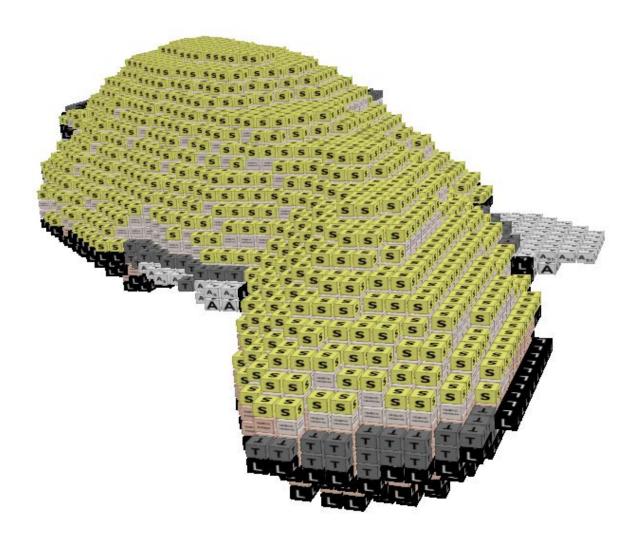
# MODUELO 4.0 USER MANUAL

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Departamento de Ciencias y Técnicas del Agua y del Medio Ambiente



# **Prologue**

MODUELO 4.0 is a completely renewed version of the program, based on the models included in the previous models; MODUELO 2 and MODUELO 3.0. Taking into account the mathematical models previously adopted to represent the different phenomena to be simulated, calculus algorithms and programming have been optimized on a new platform, which means that its program is easier to use, as is its future development and adaptation.

The aim of this manual is as an introductory guide to using the program. For justification and development of the included model, the reader is referred to the technical descriptive documents in the previous versions: "Development of MODUELO 2: a tool for the environmental assessment of solid urban waste" (2003) and "A tool for the management and bio-recuperation of land contaminated by solid urban waste. Technical Manual" (2003).

In the following sections, the functional structure of the program, the form of entering data, simulation and results management are all presented,

In the program itself, "Tooltips" have been inserted; these are explanatory texts which appear when you move the mouse over the elements in different windows. The aim of these texts is to describe the function of a specific button, show the units of data or results, the specific meaning of a specific variable, etc.

# MODUELO 4.0 USER MANUAL





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### 1 INTRODUCTION

# 1.1 General description of the program

MODUELO is a computer program whose general aim is the simulation of landfills as a tool for the design, diagnosis and follow-up of solid urban waste. Version 4 has been developed on Microsoft's .Net platform (.Net Framework 3.5) with Visual Studio 2008 development environment and the C# language program. SQL Server 2008 is used as a data-base administrator.

The program is based on a three-dimensional representation of the landfill, formed by layers which are composed of cells and which are activated throughout the simulation according to the history of operation. Simulating hydrological, biodegradation and settlement processes in a simplified way throughout allows us to calculate on a daily basis, the state of moisture and composition of the landfill, flow and organic contamination of leachates, flows through the contour, settlements and quantity and composition of bio-gas which is generated.

In the technical documentation which accompanies previous versions, a flow chart can be found which represents the basic functioning of the model and an explanation of it.

The simulation model is created by combining four different sub-models, which the user defines independently:

- Meteorological model
- Model of waste production
- Model of leachate storage
- Morphological model of the landfill

In each sub-model, the data is grouped into one or more entities which allows simulations of different scenes to be created, combining entities and sub-models. In each case, the data is defined through its corresponding windows. In order to make handling of time series data easier (meteorological series, leachates sent to treatment plants, various waste currents, etc.) there is an option to upload it directly from spreadsheets which are external to the program (Microsoft Excel), where it can be edited if you do not wish to do so directly on the program.

As in previous versions, the basic time discretization of the unit increase in time in calculations program has been set at one hour. This makes it possible to use Horton's determinist model for the calculation of infiltration, avoiding the use of experimental





charts or graphs, which moreover, are not available in Spain in a generally accepted way, as happens with S.C.S. curves in the U.S.A.

The spillage area can be discretized three-dimensionally after digitilization of the terrain, consisting of a points file with x, y, z coordinates, using the DXF Convertor. Besides, a three-dimensional graphic tool has been included (Visual Designer) which permits us to visually generate geometry and define elements and characteristics of them in a simple way: the position of each of the landfill cells, the order in which they are filled, the location of drains, ridges, etc. This tool is complemented with an image viewer which makes it easier for the user to compare representation of the landfill in MODUELO with the real characteristics of the installation to be simulated.

Data of the system (model definition, results, etc.) is stored in an SQL Server Relational Database and can be exported from the application to Microsoft Excel files for consultation and/or external edition.

As a result of each simulation, various charts are generated:

- Monitoring cells
- Monitoring leachate collection systems
- Monitoring different leachate flows
- Final state of landfill cells
- Monitoring global variables in the landfill

The program allows us to directly consult data, create graphs combining various series of data or export the results to Microsoft Excel files for management and external consultations. The state of the cells at the end of each simulation can be consulted through the Graphic Viewer.

On the other hand, the final state of the landfill cells after simulation can be used as the initial state for latter simulations, thus reducing the runtime in long simulations.





# 1.2 Installation and minimum requirements of the hardware

The minimum requirements for installation and implementation of the system are the following: Intel Pentium processor, 512 Mb Ram Memory, 2 Gb hard disk and Windows XP operating system. The recommended requirements depend on the size of the model to be simulated. As a guide-line, the following are recommended for normal-sized simulations; a Pentium Dual Core processor, 2 Gb Ram Memory, 20 Gb dedicated to hard disk and Windows XP operating system.

Regarding the monitor, the minimum resolution for correct visualization is 1024x768 pixels. In any case, and given the multi-document architecture of the interface, it is recommended that you use monitors with higher resolutions, especially for analyzing results.

As manager of the 2008 version Data-Base, the program uses the Microsoft SQL Server 2008 Express Edition package. Therefore, it is essential that the hardware has this version installed so that the program can be carried out. It also needs to have Microsoft.NET Framework 3.5 installed, as well as the Microsoft SQL Server Management Studio Express graphic tool. These three programs are distributed without any cost.

The installation process for the programs which are necessary for version 4.0 of MODUELO to work are the following;

- 1. Install Microsoft.NET Framework 3.5, following the steps which appear on the screen.
- 2. Install Microsoft SQL Server 2008 Express Edition, and then Microsoft SQL Server Management Studio Express.
- 3. Copy the executable MODUELO folder onto a directory of the hardware (for example, Program Files).
- 4. Open the SQL Server Management Studio Express program.
- 5. A window appears showing "connect to the server", in which the identifier name of the computer is shown and also the program (PCname\SQLEXPRESS). Take note of that name.
- 6. Click on the *connect* key
- 7. Once the SQL Server Management Studio Express program is open, click on the right-hand button on the Data-base file and select the *Attach* option.
- 8. The Attach data-bases window appears. Click on the Add button.
- 9. Select the data-base you want to add (Extension file.MDF, in this case Moduelo.MDF) in the corresponding window. Click on *Accept*.





- 10. Press the + symbol on the selected data-base to display all the folders.
- 11. Click on the Charts file: all the charts in the data-base appear.
- 12. Open the *dbo.Users* chart by clicking on it with the right-hand button and selecting the *Edit the first 200 rows* option.
- 13. In the *LoginWindows* section, two names which are separated by a dash (\) will appear. The first one is the name of the hardware and the second one is the Windows user. In the *LoginWindows section* of UserID 1 (*UserName* Administrator), change this data with the corresponding data to the computer in which the program is installed. Press ENTER.
- 14. Close the SQL Server Management Studio Express.
- 15. Open the configuration file Moduelo.exe.config with the Notebook in the MODUELO Executable folder. The following text will appear in row 26 of this file:
  - <dataSource id="Moduelo"... = XXX\SQLEXPRESS; Initial Catalog=...</pre>
- 16. Substitute XXX\SQL\_EXPRESS with the text which appeared on opening SQL Server Management Studio Express (instruction %). Close the notebook file, saving the changes.
- 17. The application is executed with "Moduelo.exe". Figure 1 appears and by clicking on the *Windows integrated authentication* option, the program will open.



Figure 1. Setup window of the MODUELO program

To uninstall it, the "Add or Remove Programs" option on Windows Control Panel is recommended, in order to avoid useless files being left in folders in the system.

In the display settings on the monitor, it is recommended you use "small fonts", which the design of the windows has been carried out with. Nevertheless, it has been tested with large fonts and shouldn't cause any problems. This property of Windows is





accessible using the following sequence; Start Menu -> Settings Menu -> Control Panel Menu -> Monitor Icon -> Settings Tab.

# 1.3 Program Update

The program update consists of two files, Moduelo.exe and Patch xxxxxxxxx.sql (the "x" corresponds to the time of update).

In order to have the MODUELO program updated, the installation process of these files is the following:

- 1. Copy the Patch xxxxxxxx.sql file somewhere on the hardware where it can be located.
- 2. In the current application, substitute the Moduelo.exe file with the new one (which is the new version of the application).
- 3. Run MODUELO (the new version, given that the Moduelo.exe version has been changed).
- 4. In the Explorer tree (within the application), locate the *Moduelo* node which is hanging from *Explorer* and which is below *Security*.
- 5. Click on the *Moduelo* node with the right-hand button of the mouse to show its associated contextual menu.
- 6. Click on *Apply database patch* on the menu which appears with the options saying *New Windows from here* and *Apply database patch*.
- 7. A window then appears for you to select a file. Find the location where the Patch xxxxxxxx.sql was saved and select *Open*.
- 8. The previous step is completed when the following message appears: *Patch successfully applied*. The program has then been updated.





# 2 SIMULATION UNIT

## 2.1 Introduction

The data which is necessary to define a simulation has been divided into four blocks or "sub-models":

- Meteorological Sub-model, which includes the time series of meteorological variables (relative moisture, precipitation, solar radiation, air temperature, wind speed)
- Waste Generation Sub-model, which manages all the parameters which characterize the waste that reaches the landfill (weight, composition, moisture, density, etc.)
- Leachate Storage Sub-model, where the characteristics of the leachate deposits are defined, as well as the time series of the volumes extracted from treatment plants.
- Morphological Sub-model of the landfill, with all those aspects which refer to the geometric layout of the landfill (topography of the landfill area, position of each cell, filling order.....) and discretization characteristics (horizontal dimensions of the basic elements into which the landfill model is divided, called "cells", layer thickness, cell typology, location of drains, cells subjected to recirculation, surface run-off...). The landfill sub-model is formed from the "terrain model" (discretization of the landfill), with different types of elementary units, whose characteristics are set by the user for each installation to be studied:
  - Palettes
  - Cells
  - Run-off management.
  - · Leachate drainage system
  - Leachate recirculation

For each morphological landfill sub-model, the user can define different simulation settings, combining different meteorological, waste and leachate storage sub-models.

Besides, in each case the simulation of different phenomena can be activated according to the **variables to be studied**:

- Surface hydrological balance.
- Vertical flow in the inside of the landfill
- Horizontal flow in the inside of the landfill





- Biodegradation.
- Settlement.
- Leachate storage.
- Leachate recirculation.

The basic entities, as well as the sub-models and simulations of these, are managed from the "MODUELO" main window which is shown below in Figure 2.

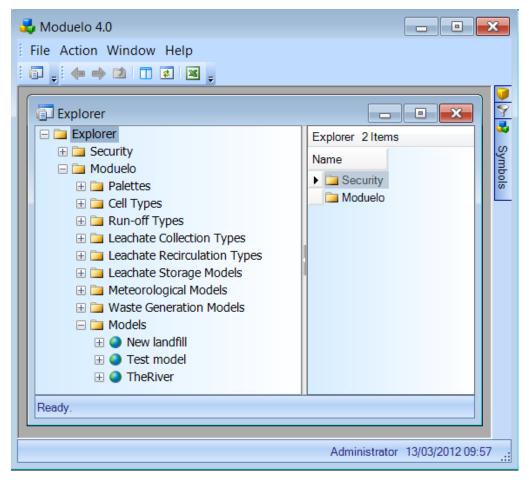


Figure 2. Main window of the MODUELO program





# 2.2 Morphological model of the landfill

# 2.2.1 Obtaining the XML file

The program reads the terrain model from XML files. This type of file can be generated from a representation of the landfill body, obtained from topographic survey or a digitalized plan in DXF format via the DF Convertor.

