
Mexico Landfill Gas Model

Version 1.0

Prepared for

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DISCLAIMER

This user's guide has been prepared specifically for Mexico on behalf of the U.S. EPA's Landfill Methane Outreach Program and the U.S. Agency for International Development. The methods contained within are based on engineering judgment and represent the standard of care that would be exercised by a professional experienced in the field of landfill gas projections. SCS does not guarantee the quantity of available landfill gas, and no other warranty is expressed or implied. No other party is intended as a beneficiary of this work product, its content, or information embedded therein. Third parties use this report at their own risk. SCS assumes no responsibility for the accuracy of information obtained from, compiled, or provided by other parties.

ABSTRACT

This document is a user's guide for a computer model, Version 1.0 of a landfill gas generation model for estimating landfill gas generation from municipal solid waste landfills in Mexico (Mexico LFG Model). The model was developed by SCS Engineers under contract to the U.S. EPA's Landfill Methane Outreach Program (LMOP). The Mexico LFG Model can be used to estimate landfill gas generation rates from landfills, and potential landfill gas recovery rates for landfills that have or plan to have gas collection and control systems.

The Mexico LFG Model is an Excel® spreadsheet model based on a first order decay equation. The model requires the user to input site-specific data for landfill opening and closing years, refuse disposal rates, average annual precipitation, and collection efficiency. The model provides default values for k and L_0. The default values were developed using site specific data gathered from representative landfills in Mexico, and the relationship between the k and L_0 values and average annual precipitation observed at landfills in the U.S. The default k and L_0 values vary depending on average annual precipitation and can be used to produce typical landfill gas generation estimates for landfills located in various regions of Mexico.

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GLOSSARY OF TERMS

TERM	DEFINITION
Collection Efficiency	The estimated percentage of generated landfill gas which is or can be collected in a gas collection system.
Collection System Coverage	The estimated percentage of a landfill's refuse mass that is potentially within the influence of a gas collection system's extraction wells. Collection system coverage describes the fraction of recoverable gas that can be captured and can reach 100% in a comprehensive collection system (unlike collection efficiency which is always less than 100%).
Design Capacity of the Landfill	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 non-methane organic compounds and air pollutants.
Methane Generation Rate Constant (k)	k is a model constant that determines the estimated 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.
Potential Methane Generation Capacity (L_o)	L_o is a model 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.
Closure Year	The year in which the landfill ceases, or is expected to cease, accepting waste.

1.0: INTRODUCTION

The Mexico Landfill Gas Model (Mexico LFG Model) provides an automated estimation tool for quantifying landfill gas generation and recovery from municipal solid waste (MSW) landfills in Mexico. This manual provides an introduction to the model and step-by-step instructions for using the model.

The main purpose of the Mexico LFG Model is to provide landfill owners and operators with a tool to use to evaluate the feasibility and potential benefits of collecting and using the generated landfill gas for energy recovery or other uses. To accomplish this purpose, this computer model provides estimates of potential landfill gas recovery rates. This is accomplished using the landfill gas generation rates estimated by the model and estimates of the efficiency of the collection system in capturing generated gas, known as the collection efficiency. The model provides landfill gas recovery estimates by multiplying the landfill gas generation by the estimated recovery efficiency.

Landfill gas is generated by the decomposition of refuse in the landfill, and can be recovered through the operation of gas collection facilities installed at the landfill. The following information is needed to estimate landfill gas generation and recovery from a landfill (see the Glossary of Terms):

- 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) constant;
- The potential methane generation capacity (L_0);
- The collection efficiency of the gas collection system; and
- The years the landfill has been and will be in operation.

The model employs a first-order exponential decay function that assumes that LFG generation is at its peak following a time lag representing the period prior to methane generation.

The model assumes a one-year time lag between placement of waste and LFG generation. For each unit of waste, after one year the model assumes that LFG generation decreases exponentially as the organic fraction of waste is consumed.

For sites with known (or estimated) year-to-year solid waste acceptance rates, the model estimates the LFG generation rate in a given year using the following equation, which is published in Title 40 of the U.S. Code of Federal Regulations (CFR) Part 60, Subpart WWW.

$$Q_M = \sum_{i=1}^{n} 2 \, k \, L_o \, M_i \, (e^{-kt_i})$$

Where:

$\sum_{i=1}^{n}$ = sum from opening year+1 (i=1) through year of projection (n);

Q_M = maximum expected LFG generation flow rate (m^3/yr);
k = methane generation rate constant (1/yr);
L_o = methane generation potential (m^3/Mg);
M_i = mass of solid waste disposed in the ith year (Mg);
t_i = age of the waste disposed in the ith year (years).

