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# Use of Spreadsheets in Environmental Education: an Application for Solid Waste Management*

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*Spreadsheets have gained increasing popularity in engineering applications, used by both students and practicing engineers. In addition to their low cost, they are easy to learn, and provide the user with the flexibility to display different sets of results just upon changing the input data. This paper illustrates the use of an Excel spreadsheet for solid waste management practices. The program, which has been developed as part of the 'Solid Waste Management' course at the Faculty of Engineering and Architecture, American University of Beirut, allows the user to determine the chemical composition of the waste and its corresponding gas generation potential which are directly linked to a module that allows the prediction of the temporal distribution of gas and leachate production from landfills. The data representing the waste composition and chemistry, gas and leachate production are then automatically plotted into a series of curves and bar charts that allow the decision maker and designer to point out important characteristics, trends and relationships among various parameters controlling solid waste management control systems and landfill operations.*

## INTRODUCTION

DESIGNED around the year 1980, spreadsheets were initially used in business and financial applications, allowing a dramatic development of deterministic simulations throughout the years. More recently, spreadsheets have found their way into many engineering and mathematical applications, where they are currently used as an educational tool in many engineering courses [1–3]. The latter often tend to emphasize mathematical steps and formulas, where students often fail to make the connection between the mathematical statement and the actual engineering problem [4]. As such, the widespread availability of spreadsheet software and their low cost and simplicity, enable students to handle complicated formulae and equations quite easily while applying the engineering concepts. In addition to mathematical functions, spreadsheets include logical, statistical, and matrix operations. Graphs can be made easily and quickly, providing the user with the capability of displaying intermediate results and observing the effect of varying different parameters almost instantly. These characteristics improve the problem-solving skills of students, and explain the continuously increasing popularity of spreadsheets, especially in the case of problems involving repetitive calculations [4, 5]. The two most significant educational disadvantages of spreadsheets are that they cannot handle algebraic variables directly and they require a computer to operate them. As such, students will not normally be permitted to use spreadsheets during examinations.

This paper illustrates the use of an Excel spreadsheet program in environmental education, as an application tool for solid waste management. The program allows the user to determine the chemical composition of the waste and its corresponding gas generation and leachate production rates. Such data contribute to the design basis of landfills (i.e. sizing gas and leachate collection systems and the choice of management alternatives). Output data are displayed into tables and plotted into a series of curves and bar charts, making the program an effective tool for designers and decision makers. These features are demonstrated through the presentation of a typical case study.

## THEORY

### *Elemental waste constituents*

The key element in designing a proper waste management plan is the determination of the waste composition. However, this is not an easy task given the heterogeneous nature of solid wastes. The procedure involves analyzing a representative quantity of the designated wastes, and determining the percentage, by mass, of each component within the analyzed sample. The chemical composition of solid wastes is then determined through what is referred to as 'ultimate analysis' of its components. The procedure involves the determination of the percentage of carbon (C), hydrogen (H), oxygen

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Table 1. Typical data on ultimate analysis of solid waste components [10]

| Component | Moisture content % | C | H | O | N | S | Ash |
|---|---|---|---|---|---|---|---|
| Organics | | | | % by mass (dry basis) | | | |
| Food waste | 9 | 48 | 6.4 | 37.6 | 2.6 | 0.4 | 5 |
| Paper | 34 | 43.5 | 6 | 44 | 0.3 | 0.2 | 6 |
| Cardboard | 6 | 44 | 5.9 | 44.6 | 0.3 | 0.2 | 5 |
| Plastics | 7 | 60 | 7.2 | 22.8 | 0 | 0 | 10 |
| Textiles | 2 | 55 | 6.6 | 31.2 | 4.6 | 0.15 | 2.5 |
| Rubber | 0.5 | 78 | 10 | 0 | 2 | 0 | 10 |
| Leather | 0.5 | 60 | 8 | 11.6 | 10 | 0.4 | 10 |
| Yard waste | 18.5 | 47.8 | 6 | 38 | 3.4 | 0.3 | 4.5 |
| Wood | 2 | 49.5 | 6 | 42.7 | 0.2 | 0.1 | 1.5 |
| Inorganics | | | | % by mass (dry basis) | | | |
| Glass | 8 | 0.5 | 0.1 | 0.4 | 0.1 | 0 | 98.9 |
| Tin cans | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aluminum | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other metals | 3 | 4.5 | 0.6 | 4.3 | 0.1 | 0 | 90.5 |
| Dirt, Ash, etc. . . . | 3 | 26.3 | 3 | 2 | 0.5 | 0.2 | 68 |

(O), nitrogen (N), sulfur (S), and ash. The results are then used to characterize the chemical composition of the organic matter in the wastes. Table 1 presents the various components of municipal solid wastes, along with typical data on their moisture content and the percentage composition by mass (dry basis) of the chemical elements within each component.

The organic components of solid wastes are often classified into rapidly biodegradable wastes (RBW), moderately biodegradable wastes (MBW), and slowly biodegradable wastes (SBW) in accordance with their ease of biodegradability. The amount of wastes within RBW, MBW, and SBW are around 90, 75, and 50 percent, respectively.

*Gas generation*

Once deposited in a landfill, solid wastes are subject to a short-lived aerobic phase (up to six months) before the prevalence of an anaerobic phase (more than 20 years). The latter phase is of more significance from a design and operation perspective. During this phase, long term anaerobic biodegradation of the waste components result in gas generation in accordance with Equation (1):

$$[C_aH_bO_cN_dS_e] + \left(\frac{4a-b-2c+3d+2e}{4}\right)[H_2O] \rightarrow \left(\frac{4a+b-2c-3e-2e}{8}\right)[CH_4] + \left(\frac{4a-b+2c+3d+2e}{8}\right)[CO_2] + d[NH_3] + e[H_2S] \quad (1)$$

When the waste components are defined, the parameters a, b, c, d, and e in Equation (1) are determined through an ultimate analysis (Table 1) and used to calculate the volume of methane ($CH_4$), carbon dioxide ($CO_2$), ammonia ($NH_3$), and hydrogen sulfide ($H_2S$) gases generated per unit mass of wastes. Equation (1) provides the total potential gas generation over the lifetime of the wastes, assuming the complete conversion of the biodegradable organic wastes into mainly $CH_4$