The operation consists of the following stages:

- Definition of discretization parameters.
- Loading the DXF file.
- Modifying original data, where necessary.
- Discretization of the original plan.
- Modification of the discretization, where necessary.
- Calculation of the cells elevations in the model.
- Creation of the XML file.

Once the program is open, click the right-hand button of the mouse on the Models folder and select the DXF file converter *Open DXF Converter*, as shown in Figure 3.

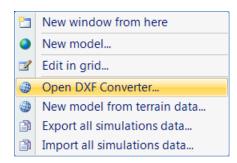


Figure 3. Models Menu of the main window of the program





#### Discretization Parameters

When you open the DXF file converter, the window shown in Figure 4 appears.

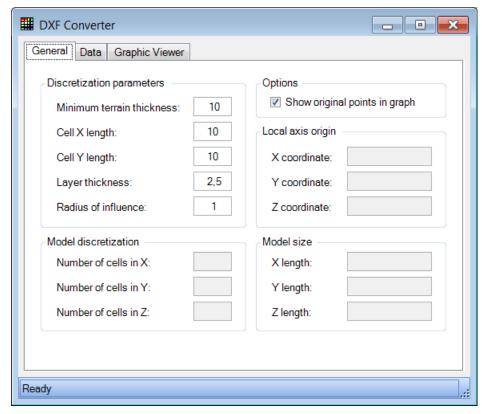


Figure 4. Setup window of the discretization parameters in the terrain model

# General tab

In this tab, the discretization parameters of the landfill model are defined.

## Discretization parameters

- Minimum terrain thickness: the minimum terrain thickness proposed for the landfill model. This is the value of the minimum elevation of the terrain model (minimum elevation expressed in the coordinate axis of the model). This parameter makes it easier to show a graphic representation of the model, reducing the length of the z axis in those cases in which the landfill is located at a high level. It should be less than the minimum elevation of the model. Data in m.
- Cell X length: length in X of each cell in the landfill model. Data in m.
- Cell Y length: length in Y of each cell in the landfill model. Data in m.





- Layer thickness: height of the layers in which the program will discretize the height of the landfill. Data in m
- Radius of thickness: the number of cells the program will create around each original point in the plan, but without increasing the limits of the model (given by the original end points on each coordinate.

Also in this tab are the following sections, which will be automatically up-dated once the terrain model has been created.

## Model discretization

- Number of cells in X axis: number of cells of the terrain model in X axis.
- Number of cells in Y axis: number of cells of the terrain model in Y axis.
- Number of cells in Z axis. Number of cells of the terrain model in Z axis.

#### **Options**

 Show original points in graph: this allows you to visualize points on the original plan when the model is graphically represented.

# Local axis origin

This shows the coordinates of the origin of the model with regards to the original plan.

- Number of cells in X coordinate: origin of the X coordinate in the model with regards to the coordinate system in the original plan.
- Number of cells in Y coordinate: origin of the Y coordinate in the model with regards to the coordinate system in the original plan.
- Number of cells in Z coordinate: origin of the Z coordinate in the model with regards to the coordinate system in the original plan.

## Model size

- X length: length of the terrain on the X axis. Data in m.
- Y length: length of the terrain on the Y axis. Data in m.
- Z length: length of the terrain on the Z axis. Data in m.

# 2.2.1.2. Loading the original points of the DXF file

Once the discretization parameters have been defined, select the Data tab (see Figure 5).





#### Data tab

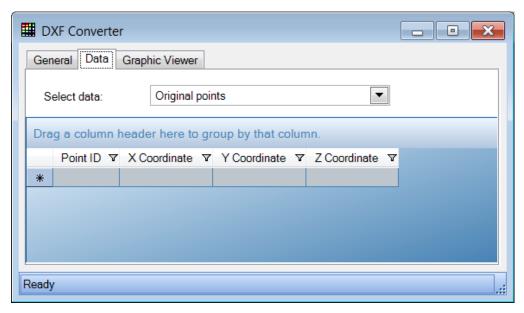


Figure 5. Data Window in the File Convertor

To import the original points in the DXF file, select the "Original points" section in the "Select data" box. When you click on the button (*Get original points from a DXF file* option), a window appears which allows you to select the DXF file to be imported. The original points on the Data tab appear automatically, as shown in Figure 6.

# 2.2.1.3 Add or remove original points

Strange or unnecessary data can be removed from the data chart and the model, and points can also be added.

To remove the points, you only have to select the row the point is on and click on the button (*Delete selected original points* option). To add a point, click on the box on the last row. The identification number of the new point automatically appears, and whose coordinate the user has to complete. To save any changes, click on the button (*Save original points in a XML file* option).





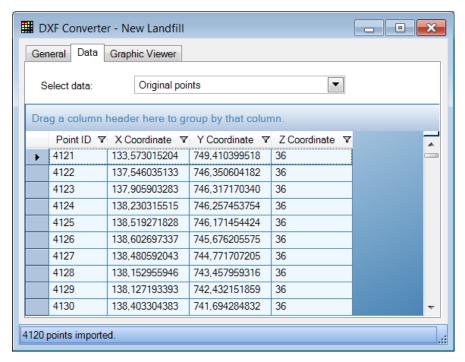


Figure 6. Data Window with the original points imported from the DXF file of the terrain

In this tab, and using the "Select data" option, you can also access other information which will automatically be up-dated when the terrain model is created:

#### Original layers

This allows the user to personalize the thickness of each layer in which the terrain will be discretized, specifying this value for each of the required layers.

#### Model points

The coordinates of the original points of the terrain appear with regards to the axes in the model, together with their X, Y and Z indexes and the quadrant of the cell where the point is. Each index indicates the position of the cell which contains the point in the model (the order the cell occupies in the corresponding axis from the origin).

# Model layers.

The number of layers in the terrain model and their thickness.

#### **Model elevations**

For each cell, represented by its X and Y indexes, it informs if it is active (it is included in the terrain model) (Active). For active cells, the elevation which is calculated by the program is presented with regards to the axes in the model (this





acts as a reference to assign the corresponding layer) (Elevation) and the number of layers the terrain model occupies in this position (Column Cells).

# 2.2.1.4 Discretization of the terrain from the original points

# Graphic Viewer tab

Once the original points have been imported and the discretization parameters have been established, click on the  $\widehat{\ \ }$  button in the "Graphic Viewer" tab (*Discretize the terrain from the original points* option) to start discretization of the plan from the original points. As a result, the representative plan of the terrain is divided into square cells. Figure 7 shows an example of terrain discretization together with the original terrain points.

#### 2.2.1.5 Add or remove terrain cells

Cells on the discretized terrain can be added or removed by clicking on the button (Change add/remove mode when clicking cells in the graph option) and moving the mouse over the cells which are to be added (in this case, empty cells) or over those which are to be deleted.

This is usually necessary when due to the low density of original points, empty cells appear in the inside of the plan in the discretization, as occurs in the example in Figure 7, or when it is necessary to increase or decrease the number of cells at the ends of the discretized terrain (see Figure 8).

In order to add cells which are outwith the limits in the generated model, it is necessary to create a terrain point in the previous editing phase of the original data. The point would have the appropriate coordinates to give way to a cell in the area in which you would like to extend the model. In this case, you should go back to Section 2.2.1.3.

## 2.2.1.6 Calculate elevations

To create the elevations of each cell in which the plan has been discretized, click on the button (*Calculate terrain model elevations* option). The result is a terrain model with elevations, as shown in Figure 9.





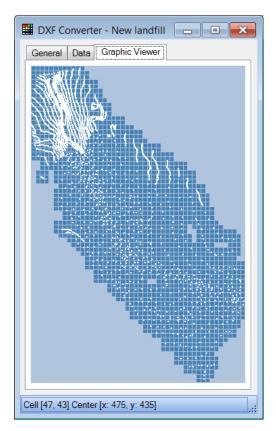


Figure 7. Discretization of the terrain and original points in the DXF file

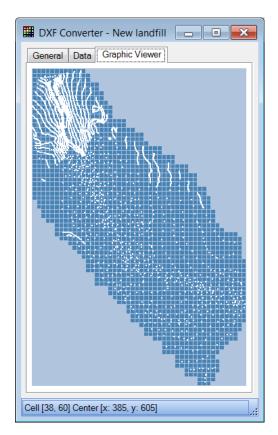


Figure 8. Discretization of the terrain and original points in the DXF file with added cells





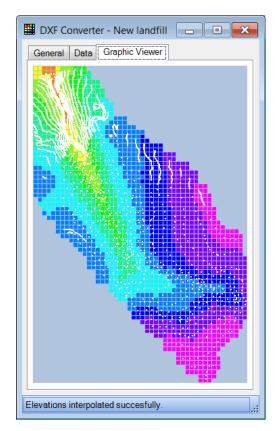


Figure 9. Model of the terrain with calculated elevations

# 2.2.1.7 Obtaining the XML file from the DXF file

The terrain model is saved in XML format from the "Data" tab. Select the "Model elevations" section in the "Select data" box and click on the ■ button (Save final discretization in an XML file option).

Once the model has been created the "Model discretization", "Local axis origin" and "Model size" data, defined in Section 2.2.1.1., are shown on the "General" tab and in the "Data" tab there is also more information available regarding the created model.

# 2.2.2 Creation of the morphological model

The landfill model is created from the terrain model, which represents the landfill premises and its surrounding area. From there on, and with the help of the Graphic View, the user configures the distribution of different types of cells to represent the landfill.

# 2.2.2.1 Terrain Model

#### 2.2.2.1.1Creation of the terrain model





The terrain model is created from the XML file, generated as indicated in the previous section.

Click the right-hand button of the mouse on the *Models* folder and select the section "New model from terrain data", as shown in Figure 10. Select the required XML file and it then opens.

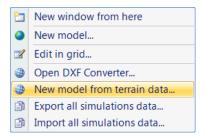


Figure 10. Models Menu on the main window of the program.

Thus, the new model is automatically created, within which there are four folders:

- Layers, which groups the layers the model includes. Any layers you wish to add to the terrain model should first be defined in this folder.
- Terrain, which includes the cells which represent the terrain where the landfill is set out in the model.
- Cells, which groups the cells which represent the landfill.
- Simulations, which gathers different simulations of the landfill the user generates.

#### 2.2.2.1.2 Properties

If you click on the new model with the right-hand button of the mouse, the window shown in Figure 11 appears. Select *Properties* and the window in Figure 12 appears, showing three tabs:

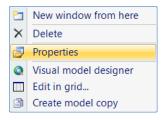


Figure 11. Main menu of the terrain model.





#### General tab

In this tab, the identification code number and the model name are defined. The origin of the X, Y and Z coordinates of the model is shown, as well as the X and Y cell sizes and the number of cells which configure the model in the X and Y axes.

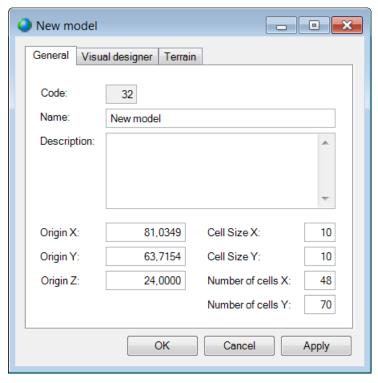


Figure 12. Window: Data of the New Model

# Visual designer tab

In this tab, the X and Y coordinates at the ends of the terrain model are shown. The user can load (or remove) a background image in order to visualize it on the *Visual model designer*. This option is useful for uploading plans or reference photos during the filling process in the landfill model.

#### Conversion of plans in image file

The first step in uploading a reference graph as an image is to capture it with the same size and coordinates as the end points in the DXF file which generated the model. To do this, you must do the following:

- 1. Copy the initial DXF file onto the reference graph.
- 2. From the end points on the initial plan, draw straight lines which frame the reference graph.
- 3. In the reference graph, cut out everything that is outside the chart.