The above equation is used to estimate LFG generation for a given year from cumulative waste disposed up through that year. Multi-year projections are developed by varying the projection year, and then re-applying the equations. The year of maximum LFG generation normally occurs in the closure year or the year following closure (depending on the disposal rate in the final years).

The Mexico LFG Model requires site-specific data for all the information needed to produce generation estimates, except for the k and L_0 values. The model provides default values for k and L_0. The default values are based on site specific data gathered from representative landfills in Mexico, and the relationship between the k and L_0 values and average annual precipitation observed at landfills in the U.S. The default k and L_0 values vary depending on average annual precipitation and can be used to produce typical landfill gas generation estimates for landfills located in various regions of Mexico.

EPA fully recognizes that modeling landfill gas generation and recovery accurately is difficult due to limitations in available information for inputs to the model. However, as new landfills are constructed and operated and better information is collected, the present modeling approach can be improved. In addition, as more landfills in Mexico develop gas collection and control systems, additional data on landfill gas generation and recovery will become available for model calibration and the development of improved model default values.

Questions and comments concerning the landfill gas model should be directed to Brian Guzzone of EPA's LMOP at (202) 564-2666, or by E-Mail at Guzzone.Brian@epamail.epa.gov.

1.1   Landfill Gas Generation

The Mexico LFG Model estimates landfill gas generation resulting from the biodegradation of refuse in landfills. The anaerobic decomposition of refuse in solid waste landfills causes generation of landfill gas. The composition of MSW landfill gas is assumed by the model to be about 50 percent methane (CH_4) and 50 percent other gases, including carbon dioxide (CO_2) and trace amounts of other compounds.

This computer model uses a first-order decomposition rate equation and estimates volumes of landfill gas generation in cubic meters per minute (m^3/min) and in cubic meters per hour (m^3/hr). It also estimates the energy content of generated landfill gas in billion joules per year (G J/yr). Total landfill gas generation is estimated by doubling methane generation (the landfill gas is assumed to be half methane and half carbon dioxide). Methane generation is estimated using two parameters: (1) L_0 is the methane generation potential of the refuse, and (2) k is the methane generation rate constant. Landfill gas generation is assumed to be at its peak upon closure of the landfill or final placement of waste at the site. Although the model allows the user to enter L_0 and k values derived using site-specific data collected at the landfill (site-specific L_0 and k values may be developed for landfills with operating gas collection and control systems by calibrating the Mexico LFG Model using known landfill gas recovery data), it is recommended that the provided default values be used for most modeling applications.

The methane generation rate constant, k, determines the rate of generation of methane from refuse in the landfill. The units for k are in year^{-1}, which means that the k value describes the rate at which refuse placed in a landfill in a given year decays and produces methane gas. The higher the value of k, the faster total methane generation at a landfill increases (as long as the landfill is still receiving waste) and then declines (after the landfill closes) over time. The value of k is a function of the following factors: (1) refuse moisture content, (2) availability of nutrients for methane-generating bacteria, (3) pH, and (4) temperature. The k values obtained from data collected from U.S. landfills range from 0.003 to 0.21 per year (EPA, 1991a). These values were obtained from theoretical models using field test data and from actual field test measurements. Unless a user-specified k value is entered into the Mexico LFG Model, default values are used for k. The following four default k values are used by the program, depending on the amount of precipitation experienced at the landfill:

TABLE 1: METHANE GENERATION RATE CONSTANT (K)

ANNUAL PRECIPITATION (mm/yr)	k (per year)
0 - 249	0.040
250 – 499	0.050
500 - 999	0.065
at least 1000	0.080

In theory, the value for the potential methane generation capacity of refuse (L_0) depends only on the type of refuse present in the landfill. The higher the cellulose content of the refuse, the higher the value of L_0. In practice, the theoretical L_0 value may not be reached in dry climates where lack of moisture in the landfill inhibits the action of methane-generating bacteria. The units of L_0 are in cubic meters per tonne of refuse, which means that the L_0 value describes the total amount methane gas produced by a tonne of refuse (no time limit is specified). The values of theoretical and obtainable L_0 range from 6.2 to 270 m^3/Mg refuse (EPA, 1991b). Unless a user-specified L_0 value is entered into the Mexico LFG Model, default values are used for L_0. The following three default L_0 values are used by the program, depending on the amount of precipitation experienced at the landfill:

TABLE 2: POTENTIAL METHANE GENERATION CAPACITY (L_0)

Annual Precipitation (mm/yr)	L_0 (cubic meters per tonne)
0 – 249	60
250 – 499	80
at least 500	84

1.2   Landfill Gas Recovery

Landfill gas generated in landfills can be captured by gas collection and control systems that typically burn the gas in flares. Alternatively, the collected gas can be used beneficially. Beneficial uses of landfill gas include use as fuel in energy recovery facilities, such as internal combustion engines, gas turbines, microturbines, steam boilers, or other facilities that use the gas for electricity generation.

In addition to the energy benefits from the beneficial use of landfill gas, collection and control of generated landfill gas helps to reduce landfill gas emissions that are harmful to the environment. The U.S. EPA has determined that landfill gas emissions from MSW landfills cause, or contribute significantly to, air pollution that may reasonably be anticipated to endanger public health or welfare. Some are known or suspected carcinogens, or cause other non-cancer health effects. Public welfare concerns include the odor nuisance from the landfill gas and the potential for methane migration, both on-site and off-site, which may lead to explosions or fires. The methane emitted from landfills is also a concern because it is a greenhouse gas and contributes to global climate change.

The main purpose of the Mexico LFG Model is to provide landfill owners and operators with a tool to use to evaluate the feasibility and potential benefits of collecting and using the generated landfill gas for energy recovery or other uses. To accomplish this purpose, this computer model provides estimates of potential landfill gas recovery rates. This is accomplished using the landfill gas generation rates estimated by the model and estimates of the efficiency of the collection system in capturing generated gas, known as the collection efficiency. The model

provides landfill gas recovery estimates by multiplying the landfill gas generation by the estimated recovery efficiency.

1.3   The Model

The Mexico LFG Model can be operated in a Windows 98®, Windows 2000®, or Windows XP® environment. The program is a Microsoft Excel® spreadsheet, which allows the user considerable control over model calculations and output appearances. Excel® software must be opened prior to running the model. Once Excel® is running, open the model file ("LMOP Mexico Model.xls") by choosing "file" "open," and then "open" when the correct file is highlighted. The model has four worksheets that are accessible by clicking on the tabs at the bottom of the Excel® window screen. The four worksheets are as follows:

- A model inputs worksheet;
- A model outputs worksheet in a table format;
- A model outputs worksheet in a graph format; and
- A model calculations worksheet.

When using the model, most of the editing by the user takes place in the model inputs worksheet. Some editing may be required in the outputs worksheet for formatting purposes. The calculations worksheet should not be changed and is password protected to prevent changes.

2.0 ESTIMATING LANDFILL GAS GENERATION AND RECOVERY

2.1 Model Inputs

All model inputs are to be put into an "Inputs" worksheet. Cells with red bold text require user inputs. Cells highlighted in yellow should not be changed. The following inputs are required to run the model properly and produce acceptable outputs (tables and graphs):

Step 1: The name and location of the landfill (goes in Cell A4 – see Figure 1 below). What you enter here will automatically appear in the heading of the output table.

Step 2: The year the landfill opened and began receiving waste (goes into Cell B5 – see Figure 1 below). What you enter here will feed into the table of numbers below and in the output table.

Step 3: The average annual precipitation in mm per year at the landfill (goes into Cell B7 – see Figure 1 below). This information can be obtained by looking up precipitation data for the closest city or town at www.worldclimate.com. This value will be used to look up appropriate default values for k and Lo.

FIGURE 1. MODEL INPUTS

	A	B	C
1	LMOP MEXICO LFG MODEL		
2	INPUT PARAMETERS:		
3	**LFG GENERATION AND RECOVERY PROJECTION**		
4	**LANDFILL NAME - CITY**		
5	Year opened:	**1991**	
6			
7	Average annual precipitation:	**500**	mm/y
8	Methane Content of LFG Adjusted to:	50%	
9	Methane generation rate constant (k):	0.065	1/yr
10	Ultimate methane generation potential (L_0):	84	m3/Metric
11	English Unit equivalent L_0:	2690	ft3/to

STEP 4: Metric tonnes disposed for each year the site is open (goes into Cells B16 – B115 – see Figure 2 on the following page).