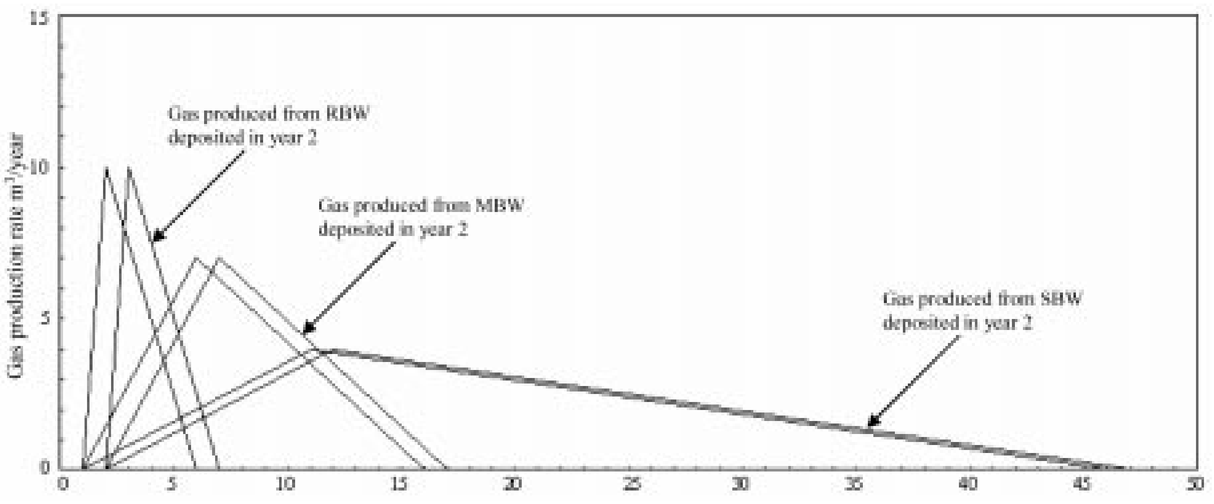


Fig. 1. Triangular gas production models over a 5-year period for RBW and MBW.

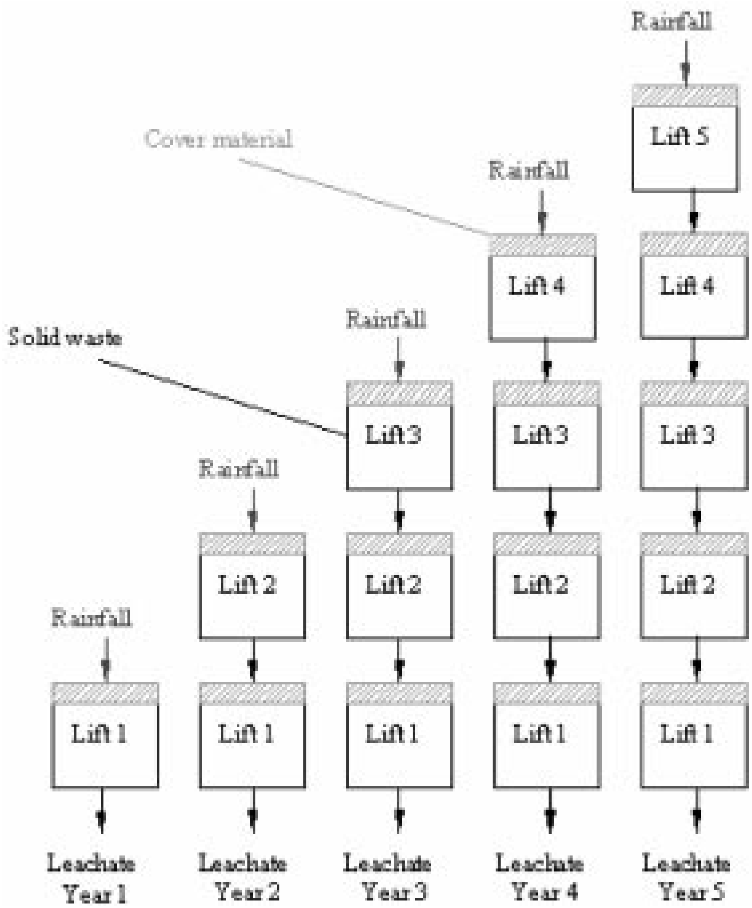


Fig. 2. Leachate production.

Table 2. Input parameters for landfill analysis

| | |
|---|---|
| *Waste quantities* | |
| Waste deposited per day | 1000 Tons |
| Number of operating days per year | 300 days |
| *Waste characteristics* | |
| Specific weight | 600 kg/m$^3$ |
| Time for rapid decomposition | 5 years |
| Time for moderate decomposition | 15 years |
| Time for slow decomposition | 45 years |
| Amount of yard decomposing moderately | 60% |
| Amount of yard decomposing slowly | 40% |
| *Landfill characteristics* | |
| Lift height | 3 m |
| Waste to cover ratio | 5:1 |
| Number of lifts | 5 |
| Specific weight of cover material | 1800 kg/m$^3$ |
| *Rainfall quantities* | |
| Intensity of rainfall | 100 mm/year |
| *Gas generation* | |
| Water consumed for gas production | 0.16 kg/m$^3$ of gas produced |
| Water vapor escaping with gas from landfill | 0.016 kg/m$^3$ of gas produced |
| Specific weight of gas | 1.34 kg/m$^3$ |

Table 3. Waste composition

| Waste component | % by weight (wet basis) | Moisture content (%) |
|---|---|---|
| *Organics* | | |
| Food waste | 9 | 70 |
| Paper | 34 | 6 |
| Cardboard | 6 | 5 |
| Plastics | 7 | 2 |
| Textiles | 2 | 10 |
| Rubber | 0.5 | 2 |
| Leather | 0.5 | 10 |
| Yard waste | 18.5 | 60 |
| Wood | 2 | 20 |
| Misc. organics | 0 | 0 |
| *Total organics* | *79.5* | |
| *Inorganics* | | |
| Glass | 8 | 2 |
| Tin cans | 6 | 3 |
| Aluminum | 0.5 | 2 |
| Other metals | 3 | 3 |
| Dirt, ash, etc. . . | 3 | 8 |
| *Total inorganics* | *20.5* | |
| *Total* | *100* | *21.22* |