- 4. Print the screen.
- 5. Paste the printed screen onto an image-editing program.
- 6. Cut the chart and delete the rest.
- 7. Paste what has been cut out and reduce the screen of the drawing until only the box with the reference plan remains
- 8. Save it in any image format. This will be the one that loads onto the terrain model.

#### Terrain tab

The user defines two parameters which will condition leakage towards (or away from) the outside of the landfill through its contour:

- Equivalent conductance: the easiness to transmit the water from the landfill, which depends on the waterproofing system which is installed and the properties of the adjacent terrain. Data in s<sup>-1</sup>.
- External Water Table: piezometric elevation of the aquifer which affects the landfill. Data en m., expressed in the coordinate system of the model.

# 2.2.2.2 Graphic viewer

#### 2.2.2.1.3 Managing the viewer

In order to distinguish the different layers of the model in the graphic viewer, and before opening the graphic model, the user must assign a palette of colors to the *Layers* folder in the model. To do so, the user should drag the selected palette from the *Palettes* folder to the *Layers* folder.

The graphic model opens by clicking the right-hand button of the mouse over the model, and choosing the *Visual model designer* option. A three-dimensional representation of the created terrain model is then shown.

The Activate selection mode option, ( button), allows the user to define the most appropriate view of the model. If you keep the left-hand button of the mouse pressed, the drawing moves horizontally and vertically; if you click with the right-hand button it will spin and if you move the mouse wheel, the screen will zoom in or out.

The button (Save current view option), located on the toolbar on the top bar in the window, allows the user to save a specific view of the model. By clicking on this button, Figure 13 appears in order to assign a name to the view.







Figure 13. Window with Select view name

# 2.2.2.2. Visualization options

The *Show model view options* ( button) offers three view options of the model on the right-hand part of the screen.

# Visibility

In a diagram of the model, the user can enable or disenable the view of part or all of the model, leaving specific visible areas of it on the main three-dimensional representation (see Figure 14). On the left part of the same window, a column is shown in which the layers of the model are represented with the colors of the selected palette; these can be enabled or disenabled to make visualization of the model easier.

# Symbols

This allows the user to select the part of the model and the properties he wants to visualize in the main three-dimensional representation (see Figure 15).

### <u>General</u>

- Image visible
- Floor visible
- Terrain visible
- Cell visible

#### **Altitude**

- Terrain altitude color
- Cell altitude color

# Cell types





- Cell type color
- Cell type image
- Cell filling order

# Run-off types

- Run-off direction color
- Run-off direction image
- Run-off management color
- Run-off management image

# Leachate collection types

- LCS color
- LCS image

# Leachate recirculation types

- LRS operation color
- LRS operation image
- LRS closure color
- LRS closure image

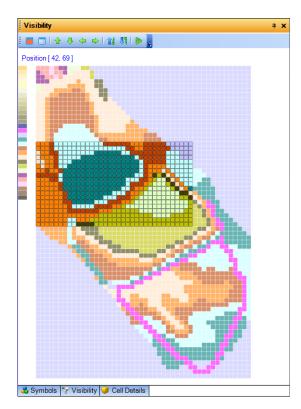


Figure 14. Window of the Visibility view option of the model





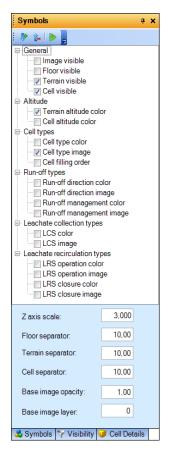


Figure 15. Window of the Symbols view option of the model

# Cell details

This tab allows you to consult the state of each cell after a simulation. Select the *Results in designer* option in the viewer when clicking the right-hand button over the simulation that took place (see Section 4.3).

It is also possible to consult the state of the cells throughout the simulation: in this tab, the results are shown after each interval, when a visual simulation is carried out.

# 2.2.2.3 Morphological model of the landfill

The morphological model of the landfill is constructed using the successive positioning of the cells which represent the different materials/waste according to the operational records which you want to simulate.

To do this, use the *Cell type* toolbar, where you then select the type of corresponding cell. To open this toolbar, click on the top toolbar in the window with the right-hand button and select the *Cell Type Toolbar* tools.





Once you have chosen the work view, click the 🗵 button (*Activate selection mode* option) which freezes the viewer and allows you to select the area in which you wish to add new cells of the selected type.

Once you have marked the area where cells and their type have to be added, click the button (*Add cells of the specified type over the selection* option), with which a layer of cells of the specified type over the selected area is added (see the example in Figure 16).

The button (Delete selected cells option) allows you to remove the selected cells, and the button (Change selected cells type option) changes the type of cell.

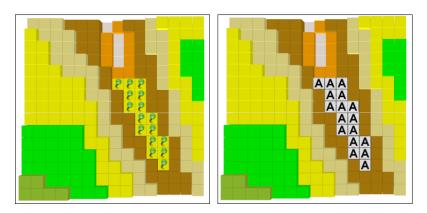


Figure 16. Selecting and adding cells on the terrain

#### 2.2.3 Palettes

To make visualization of the data in the XML file easier, a palette of colors is applied to the model, allowing cells to be differentiated according to their elevation. Three palettes are proposed in the program; Classic 1, Classic 2 and High contrast, but the user can create and personalize as many as he/she wants.

In the visual model, each layer of the terrain and the landfill will be represented by a color on the palette, and therefore, the palette selected or defined by the user must comprise a number of cells which is sufficient to cover all the layers in the model.

Creation of a new palette of colors.

To create a new palette, click the right-hand button of the mouse on the *Palettes* folder and select *New palette*. A window will appear with only one General tab (General), in which the name of the new color palette is defined.

Once the new palette has been created, the desired colors will be incorporated in an orderly fashion. An option for this is to click the right-hand button of the mouse over





the new palette and select *New color in palette*. The window in Figure 17 appears where you can then select the chosen color.

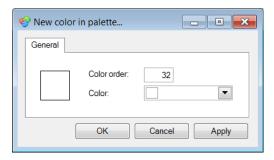


Figure 17. Setup window of a new color in palette.

Another way of introducing colors in the newly-created palette is by editing the palette in charts, as shown in Figure 18. In the *Color Order* column, write the order code of the chosen color in the display in the right-hand column "Color". This operation is repeated successively until all the colors in the palette have been created.

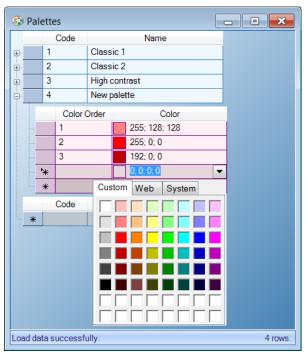


Figure 18. Edit in grid of the color palettes.

Assigning the color palette to the generated terrain model.

To assign the color palette to a terrain model, the *Palettes* folder and the folder of the selected model are displayed (in this way all the sub-folders are visible) as shown in Figure 19.





Select the selected palette and "drag" it to the *Layers* folder in the model, as shown also in Figure 19.

Once this has been done and you open the model using the *Visual model designer*, the layers in the model will be distinguished with the colors of the selected palette.

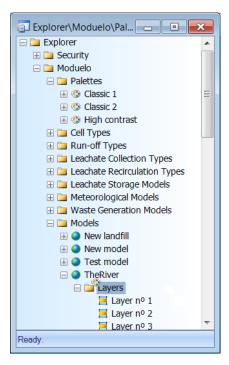


Figure 19. "Drag" the palette to the Layers folder in the model

# 2.2.4 Cell types

Once the .XML file has been created, the landfill can be filled with different types of cells with the dimensions selected in the discretization parameters. In MODUELO there are two main types of cell; "Landfill" and "Ground". The Landfill type includes a layer of waste and its corresponding coating, whereas the Ground type is composed of an homogenous material (such as that used for ridges, walls or drainage screens). If they are in the last layer, both will be of the "Closed" type, different from the previous ones because of the surface hydrological properties (evapotranspiration is produced in the latter instead of simple evaporation).

#### 2.2.4.1 Landfill and Closed landfill

To create a "Landfill" or "Closed Landfill" sub-type of cell, click the right-hand button of the mouse on the *Landfill* or *Closed Landfill* folder, as appropriate, and select *New cell type*. This opens the window shown in Figure 20.





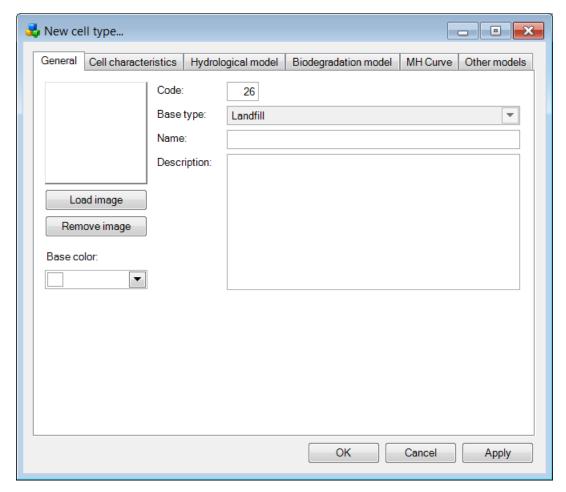


Figure 20. Setup Window of a new type of Landfill cell

# General tab

In this tab, the name of the sub-type or the specific cell type is defined. A brief description is included and the base color is assigned to identify the cell in the visual terrain model. The user can also load an image to this end.

#### · Cell characteristics tab

The initial hydrological characteristics of the waste and coating material of the cell are defined here.

#### Waste characteristics

- Initial residual moisture: minimum moisture contents the waste can reach when it is not subjected to evaporation or evapotranspiration processes. Data in percentage in wet weight.
- Initial field capacity: moisture content of the residue, below which there is no loss through gravity. It is directly related to the values of initial residual moisture and saturation moisture. Data in percentage in wet weight.





- Initial saturation moisture: moisture value for which the residue has all its pores full of water. Data in percentage in wet weight.
- Initial vertical hydraulic conductivity: initial vertical hydraulic conductivity in residual saturation conditions. Data in m/s.
- Initial horizontal hydraulic conductivity: initial horizontal hydraulic conductivity in residual saturation conditions. Data in m/s.

#### Cover characteristics

- Cover thickness: cover thickness of the cell. Data in m.
- Initial moisture content: initial moisture content of the cell cover material. Data in percentage in wet weight.
- Initial density: initial density of the cell cover material. Data in kg/m3 in wet weight.
- Initial residual moisture: minimum moisture content the cover material can reach. Data in percentage in wet weight.
- Initial field capacity: moisture content of the cover material, below which there
  is no water loss due to gravity. Data in percentage in wet weight.
- Initial saturation moisture: moisture value for which the cover material has all its pores full of water. Data in percentage in wet weight.
- Initial vertical hydraulic conductivity: vertical hydraulic conductivity in saturation conditions of the cover material. Data in m/s.

### Hydrological model tab

Here, the user enters the value of the parameters which are necessary to apply different hydrological models.

### Surface infiltration model

The infiltration rate of the cover layer of the cell is defined here according to Horton's equation.

- Minimum infiltration rate: water infiltration rate after the downpour. Data in mm. This varies depending on the type of ground used as a cover material, ranging from 11.43 to 0 for sandy and clay soil. A range of 7.62-1.27 mm is used in silts and loams. In solid urban waste landfills, 3.8 mm is normally used.
- Maximum infiltration rate: water infiltration rate at the beginning of the downpour. Data in mm. This varies depending on the type of ground used as a





cover material, ranging from 127 to 25.4 for sandy and clay soil. In loams without vegetation, 76.2 mm is used.

Horton parameter: rate of decline of the infiltration through time. Data in h-1.
 If this data is not available, a value of 4.14 h-1 is recommended.

# **Evapotranspiration model**

- Evaporation depth: maximum depth which can be affected by evaporation or evapotranspiration phenomena. This depends on the permeability of the surface materials: in sandy soil it varies between 0.1 and 0.2 m; in loamy soil between 0.2 and 0.46 m; and in sandy soils, between 0.3 and 1.5 m. Data in m.
- Wilting point: minimum moisture content in which the cell can remain due to the effect of evapotranspiration. Data in % with regards to residual moisture, that is, the percentage of residual moisture below which the cell cannot remain.

