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User's Manual
China Landfill Gas Model

Version 1.1

Prepared on behalf of:

Landfill Methane Outreach Program
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DISCLAIMER

This user's manual has been prepared specifically for China on behalf of the U.S. EPA's Landfill Methane Outreach Program, U.S. Environmental Protection Agency. 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. The U.S. EPA and its contractors ERG and OWT do 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. The U.S. EPA and its contractors ERG and OWT assume no responsibility for the accuracy of information obtained from, compiled, or provided by other parties.

ABSTRACT

This document is a user's manual for a computer model, Version 1.1 of a landfill gas (LFG) generation model for estimating LFG generation and recovery from existing or future municipal solid waste (MSW) landfills in China (China Landfill Gas Model v 1.1; referred to as China LFG Model hereafter). The model was developed by ERG and OWT under contract to the U.S. EPA's Landfill Methane Outreach Program (LMOP). The China LFG Model can be used to estimate LFG generation rates from landfills, and potential LFG recovery rates for landfills that have, or plan to have, gas collection and control systems in China.

The China 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, landfill location (in terms of climate zones), approximate coal ash content of the waste, history of landfill fires, and a number of landfill characteristics that determine LFG collection efficiency. Based on the site-specific data supplied by the user, the model selects recommended values for input variables, including methane generation rate constant (k), potential methane generation capacity (L_0), collection efficiency, and fire discount factor and estimates generation and recovery rates. Users can also specify their own values for these input variables, provided the information is reliable. The recommended values for input

variables were developed using data on climate, waste characteristics, and disposal practices in China, and the estimated effect of these conditions on the amounts and rates of LFG generation. Actual LFG recovery rates from four landfills in China were evaluated, but insufficient data were available to accurately calibrate the model results to actual recovery rates. Default values are recommended when site specific data are not available or are insufficient.

The China LFG Model was developed with the goal of providing general estimation of LFG generation and recovery potential. Other models evaluated during the model development process included the U.S. EPA Central America Landfill Gas Model Version 1 (SCS, 2007), and the Intergovernmental Panel on Climate Change (IPCC) 2006 Waste Model. The China LFG Model incorporates components of each of these models that help it to reflect conditions at disposal sites in China.

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GLOSSARY OF TERMS

TERM	DEFINITION
Climate Zone	One of three zones in China (1 – Cold and Dry; 2 – Cold and Wet; and 3 – Hot and Wet) characterized by the mean annual temperature (MAT), mean annual precipitation (MAP), and the ratio of MAP to potential evapotranspiration (PET).
Closure Year	The year in which the landfill ceased, or is expected to cease, accepting waste.
Coal-based Landfill	Coal-based landfill means the area served by the landfill uses predominantly coal for heating and cooking, and the coal ash is disposed of in the landfill.
Collection Efficiency	The estimated percentage of generated landfill gas that is or can be collected by a gas collection system.
Collection System Area Coverage	The percentage of the landfilled area that has (or will have) a comprehensive and operating landfill gas collection system.
Landfill Fire	Uncontrolled combustion of waste placed in a landfill. Landfill fires can be above ground or underground (subsurface). Signs of landfill fires include smoke (especially from cracks and fissures in the waste mass), elevated gas temperature and carbon monoxide levels, smoke-stained gas vents, smoldering wastes, excessive settlement, etc.
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.

TERM	DEFINITION
Methane Generation Rate Constant (k)	k is a model constant that determines the estimated rate of landfill methane 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. (Units = 1/year)
Opening Year	The year in which the landfill begins, or is expected to begin, accepting waste.
Ultimate Methane Generation Potential (L_0)	L_0 is a model constant that represents the potential capacity of a landfill to generate methane (a primary constituent of landfill gas). L_0 depends on the amount of degradable organic carbon in the refuse. (Units = cubic meters per megagram (m^3/Mg))

1.0 INTRODUCTION

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

The main purpose of the China LFG Model is to provide landfill owners, operators, and potential developers with a tool to evaluate the feasibility and potential benefits of collecting and using the generated LFG for energy recovery or other uses. To accomplish this purpose, this computer model provides estimates of potential LFG recovery rates and available emission reductions. This is accomplished using the LFG 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 LFG recovery estimates by multiplying the LFG generation by the estimated collection efficiency; potentially available emission reductions estimates are obtained by multiplying the LFG recovery estimates by the methane content, the density of methane, and the global warming potential of methane (21). The model also estimates energy output from either a direct use project or an electricity generation project.

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 LFG generation and recovery from a landfill (see the Glossary of Terms):

- The annual refuse disposal rate for the landfill;
- The methane generation rate (k) constant;
- The ultimate methane generation potential (L_0);
- The collection efficiency of the gas collection system;
- Whether there are (and/or have been) landfill fires at the site; and
- The opening and closure years of the landfill.

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 six month time lag between placement of waste and LFG generation. For each unit of waste, after six months 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 disposal rates, the model estimates the LFG generation rate in a given year using the following equation, which is used by the U.S. EPA's Landfill Gas Emissions Model (LandGEM) version 3.02 (EPA, 2005).

$$Q_M = \frac{1}{C_{CH4}} \sum_{i=1}^{n} \sum_{j=0.1}^{1} k\, L_O \left(\frac{M_i}{10}\right)\left(e^{-kt_{ij}}\right)$$

Where:

Where:	Q_M	=	maximum expected LFG generation flow rate (m^3/yr);
	i	=	1 year time increment
	n	=	(year of the calculation) – (initial year of waste acceptance)
	j	=	0.1 year time increment
	k	=	methane generation rate (1/yr);
	L_0	=	ultimate methane generation potential (m^3/Mg);
	M_i	=	mass of solid waste disposed in the i^{th} year (Mg);
	t_{ij}	=	age of the j^{th} section of waste mass disposed in the i^{th} year (decimal years).
	C_{CH4}	=	methane concentration (volume fraction).

The above equation is used to estimate LFG generation for a given year from each increment of 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 and the value of the methane generation rate constant).