- If the disposal history is unknown, calculate the landfill's average annual disposal rate by dividing the number of years the site was/will be open into the total site capacity (in metric tonnes).
- Enter the resulting value into Cell B16.
- Whatever value gets typed into Cell B16 will be automatically copied into cells below it until Cell B76, which has a "hard value" of zero typed in.
- Enter a "0" into the cell corresponding the year following site closure. If the site's disposal history is longer than 60 years, cell B76 will need to be changed.

Step 5: Estimated collection efficiency for each year after a gas collection system was/will be installed (goes into Cells D16 – D115; see Figure 2 on the following page).

- The input sheet currently has 0% collection efficiency for the first 10 years of site operation and 60% for the remaining years.
- Collection system efficiency for years prior to the present should reflect the status of the collection system in prior years.
- Collection system efficiency for future years should reflect the estimated collection system build-out in future years.
- Additional instruction on how to estimate collection efficiency is provided in Subsection 2.1.1.

Step 6: Actual landfill gas recovery rates in cubic meters per hour (for sites with active gas collection systems). Input into Cells E16 – E115 (see Figure 2 on the following page) the average annual total landfill gas flow at the flare station and/or energy recovery plant (NOT the sum of flows at individual wells). Adjust all flow rates to 50% methane equivalent by multiplying the measured flow by the measured methane content of the landfill gas and then dividing the result by 50%. The numbers placed in these cells will

be displayed in the graph output sheet, so do not input zeros for years with no flow data (leave blank).

> Equation for adjusting methane content to 50%:
>
> $$\text{Measured Flow Rate} \quad \times \quad \frac{\text{Measured methane \%}}{50 \text{ \% methane}} \quad = \quad \text{Flow rate at 50\% methane}$$

FIGURE 2. MODEL INPUTS (Continued)

	A	B Metric Tonnes Disposed	C Cumulative Metric Tonnes	D LFG Collection System Efficiency	E Actual Recovery (m3/hr)
15	Year				
16	1991	50,000	50,000	0%	
17	1992	50,000	100,000	0%	
18	1993	50,000	150,000	0%	
19	1994	50,000	200,000	0%	
20	1995	50,000	250,000	0%	
21	1996	50,000	300,000	0%	
22	1997	50,000	350,000	0%	
23	1998	50,000	400,000	0%	
24	1999	50,000	450,000	0%	
25	2000	50,000	500,000	0%	
26	2001	50,000	550,000	60%	280
27	2002	50,000	600,000	60%	300
28	2003	50,000	650,000	60%	320
29	2004	50,000	700,000	60%	
30	2005	50,000	750,000	60%	
31	2006	50,000	800,000	60%	
32	2007	50,000	850,000	60%	
33	2008	50,000	900,000	60%	
34	2009	50,000	950,000	60%	
35	2010	50,000	1,000,000	60%	
36	2011	50,000	1,050,000	60%	
37	2012	50,000	1,100,000	60%	
38	2013	50,000	1,150,000	60%	
39	2014	50,000	1,200,000	60%	
40	2015	50,000	1,250,000	60%	
41	2016	50,000	1,300,000	60%	
42	2017	50,000	1,350,000	60%	
43	2018	50,000	1,400,000	60%	
44	2019	50,000	1,450,000	60%	
45	2020	50,000	1,500,000	60%	
46	2021	50,000	1,550,000	60%	
47	2022	50,000	1,600,000	60%	
48	2023	50,000	1,650,000	60%	
49	2024	50,000	1,700,000	60%	
50	2025	50,000	1,750,000	60%	
51	2026	50,000	1,800,000	60%	
52	2027	50,000	1,850,000	60%	
53	2028	50,000	1,900,000	60%	
54	2029	50,000	1,950,000	60%	
55	2030	50,000	2,000,000	60%	
56	2031	50,000	2,050,000	60%	
57	2032	50,000	2,100,000	60%	
58	2033	50,000	2,150,000	60%	
59	2034	50,000	2,200,000	60%	
60	2035	50,000	2,250,000	60%	
61	2036	50,000	2,300,000	60%	
62	2037	50,000	2,350,000	60%	
63	2038	50,000	2,400,000	60%	
64	2039	50,000	2,450,000	60%	
65	2040	50,000	2,500,000	60%	

2.1.1   *Estimating Collection Efficiency*

Collection efficiency is a measure of the ability of the gas collection system to capture generated landfill gas. It is a percentage value that is applied to the landfill gas generation projection produced by the model to estimate the amount of landfill gas that is or can be captured for flaring or beneficial use. Although rates of landfill gas capture can be measured, rates of generation in a landfill cannot be measured (hence the need for a model to estimate generation); therefore there is considerable uncertainty regarding actual collection efficiencies achieved at landfills.