# Run-off model

 Maximum surface accumulation: maximum height of water storage on the surface before run-off is produced. Data in m.

# Preferential flow model

The parameters of the flow model through preferential channels are defined.

- Fraction of volume affected by preferential channels: percentage of volume of the cell which is found with preferential channels. This value usually varies between 5 and 50%. Data in %.
- Permeability factor of the material in the channeled area. This is the relation between hydraulic conductivity in the area of preferential flow and hydraulic conductivity in the area of homogenous flow. It represents the increase in permeability in the channeled area with regards to the rest of the cell volume.
   Non-dimensional.

## Residual moisture model

- Minimum residual moisture of waste: minimum residual moisture that the residue will reach when pressure put upon it is infinite. Data in percentage in wet weight.
- Influence of load on the residual moisture: it expresses the variation of residual moisture of the waste with over-pressure. Data in kg/m².

\_





# · Biodegradation model tab

The parameters which are necessary to model waste degradation are defined here.

- Readily hydrolysis activation time: hydrolysis activation time of components which are rapidly biodegradable. Data in d.
- Slowly hydrolysis activation time: hydrolysis activation time of components which are slowly biodegradable. Data in d.
- Methanogenesis activation time: methanogenesis activation time. Data in d.
- Ready hydrolysis rate: first-order speed for hydrolysis of the materials which are rapidly biodegradable in maximum moisture and temperature conditions.
   Data in d<sup>-1</sup>.
- Slowly hydrolysis rate: first-order speed of hydrolysis of the materials which are slowly biodegradable in maximum moisture and temperature conditions. Data in d<sup>-1</sup>.
- Acetogenesis rate: production rate of acetate from intermediate compounds in ideal conditions. Data in d<sup>-1</sup>.
- Acetoclastic methanogenesis rate: production rate of methane from acetate in ideal conditions. Data in d<sup>-1</sup>.
- Hydrogenophilic methanogenesis rate: production rate of methane from hydrogen in ideal conditions. Data in d<sup>-1</sup>.
- Fraction of carbon transformed into intermediate compounds in the hydrolysis: stoichiometric hydrolysis factor. 0.76 by default.
- Fraction of carbon transformed into acetate in the hydrolysis: stoichiometric hydrolysis factor. 0.2 by default
- Fraction of carbon transformed into acetate in the acetogenesis: stoichiometric hydrolysis factor. 0.68 by default.

## MH Curve tab

Defined here is the curve which relates the speed of hydrolysis with the degree of moisture in the cell. This factor is a percentage which multiplies the rates of hydrolysis according to the moisture which exists in the cell.

# Moisture Hydrolysis Curve Points

In this section there are two points on the curve which are used as a reference. To change the curve, you only have to change the points in this section. To check the curve, a moisture value can be entered in the *Moisture* (%) section: if you click on





the *Test value* button, the percentage of the maximum hydrolysis speed from this moisture will appear on the screen.

To return to the general curve, click on the Set default curve button.

#### · Other models tab

The parameters of the temperature and settlement models are defined here.

# Temperature model

- Specific heat capacity: specific heat of dry waste in the conditions in which it is placed in the landfill. A reference value for mixed urban waste is 1.500 J/kg·°C.
   Data en J/kg·°C.
- Thermal conductivity: thermal conductivity of dry waste in the conditions in which it is placed in the landfill. 10 J/m·s·°C. Data en J/m·s·°C is used as a reference value.
- Oxygen uptake rate: this depends on the contact time between the waste and the air. Data in moles of O<sub>2</sub> per Kg of dry biodegradable material exposed to aerobic conditions and per hour (mol O<sub>2</sub>/kg dry mass·h).
- Aerobic heat generation ratio: heat generation for each mole of aerobically degraded material. 460 kJ/mol  $O_2$  is used as a reference value. Data en Joules per mol of  $O_2$  consumed (J/mol  $O_2$ ).
- Anaerobic heat generation ratio: heat generated in methane production. The most used value is  $45kJ/mol\ CH_4$ . Data in Joules per mol of  $CH_4$  generated (J/mol  $CH_4$ ).
- Thickness of waste compaction lift: height of the lifts as they are made available throughout the cell. Data in m.
- Time interval between lifts: time in which each lift remains exposed during construction of the cell. Data in h.

#### Settlement model

- Compression ratio: compression ratio for calculating Primary Settlements as a result of the weight on the waste. The values of this index in bibliography range between 0.08 and 0.5, the majority between 0.15 and 0.3. Nondimensional Data.
- Mass-loss to settlement ratio: this relates Secondary Settlements with mass-loss of the cell during degradation. The range of this ratio varies between 0.178 and 0.327, the typical value being 0.264. Non-dimensional Data.





#### 2.2.4.2 Soil and Closed Soil

To create a Soil or Closed Soil cell subtype, the procedure is the same as for the creation of Landfill or Closed Landfill cells, but in the *Soil* or *Closed Soil* folder. This time the tab for the biodegradation model doesn't appear (see Figure 21), since this type of cells includes non-biodegradable materials.

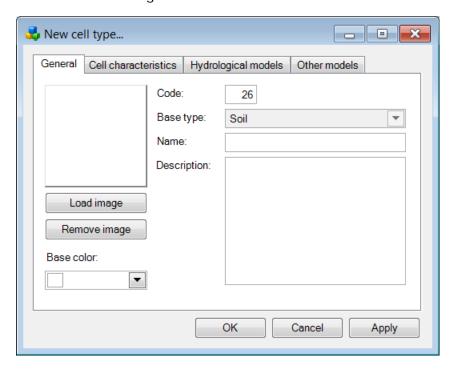


Figure 21. Setup window of a new type of Soil cell

#### General tab

In this tab the name of the subtype or specific cell type is defined; it includes a brief description and a color is assigned to identify the cell in the visual model of the terrain. The user can also load an image to this end.

#### · Cell characteristics tab

The initial hydrological characteristics of the material deposited in the cell are defined here.

- Initial moisture content: initial moisture content that the cell forms. Data in percentage in wet weight.
- Initial cell density: initial density of the material the cell forms. Data in kg/m³ (in wet weight).





- Initial residual moisture: minimum moisture content the material forming the cell can manage to retain when it is not subjected to evapotranspiration phenomena. Data in percentage in wet weight.
- Initial field capacity: moisture content of the material that the cell forms, below which there is no water loss because of gravity. Directly linked to the values of residual moisture and saturation. Data in percentage in wet weight.
- Initial saturation moisture: moisture value for which the cell material has all its pores full of water. Data in percentage in wet weight.
- Initial vertical hydraulic conductivity: vertical hydraulic conductivity in saturation conditions of the material deposited in the cell. Data in m/s.
- Initial horizontal hydraulic conductivity: horizontal hydraulic conductivity in saturation conditions of the material deposited in the cell. Data in m/s.

## · Hydrological model tab

The parameters which are necessary to apply the hydrological models are defined here.

## **Evapotranspiration model**

- Evaporation depth: maximum depth which can be affected by evaporation. It depends on the permeability of the cell material: in sandy soils, it varies between 0.1 and 0.2 m; in clay soils it varies between 0.3 and 1.5 m. Data in m.
- Wilting point: this is the minimum moisture content in which the cell can remain as an effect of evapotranspiration. Data in % with respect to residual moisture.

#### Surface infiltration model

This defines the infiltration rate of the material the cell forms, according to Horton's equation.

- Minimum infiltration rate: infiltration rate of water at the end of the downpour.
   Data in mm. It varies depending on the type of soil; ranging between sandy and clay soils from 11.43 to 0. A range of 7.62 to 1.27 mm is used in silts and loams.
- Maximum infiltration rate: infiltration rate of water at the beginning of the downpour. Data in mm. It varies depending on the type of soil; the range for soils which are between sandy and clay soils varies from 127 to 25.4. In loams without vegetation, 76.2 mm is used.





 Horton parameter: Rate of decline in infiltration through time. Data in h<sup>-1</sup>. If this data is not available, a value of 4.14 h<sup>-1</sup> is recommended.

#### Run-off model.

 Maximum surface accumulation: maximum height of surface water storage before run-off is produced. Data in m.

#### Other models tab

The parameters of the temperature and settlement models are defined here.

## Temperature model

- Specific heat capacity: specific heat of dry waste in the conditions in which it is placed in the landfill. Data in J/kg·°C.
- Thermal conductivity: thermal conductivity of dry waste in the conditions in which it is placed in the landfill. Data en J/m·s·°C.

## Settlement model

 Compression ratio: consolidation ratio to calculate Primary Settlements as a result of the weight on the material. Non-dimensional Data.

#### Residual moisture model

- Minimum residual moisture: minimum residual moisture the material will reach when pressure on it is infinite. Data in percentage in wet weight.
- Influence of load on the residual moisture: this expresses the variation of residual moisture of the material with overpressure. Data in kg/m².

## 2.2.5 Leachate collection types

Once the landfill has been filled, the leachate collection system will be defined. In MODUELO, there are three main leachate collection types: "Gravel", "Pipe" and "Sump".

#### 2.2.5.1 Gravel

To create a leachate collection type with gravel, click the right-hand button of the mouse on the *Gravel* folder and select *New gravel LCS type*. This will open the window shown in Figure 22.





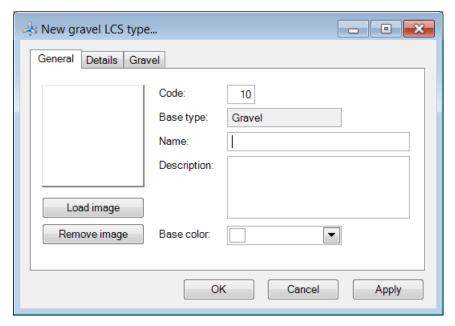


Figure 22. Setup window of a new leachate collection system; Gravel type

#### General tab

In this tab, the name of the subtype or specific type of leachate collection type is defined. It includes a brief description of it and the base color is assigned to identify the leachate collection system in the visual model of the terrain. The user can also load an image to this end.

## Details tab

- Drainage slope: slope of the leachate collection system. Dimensionless data.
- Number of cells served by the drain: Number of cells in the model whose leachate is led by the same drainage system. It conditions the total evacuation capacity of it.
- Layer slope towards the drain: slope of the terrain towards the drainage system. Dimensionless data.
- Equivalent hydraulic conductance under the drain: this allows particular waterproofing conditions to be specified under the drain (as in those cases in which a geo-membrane is inserted below the conduct: in this case, the hydraulic conductance under the drain would be less than on the rest of the layer). Data in s<sup>-1</sup>.

#### Gravel tab

 Gravel thickness: thickness of the gravel layer which forms the leachate collection system. Data in m.





 Hydraulic conductivity of drainage gravel: hydraulic conductivity of drainage level. Data in m/s.

#### 2.2.5.2 Pipe

To create a leachate collection system with pipe, we use the same procedure as with the creation of leachate collection systems with gravel, but in the *Pipe* folder.

#### · General tab.

This tab defines the subtype name or specific type of leachate collection system. It includes a short description of it and the base color is assigned to identify the leachate collection system in the visual terrain of the model. The user can also load an image to this end.

#### Details tab

- Drainage slope: slope of the leachate collection system. Dimensionless data.
- Number of cells served by the drain: the number of cells in the model whose leachate is collected by the same drainage pipe. It conditions the total evacuation capacity of it.
- Layer slope towards the drain: slope of the terrain towards the axis of leachate evacuation. Dimensionless data.
  - Equivalent hydraulic conductance under the drain: this allows us to specify particular impermeability conditions under the drain. Data in s<sup>-1</sup>.

## Pipe tab

- Pipe diameter: diameter of the pipe which collects and transports the leachate.
   Data in m.
- Manning coefficient: Manning roughness coefficient, whose value depends on the material and state of conservation of the pipe. Non-dimensional Data.
   0.013 is used in concrete pipe and in PVC pipes with smooth inner walls between 0.009 and 0.011 is used.

## 2.2.5.3 Sump

To create a leachate collection system through a sump, we use the same procedure as with the creation of leachate collection systems with gravel, but in the *Sump* folder.