The China 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 selects recommended values for k and L_0 based on information provided by the user regarding landfill location and approximate coal ash content of the waste. The recommended values were calculated using waste composition data gathered from representative landfills in different cities in China, in accordance with the methodology presented in the IPCC 2006 guidelines (IPCC, 2006). The recommended k and L_0 values vary depending on the climate zone and waste composition, and can be used to produce typical LFG generation estimates for landfills located in each of the three climate zones in China. Users can also specify their own values for k and L_0 provided that the information is reliable.

The China LFG Model also requires the user to provide information, either actual or anticipated/planned, on certain landfill construction and operation characteristics that determine the collection efficiency of the existing or potential future gas collection system. Based on the information provided by the user, the model would recommend a value for the collection efficiency. The recommended collection efficiency would then be used in combination with the LFG generation estimates to arrive at LFG recovery estimates. The user also has the option to input an alternative collection efficiency assumption or a site-specific collection efficiency.

EPA recognizes that modeling LFG 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 China develop gas collection and control systems, additional data on LFG generation and recovery will become available for model calibration and the development of improved model recommended values.

1.1 Landfill Gas Generation

The China LFG Model estimates LFG generation resulting from the biodegradation of refuse in landfills. The anaerobic decomposition of refuse in solid waste landfills generates LFG. The composition of MSW LFG is assumed by the model to be approximately 50 percent methane (CH_4) and 50 percent other gases, primarily carbon dioxide (CO_2) with trace amounts of other compounds.

This computer model uses a first-order decomposition rate equation and estimates volumes of LFG generation in cubic meters per minute (m^3/min) and cubic meters per hour (m^3/hr). Methane generation is estimated using two parameters: (1) L_0 is the ultimate methane generation potential of the refuse, and (2) k is the methane generation rate constant. For a unit of waste, LFG generation is assumed to be at its peak the first year following placement in the landfill. The model provides recommended values of L_0 and k based on input provided by the user; however, the model also allows the user to enter L_0 and k values derived using site-specific data collected at the landfill.[1]

1.1.1 Methane Generation Rate Constant (k)

The methane generation rate constant, k, determines the rate of generation of methane from refuse in the landfill. Its unit is 1/year, and describes the rate at which refuse placed in a landfill decays and produces biogas. 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.

Different waste types can have significantly different k values as a result of differences in decay rates. Food waste, for example decays faster than paper or wood. The k value also varies with climate, especially temperature, precipitation, and evapotranspiration. In the current model, a location in China is categorized as “cold or hot” and “dry or wet” based on the following two criteria in accordance with Table 3.4 in the IPCC 2006 Guidelines:

Cold vs. Hot:

- A location is “cold” if the mean annual temperature (MAT) is 20^{o}C or lower
- A location is “hot” if the MAT is higher than 20^{o}C

Dry vs. Wet:

For “hot” locations,

- It is dry if the mean annual precipitation (MAP) is less than 1000 millimeters (mm)
- It is wet if the MAP is 1000 mm or more

For “cold” locations,

- It is dry if the ratio of mean annual precipitation (MAP) to potential evapotranspiration (PET) is less than 1
- It is wet if the ratio of MAP to PET is greater than 1

Using the above two criteria, each location in China can be classified as belonging to one of the following three climatic zones (or regions):

Region 1: Cold and Dry

Region 2: Cold and Wet

Region 3: Hot and Wet

It should be noted that there are no hot and dry locations in China. To facilitate identification of the climatic zone in which a landfill is located, a map of China with the climatic zones delineated has been developed (see Figure 2 in Section 2.1); the user only needs to locate the landfill on the map to identify the corresponding climatic zone.

Unless a user-specified k value is entered into the China LFG Model, the model uses a recommended value of k selected based on the climatic zone in which the landfill is located. The recommended values of k were developed based on values calculated using IPCC methodology and waste composition data from landfills in different locations of China, adjusted through comparison with actual LFG recovery data from several landfills in China. The recommended k values for the three climatic zones are shown in Table 1 below.

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[1] Site-specific L_0 and k values may be developed for landfills with operating gas collection and control systems by calibrating the China LFG Model using known landfill gas recovery data; alternatively, L_0 and k values can be estimated based on climate and waste composition using IPCC methodologies (IPCC, 2006).

TABLE 1: METHANE GENERATION RATE (k)

Climatic Zone	k (per year)
Cold and Dry	0.04
Cold and Wet	0.11
Hot and Wet	0.18

It should be noted that the value of k for the "Cold and Wet" climate zone in Table 1 was based on typical national waste composition because no typical waste composition for that climate zone was available during model development; the value of k for this climate zone was also not adjusted through comparison with actual LFG recovery data because such data were not available.

1.1.2 Ultimate Methane Generation Potential (L_0)

Except in dry climates where a lack of moisture limits methane generation, the value for the ultimate methane generation potential of refuse (L_0) depends almost exclusively on the type of refuse present in the landfill. The higher the biodegradable organic carbon content of the refuse, the higher the value of L_0. The units of L_0 are in cubic meters of methane per metric tonne of refuse, which means that the L_0 value describes the total amount of methane gas potentially produced by a metric tonne of refuse as it decays over its lifetime. The values of theoretical and obtainable L_0 range from 6.2 to 270 m^3/Mg refuse (EPA, 1991).

Unless a user-specified L_0 value is entered into the China LFG Model, the model uses a recommended value of L_0 selected based on the climatic zone in which the landfill is located. The recommended values of L_0 are based on values calculated using IPCC methodology and waste composition data from landfills in different locations of China, adjusted through comparison with actual LFG recovery data from several landfills in China.

In addition to the landfill location, it has been reported that a major factor affecting waste composition (and thus L_0) in China is whether residents and businesses in the area served by a landfill predominantly use coal for heating and cooking purposes (such an area can be referred to as "coal-based"). The reason is that the wastes in coal-based areas, if coal ash is disposed of in the landfill, tend to have a much higher inert/ash content (typically more than 30%). In the absence of detailed data, it is assumed for the development of the current model that the value of L_0 for wastes in a coal-based landfill is half of the value of L_0 for wastes in a non-coal-based landfill in the cold regions of China. In the hot region of China, the value of L_0 for wastes in a coal-based landfill is assumed to be ¾ of the value of L_0 for wastes in a non-coal-based landfill.