In response to the uncertainty regarding collection efficiencies, the U.S. EPA (EPA, 1998) has published what it believes are reasonable collection efficiencies for landfills in the U.S. that meet U.S. design standards and have "comprehensive" gas collection systems. According to the EPA, collection efficiencies at such landfills typically range from 60% to 85%, with an average of 75%. Table 3, "Landfill Collection Efficiency," shows an example of how to determine the collection efficiency using the landfill characteristics listed and deducting percentages for landfills without these characteristics. For example, if a landfill has all the characteristics listed then the estimated efficiency is 85%.

TABLE 3: LANDFILL COLLECTION EFFICIENCY

Item No.	Landfill Characteristic	Collection Efficiency			
		85%	75%	65%	60%
1	A composite bottom liner consisting of synthetic (plastic) layer over 2 feet (0.6 meter) of clay or similar material.	✓			
2	Soil cover applied over newly deposited refuse on a daily basis. Closed sites should have a final soil cover installed within a few years of closure.	✓	✓		
3	No significant off-site lateral migration of landfill gas. (U.S. landfills are required to monitor for off-site landfill gas migration.)	✓	✓	✓	
4	A comprehensive landfill gas collection system with vertical wells and/or horizontal collectors providing 100% collection system coverage of all areas with waste within a few years after the waste is deposited.	✓	✓	✓	✓
5	A gas collection system which is operating effectively so that all wells are fully functioning (i.e., relatively free of liquids and drawing landfill gas under vacuum).	✓	✓	✓	✓

Note that the range of collection efficiencies which the EPA believes are achievable implies that there will always be some portion (at least 15%) of generated landfill gas that will escape collection, no matter how well designed the landfill or how comprehensive the gas collection system is. The following steps are recommended to adjust the efficiency below 85%:

- To evaluate collection efficiency, start at 85% for sites that fully meet all 5 criteria listed above, and then apply a discount to the extent the site does not meet the criteria, as described below.
- We suggest up to a 10% discount for not meeting item number 1, up to a 10% discount for not meeting item number 2, and up to a 5% discount for not meeting item number 3 (i.e., a 25% discount to collection efficiency if the landfill does not, even in part, meet any of the first three criteria).

- To account for item number 4, the resulting discounted estimate should then be multiplied by the collection system coverage of the refuse mass (see glossary for a definition of collection system coverage). Tips to consider when evaluating collection system coverage are provided below.

- The final discount to collection efficiency (item 5 above) involves an evaluation of collection system operations to determine the percentage of operational wells. The determination of whether or not a well is operational should be based on available wellfield monitoring data, including wellhead pressure (all wells should be under vacuum), well methane content, and well oxygen contents (low methane percentages under 40% and high oxygen percentages over 5% indicate that air instead of landfill gas is being drawn into the well). After accounting for the importance of the non-functioning wells (see below), multiply the percentage of operational wells by the value calculated in the above steps to develop a collection efficiency estimate.

The importance of a non-functioning well should be taken into account when estimating the percentage of non-functioning wells. For example, a site with a non-functioning well in the vicinity of other wells that are functional should cause less of a collection efficiency discount than a site with a non-functioning well that is the only well in the area available to draw landfill gas from a significant portion of the site.

Evaluation of collection system coverage requires a fair degree of familiarity with the system design. Well spacing and depth are important factors. The following describes the various scenarios to consider:

- Deeper wells can draw landfill gas from a larger volume of refuse than shallow wells because greater vacuum can be applied to the wells without drawing in air from the surface.

- Landfills with deep wells (greater than about 20 meters) can effectively collect landfill gas from all areas of the site with vertical well densities as low as two wells or less per hectare.

- Landfills with shallower wells will require greater well densities, perhaps more than 2

wells per hectare, to achieve the same coverage.

- Although landfills with a dense network of wells will collect more total gas than landfills with more widely spaced wells, landfills with a small number of well-spaced wells typically collect more gas per well (due to their ability to influence a larger volume of refuse per well) than wells at landfills with a dense network of wells.