#### General tab

This tab defines the subtype name or specific type of leachate collection system. It includes a short description of it and the base color is assigned to identify the leachate





collection system in the visual terrain of the model. The user can also load an image to this end.

#### Details tab

- Drainage slope: slope of the leachate collection system. Data from 0 to 1.
- Number of cells served by the drain: number of cells in the model whose leachate is collected by the same drainage pipe. It conditions the total evacuation capacity of it.
- Equivalent hydraulic conductance under the drain: this allows us to specify particular impermeability conditions under the drain. Data in s<sup>-1</sup>.

# Sump tab

Maximum pumping flow: maximum flow that can be pumped from the sump.
 Data in m<sup>3</sup>/s.

# 2.2.6 Run-off types

This is used to represent the surface drainage of the landfill: management of those volumes of water which do not seep into the upper cells and when they accumulate on the surface, on exceeding the depth of surface storage, flow in the form of surface run-off.

Once the leachate collection system has been represented in the model, the type of run-off for each layer is defined. In order to do this, the exit direction of the run-off water and how to manage it is specified. In MODUELO there are five type of run-off water management: "Combined", "Connected", "Dike", "No evacuation" and "Not-connected".

#### 2.2.6.1 Run-off direction

As seen in Figure 23, four directions can be defined in MODUELO: "Down", "Left", "Right" and "Up".





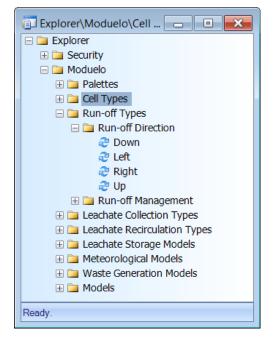


Figure 23. Setup window with run-off directions

1. Maximum surface accumulation is entered by the user in the Run-off model in the Hydrological Model of each cell type.

The direction of run-off drainage applies in the case when selecting a combined or mixed system, or a system of ridges. In other cases, it is not necessary to indicate the direction of drainage of the landfill surface in the program.

## 2.2.6.2 Run-off management

The run-off toolbar opens up when you click the right-hand button on the top bar of the main window. Select *Run-off Toolbar*. To assign each cell a type of run-off management, select the type of corresponding run-off management on the toolbar.

Once the work view has been selected, click the button (*Activate selection mode* option), which freezes the view and allows you to select the area in which you wish to add the selected run-off type.

Once the area with the selected run-off type has been marked, click the button (Add selected run-off management option), which you can add this type of management to selected cells with, as seen in Figure 24 and Figure 25.

MODUELO allows five types of surface run-off management (see Figure 26):





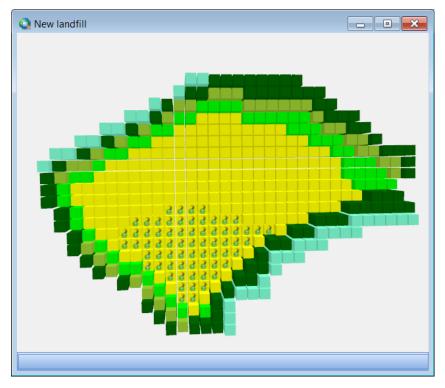


Figure 24. Example of selection of cells to define a type of surface run-off management.

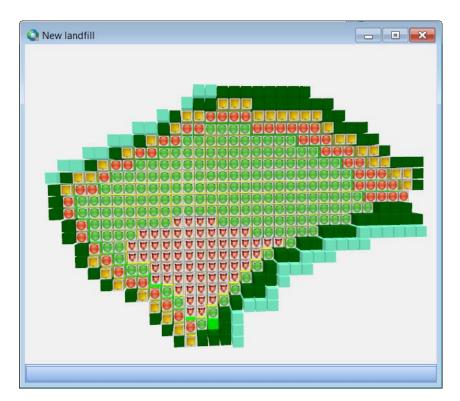


Figure 25. Example of terrain with four types of surface run-off management





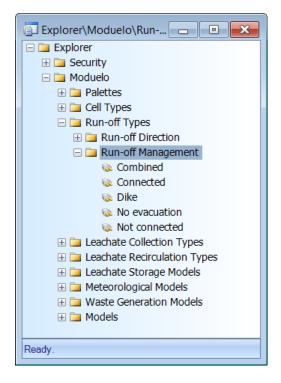


Figure 26. Types of surface run-off management

#### No evacuation. Some No evacuation

The volume of unfiltered water cannot be evacuated from the landfill and it remains over the cells until filters through, or until it evaporates or evapotranspires.

## 

This characteristic is assigned to the cell when the volume of water that is released is evacuated through a run-off collection system (for example, a perimeter trench), which is connected to the leachate collection system.

# Not connected. ⊕ Not connected.

In this case, the evacuation system for surface water is not connected to any leachate collection system: surface run-off is independently managed.

# Combined. Combined

This represents a way of managing the lower drainage systems with several conducts in parallel. Each duct provides service to an area of the landfill, and is not connected to the leachate evacuation system until that area begins to be used





by depositing waste. Meanwhile, the conduct is used to evacuate run-off waters, which will not be contaminated.

In a cell with "combined" surface drainage, run-off is considered "not connected" as long as another cell has not been placed in the upper layer upstream in the direction of drainage (the lower drainage system in this layer is still not connected to the general leachate evacuation network) and it will be otherwise considered "connected".

# Management through ridges (Dike).

In many landfills, waste placement is carried out by sectioning the surface using low permeability ridges (dikes) which allow the run-offs to be controlled, connecting only those coming from the operational areas to the general leachate network (see Figure 27).

In a cell with this type of management, run-off will be considered "not connected" as long as cells have not been placed over the area between ridges to which it belongs. When starting the operation in a specific compartment (limited by one or more ridges), all the run-off in the cells located upstream in the drainage direction in the ridge is considered "connected", whereas run-off in the cells located downstream is "not connected". According to how the landfill operation evolves, the "active" ridges vary and the run-off in each cell also varies with them, changing from "not connected" to "connected".

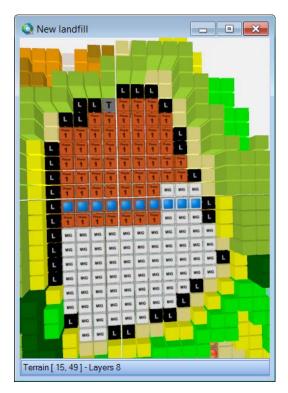






Figure 27. Example of definition of a water management system using ridges (dike).

## 2.2.7 Leachate recirculation types

Leachate recirculation types can be defined during landfill operation and in the after landfill closure period.

## 2.2.7.1 Leachate recirculation types during landfill operation

In MODUELO there are seven main types of leachate recirculation during the operational stage of the landfill: "Prewetting", "Tipping area spraying", "Surface spraying", "Surface pond", "Horizontal injection", "Vertical injection" and "Vertical extraction".

# 2.2.7.1.1 Prewetting, Tipping area spraying, Surface spraying, Surface pond, Horizontal injection

To create a leachate recirculation system using Prewetting, click the right-hand button of the mouse on the *Prewetting* folder and select *New LRS type*, opening the window shown in Figure 29.

#### General tab

This tab defines the code and subtype name, or the specific type of the leachate collection system. It includes a short description of it and the base color is assigned to identify the leachate collection system in the visual terrain of the model. The user can also load an image to this end.





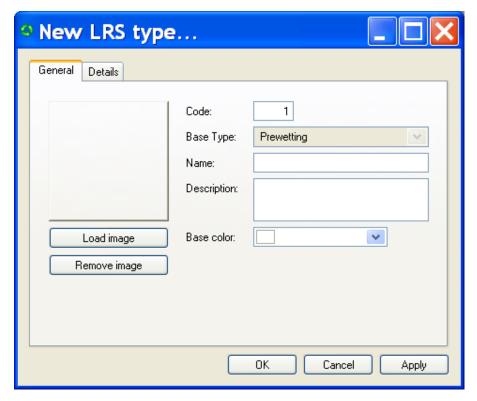


Figure 28. Setup window of a new leachate recirculation system; "Prewetting" type

## Details tab

Daily volume of recirculation flow per cell: the volume of leachate that will be entered in the cell provided that its reception capacity of moisture and the availability of stored leachate allow it. Data in m<sup>3</sup>/d.

# Recirculation condition

This allows you to select one or two conditions without which this type of recirculation will not be produced: run-off in the previous day must not exceed the value entered by the user and/or the volume of leachate collected the previous day must not exceed the corresponding value, also entered by the user.

- Run-off lower than: this allows the user to establish the value of surface runoff, above which no recirculation is produced the following day in the system of
  the defined type. Data in m<sup>3</sup>/d.
- Leachate lower than: this allows the user to establish the value of the volume of leachate collected, above which no recirculation is produced the following day in the system of the defined type. Data in m³/d.

Once a subtype for the leachate recirculation system by humidification has been created, it is necessary to define in which time periods it will be active. In order to do





so, click the right-hand button of the mouse on the created subtype and select *New LRS period*, which will open a window as shown in Figure 30.

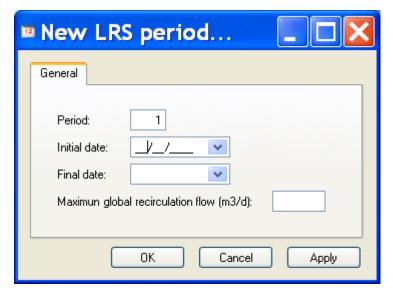


Figure 29. Setup window of a recirculation period

#### General tab

- Period: identification number for the period to be defined.
- Initial date: day on which the recirculation sub-type to be dealt with starts.
- Final date: day on which recirculation of the corresponding sub-type finishes.
- Maximum global recirculation flow: maximum volume which can recirculate among all the cells in the corresponding subtype. Data in m³/d.

For Irrigation types on the landfill front, Surface spraying, Surface pond and Horizontal injection, the user should carry out a similar procedure to the previous one, from the corresponding file in each case.

## 2.2.7.1.2 Vertical injection

To create a leachate recirculation system in vertical Wells, proceed in a similar way as for the creation of other leachate recirculation systems (from the Vertical injection file on this occasion). In this case, the parameters which are to be entered are different.

#### General tab

In this tab, the code and name of the sub-type or the specific leachate recirculation type is defined. A brief description is included and the base color is assigned to identify the cell in the visual terrain model. To this end, the user can also load an image.





#### Details tab

Daily volume of recirculation flow per well: the volume of leachate that will be entered in the cell provided that its reception capacity of moisture and availability of stored leachate allow it. Data in m<sup>3</sup>/d.

## Recirculation condition

This allows you to select one or two conditions without which this type of recirculation will not be produced: that run-off in the previous day must not exceed the value entered by the user and/or that the volume of leachate collected the previous day must not exceed the corresponding value, also entered by the user.

- Run-off lower than: this allows the user to establish the value of surface runoff, above which no recirculation is produced the following day within the
  system of the type which is defined. Data in m³/d.
- Leachate lower than: this allows the user to establish the value of the volume of leachate collected, above which no recirculation is produced the following day within the system of the type which is defined. Data in m<sup>3</sup>/d.

#### Well characteristics

Perforated lateral surface: percentage of the lateral surface of the well which is perforated (through which water will flow from the inside of the well towards the waste).

- Well radius: radius of the leachate vertical injection well. Data in m.
- Well depth: length of the well from the cell in which it is defined (the well is active when the cell is on the surface). Data in number of layers from the surface cell to the bottom.

As with the rest of the recirculation subtypes, once the previous parameters have been defined, the corresponding recirculation periods have to be created, according to explanations in the previous section.

## 2.2.7.1.3 Vertical extraction

To create a leachate extraction system with pipe, proceed in a similar way as for the creation of other leachate recirculation systems (from the Vertical extraction folder on this occasion). In this case, the parameters to be entered are different.

#### General tab





In this tab, the code and name of the sub-type, or the specific leachate recirculation type is defined. A brief description is included and the base color is assigned to identify the cell in the visual terrain model. To this end, the user can also load an image to this end.