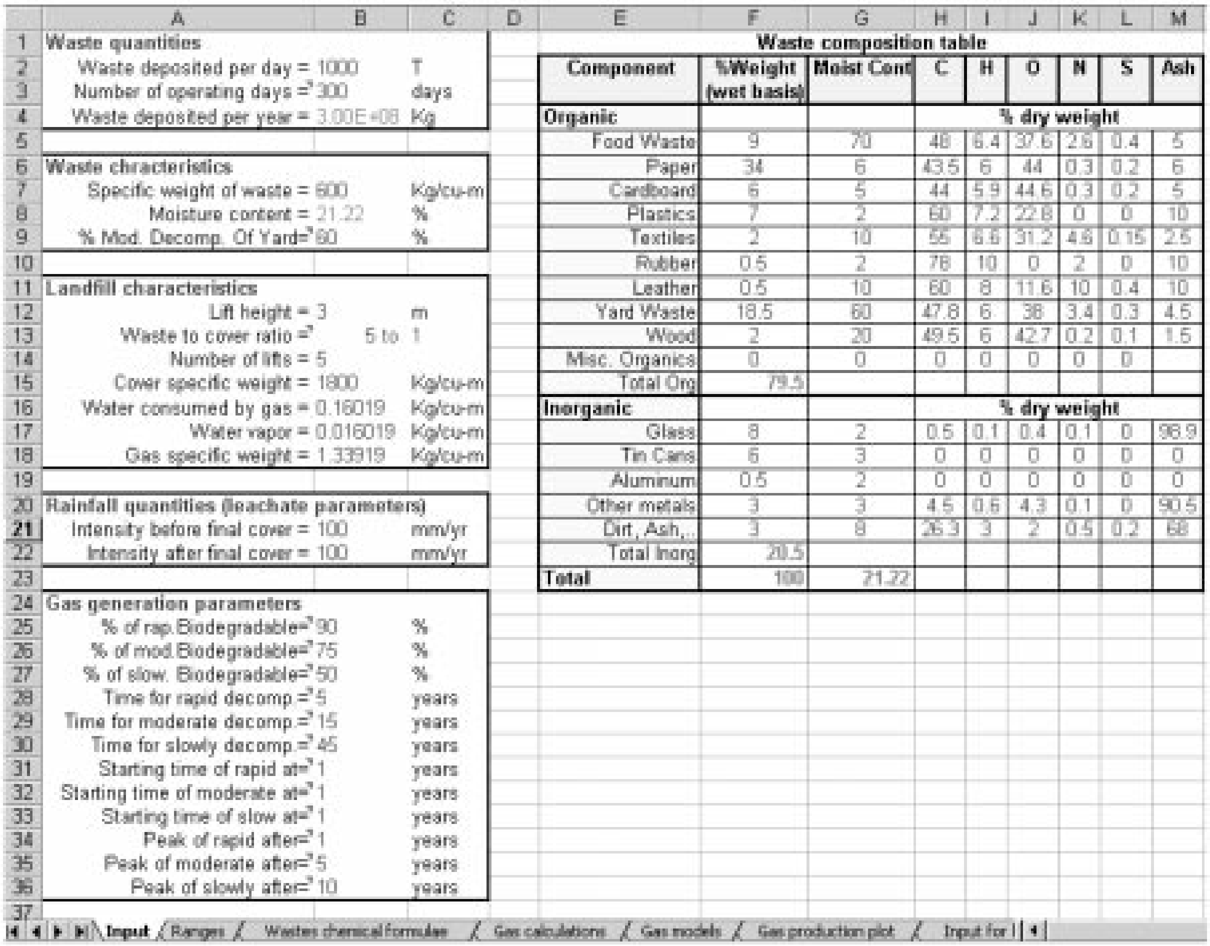


Fig. 3. Excel input sheet.

and $CO_2$. The yearly gas production rates for rapidly, moderately, and slowly decomposable wastes can be determined graphically, using a predefined gas production function. The amount of gas produced at a certain period of time is linearly interpolated along the given model. The gas generation models assume that the time periods for total decomposition of RBW, MBW, and SBW are 5, 15 and 45 years, respectively, with the peak rate of gas production occurring 1, 5 and 10 years after gas production starts (Fig. 1), which normally occurs at about 1 year after waste deposition into the landfill.

*Leachate generation*

A landfill is composed of a set of cells or compartments in which the wastes are buried. Leachate is the liquid created when rain, melting snow, or liquid within garbage seeps through the waste, picking up and carrying with it dissolved material. These cells are placed in layers, and the calculations for leachate production are conducted for the separate layers (Fig. 2). These calculations involve summing up the amounts of water entering the landfill in the form of rainfall and subtracting those consumed in chemical reactions and leaving as water vapor. The potential leachate formed is thus the quantity of water in excess of the moisture-holding capacity of the landfill material, consisting of the minimum amount of water that can be held in the solid wastes, which in turn cannot be used by the reactions taking place within the landfill. As such, leachate production rates are calculated using the water balance equation (2):

$$\Delta S_{SW} = W_{SW} + W_{TS} + W_{CM} + W_{AR} - (W_E + W_{LG} + W_{WV} + W_{BL}) \quad (2)$$

where:

- $\Delta S_{SW}$ = change in the amount of water stored in solid waste in the landfill
- $W_{SW}$ = water (moisture) in solid waste
- $W_{TS}$ = water (moisture) in incoming sludge
- $W_{CM}$ = water (moisture) in cover material
- $W_{AR}$ = water from above (for upper landfill layer, water from above corresponds to rainfall or water from snowmelt)
- $W_E$ = water lost due to surface evaporation
- $W_{LG}$ = water consumed in the formation of landfill gas
- $W_{WV}$ = water (vapor) lost with the landfill gas
- $W_{BL}$ = water from below (for the cell placed directly above a leachate collection system, water from the bottom corresponds to leachate)