2.2   Model Outputs - Table

Model results are displayed in a table located in the "Outputs-Table" worksheet that is ready for printing with minimal editing (see Figure 3 on the following page for a sample table layout). The title of the table has been set by user inputs in the Inputs worksheet. The table provides the following information which was either copied from the Inputs worksheet or calculated by the model:

- Projection years starting with the landfill opening year and ending in a year of the user's choosing.
- Annual disposal rates.
- Cumulative amount of waste in place for each projection year.
- Landfill gas generation rates for each projection year in cubic meters per minute, cubic meters per hour, and billion joules (G J) per year.
- Collection system efficiency for each projection year.
- Landfill gas recovery rates for each projection year in cubic meters per minute, cubic meters per hour, and billion joules (G J) per year.
- The methane content assumed for the model projection (50% in most cases).
- The k value used for the model run.
- The L_0 value used for the model run.

The table is set up to display up to 100 years of landfill gas generation and recovery estimates. As provided, the table shows 60 years of information. The last 40 years are in hidden rows. The user will likely want to change the number of years of information displayed, depending on how old the site is and how many years into the future the user wants to display information.

Typically, projections up to the year 2030 are adequate for most uses of the model. To hide additional rows, highlight cells in the rows to be hidden and select "Format" "Row" "Hide". To unhide rows, highlight cells in rows above and below rows to be displayed, and select "Format" "Row" "Unhide".

To print the table, select "File" "Print" "OK". The table should print out correctly formatted.