#### **Details tab**

Daily volume of extraction per well (Extraction flow per well): the volume of leachate that will be entered in the cell provided that its reception capacity of moisture and the availability of stored leachate allow it. Data in m³/d

#### Well characteristics

- Well radius: radius of the leachate vertical injection well. Data in m.
- Well depth: length of the well from the cell in which it is defined (the well is active when the cell is on the surface). Data in number of layers from the surface cell to the bottom.

As with the rest of recirculation subtypes, once the previous parameters have been defined, the corresponding recirculation periods have to be created, according to explanations in the previous section.

## Leachate recirculation types after landfill closure

In MODUELO there are five main types of leachate recirculation systems during the post-closure stage of the landfill: "Surface spraying", "Surface pond", "Horizontal injection", "Vertical injection", and "Vertical extraction".

To create subtypes of any of these systems, proceed in a similar way as in the cases for the landfill being operated.

# 2.3 Waste generation model

Waste generation models allow different residues that are dumped in the landfill to be represented throughout their history of operations and/or evaluating various waste management strategies independently from their effect in the landfill. Each model has three modules: components, generation periods and simulations.

# 2.3.1 Components

This module is used when the user has information about the quantity of different materials (components: paper, wood, metal, etc.) which arrive at the landfill.





Here, the properties of each component are defined with regards to their elemental composition, biodegradability and other characteristics.

To generate a new component, click the right-hand button on the *Components* folder and select the *New component* option. A window with two tabs appears:

#### General tab

The identification number and the name of the component are defined and a brief description can be included.

## · Composition tab

#### Composition

Elemental composition of the component: contents in carbon, hydrogen, oxygen, nitrogen, sulphur and ashes. Data in percentage in dry weight.

## **Biodegradability**

- Biodegradability: it is indicated if the component is inert, or quickly or slowly biodegradable.
- Biodegradable fraction: if the component is biodegradable, the fraction that can be biodegraded is specified. Data in percentage.

## Other characteristics

- Global moisture content): initial moisture of the component. Data in percentage in dry weight.
- Global density: initial density of the component. Data in Tn/m³ expressed in wet weight.
- Calorific power: calorific power of the component. Data in kcal/kg in dry weight.

## 2.3.2 Generation periods

Generation periods allow the user to define the different streams of waste that arrive at the landfill throughout time.

To create a generation period, click the right-hand button of the mouse over the *Generation periods* folder and select *New generation period*, which opens the window shown in Figure 30.





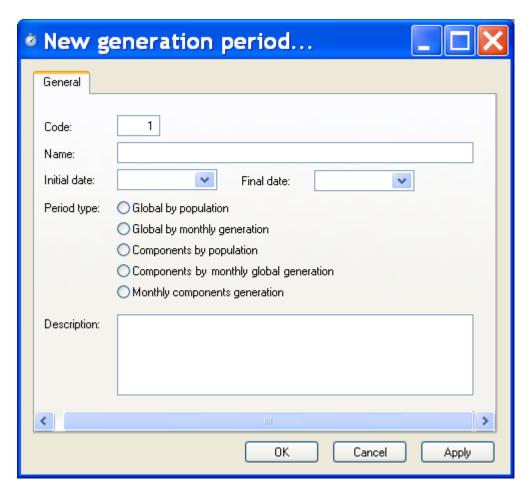


Figure 30. Setup window of a new waste generation period

#### General tab

In this tab the numeric identification code and the name of the new waste generation period, the start and finish date, and a brief description are all included. Besides, one of the five periods described below is selected, according to the data which is available.

- Global generation by population: specified in this type of period is the population (number of inhabitants) who generate the waste, the daily amount of waste generation per capita and growth rates, both of the population and of waste generation.
- Monthly global generation: the monthly waste generation during the period to be defined is known.
- Generation by components and population: this specifies the composition of waste by components, as well as the recycled fraction of each. The population (number of inhabitants) generating the waste is also entered, as well as the growth rate of waste generation, the daily rate of waste generation per capita





and the growth rate of waste generation. There is a possibility of selecting the *Growth rate by components* option and defining the production growth rates of each component; in this case, the user doesn't define the growth rate of the population nor of the global waste generation.

- Generation by components and monthly generation: the composition of the waste by components is known over time, as is the recycled fraction of each one and the global monthly waste generation during the period to be defined.
- Monthly components generation: the components are specified and so is the monthly generation of each one during the period to be defined.

For each type of generation period, different tabs are generated by selecting the introduction of data, described below.

# 2.3.2.1 Global by population

## · Global composition tab

#### Composition

Global composition of the waste: contents in carbon, hydrogen, oxygen, nitrogen, sulphur and ashed. Data in percentage.

## **Biodegradability**

The fraction which is quickly biodegradable, slowly biodegradable and the inert fraction are indicated. The total for the three must be 100. Data in percentage.

## · Generation by population tab

- Initial served population: the number of inhabitants who generate the waste in the corresponding stream.
- Daily unit waste generation: the amount of waste that arrives at the landfill per capita and day. Data in kg/cap/d in wet weight.
- Population annual accumulative growth rate: data in percentage.
- Global annual accumulative growth rate of unit waste generation: data in percentage.

## Other characteristics tab

- Accessibility factor: this represents the fraction of waste that remains accessible to micro-organisms for its decomposition in the landfill.
- Dragging factor: the fraction of organic, non-biodegradable material that passes to the leachate by "dragging" in the hydrolysis of degradable material.





- Global moisture content: moisture content of the waste. Data in percentage in wet weight.
- Global density: density of the waste. Data in Tn/m<sup>3</sup> in wet weight.
- Calorific Power: data in kcal/kg in dry weight.

## 2.3.2.2. Monthly global generation

## Global composition tab

## Composition

Global composition of the waste: contents in carbon, hydrogen, oxygen, nitrogen, sulphur and ashes. Data in percentage in dry weight.

## **Biodegradability**

The fraction which is quickly biodegradable, slowly biodegradable and the inert fraction are indicated. The total for the three must be 100. Data in percentage.

# Monthly global generation tab

The user must complete the *Generation* column with the tons of waste which arrive at the landfill every month.

#### · Other characteristics

- Accessibility factor: this represents the fraction of residue which remains accessible to micro-organisms for its decomposition in the landfill.
- Dragging factor: the fraction of organic, non-biodegradable material that passes to the leachate by "dragging" in the hydrolysis of degradable material.
- Global moisture content: moisture content of the waste. Data in percentage in wet weight.
- Global density: density of the waste. Data in Tn/m³ in wet weight.
- Calorific Power: data in kcal/kg in dry weight.

## 2.3.23. Components by population

## Composition by components tab

All the components which appear in the waste stream to be defined are dragged from the *Components* folder. For each component, the percentage represented





initially in the total generated mix and the recycled fraction of it is defined; both of these are in wet weight.

## Generation by population tab

- Initial served population: the number of inhabitants who generate waste in the corresponding stream.
- Daily unit waste generation: the amount of waste generated per capita per day.
   Data in kg/cap/d in wet weight.
- Growth rate by components: this allows us to define the growth of waste generation, component by component. If this box is selected, no more data will be entered in this tab. On the other hand, the following parameters are also entered.
- Annual cumulative growth rate of the population: data in percentage.
- Global annual accumulative growth rate of unit waste generation: data in percentage.

#### Other characteristics tab

- Accessibility factor: this represents the fraction of waste that remains accessible to micro-organisms for its decomposition in the landfill.
- Dragging factor: the fraction of organic, non-biodegradable material that passes to the leachate by "dragging" in the hydrolysis of degradable material.
- Global density: the user can opt to define the global density of waste in the landfill, or select the density of the mix from the density of each component in the landfill to be calculated, in which case the *By components* box should be selected. In the first case, the data in Tn/m³ in wet weight is entered.
- Calorific Power: the user can opt to define a global calorific power of the waste
  or select it to be calculated from the characteristics of each component, in
  which case the *By components* box should be selected. In the first case, the
  data in kcal/kg in dry weight is entered.

## Components by monthly global generation

## · Composition by components tab

 All the components which appear in the waste stream to be defined are dragged from the *Components* folder. For each component, the percentage represented initially in the total generated mix and the recycled fraction of it is defined; both of these are in wet weight.





## Monthly global generation tab

The user must complete the *Generation* column with the tons of waste generated monthly during the selected period.

#### Other characteristics tab

- Accessibility factor: this represents the fraction of waste that remains accessible to micro-organisms for its decomposition in the landfill.
- Dragging factor: the fraction of organic, non-biodegradable material that passes to the leachate by "dragging" in the hydrolysis of degradable material.
- Global density: the user can opt to define a global density of waste in the landfill, or select the density of the mix from the density of each component in the landfill to be calculated, in which case the *By components* box should be selected. In the first case, the data in Tn/m³ in wet weight is entered.
- Calorific Power: the user can opt to define a global calorific power of the waste, or select it to be calculated from the characteristics of each component, in which case the *By components* box should be selected. In the first case, the data kcal/kg in Tn/m³ in dry weight is entered.

## 2.3.2.5 Monthly components generation

## Composition by components tab

All the components which appear in the waste stream to be defined are dragged from the *Components* folder.

## · Generation by components tab

The user must complete the *Generation* column with the tons of waste which arrive at the landfill every month

## Other characteristics tab

- Accessibility factor: this represents the fraction of waste that remains accessible to micro-organisms for its decomposition.
- Dragging factor: the fraction of organic, non-biodegradable material that passes to the leachate through washing.
- Global density: the user can opt to define a global density of waste, in which
  case the data will be in Tn/m³ in wet weight, or select the density of the waste
  to be calculated by components, in which case the *By components* box should
  be selected.





 Calorific Power: the user can opt to define a global calorific power of the waste, in which case the data would be in kcal/kg in dry weight, or select it to be calculated from the characteristics of each component, in which case the *By* components box should be selected.

## 2.3.3 Simulations

To create a simulation of waste generation, click the right-hand button of the mouse on the *Simulations* folder and select *New waste simulation*, which opens the window shown in Figure 31.

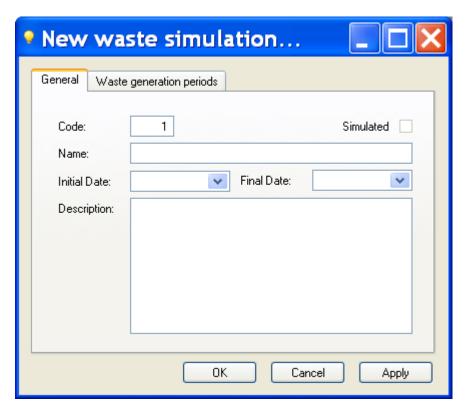


Figure 31. Setup window of a new waste generation simulation

#### General tab

In this tab the identification code number, the name of the new waste generation simulation, the start and finish date of the simulation and a brief description of it are defined.

# · Waste generation periods tab

The waste generation periods which are included in the simulation are dragged from the *Generation periods* folder to this tab.





#### Results of the simulation

The results saved after the simulation can be consulted by the user with the *View in Grid* option, which appears by clicking on the right-hand button after carrying out the simulation (once a simulation is finished, the | | | icon turns into a lit bulb | | | |).

The general results of the simulation are the following:

- Generated Waste: Global amount of waste generated during the simulated period. Data in Tn in wet weight.
- Recycled Waste: Global amount of waste recycled during the simulated period.
   Data in Tn in wet weight.
- Landfilled Waste: Global amount of waste that arrives at the landfill during the simulated period. Data in Tn in wet weight.
- Moisture content: Data in percentage in wet weight, referring to waste that arrives at the landfill.
- Density: data in Tn/m<sup>3</sup> in wet weight, referring to waste that arrives at the landfill.
- Calorific power: data in kcal/kg in dry weight, referring to waste that arrives at the landfill
- Readily biodegradable material: data in Tn in dry weight, referring to waste that arrives at the landfill.
- Slowly biodegradable material: data in Tn in dry weight, referring to waste that arrives at the landfill.
- Organic non-biodegradable material: data in Tn in dry weight, referring to waste that arrives at the landfill.
- Ashes: data in Tn in dry weight, referring to waste that arrives at the landfill.
- Accessibility factor.
- Dragging factor.