B6 = =VLOOKUP(A6,Composition,2,FALSE)

| | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **Component** | **% Weight** | **% Dry Weight** | **C** | **H** | **O** | **N** | **S** | **Ash** |
| 2 | **Rapidly** | | | | | | | | |
| 3 | Food Waste | 9 | 2.7 | 1.30 | 0.17 | 1.02 | 0.07 | 0.01 | 0.14 |
| 4 | Total | 9 | 2.7 | 1.3 | 0.2 | 1.0 | 0.1 | 0.0 | 0.1 |
| 5 | **Moderately** | | | | | | | | |
| 6 | Paper | 34 | 32.0 | 13.90 | 1.92 | 14.06 | 0.10 | 0.06 | 1.92 |
| 7 | Cardboard | 6 | 5.7 | 2.51 | 0.34 | 2.54 | 0.02 | 0.01 | 0.29 |
| 8 | Yard Waste | 11.1 | 4.4 | 2.12 | 0.27 | 1.69 | 0.15 | 0.01 | 0.20 |
| 9 | Total | 51.1 | 42.1 | 18.53 | 2.52 | 18.29 | 0.26 | 0.09 | 2.40 |
| 10 | **Slowly** | | | | | | | | |
| 11 | Textiles | 2 | 1.8 | 0.99 | 0.12 | 0.56 | 0.08 | 0.00 | 0.05 |
| 12 | Rubber | 0.5 | 0.5 | 0.38 | 0.05 | 0.00 | 0.01 | 0.00 | 0.05 |
| 13 | Leather | 0.5 | 0.5 | 0.27 | 0.04 | 0.05 | 0.05 | 0.00 | 0.05 |
| 14 | Yard Waste | 7.4 | 3.0 | 1.41 | 0.18 | 1.12 | 0.10 | 0.01 | 0.13 |
| 15 | Wood | 2 | 1.6 | 0.79 | 0.10 | 0.68 | 0.00 | 0.00 | 0.02 |
| 16 | Total | 12.4 | 7.3 | 3.85 | 0.48 | 2.42 | 0.24 | 0.01 | 0.30 |
| 17 | | | | | | | | | |
| 18 | | Kg/mole | 12.01 | 1.01 | 16.00 | 14.01 | 32.06 | | |
| 19 | | Rapidly | 0.1079 | 0.1711 | 0.0635 | 0.0050 | 0.0003 | | |
| 20 | | Moderately | 1.5431 | 2.4953 | 1.1432 | 0.0188 | 0.0028 | | |
| 21 | | Slowly | 0.3205 | 0.4727 | 0.1514 | 0.0172 | 0.0005 | | |
| 22 | | | | | | | | | |
| 23 | | | **a** | **b** | **c** | **d** | | | |
| 24 | | Rapidly | 22.00 | 34.00 | 13.00 | 1.00 | | C22 H34 O13 N1 | |
| 25 | | Moderately | 82.00 | 132.00 | 61.00 | 1.00 | | C82 H132 O61 N1 | |
| 26 | | Slowly | 19.00 | 27.00 | 9.00 | 1.00 | | C19 H27 O9 N1 | |
| 27 | | | | | | | | | |
| 28 | | | Rapidly | Moderately | Slowly | | | | |
| 29 | | Waste molar mass | 521.00 | 2108.00 | 413.00 | | | | |
| 30 | | H2O= | 108.00 | 324.00 | 126.00 | | | | |
| 31 | | CH4= | 193.00 | 674.00 | 161.00 | | | | |
| 32 | | CO2= | 440.00 | 1760.00 | 396.00 | | | | |
| 33 | | NH3= | 17.00 | 17.00 | 17.00 | | | | |
| 34 | | | | | | | | | |
| 35 | | | Rapidly | Moderately | Slowly | | | | |
| 36 | | CH4 (cu-m) | 1.39 | 18.76 | 3.97 | | | | |
| 37 | | CO2 (cu-m) | 1.15 | 17.77 | 3.54 | | | | |
| 38 | | | | | | | | | |
| 39 | | | Rapidly | Moderately | Slowly | | | | |
| 40 | | Gas (cu-m/Kg) | 0.94 | 0.87 | 1.03 | | | | |

Input / Ranges / **Wastes chemical formulae** / Gas calculations / Gas models / Gas production plot

Fig. 4. Estimation of the waste chemical composition.

## CASE STUDY

This section presents a typical case study involving the characterization of a given waste composition, and calculation of gas generation and leachate production rates using an Excel spreadsheet. The waste composition, biodegradability, landfill specifications, and other characteristics and assumptions were extracted from Tchobanoglous *et al.* [10], which is a standard reference used in the instruction of a solid waste management course for senior or graduate level students in Civil and Environmental Engineering.

### *Problem description*

The following example applies the developed spreadsheet for the analysis of a landfill with a 5-year life period, and in which 1000 tons/day of municipal solid wastes are to be deposited. The amount of rainfall infiltrating the daily cover is given during and after the first 5 years of landfill operation. No sludge from wastewater treatment plants is disposed with the wastes, and the peak rate of gas production occurs 1, 5, and 10 years after gas production starts, for RBW, MBW, and SBW, respectively (Fig. 1). Table 2 summarizes the input parameters for use within the spreadsheet. The general composition and the moisture content of the solid wastes are presented in Table 3. Such data are normally obtained from a typical waste characterization study conducted at the field level.

### *Spreadsheet implementation*

The spreadsheet, written using Microsoft Excel, is composed of multiple sheets linked to perform the calculations and display the results into tables, graphs, and bar charts. The user first inputs the parameters defined in Table 2, specifying the