	A	B	C	D	E	F	G	H	I	J
1						**LFG GENERATION AND RECOVERY PROJECTION**				
2						**LANDFILL NAME - CITY, STATE**				
3										
4							Collection			
5		Disposal	Waste				System		LFG Recovery from	
6		Rate	In-Place		LFG Generation Rate		Efficiency		Existing and Planned System	
7	Year	(Tonnes/yr)	(Tonnes)	(m3/min)	(m3/hr)	(mmBtu/yr)	(%)	(m3/min)	(m3/hr)	(mmBtu/yr)
8	1991	50,000	50,000	0.0	0	0	0%	0.0	0	0
9	1992	50,000	100,000	1.0	62	9,753	0%	0.0	0	0
10	1993	50,000	150,000	2.0	121	18,891	0%	0.0	0	0
11	1994	50,000	200,000	2.9	175	27,455	0%	0.0	0	0
12	1995	50,000	250,000	3.8	227	35,480	0%	0.0	0	0
13	1996	50,000	300,000	4.6	275	43,000	0%	0.0	0	0
14	1997	50,000	350,000	5.3	320	50,046	0%	0.0	0	0
15	1998	50,000	400,000	6.0	362	56,649	0%	0.0	0	0
16	1999	50,000	450,000	6.7	401	62,837	0%	0.0	0	0
17	2000	50,000	500,000	7.3	438	68,635	0%	0.0	0	0
18	2001	50,000	550,000	7.9	473	74,068	60%	4.7	284	44,441
19	2002	50,000	600,000	8.4	506	79,159	60%	5.1	303	47,496
20	2003	50,000	650,000	8.9	536	83,930	60%	5.4	322	50,358
21	2004	50,000	700,000	9.4	565	88,401	60%	5.6	339	53,041
22	2005	50,000	750,000	9.9	592	92,590	60%	5.9	355	55,554
23	2006	50,000	800,000	10.3	617	96,516	60%	6.2	370	57,910
24	2007	50,000	850,000	10.7	640	100,195	60%	6.4	384	60,117
25	2008	50,000	900,000	11.0	662	103,642	60%	6.6	397	62,185
26	2009	50,000	950,000	11.4	683	106,872	60%	6.8	410	64,123
27	2010	50,000	1,000,000	11.7	702	109,899	60%	7.0	421	65,939
28	2011	50,000	1,050,000	12.0	720	112,735	60%	7.2	432	67,641
29	2012	50,000	1,100,000	12.3	737	115,393	60%	7.4	442	69,236
30	2013	50,000	1,150,000	12.6	753	117,884	60%	7.5	452	70,730
31	2014	50,000	1,200,000	12.8	768	120,218	60%	7.7	461	72,131
32	2015	50,000	1,250,000	13.0	782	122,405	60%	7.8	469	73,443
33	2016	50,000	1,300,000	13.3	795	124,454	60%	8.0	477	74,672
34	2017	50,000	1,350,000	13.5	807	126,374	60%	8.1	484	75,825
35	2018	50,000	1,400,000	13.6	819	128,174	60%	8.2	491	76,904
36	2019	50,000	1,450,000	13.8	830	129,860	60%	8.3	498	77,916
37	2020	50,000	1,500,000	14.0	840	131,440	60%	8.4	504	78,864
38	2021	50,000	1,550,000	14.2	849	132,921	60%	8.5	509	79,753
39	2022	50,000	1,600,000	14.3	858	134,309	60%	8.6	515	80,585
40	2023	50,000	1,650,000	14.4	866	135,609	60%	8.7	520	81,365
41	2024	50,000	1,700,000	14.6	874	136,827	60%	8.7	524	82,096
42	2025	50,000	1,750,000	14.7	881	137,969	60%	8.8	529	82,781
43	2026	50,000	1,800,000	14.8	888	139,039	60%	8.9	533	83,423
44	2027	50,000	1,850,000	14.9	895	140,041	60%	8.9	537	84,025
45	2028	50,000	1,900,000	15.0	901	140,981	60%	9.0	540	84,588
46	2029	50,000	1,950,000	15.1	906	141,861	60%	9.1	544	85,117
47	2030	50,000	2,000,000	15.2	912	142,686	60%	9.1	547	85,612
48	2031	50,000	2,050,000	15.3	916	143,459	60%	9.2	550	86,075
49	2032	50,000	2,100,000	15.4	921	144,183	60%	9.2	553	86,510
50	2033	50,000	2,150,000	15.4	925	144,862	60%	9.3	555	86,917
51	2034	50,000	2,200,000	15.5	929	145,498	60%	9.3	558	87,299
52	2035	50,000	2,250,000	15.6	933	146,094	60%	9.3	560	87,657
53	2036	50,000	2,300,000	15.6	937	146,653	60%	9.4	562	87,992
54	2037	50,000	2,350,000	15.7	940	147,176	60%	9.4	564	88,306
55	2038	50,000	2,400,000	15.7	943	147,667	60%	9.4	566	88,600
56	2039	50,000	2,450,000	15.8	946	148,126	60%	9.5	568	88,876
57	2040	50,000	2,500,000	15.8	949	148,557	60%	9.5	569	89,134
58	2041	50,000	2,550,000	15.9	952	148,960	60%	9.5	571	89,376
59	2042	50,000	2,600,000	15.9	954	149,338	60%	9.5	572	89,603
60	2043	50,000	2,650,000	15.9	956	149,693	60%	9.6	574	89,816
61	2044	50,000	2,700,000	16.0	958	150,025	60%	9.6	575	90,015
62	2045	50,000	2,750,000	16.0	960	150,336	60%	9.6	576	90,202
63	2046	50,000	2,800,000	16.0	962	150,628	60%	9.6	577	90,377
64	2047	50,000	2,850,000	16.1	964	150,901	60%	9.6	578	90,540
65	2048	50,000	2,900,000	16.1	966	151,157	60%	9.7	579	90,694
66	2049	50,000	2,950,000	16.1	967	151,397	60%	9.7	580	90,838
67	2050	50,000	3,000,000	16.1	969	151,622	60%	9.7	581	90,973
108	NOTES:									
109	Methane Content of LFG Adjusted to:				50%					
110	Methane generation rate constant (k):				0.065	/year				
111	Methane generation potential (L0):				84	cubic meters / metric tonne				

FIGURE 3. SAMPLE MODEL OUTPUT TABLE

2.3   Model Outputs - Graph

Model results are also displayed in graphical form in the "Outputs-Graph" worksheet (see Figure 4 on the following page for a sample graph layout). Data displayed in the graph includes the following:

- Landfill gas generation rates for each projection year in cubic meters per minute.
- Landfill gas recovery rates for each projection year in cubic meters per minute.
- Actual (historical) landfill gas recovery rates in cubic meters per minute.

As noted in the instructions listed below the graph, the title of the graph will need to be edited by clicking on the graph title and typing the desired title. The timeline shown in the x-axis will need editing if the user wishes to not have the projection end in 2030. To edit the x-axis for displaying an alternative time period, click on the x-axis and select "Format" "x-axis". Then select the "Scale" tab and input the desired opening and closing year for the projection. Also, because the graph is linked to the table, it will show data for all projection years shown in the table (given the limits set for the x-axis). It will not show any hidden rows. If the table shows years beyond the range set for the x-axis, the line of the graph will appear to go off of the edge of the graph. To correct this, the user will need to either hide the extra rows or edit the x-axis range to display the additional years.