The results of composition are also shown: amounts of carbon, hydrogen, oxygen, nitrogen, sulphur and ashes (data in Tn in wet weight) which compose each fraction of the waste: Readily biodegradable, Readily non-biodegradable, Slowly biodegradable, Slowly non-biodegradable, Inert and Total non-biodegradable. The general results, as well as the composition results, can be consulted for every month of the simulation (Figure 32).







Figure 32. Example of results window of waste generation simulation.

# 2.4 Meteorological models

To begin editing the meteorological data, click the right-hand button on the *Meteorological models* folder and select the *New meteorological model* folder. The window in Figure 33 will appear, specifying the numeric identification code, the model number and the latitude in which the landfill is located. If the user also wishes, he can have a description of the meteorological model.

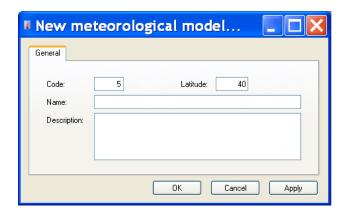


Figure 33. Setup window of a new meteorological model

The data is loaded from an XLS type file, which has been previously created. Click the right-hand button of the mouse on the new model and select the *Import meteorological records* option.





The XLS file which is to be loaded can have any name, but it must consist of only one sheet with data that is called MeteoreolgicalRecords. On the first line, the following sections should appear (see Figure 34).

- **RelativeHumidity**: average daily relative humidity in percentage.
- AverageTemperature: average daily temperature in <sup>o</sup>C
- **AverageWindSpeed**: average daily wind speed in km/h.
- Insolation: daily number of hours of sunshine
- PH1; PH2; PH3; PH4; PH5; PH6; PH7; PH8; PH9; PH10; PH11; PH12;
   PH13; PH14; PH15; PH16; PH17; PH18; PH19; PH20; PH21; PH22;
   PH23; PH24: hourly precipitation corresponding to each of the hours during the day, in mm.
- **DailyPrecipitation**: daily precipitation in mm.
- MaximumTemperature: maximum daily temperature in °C
- MinimumTemperature: minimum daily temperature in °C

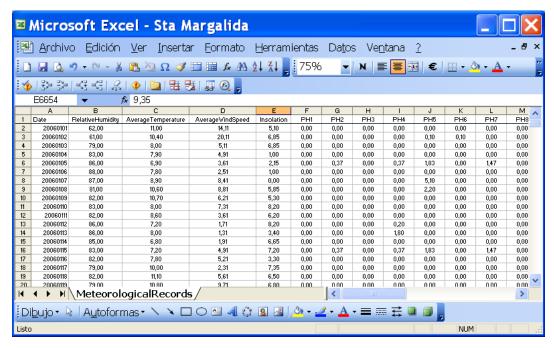


Figure 34. View of XLS file to be loaded with meteorological data

With the XLS file, all the data in the created model is loaded, and from there it can be edited in the tables which are shown by clicking on the meteorological model with the right-hand button and selecting the *View in grid* option, as shown in Figure 35.





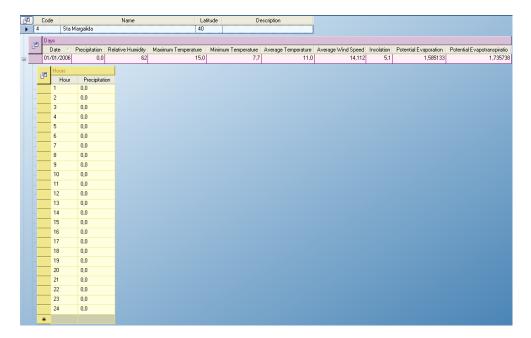


Figure 35. View of one-day data in a climatological model

# 2.5 Leachate storage models

The leachate storage model allows storage deposits to be simulated, where different streams of liquid generated in the landfill for their subsequent recirculation are mixed, transport to treatment stations, etc.

The storage model establishes the amount and main characteristics (content of contaminants) of leachate stored in the deposit throughout the simulation.

To create a leachate storage model, click on the right-hand button of the mouse on the *Leachate storage models* folder and select *New storage model*, which opens the window shown in Figure 36.





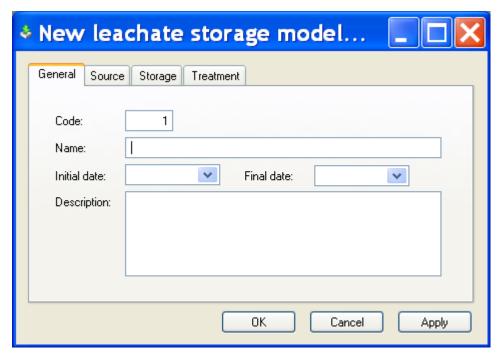


Figure 36. Setup window of a new leachate storage model.

#### General tab

• In this tab, the numeric identification code and the name of the leachate storage model, the start and finish date in which the storage deposit is active are defined, and a brief description can also be included.

#### Source tab

This allows us to show which currents are lead to the deposit for storage. To select *Connected run-off* and *Non-connected run-off*, click the corresponding button. The collection systems whose leachates are lead to the deposit are incorporated in the model by "dragging" them to this tab in the Leachate Collection System (*LCS type*).

## Storage tab

The parameters connected with the deposit of leachate storage are shown (Figure 37):

- Storage capacity: the maximum volume of leachate that can be stored. Data in m<sup>3</sup>.
- Horizontal surface: area of free surface in the place where leachate is stored.
   Data in m<sup>2</sup>.
- Average evaporation rate: daily average evaporation rate. Data en (m³/d).





- Sedimentation rate: sedimentation rate (first order) of the sedimentable fraction of leachate contaminants. Data en d<sup>-1</sup>.
- Sedimentable fraction: of contaminants in the leachate. Data in %.
- Degradation rate at 10°C: sedimentation rate (first order) of contaminants in the leachate. Data in d<sup>-1</sup>.
- Arrhenius coefficient: variation constant of the degradation rate with the temperature. Non-dimensional data.

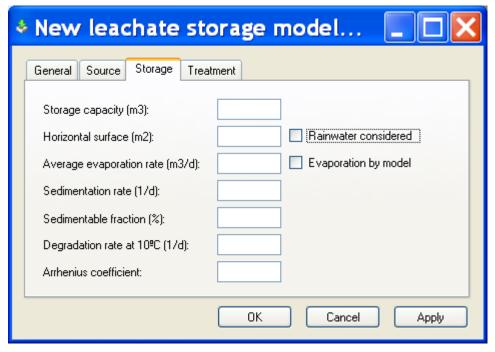


Figure 37. Setup window of characteristics of leachate storage

In this tab the user can define if the effect of rainwater directly on the deposit (*Rainwater considered*) and the evaporation model (*Evaporation by model*) is considered, by selecting the corresponding box. To consider the evaporation phenomenon, an average evaporation rate can be defined, instead of using the model incorporated in MODUELO (also applied to the surface water balance in the landfill).

#### Treatment tab

The user defines the volume of leachate extracted daily from storage for its treatment (Daily treated), using a series of data in m<sup>3</sup>.





## 3 SIMULATION

## 3.1 New model simulation

Once the morphological, meteorological, waste generation and leachate storage models have been created, a simulation can be considered. To do so, click the right-hand button of the mouse on the *Simulations* folder in the landfill model and select the *New Model simulation* option. The window shown in Figure 38 then appears.

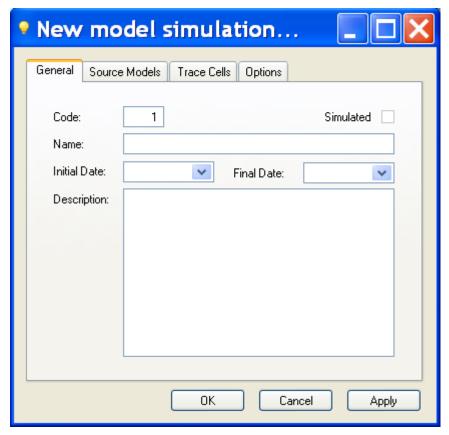


Figure 38. Setup window of a new simulation.

## General tab

The name of the simulation is defined here, as well as the start and finish dates. A description of the simulation can also be included.

## • Source models tab (Figure 39)

The *Meteorological model* and the selected *Waste generation model and simulation* are "dragged" to this window.





If the simulation includes leachate recirculation, it is necessary to indicate the defined *Leachate storage model* (in the same way as the meteorological and waste generation models).

There is a possibility of carrying out "chained" simulations: simulations whose initial situation is defined by the results of a previous simulation which finishes on a date which is previous to the start of the next one. In order to do so, the initial simulation must be "dragged" to the *Base model simulation*.

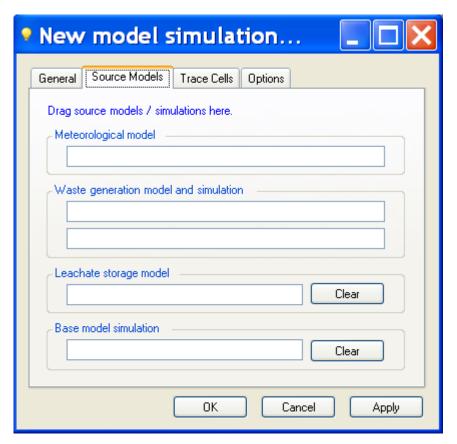


Figure 39. Setup window of simulation models.

# • Trace cells tab (Figure 40)

In this tab, the cells which the user wants to have a detailed follow-up of throughout the simulation period are defined. The *Cell ID* which the user wants to follow up is written in the corresponding box and the *Add* button is then clicked. Throughout the simulation, the program will save a series of variables of the selected cells, which will remain available amongst the results at the end of the simulation (see Section 4.4.1.).





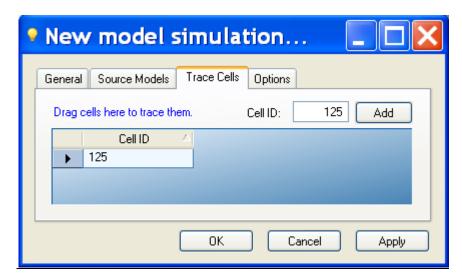


Figure 40. Setup window of cells to be followed up in detail throughout the simulation.

## • Options tab (Figure 41)

This defines how often daily simulations results are saved and the interval between them.

On the other hand, the user must select the models which are to be simulated (left-hand column in Figure 41) and the type of data to be saved in results (right-hand column in Figure 41) (see Section 4).

For a similar type of simulation (with the same active models), the lower the interval between results the higher frequency of the data register, and, the higher the amount of results to be registered the slower the simulation will be.

## Left-hand column of the Options window

- Evaluate surface water: this activates surface water balance models
- Evaluate vertical flow: this activates the vertical flow models between cells.
- Evaluate horizontal flow: this activates the horizontal flow models between cells.
- Evaluate biodegradation: this activates the waste degradation models.
- Evaluate leachate storage: this activates the leachate storage model.
- Evaluate recirculation: this activates leachate recirculation models.





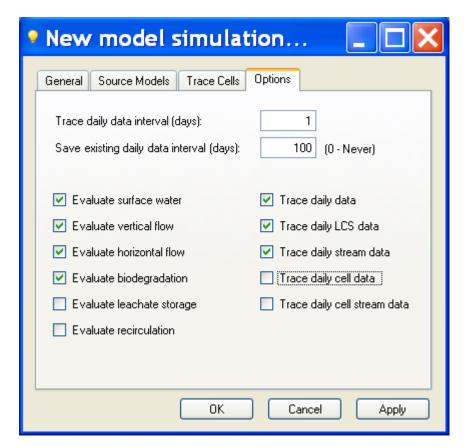


Figure 41. Setup window of simulation options.

## Right-hand column in Options window

- Trace daily data: global daily results of the landfill are registered throughout the entire simulation (see Section 4.2).
- Trace daily LCS data: this compiles daily results of the leachates collected by each leachate collection system. (see Section 4.4.2).
- Trace daily stream data: this compiles daily results of the various liquid flows in the landfill: Available leachate, Collected leachate, Lateral seepage, Bottom leakage, Recirculated leachate, Treated leachate, Surplus leachate and Extracted leachate (see Section 4.4.3.)
- Trace daily cell data: this collects daily results corresponding to the cells selected in the *Trace Cells* tab (see Section 4.1).
- Trace daily cell stream data: this compiles the characteristics of the various liquid flows in cells selected in the *Trace cells* tab (see Section 4.1).