Alternatively, if information on waste composition is available, whether coal ash makes up a significant fraction of the waste could be used to infer whether a landfill is in a coal-based area. Specifically, if the data indicate that coal ash makes up more than 30% of the waste, the waste's coal ash content can be described as significant and the landfill can be assumed to be in a coal-based area.

The recommended L_0 values for the three climatic zones are shown in Table 2 below.

TABLE 2: ULTIMATE METHANE GENERATION POTENTIAL (L_0)

Climatic Zone	**L_0 (m^3/Mg)**	
	Coal Ash Content <30% (Non-Coal-Based Landfill)	**Coal Ash Content >30% (Coal-Based Landfill)**
Cold and Dry	70	35
Cold and Wet	56	28
Hot and Wet	56	42

It should be noted that the value of L_0 for the "Cold and Wet" climate zone in Table 2 was based on typical national waste composition because no typical waste composition for that climate zone was not available during model development; the value of L_0 for this climate zone was also not adjusted through comparison with actual LFG recovery data because such data were not available.

1.1.3 Landfill Fires

Landfill fires have been reported or observed at a number of landfills in China. Landfill fires can be above ground or underground (subsurface). Once fires are started, especially subsurface landfill fires, they are very difficult to extinguish or control. Signs of landfill fires include smoke (especially from cracks and fissures in the waste mass), elevated LFG temperatures or carbon monoxide levels, smoke-stained gas vents, smoldering wastes, and accelerated settlement.

Landfill fires can consume a significant amount of the organic matter and thus drastically reduce the LFG generation rate. Landfill fires can also damage the LFG collection system, poison the methanogenic bacteria, and reduce the collection efficiency. For landfills where current or past landfill fires have been observed or are likely present, a reduction of 20 to 40% in the methane estimate might occur as the combined result of loss of organics and damaged collection system. If the user indicates that signs of current or past landfill fires were observed, the model applies a default fire discount factor (30% percent reduction) to the methane estimate.

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 or, alternatively, the collected gas can be used beneficially. Beneficial uses of LFG include use as fuel in energy recovery facilities, such as internal combustion engines, gas turbines, microturbines, steam boilers, furnaces, kilns, or other equipment that uses the gas as fuel to generate electricity or useable heat.

In addition to the energy benefits from the use of LFG, collection and control of generated LFG helps to reduce emissions that are harmful to the environment. Control of LFG destroys methane, which is a greenhouse gas that contributes to global climate change. Control of LFG also destroys organic compounds that could adversely affect human health. The collection and control of LFG also reduces the potential for methane migration, both on-site and off-site, thus mitigating the risks of explosions or fires.

1.2.1 Estimating Collection Efficiency

Collection efficiency is a measure of the ability of the gas collection system to capture generated LFG. It is a percentage value that is applied to the LFG generation projection produced by the model to estimate the amount of LFG that is or can be captured for flaring or beneficial use. Although rates of LFG 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 United States (U.S.) that meet U.S. design standards and have "comprehensive" gas collection systems. According to the U.S. EPA, collection efficiencies at such landfills typically range from 60% to 85%, with an average of 75%. A comprehensive LFG collection system is defined as a system of vertical wells and/or horizontal collectors providing 100%collection system coverage of all areas with waste within one year after the waste is deposited. Most landfills, particularly those that are still receiving wastes, have less than 100%collection system coverage, and require a "coverage factor" adjustment to the estimated collection efficiency. Sites with security issues or large numbers of uncontrolled waste pickers will not be able to install equipment in unsecured areas and cannot achieve comprehensive collection system coverage.

Table 3, "Landfill Collection Efficiency," shows an example of how to estimate the collection efficiency using responses to several questions related to landfill construction and operation to determine discounts to the collection efficiency. For example, if the responses are "Yes" to questions 1 to 2 and 4 to 7 and "No" to question 3, then there is no discount beyond the collection efficiency value of 85% related to questions 1 to 7. Furthermore, if the LFG System Area Coverage Percentage falls in bracket I, then the final estimated collection efficiency is 85% times the Area Coverage Factor (ACF) (0.95 in this case), or approximately 81%.

TABLE 3: LANDFILL COLLECTION EFFICIENCY

No.	Question	Collection Efficiency Discount (below 85%)	
		Yes	No
1	Is the waste placed in the landfill properly compacted on an ongoing basis?	0%	3%
2	Does the landfill have a focused tipping area?	0%	5%
3	Are there leachate seeps appearing along the landfill side slopes? Or is there ponding of water/leachate on the landfill surface?	10%	0%
4	Is the average depth of waste 10 m or greater?	0%	10%
5	Is any daily or weekly cover material applied to newly deposited waste?	0%	10%
6	Is any intermediate/final cover applied to areas of the landfill that have reached interim or final grade?	0%	5%
7	Does the landfill have a geosynthetic or clay liner?	0%	5%
8	In which bracket (I to V) does the LFG System Area Coverage Percentage fall?	Multiply by Area Coverage Factor (see below)	

The LFG System Area Coverage Percentage is defined as the percentage of the landfilled area that has a comprehensive and operating LFG collection system; brackets I to V are defined in the table below. The collection efficiency would be reduced by the ACF, which is estimated in accordance with the following table:

LFG System Area Coverage Percentage	Bracket	Area Coverage Factor (ACF)
80 – 100%	I	95%
60 – 80%	II	75%
40 – 60%	III	55%
20 – 40%	IV	35%
< 20%	V	15%