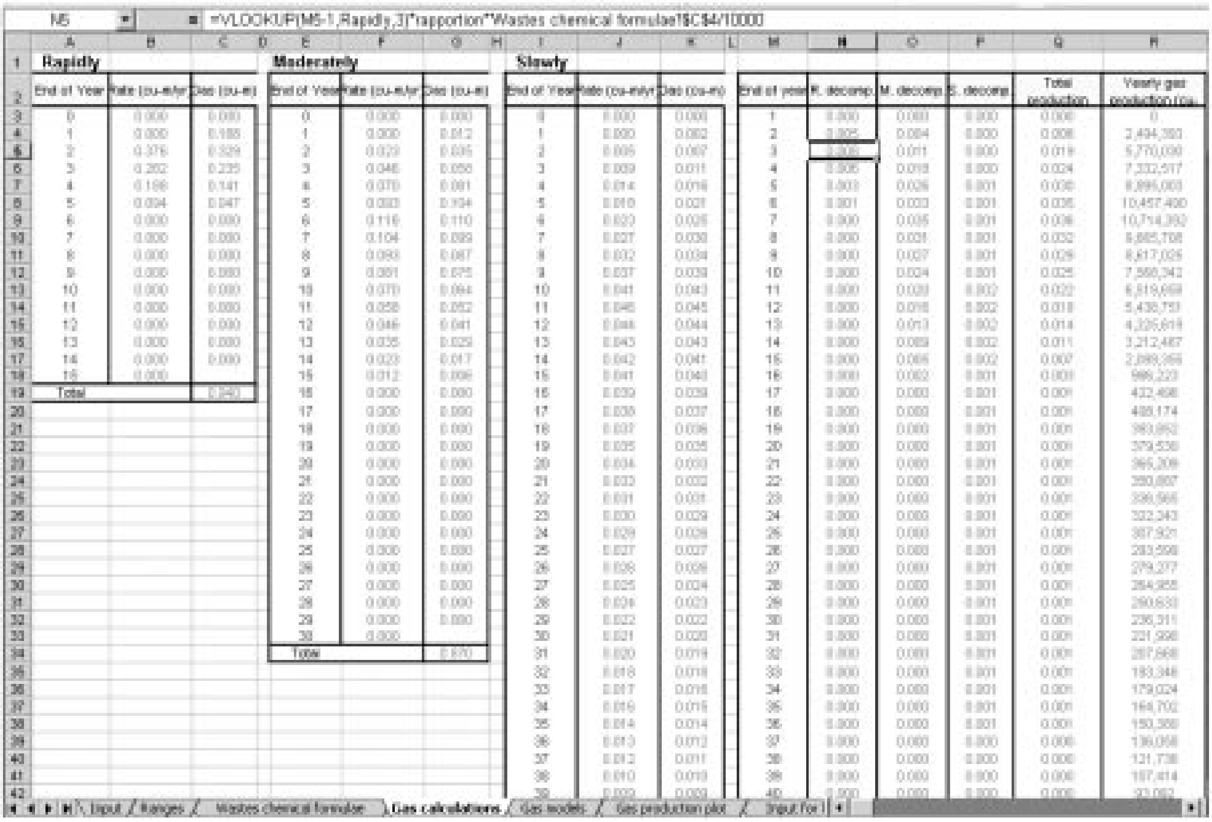


Fig. 5. Calculation of gas generation rates at the landfill.

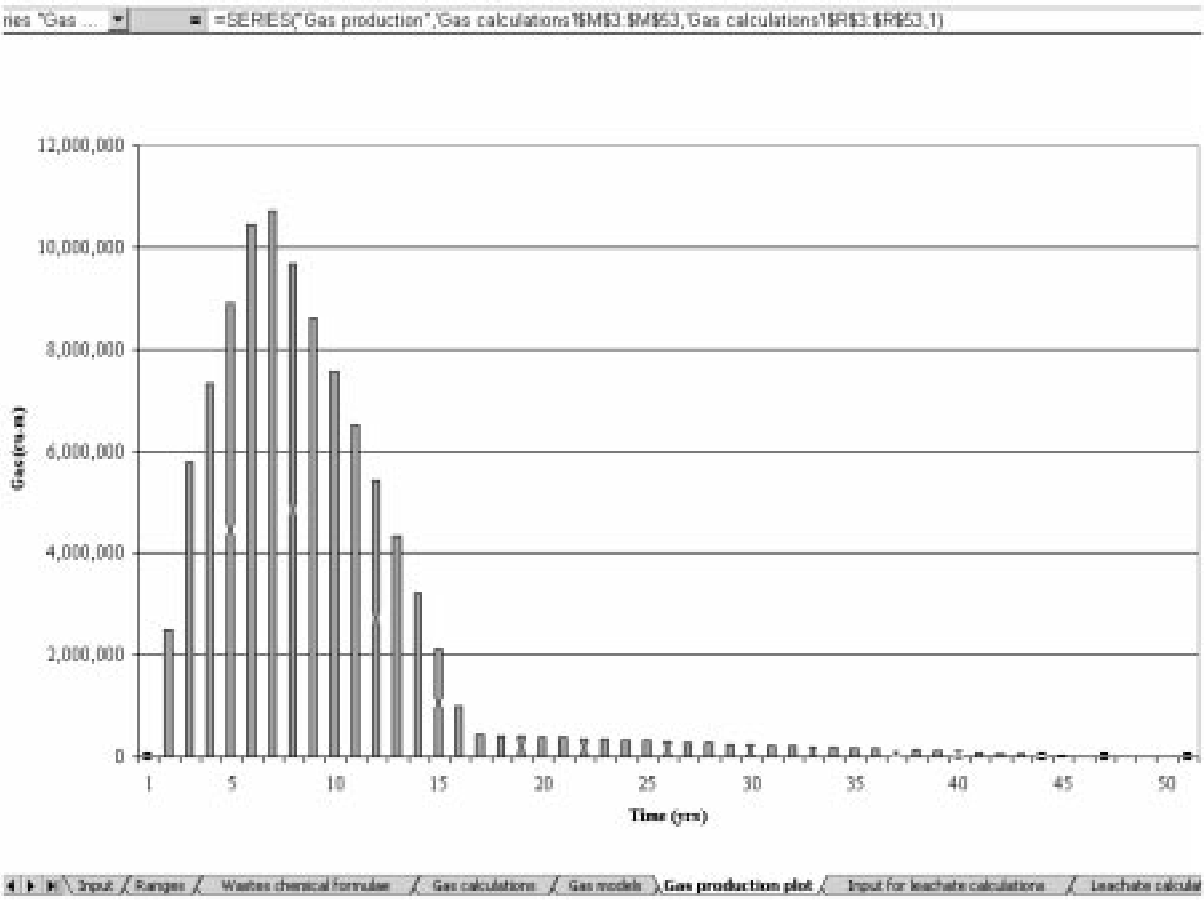


Fig. 6. Gas generation from SBW, MBW, and RBW.