To print the graph, click anywhere on the graph and select "File" "Print" OK". If the user does not click on the graph prior to printing, the instructions will also appear in the printout.

FIGURE 4. SAMPLE MODEL OUTPUT GRAPH

LFG Generation and Recovery - Sample Landfill
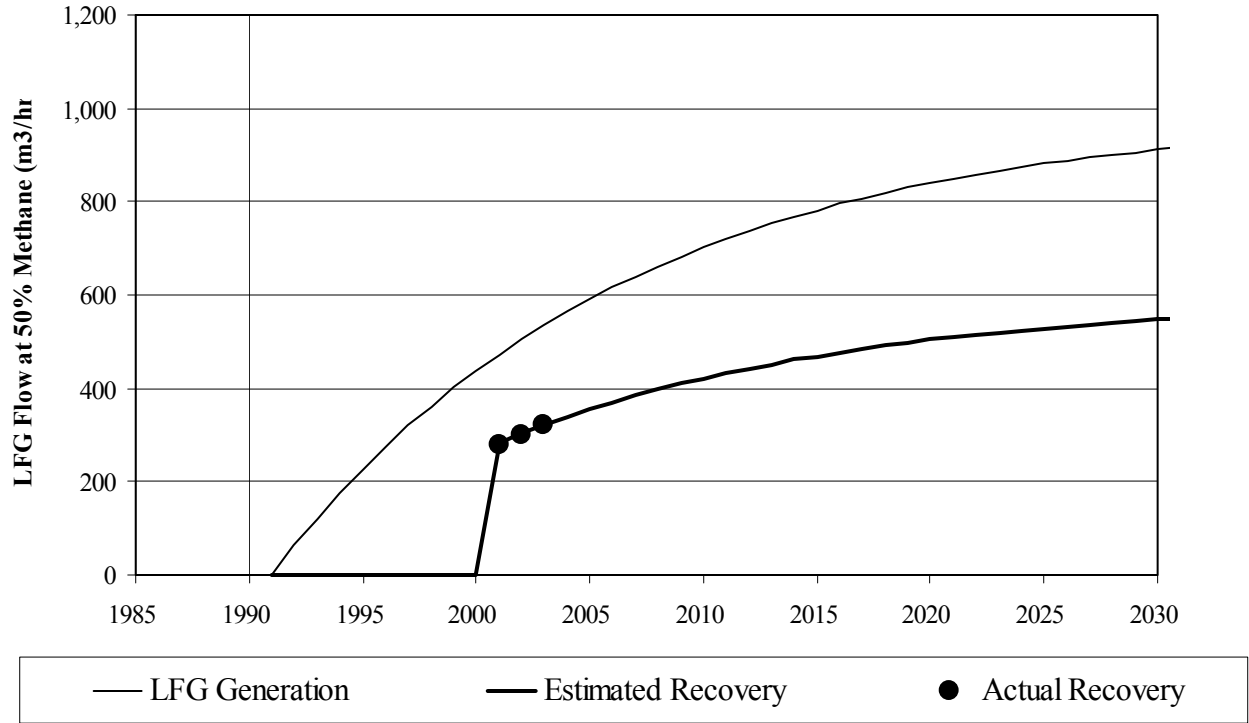
3.0 REFERENCES

EPA, 1991a. *Air Emissions from Municipal Solid Waste Landfills. Background Information for Proposed Standards and Guidelines,* EPA-450/3-90-011a (NTIS PB91-197061), Research Triangle Park, NC. U.S. Environmental Protection Agency.

EPA, 1991b. *Regulatory Package for New Source Performance Standards and III(d) Guidelines for Municipal Solid Waste Air Emissions.* Public Docket No. A-88-09 (proposed May 1991). Research Triangle Park, NC. U.S. Environmental Protection Agency.

EPA, 1998. *Compilation of Air Pollutant Emission Factors, AP-42, Volume 1: Stationary Point and Area Sources*, 5th ed., Chapter 2.4. Office of Air Quality Planning and Standards. Research Triangle Park, NC. U.S. Environmental Protection Agency.