Note that the recommended method for estimating collection efficiency assumes that some portion (at least 15%) of generated LFG 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%, and then apply a discount based on the responses to each of seven questions, as described in Table 3 and below.
- We suggest a 3% discount for "No" to Question 1, a 5% discount for "No" to Question 2, a 10% discount for "Yes" to Question 3, a 10% discount each for "No" to Questions 4 and 5, and a 5% discount each for "No" to Questions 6 and 7 (i.e., a maximum of 48% discount to the collection efficiency) for the seven questions.
- Question 1 asks whether the waste placed in the landfill is properly compacted on an ongoing basis. The response should be "Yes" only if the incoming waste is compacted thoroughly as the waste is placed (or if the waste arrives at the landfill already compacted and baled). Thorough and timely compaction of the waste placed in the landfill reduces the amount of air (thus oxygen) in the waste mass, promoting anaerobic decomposition that generates LFG. Proper compaction of the waste would also minimize differential settlement (thus reducing potential problems with the collection piping), and decrease the amount of surface water infiltration (thus lowering the amount of leachate).
- Question 2 asks whether the landfill has a focused tipping area. The response should be "Yes" only if the tipping area is smaller than approximately 30 m by 30 m. A focused tipping area minimizes the area through which air and surface water can infiltrate into the waste mass. It is also a good landfill practice as there would be less exposed waste, thereby minimizing odor and pest nuisances.
- Question 3 asks whether there are leachate seeps appearing along the landfill side slopes, and whether there are ponds of water/leachate on the landfill surface. The response should be "No" only if there are neither leachate seeps nor ponds of water/leachate. The absence of leachate seeps and surficial ponds of water/leachate is indicative of a relatively well-drained waste mass with low leachate levels, which is beneficial to LFG collection.
- Question 4 asks whether the average depth of waste is 10 m or greater. The response should be "Yes" only if the depth of waste averaged over the entire landfill exceeds 10 m. Since the waste close to the top of the landfill tends to decompose aerobically and does not contribute to LFG generation, a shallower landfill would have a lower apparent collection efficiency since it has a larger proportion of such waste.
- Question 5 asks whether any daily or weekly cover material is applied to newly deposited waste. The response should be "Yes" only if newly deposited waste is covered with an appropriate material (such as soil, plastic tarp, or geosynthetics) on a regular basis, preferably daily but at least weekly; material with large voids such as gravels, construction and demolition debris or leaves and branches are not considered appropriate cover material. The timely application of appropriate cover material to newly deposited waste is essential to minimize the amount of rapidly decomposing waste (such as food waste) that undergoes aerobic decomposition; it is also necessary for the reduction of air and surface water infiltration and thus promote anaerobic

decomposition. Furthermore, it allows the collection system to operate under the necessary vacuum without drawing excessive air/oxygen into the system.

- Question 6 asks whether any intermediate/final cover is applied to areas of the landfill that have reached interim or final grade. The response should be "Yes" only if areas of the landfill that have reached interim or final grade receive an intermediate or final cover in a timely manner; i.e., preferably within one year of reaching such grades. Similar to daily or weekly cover, it is also necessary for the reduction of air and surface water infiltration, and allows the collection system to operate under the necessary vacuum.
- Question 7 asks whether the landfill has a geosynthetic or clay liner. The response should be "Yes" only if most, if not all, of the landfill has a properly designed bottom liner made of geosynthetics, clay or other appropriate material.
- Question 8 is related to the LFG System Area Coverage Percentage, namely in which bracket (I to V) does it fall. The LFG System Area Coverage Percentage is defined as the percentage of the landfill area that has a comprehensive and operating LFG collection system. The response to Question 8 should be selected based on the value of the LFG System Area Coverage Percentage according to the following table:

LFG System Area Coverage Percentage	**Bracket**
80 – 100%	I
60 – 80%	II
40 – 60%	III
20 – 40%	IV
< 20%	V

The estimation of collection efficiency has been partly automated in the model; the adjustment of the collection efficiency below 85% will be performed automatically, if a "Yes" or "No" response is provided to each of the seven questions. The model will also select the appropriate ACF, if the bracket (I to V) in which the LFG System Coverage Percentage falls is identified. The model will then reduce the adjusted collection efficiency by the ACF to calculate the final collection efficiency. Users can also specify their own value for the collection efficiency, if the information is reliable.

1.3 The Model

The China LFG Model can be operated in a Windows 2000®, Windows XP®, or Vista environment. The program is a Microsoft Excel® spreadsheet. Open the model file ("LMOP

China Model v1-1.xls") by choosing "file," "open," and then "open" when the correct file is highlighted. To enable the model to run correctly, the user will need to "enable macros" when prompted; since high security settings may automatically disable macros, it may be necessary to change the computer's security settings to enable macros.

The model has three worksheets as follows:

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

Only the inputs worksheet is accessible initially. The output table and output graph worksheets will become accessible, once all necessary information has been entered, by clicking on the "View Output Table" and "View Output Graph" buttons.

When using the model, all of the editing by the user should take place in the model inputs worksheet.

2.0 ESTIMATING LANDFILL GAS GENERATION AND RECOVERY

2.1 Model Inputs

All model inputs are entered into the model inputs worksheet. Cells highlighted in yellow require user inputs. See Figure 1 for model inputs. The following inputs are required to run the model properly and produce acceptable outputs (tables and graphs). If the landfill is an existing landfill, the inputs should be based on recorded data and actual conditions (where available), although inputs based on anticipated (or planned) conditions can be entered in some steps to obtain hypothetical estimates for evaluation purposes. For future landfills, by definition, inputs can only be based on anticipated (or planned) conditions.

Step 1. Enter the landfill name and title of the case study/project (Cell E10). The information entered here will automatically appear in the first heading of the output table and the output graph.

Step 2. Enter the location (city and province) of the landfill (Cell E11). The information entered here will automatically appear in the second heading of the output table and the output graph.

Step 3. Enter the year the landfill opened and began receiving waste (Cell E12). This value will feed into the annual landfill activity data table below and into the output table.

Step 4. Enter the year the landfill closed (or is projected to close) (Cell E13). This value will feed into the annual landfill activity data table below and into the output table.

Step 5. Enter the expected methane content of the LFG (Cell E14). This value will be used to calculate the net flow of the recovered gas. It is recommended that this value be left at 50% unless specific information is available from the site that warrants a different value.

Steps 6 through 16 are required if you want the model to recommend values for k, L_0, collection efficiency, and fire discount factor. You can skip to Step 17 if you have reliable information on these parameters and would like to enter site-specific values for these parameters (except the fire discount factor) instead.

Step 6. Select the climatic zone (region) of China where the landfill is located. This will impact the k and L_0 values. To see a map of China with the three climatic zones delineated (Figure 2), click the ‘Show Map of Regions of China’ button; click the ‘Hide Map of Regions of China’ button afterwards to continue entering inputs.