B7 = =Temporary calculations!$B$5+Temporary calculations!$B$6

| | A | B | C | D | E | F | K | P | U | Z | AE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | AT end of year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2 | Variables | | | | | | | | | | |
| 3 | Gas produced (cu-m) | 0.0 | 4.2 | 9.6 | 12.2 | 14.8 | 17.4 | 17.9 | 16.1 | 14.4 | 12.6 |
| 4 | Weight of gas produced (Kg) | 0.0 | 5.6 | 12.9 | 16.4 | 19.9 | 23.3 | 23.9 | 21.6 | 19.2 | 16.9 |
| 5 | Weight of water consumed (Kg) | 0.0 | 0.7 | 1.5 | 2.0 | 2.4 | 2.8 | 2.9 | 2.6 | 2.3 | 2.0 |
| 6 | Weight of water vapor (Kg) | 0.0 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 |
| 7 | Weight of water (Kg) | 206.1 | 205.4 | 203.7 | 201.5 | 198.9 | 249.9 | 261.8 | 256.6 | 251.4 | 245.3 |
| 8 | Dry weight of solid waste (Kg) | 393.9 | 389.0 | 377.7 | 363.3 | 345.8 | 326.2 | 304.2 | 286.2 | 268.2 | 253.4 |
| 9 | Average weight (Kg) | 600.0 | 1497.2 | 2385.0 | 3241.0 | 4063.3 | 4022.7 | 3923.7 | 3803.0 | 3676.2 | 3560.4 |
| 10 | Field Capacity | 0.569 | 0.528 | 0.494 | 0.465 | 0.441 | 0.442 | 0.445 | 0.4 | 0.5 | 0.5 |
| 11 | Water held in lift 1 (Kg) | 224.1 | 205.5 | 186.6 | 169.0 | 152.5 | 143.8 | 136.4 | 127.9 | 121.3 | 115.5 |
| 12 | Leachate formed (Kg) | -18.0 | -0.2 | 17.1 | 32.5 | 46.4 | 106.1 | 126.5 | 128.7 | 130.1 | 129.7 |
| 13 | Water remaining (Kg) | 206.1 | 205.4 | 186.6 | 169.0 | 152.5 | 143.8 | 136.4 | 127.9 | 121.3 | 115.5 |
| 14 | Total weight of lift (Kg) | 900.0 | 894.4 | 864.3 | 832.3 | 798.3 | 769.0 | 739.5 | 713.1 | 689.5 | 668.9 |

Wastes chemical formulae / Gas calculations / Gas models / Gas production plot / Input for leachate calculatio

Fig. 7. Calculation of input data used for leachate generation in the landfill.

characteristics of the solid wastes to be disposed, the design specifications of the proposed landfill, and the expected rainfall quantities within the area of concern. Typical values for waste characteristics and essential design parameters for landfills are included in the 'Ranges' spreadsheet. These include a range for the specific weight of solid wastes and soil cover material, as well as the lift height and waste-to-cover ratio usually used in landfilling practices. The 'input' Excel sheet is shown in Fig. 3, and it includes the input parameters and composition table of the waste. The moisture content data and percent composition of the chemical elements within each waste component type (Table 1) are built in within the 'input' sheet, and are used in the calculations performed inside the 'waste chemical formulae' sheet for determining the chemical composition of the waste.

As such, the 'waste chemical formulae' sheet retrieves the percent composition and moisture contents of the waste elements from the 'waste composition table' in the 'input' sheet. The moisture content is used to get the dry weight of each waste component, and then calculate the percentage distribution of the chemical elements composing the given wastes (ultimate analysis). The percentages of C, H, O, N, S, and ash within the wastes are calculated by summing up their values for the different waste components. The molar ratio of each element is then normalized with respect to the element with the lowest percentage. The negligible amounts of S and ash present in the wastes are usually disregarded when computing the molar compositions of the waste components. In this example, the coefficients in the formulae are normalized with respect to N to provide normalized mole ratios of the organic wastes, as shown in Fig. 4. The percent composition and mass of each waste component are finally used within the 'waste chemical formulae' sheet to calculate the coefficients in Equation (1). The resulting chemical compositions for RBW, MBW, and SBW are $C_{22}H_{34}O_{13}N$, $C_{82}H_{132}O_{61}N$, and $C_{19}H_{27}O_{9}N$, respectively. The volume of $CH_4$ and $CO_2$, representing the total amount of gases produced from biodegradable wastes, is then calculated using the mass and density of each gaseous component.

The yearly gas production rate from the decomposition of organic wastes is assumed to follow a triangular model. The time periods for total decomposition of RBW, MBW, and SBW are 5, 15, and 45 years respectively, with the peak rate of gas production occurring 1, 5, and 10 years after gas production starts (Fig. 1). The latter is assumed to occur at the end of the first year of landfill operation. As such, the volume of gas produced at the end of each year from a unit

B6 = =IF(HLOOKUP(A6,table1,12)<0,0,HLOOKUP(A6,table1,12))