Step 7. Select the appropriate answer to the question “Does coal ash make up a significant fraction (more than 30%) of the waste placed in the landfill?”. This will impact the L_0 value, which is lower if a significant fraction of the waste is coal ash.

Step 8. Indicate whether there are signs of current or past subsurface fires at the landfill. This will impact the L_0 value.

The following eight steps require the user to provide information on the construction and operation of the landfill that determines the collection efficiency of the gas collection system. For Steps 9 through 15, select “Yes” or “No” as appropriate in response to each question; for Step 16, select the appropriate bracket (I to V) based on the value of the LFG System Area Coverage Percentage. Detailed discussions on how to select the appropriate responses to these eight questions were presented in Section 1.2.1.

Step 9. Is the waste placed in the landfill properly compacted on an ongoing basis?

Step 10. Does the landfill have a focused tipping area?

Step 11. Are there leachate seeps appearing along the landfill side slopes? Or are there ponds of water/leachate on the landfill surface?

Step 12. Is the average depth of waste 10 m or greater?

Step 13. Is any daily or weekly cover material applied to newly deposited waste?

Step 14. Is any intermediate/final cover applied to areas of the landfill that have reached interim or final grade?

Step 15. Does the landfill have a geosynthetic or clay liner?

Step 16. Which bracket (I to V) applies to the LFG System Area Coverage? The LFG System Area Coverage Percentage is defined as the percentage of the landfill area that has a comprehensive and operating LFG collection system.

LFG System Area Coverage Percentage	Bracket
80 – 100%	I
60 – 80%	II
40 – 60%	III

20 – 40%	IV
< 20%	V

If you do not have sufficient information to answer all of the questions in Steps 9 through 16, the model will not provide a recommended value for the collection efficiency. In such case, you can skip to Step 17 to enter an assumed/nominal value for collection efficiency. For a typical landfill constructed and operated in accordance with the state of practice in China, it is reasonable to use 25 to 40% as the collection efficiency before landfill closure /completion of the gas collection system and 50 to 65% subsequently.

FIGURE 1 – MODEL INPUTS

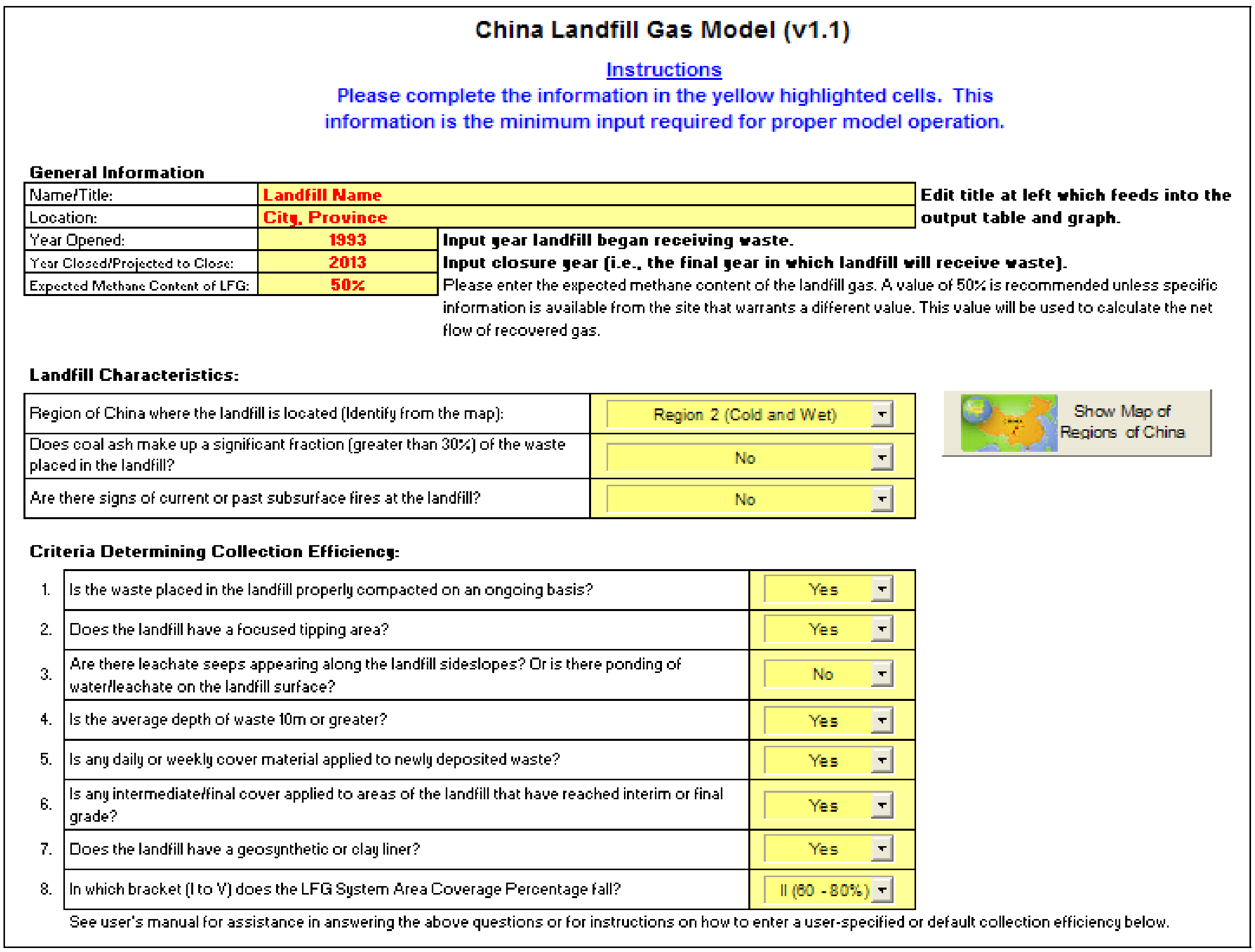
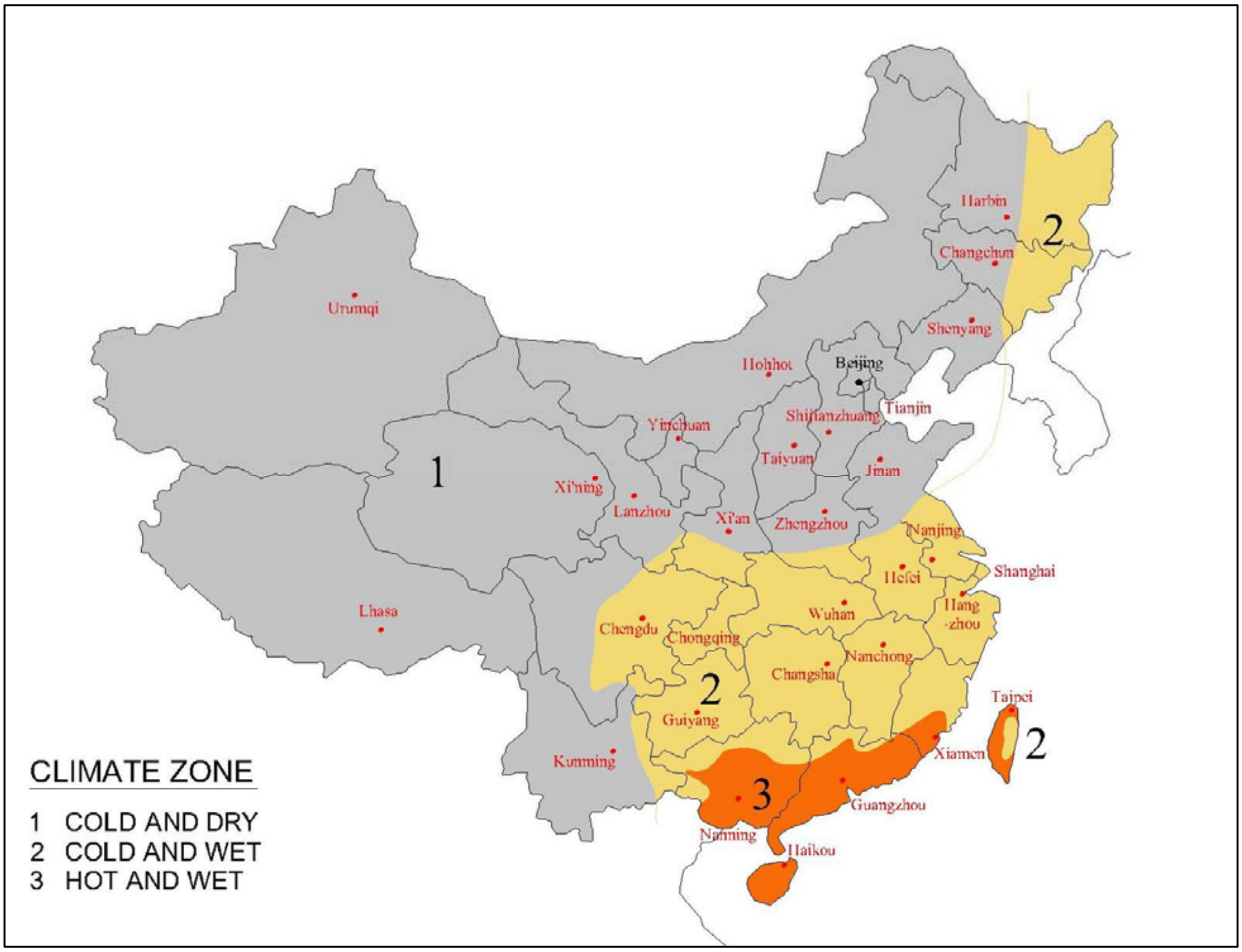