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | | Total | | | | | |
| 2 | Year | Kg/sq-m | Thous. cu-m | Min | Max | % Diff | Cumulave leachte |
| 3 | 1 | 0.0 | 0.00 | 0.00 | 0.00 | #DIV/0! | 0.00 |
| 4 | 2 | 0.0 | 0.00 | 0.01 | 0.00 | -100.00 | 0.00 |
| 5 | 3 | 17.1 | 10.25 | 10.60 | 1.04 | -90.21 | 10.25 |
| 6 | 4 | 32.5 | 19.48 | 20.13 | 11.33 | -43.72 | 29.73 |
| 7 | 5 | 46.4 | 27.83 | 28.81 | 20.29 | -29.58 | 57.56 |
| 8 | 6 | 106.1 | 63.65 | 65.37 | 9.30 | -85.77 | 121.21 |
| 9 | 7 | 126.5 | 75.89 | 78.04 | 10.52 | -86.52 | 197.10 |
| 10 | 8 | 128.7 | 77.24 | 79.75 | 28.57 | -64.17 | 274.34 |
| 11 | 9 | 130.1 | 78.04 | 80.75 | 30.22 | -62.57 | 352.38 |
| 12 | 10 | 129.7 | 77.85 | 80.58 | 30.15 | -62.58 | 430.23 |
| 13 | 11 | 127.6 | 76.58 | 79.15 | 28.91 | -63.48 | 506.82 |
| 14 | 12 | 124.5 | 74.73 | 77.00 | 26.98 | -64.96 | 581.54 |
| 15 | 13 | 121.3 | 72.79 | 74.76 | 24.96 | -66.62 | 654.34 |
| 16 | 14 | 118.0 | 70.78 | 72.42 | 22.82 | -68.49 | 725.12 |
| 17 | 15 | 114.5 | 68.69 | 69.99 | 20.59 | -70.59 | 793.81 |
| 18 | 16 | 110.9 | 66.54 | 67.48 | 18.26 | -72.94 | 860.35 |
| 19 | 17 | 107.6 | 64.54 | 65.15 | 16.09 | -75.30 | 924.88 |
| 20 | 18 | 104.9 | 62.94 | 63.29 | 14.35 | -77.33 | 987.83 |
| 21 | 19 | 103.0 | 61.77 | 61.92 | 13.06 | -78.91 | 1049.60 |
| 22 | 20 | 101.7 | 61.05 | 61.08 | 12.26 | -79.93 | 1110.65 |
| 23 | 21 | 101.3 | 60.79 | 60.78 | 11.98 | -80.29 | 1171.44 |
| 24 | 22 | 101.3 | 60.77 | 60.76 | 11.96 | -80.32 | 1232.20 |
| 25 | 23 | 101.2 | 60.74 | 60.73 | 11.93 | -80.35 | 1292.94 |
| 26 | 24 | 101.2 | 60.71 | 60.70 | 11.91 | -80.38 | 1353.65 |
| 27 | 25 | 101.1 | 60.68 | 60.67 | 11.88 | -80.42 | 1414.34 |
| 28 | 26 | 101.1 | 60.65 | 60.65 | 11.85 | -80.45 | 1474.99 |
| 29 | 27 | 101.0 | 60.62 | 60.62 | 11.83 | -80.49 | 1535.61 |
| 30 | 28 | 101.0 | 60.60 | 60.59 | 11.80 | -80.52 | 1596.21 |
| 31 | 29 | 100.9 | 60.57 | 60.56 | 11.78 | -80.56 | 1656.78 |
| 32 | 30 | 100.9 | 60.54 | 60.53 | 11.75 | -80.59 | 1717.32 |
| 33 | 31 | 100.8 | 60.51 | 60.50 | 11.72 | -80.63 | 1777.82 |
| 34 | 32 | 100.8 | 60.48 | 60.48 | 11.70 | -80.66 | 1838.31 |
| 35 | 33 | 100.8 | 60.45 | 60.45 | 11.67 | -80.70 | 1898.76 |

Gas production plot / Input for leachate calculations / **Leachate calculations** / Leachat

Fig. 8. Calculation of leachate generation within the landfill.

mass of the waste materials is calculated within the 'gas calculations' sheet. The rate of yearly gas production is linearly interpolated along the adopted triangular models, while the total gas is the area under the gas production curves for the specific year. As such, the first three tables in Fig. 5 determine the yearly rate and volume of gases for a unit mass of RBW, MBW, and SBW, each calculated separately. Note that the triangular models depicting the gas production rate from the various waste components are plotted in the 'gas models' sheet.

In order to express the gas production in terms of unit mass of the total wastes, the ratio (by mass) of each waste classification is multiplied by the rates obtained from their corresponding triangular models. This is done in the rightmost table of the 'gas calculations' sheet, where the cumulative gas volume is determined by summing the individual yearly amounts. Finally, the total gas volume produced in the landfill is calculated by multiplying the cumulative gas rate per unit mass by the total amount of wastes deposited over each year (Fig. 6).

The final module in the spreadsheet calculates the amount of leachate generated during and after landfill operation. Equation (2) is used to determine the quantity of leachate produced in the landfill over a 50-year period, by summing the amounts of water entering the landfill and subtracting those consumed in chemical reactions and leaving as water vapor. Variables such as the total weights of soil cover material, solid wastes, and water within every lift and the area required for the proposed landfill are first calculated within the 'temporary calculations' sheet. The potential leachate is thus the quantity of water in excess of the moisture-holding capacity of the landfill material. As such, the different parameters in Equation (2) are calculated within the 'input for leachate calculation' sheet (Fig. 7), while the amounts of leachate produced at the end of each year are

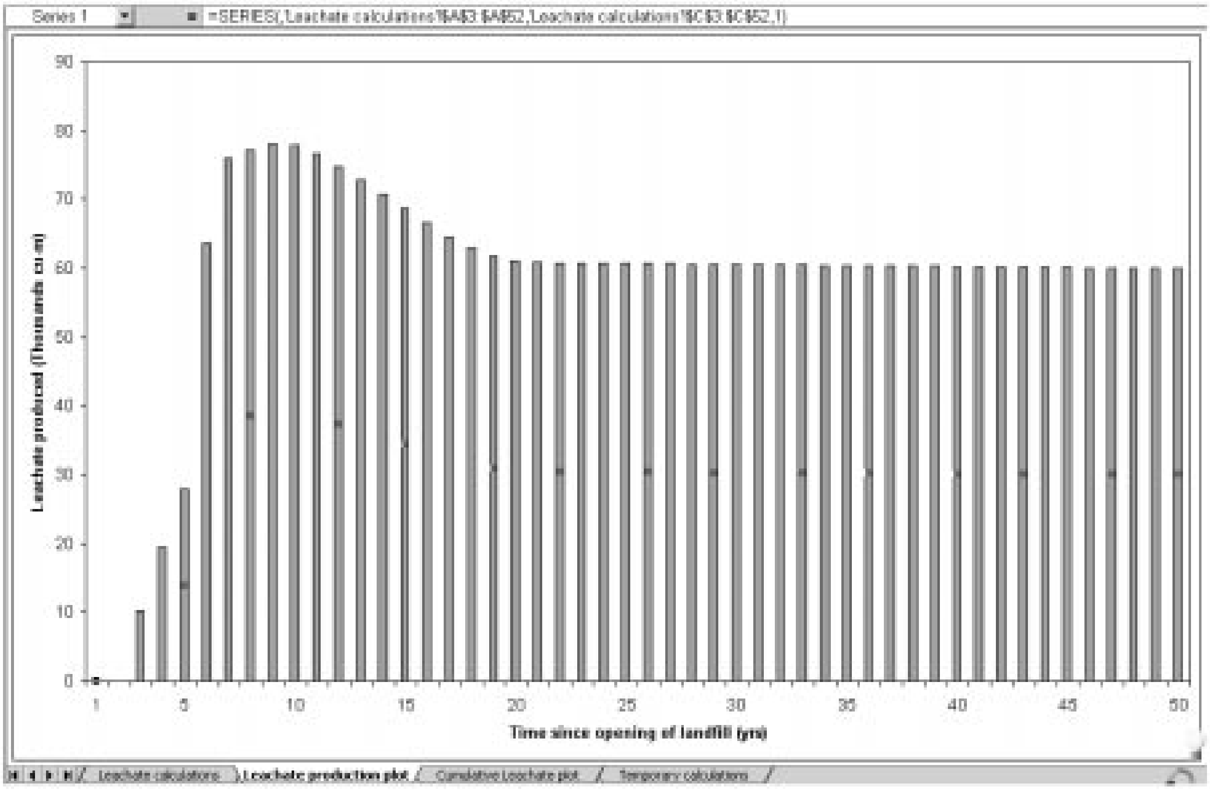


Fig. 9. Leachate generation during and after landfill operation.