FIGURE 2 – CLIMATIC ZONES IN CHINA



Step 17. Review the values of k, L_0, collection efficiency, and fire discount factor recommended by the model based on his inputs in Steps 6 through 16. These appear under "Model Recommended Value." If you wish to change one or more of these values, or if you did not complete Steps 6 through 16 and want to enter site-specific value(s) for one or more of these parameters (except for the fire discount factor), enter the preferred value(s) under "User Recommended Value." Specifically, enter single values for k, L_0, and collection efficiency into Cells H43 through H45, respectively. This should be done only if you have reliable site-specific information on these parameters, or if you do not have sufficient information to answer the questions in Steps 9 through 16 and would like to enter an assumed/nominal value for the collection efficiency. If you enter a value for collection efficiency into cell H45, then the model will feed it into the annual landfill activity data table below and use it to estimate the LFG recovery rates.

Step 18. For collection efficiency, if you want to enter different values for different years, enter them into the corresponding cells in Column 4 of the Annual Landfill Activity Data table, see Figure 3. If not, skip to Step 19. The model defaults to assume that each year's collection efficiency is the same as the previous year; therefore, values for collection efficiency need to be entered only in the years it changes. For example, if the landfill improves (or plans to improve) the gas collection system or puts a final cap in place during a given year, you might want to enter a higher collection efficiency in Column 4 for that year. The model will automatically apply that collection efficiency to the subsequent years.

Step 19. Enter the average or actual annual waste disposal rate for the landfill in the opening year in Column 2 of the Annual Landfill Activity Data table (Cell E56). The model defaults to assume that the annual disposal rate for the years between the opening year and the closure year (inclusive) remains constant. If you want to enter different disposal rates for different years, continue to Step 20; otherwise, skip to Step 21.

Step 20. Enter the amount of waste disposed (in metric tonnes) for each year the site is open in Column 2, see Figure 3. The model accommodates up to 100 years of waste disposal history or projection. The model defaults to assume that each year's waste disposal amount is the same as that of the previous year; therefore, values for amount of waste disposed needs to be entered only in the years it changes. The disposal estimates should be based on available records of actual disposal rates and be consistent with site-specific data on amount of waste in place, total site capacity, and projected closure year. For years without historical data, adjust the disposal amounts until the calculated total tonnes in place matches estimated actual tonnes in place (as of the most recent year with waste-in-place data).