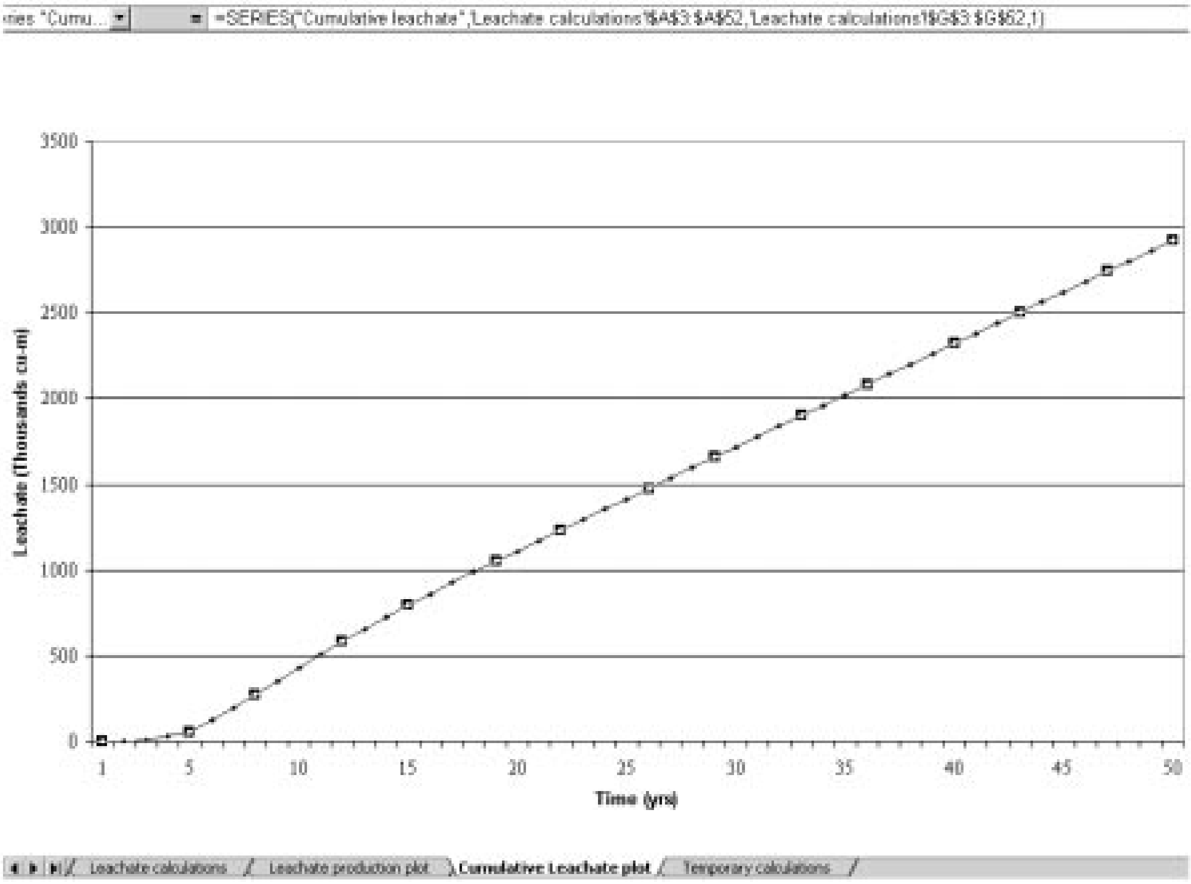


Fig. 10. Cumulative amount of leachate generation at the landfill.

computed inside the 'leachate calculations' sheet (Fig. 8).

The amount of water consumed in the formation of gases is first calculated. As such, the volumes of the gases tabulated in the 'gas calculations' sheet are used to calculate their corresponding weights, and are then multiplied by the factor for water consumption by gases, provided by the user in the 'input' sheet. The emitted gases carry additional amounts of water in the form of water vapor, which are computed by multiplying the volume of the evolved gases with the ratio of water vapor present within the gases. The formation of leachate in the landfill occurs when the moisture content of the soil and wastes, as well as water supplied by rainfall, minus the amount of water needed for the formation and generation of gases, exceed the field capacity factor of the landfill. These calculations are followed along the different layers of the landfill, during the 5-year operation period. Note that at the end of year 4 for example, lift 4 is equivalent to lift 3 in year 3; lift 3 is equivalent to lift 2 in year 2; and so on (Fig. 2).

The disposal of wastes into the landfill terminates at the end of the fifth year of operation, and the landfill is covered with a final soil layer, which is different from the intermediate layers of the landfill. As such, the computations of leachate generation are different after year 6, since the final cover material reduces the amount of water infiltrating into the landfill, and hence the amount of leachate produced. After year 6, a steady rate of leachate production is established, where the amount of leachate from each lift is calculated along with the total lift weight, the latter being used in the calculations of the successively lower lifts. The yearly rates in addition to the cumulative amounts of leachate produced in the landfill over a 50-year period are outlined in Figs 9 and 10.

## CONCLUSION

A spreadsheet program was developed to determine the chemical composition of waste materials, and compute gas generation and leachate production in a landfill during operation and after closure. The program is menu-driven and interactive, where repetitive calculations are avoided. The data are entered in a user-friendly environment, which allows the user to conduct a sensitivity analysis while observing the effect of changing various variables and parameters in graphical form. This design implication tool constitutes a first attempt at introducing the use of spreadsheets in environmental education (solid waste management). Besides its usage at the educational level in a classroom setting, the spreadsheet can contribute to the design of the most important elements of a landfill: gas and leachate collection systems and corresponding management alternatives.

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