Step 21. Enter the actual LFG recovery rates in cubic meters per hour (for sites with active gas collection systems) in Column 5 of the Annual Landfill Activity Data table (see Figure 3). This should be the average annual total LFG flow at the flare station and/or energy recovery plant (NOT the sum of flows at individual wells) and is usually based on gas flow measurements. If the measured methane content was not entered in Step 5, adjust all flow rates to 50% methane equivalent by multiplying the measured flow by the measured methane content of the LFG and then dividing the result by 50% as indicated in the table below. (This is not necessary if the measured methane content was entered in Step 5.) The numbers placed in these cells will be displayed as data points in the graph output sheet, so do not input zeros for years with no flow data (leave blank instead). The actual measured values entered will not change the gas generation and recovery curves. Comparing the gas recovery projected by the model to actual data points provides an indication of how well the model is predicting gas recovery at the landfill.

Equation for adjusting methane content to 50%:

$$\text{Measured Flow Rate} \times \frac{\text{Measured methane \%}}{\text{50 \% methane}} = \text{Flow rate at 50\% methane}$$

FIGURE 3 - MODEL INPUTS

Modeling Parameters

Based on your inputs, the model will use the "model recommended" values below to estimate the gas potential of the landfill. If you have reliable data that suggest a different value should be used, you may enter it uder the user recommended value and it will be used to generate the gas estimates.

	Model Recommended Value	User Recommended Value
k (1/yr)	0.11	
L_0 (m^3/metric tonne)	56	
Collection Efficiency	64%	
Fire Discount Factor	None	**Cannot Be Changed**

Annual Landfill Activity Data

Input into column 2 the landfill's annual waste acceptance rate. The model recommended or user recommended collection efficiencies have been entered into column 4. You may change these if you have better data for any given year. If the landfill has a gas collection system in place and has measured actual gas recovery for given years, these data may be entered into column 5 (do not enter zeros).

1	2	3	4	5
Year	**Disposal Rate (metric tonnes/yr)**	**Waste-in-Place (metric tonnes)**	**LFG Collection System Efficiency**	**Actual Measured Recovery (m^3/hr)**
1993	20,671	20,671	64%	
1994	637,940	658,611	64%	
1995	710,128	1,368,739	64%	
1996	683,853	2,052,592	64%	
1997	796,020	2,848,612	64%	
1998	839,742	3,688,354	64%	
1999	891,953	4,580,307	64%	
2000	581,686	5,161,993	64%	
2001	657,914	5,819,907	64%	
2002	794,154	6,614,061	64%	
2003	1,176,472	7,790,533	64%	
2004	1,212,000	9,002,533	64%	
2005	1,343,320	10,345,853	64%	
2006	1,477,016	11,822,869	64%	
2007	1,681,515	13,504,384	64%	2,468
2008	1,788,500	15,292,884	64%	3,947
2009	1,860,040	17,152,924	64%	
2010	1,934,442	19,087,366	64%	
2011	1,354,819	20,442,185	64%	
2012	1,435,292	21,877,477	64%	
2013	1,227,323	23,104,800	64%	
2014	0	23,104,800	64%	

View Output Table

View Output Graph

2.2 Model Output - Table

Model results are displayed in a table located in the model “Output Table” worksheet (see Figure 4 for a sample table layout). The model output - table worksheet (and the model output - graph worksheet) is accessible only after all required information has been entered in the model input worksheet. The titles of the table have been set by user inputs in the model inputs worksheet. The table provides the following information, which was either copied from the model inputs worksheet or calculated by the model:

- Projection years starting with the landfill opening year and continues for 100 years in total.
- Annual disposal rates.
- Cumulative amount of waste in place at the end of each projection year.
- LFG generation rates for each projection year in cubic meters per minute and cubic meters per hour.
- Collection system efficiency for each projection year.
- LFG recovery rates for each projection year in cubic meters per minute and cubic meters per hour.
- Carbon dioxide equivalent of recoverable methane gas in metric tonnes per year ($MTCO_2e$/year).
- Potentially available energy output from a direct use project in megajoules per hour (MJ/hr) (assuming the gas is combusted in a boiler with 85% efficiency to produce steam).
- Potentially available energy output from a electric generation project in megawatts (MW) (assuming the gas is combusted in an engine with 30% efficiency to produce electricity).

Beneath the table, the following information is provided:

- The methane content assumed for the model projection (50%, unless changed by the user in the Inputs worksheet).
- The k value used for the model run.
- The L_0 value used for the model run.

To print the table, select “File”, “Print”, “OK”.

FIGURE 4 - SAMPLE MODEL OUTPUT TABLE

Return to Inputs Page

Landfill Name
City, Province

Year	Disposal Rate	Waste In-Place	LFG Generation Rate		Collection System Efficiency	LFG Recovery from Existing and Planned System			Energy Output From Direct Use Project[a]	Energy Output From Electric Generation Project[b]
	metric tonnes/yr	metric tonnes	(m^3/min)	(m^3/hr)	(%)	(m^3/min)	(m^3/hr)	$MTCO_2e$	(MJ/hr)	(MW)
1993	20,671	20,671	0	0	64%	0	0	0	0	0.000
1994	637,940	658,611	0	28	64%	0	18	1,163	298	0.028
1995	710,128	1,368,739	15	879	64%	9	560	36,937	9,452	0.902
1996	683,853	2,052,592	29	1,737	64%	18	1,108	73,046	18,692	1.783
1997	796,020	2,848,612	41	2,472	64%	26	1,576	103,916	26,591	2.537
1998	839,742	3,688,354	55	3,280	64%	35	2,091	137,881	35,282	3.366
1999	891,953	4,580,307	68	4,062	64%	43	2,589	170,769	43,698	4.169
2000	581,686	5,161,993	81	4,832	64%	51	3,081	203,168	51,988	4.960
2001	657,914	5,819,907	85	5,108	64%	54	3,256	214,735	54,948	5.242
2002	794,154	6,614,061	91	5,456	64%	58	3,478	229,386	58,697	5.600
2003	1,176,472	7,790,533	99	5,951	64%	63	3,793	250,176	64,017	6.107
2004	1,212,000	9,002,533	115	6,905	64%	73	4,402	290,313	74,287	7.087
2005	1,343,320	10,345,853	130	7,808	64%	83	4,978	328,268	84,000	8.014
2006	1,477,016	11,822,869	147	8,792	64%	93	5,605	369,659	94,591	9.024
2007	1,681,515	13,504,384	164	9,853	64%	105	6,281	414,261	106,004	10.113
2008	1,788,500	15,292,884	185	11,077	64%	118	7,062	465,723	119,173	11.369
2009	1,860,040	17,152,924	205	12,317	64%	131	7,852	517,844	132,510	12.641
2010	1,934,442	19,087,366	225	13,523	64%	144	8,621	568,562	145,488	13.880
2011	1,354,819	20,442,185	245	14,704	64%	156	9,374	618,183	158,185	15.091
2012	1,435,292	21,877,477	250	14,985	64%	159	9,553	630,021	161,214	15.380
2013	1,227,323	23,104,800	256	15,345	64%	163	9,783	645,154	165,087	15.749
2014	0	23,104,800	256	15,389	64%	164	9,811	647,009	165,561	15.795
2015	0	23,104,800	230	13,786	64%	146	8,789	579,613	148,316	14.149
2016	0	23,104,800	206	12,350	64%	131	7,873	519,237	132,866	12.675
2017	0	23,104,800	184	11,064	64%	118	7,053	465,150	119,026	11.355
2018	0	23,104,800	165	9,911	64%	105	6,318	416,698	106,628	10.172
2019	0	23,104,800	148	8,879	64%	94	5,660	373,292	95,521	9.113
2020	0	23,104,800	133	7,954	64%	85	5,071	334,408	85,571	8.163
2021	0	23,104,800	119	7,125	64%	76	4,542	299,574	76,657	7.313
2022	0	23,104,800	106	6,383	64%	68	4,069	268,368	68,672	6.551
2023	0	23,104,800	95	5,718	64%	61	3,645	240,414	61,519	5.869
2024	0	23,104,800	85	5,123	64%	54	3,266	215,371	55,111	5.258

2.3 Model Output - Graph

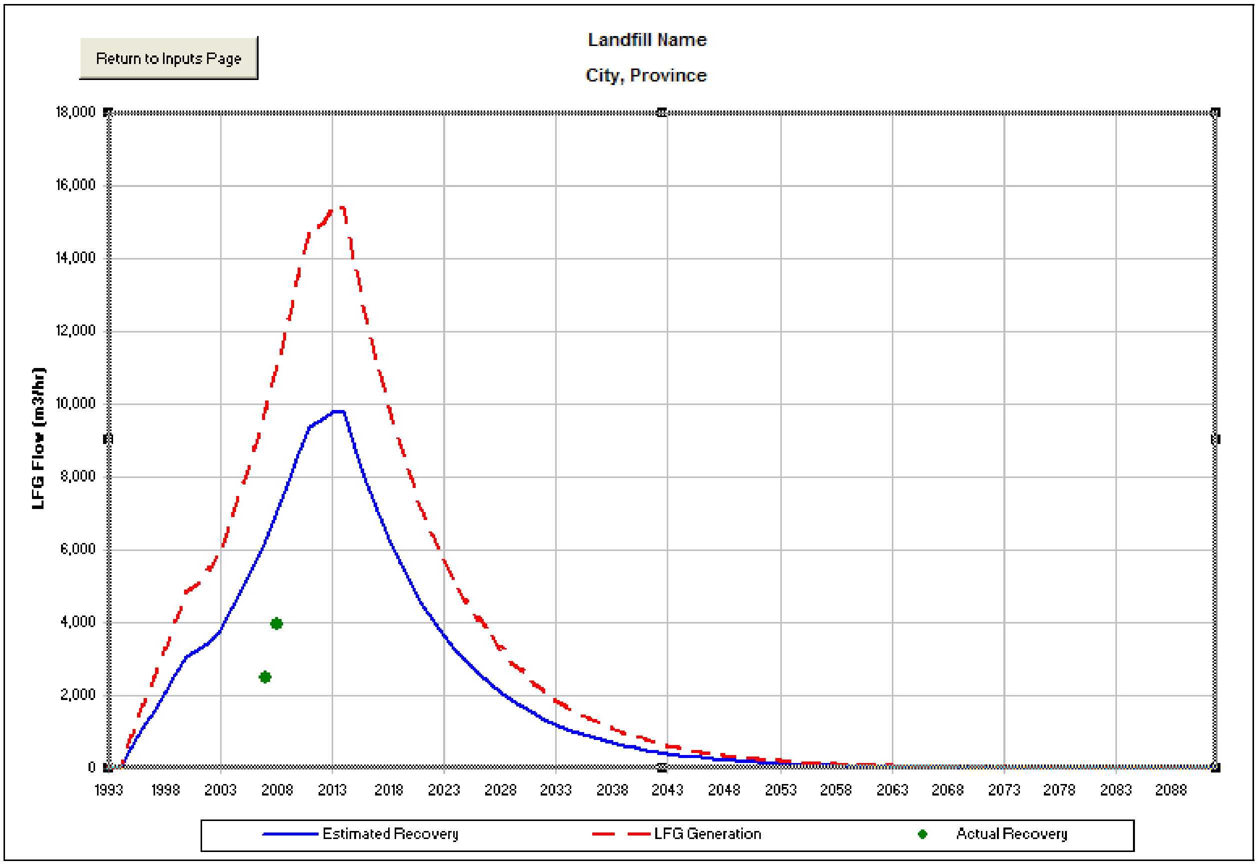
Model results are also displayed in graphical form in the model "Output Graph" worksheet. See Figure 5 for a sample graph layout. Data displayed in the graph includes the following:

- A curve of LFG generation rates during the projection years in cubic meters per hour.
- A curve of LFG recovery rates during the projection years in cubic meters per hour
- Actual (historical) LFG recovery rates in cubic meters per hour, shown as individual data points.

The titles of the graph have been set by user inputs in the model inputs worksheet.

To print the graph, click anywhere on the graph and select "File", "Print", "OK".

FIGURE 5 - SAMPLE MODEL OUTPUT GRAPH



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