To carry out a new simulation which substitutes a previous one (the symbol appears) simulation parameters should be changed (by activating new models, for example). First, the simulation must be "cleared" (*Clear simulation*): the program





deletes all the results and the simulation is shown as not-simulated (the  $\overline{y}$  symbol appears).

## 3.2 Visual simulate

To check if the constructed model is correct (for example, filling order of cells) or to carry out a follow-up of some cells during simulation, the user can carry out a Visual Simulate.

Once the desired simulation has been defined, click the right-hand button of the mouse on the *Visual simulate* option. A window is then shown with the terrain model, without any landfill cells. The parameters of the simulation are defined on the simulation toolbar, which is shown on the top bar when you click the right-hand button on it and select *Simulation toolbar* (see Figure 42).

Enter the number of days to be simulated in each step in the corresponding box in this tool. The button, (Simulate next selected days number), activates the simulation of the marked interval: the incorporation of new cells according to the exploitation model (waste and terrain generation), which is defined by the user, is observed on the visual model. The button, (Simulate all remaining days with the specified step), activates simulation until the final date defined by the user. Finally, the button, (Stop simulation) stops the simulation (see Figure 43).







Figure 42. Setup window of a visual simulation.

The *Visibility* and *Symbols* tools allow the user to modify visualization options, as commented in Section 2.2.2.2.2, whereas the *Cell details* option allows us to consult the state of each cell at the end of the simulation interval (see Section 4.3).





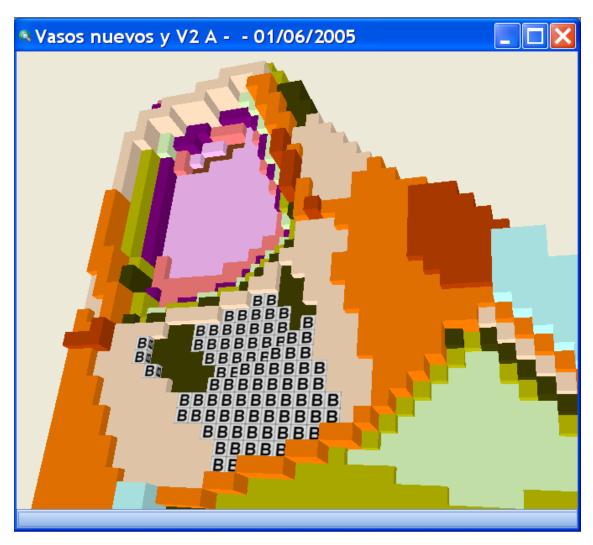


Figure 43. View of a simulation project after a month's simulation





## 4 ANALYSIS OF RESULTS

There are various options for consulting the results of each simulation:

- Final cell data in grid.
- Global daily data in grid.
- Results in designer.
- View current data in graphic format.

# 4.1 Final cell data in grid

The condition of all the cells in the model on the final date of simulation can be consulted by clicking the right-hand button on the final simulation (a lit bulb) and selecting the *Final cell data option in grid*. The window shown in Figure 44 then appears.

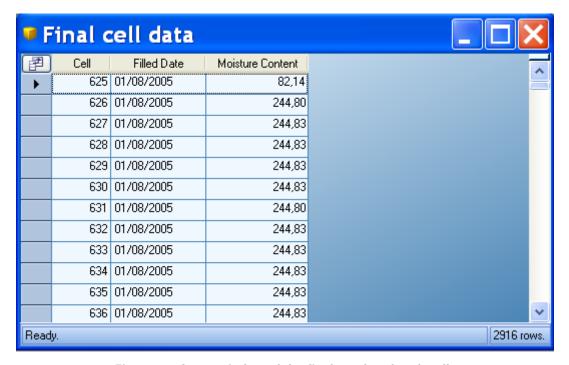


Figure 44. Setup window of the final results of each cell.

If you click on the button, a list with the available data will appear. Once you have selected the data of interest, they are then shown in the window showing the final results of each cell. The following results can be consulted:

- Cell identification code (Cell).
- Date of filling or location of the cell (Filled date)





- Total thickness of the cell: data in m.
- Waste thickness: data in m.
- Total weight: data in kg in dry weight.
- Waste weight: data in kg in dry weight.
- Cover weight: data in kg in dry weight.
- Bottom elevation: data in m.
- Surface elevation (Top elevation): data in m.
- Saturation moisture: data in percentage in dry weight.
- Residual moisture: data in percentage in dry weight.
- Field capacity moisture (Capacity moisture): data in percentage in dry weight.
- Moisture content: data in percentage in dry weight.
- Saturation moisture of the cover (Cover saturation moisture): data in percentage in dry weight.
- Residual moisture of the cover (Cover residual moisture): data in percentage in dry weight.
- Field capacity moisture of the cover (Cover capacity moisture): data in percentage in dry weight.
- Moisture content of the cover (Cover moisture content): data in percentage in dry weight.
- Depth of water accumulated on the surface (Surface water depth): data in m.
- Vertical hydraulic conductivity: data in m/s, corresponding to the waste in the Landfill or Closed Landfill cells, or to the whole cell in Soil or Closed Soil cells.
- Vertical hydraulic conductivity of the cover (Cover vertical hydraulic conductivity):
   data in m/s.
- Horizontal hydraulic conductivity: data in m/s, corresponding to the waste in the Landfill or Closed Landfill cells, or to the whole cell in Soil or Closed Soil cells.
- Minimum moisture: data in percentage in dry weight.
- Fraction of preferential channels (Preferential channels fraction): data in percentage.
- Vertical flow model: type of vertical flow model which currently applies.
- Minimum moisture: data in percentage in dry weight.
- Value of the moisture curve which currently applies (Moisture curve value): data in percentage in dry weight.
- Modified time for the slow vertical flow (Vertical flow time): data in d.





- Maximum gradient time for the slow vertical flow (Maximum gradient time): data in d.
- Maximum saturation thickness for the slow vertical flow (Maximum saturation thickness): data in m.
- Parameter  $\beta$  (Beta): of the slow vertical flow which currently applies. Non-dimensional data.
- Saturation elevation: data in m.
- Modified time for the preferential vertical flow (Preferential vertical flow time):
   data in days.
- Maximum gradient time for the preferential flow (Preferential maximum gradient time): data in days.
- Maximum saturation thickness for the preferential flow (Preferential maximum saturation thickness): data in m.
- Parameter  $\beta$  for preferential flow (Preferential beta): non-dimensional data.
- Saturation elevation for the preferential flow (Preferential saturation elevation):
   data in m.
- Methane in gas mix: data in kg.
- Carbon dioxide in gas mix: data in kg.
- Hydrogen in gas mix: data in kg.
- Oxygen in gas mix: data in kg.
- Nitrogen in gas mix: data in kg.
- Accumulated primary settlement (Primary settlement): data in m.
- Remaining primary settlement: data in m.
- Secondary settlement: data in m.
- Remaining secondary settlement: data in m.
- Average overload pressure: data in kg/m<sup>2</sup>.
- Maximum average overload pressure: data in kg/m².
- Solid density: data in kg/m³.
- Apparent specific weight of the cell (Apparent specific weight): data in kg/m³.
- Thermal conductivity: data in J/m∘s∘°C
- Accesibility factor: non-dimensional data.
- Dragging factor: non-dimensional data.
- Drain operated full in the last hour (Is drain full): true or false data.
- Position X: non-dimensional data.





- Position Y: non-dimensional data.
- Position Z: non-dimensional data.
- Cna (solid non-accessible carbon): data in kg.
- Crb (solid accessible readily biodegradable carbon): data in kg.
- Csb (solid accessible slowly biodegradable carbon): data in kg.
- Cnb (solid accessible non-biodegradable carbon): data in kg.
- Hna (solid non-accessible hydrogen): data in kg.
- Hrb (solid accessible readily biodegradable hydrogen): data in kg.
- Hsb (solid accessible slowly biodegradable hydrogen): data in kg.
- Hnb (solid accessible non-biodegradable hydrogen): data in kg.
- Ona (solid non-accessible oxygen): data in kg.
- Orb (solid accessible readily biodegradable oxygen): data in kg.
- Osb (solid accessible slowly biodegradable oxygen): data in kg.
- Onb (solid accessible non-biodegradable oxygen): data in kg.
- Nna (solid non-accessible nitrogen): data in kg.
- Nrb (solid accessible readily biodegradable nitrogen): data in kg.
- Nsb (solid nitrogen accessible slowly biodegradable): data in kg.
- Nnb (solid accessible non-biodegradable nitrogen): data in kg.
- Sna (solid non-accessible sulphur): data in kg.
- Srb (solid sulphur accessible readily biodegradable): data in kg.
- Ssb (solid sulphur accessible slowly biodegradable): data in kg.
- Snb (solid accessible non-biodegradable sulphur): data in kg.
- DCcho (dissolved intermediate carbon): data in kg.
- DHcho (dissolved intermediate hydrogen): data in kg.
- DOcho (dissolved intermediate oxygen): data in kg.
- DAC (Dissolved acetate): data in kg.
- DNH3 (Dissolved ammonia nitrogen): data in kg.
- DSH2 (Dissolved hydrogen sulphide): data in kg.
- DCO2 (Dissolved carbon dioxide): data in kg.
- DH2 (Dissolved hydrogen): data in kg.
- DCH4 (Dissolved methane): data in kg.
- DN2 (Dissolved nytrogen): data in kg.
- DO2 (Dissolved oxygen): data in kg.





- DCnb (Dissolved non-biodegradable carbon): data in kg.
- DHnb (Dissolved non-biodegradable hydrogen): data in kg.
- DOnb (Dissolved non-biodegradable oxygen): data in kg.
- DNnb (Dissolved non-biodegradable nitrogen): data in kg.
- DSnb (Dissolved non-biodegradable sulphur): data in kg.

# 4.2 Global daily data in grid

To consult the global daily results which refer to the landfill at the end of the simulation, click the right-hand button on the finalized simulation (a lit bulb) and select the *Global daily data in grid* option: the window in Figure 45 then appears.



Figure 45. Setup window of global daily results

If you click on the button, a list will appear with the results that are available: select the data of interest and they will appear in the global daily results window. The following results can be consulted:

Day





- Total precipitation height: data in mm.
- Total precipitation volume on the landfill surface (Total precipitation volume):
   data in m³.
- Evaporated precipitation volume: data in m³.
- Evaporated surface volume: data in m<sup>3</sup>.
- Infiltrated volume: data in m<sup>3</sup>.
- Volume of water absorbed by the cells placed on another cell which has a "pool" of water (Absorbed volume): data in m<sup>3</sup>.
- Connected run-off: data in m<sup>3</sup>.
- Non-connected run-off: data in m<sup>3</sup>.
- Total surface water: data in m<sup>3</sup>.
- Total landfill moisture content: data in m<sup>3</sup>.
- Maximum landfill moisture content: data in m<sup>3</sup>.
- Released methane: data in kg.
- Released carbon dioxide: data in kg.
- Released hydrogen: data in kg.
- Released oxygen): data in kg.
- Released nitrogen: data in kg.
- Generated methane: data in kg.
- Generated carbon dioxide: data in kg.
- Generated hydrogen: data in kg.
- Average primary settlement: data in m.
- Average primary settlement: data in m.
- Landfill volume: data in m<sup>3</sup>.
- Volume "released" by the settlement (Extra volume): data in m<sup>3</sup>.

# 4.3 Results in designer

#### 4.3.1 Results in designer.

There is another way of consulting the results on screen which is by using the *Results* in designer option that appears when you click the right-hand button on the finished simulation (a lit bulb).





In this option, the terrain model of the landfill is shown with all the cells placed during the simulation with the settlement caused during it. The state of each one at the end of the simulation can be consulted by clicking the *Cells details* tab in the window which appears on the right when you click on the button (Show model view options) on the top bar in the main window.

Once the work view has been selected, click the button (*Activate selection mode* option). This freezes the view and allows you to select the cell in which you wish to consult the final results. In the *Cells details* window, the results of different cells are shown when you move the cursor over them.

Figure 46 shows an example of the visualization of results on the viewer.

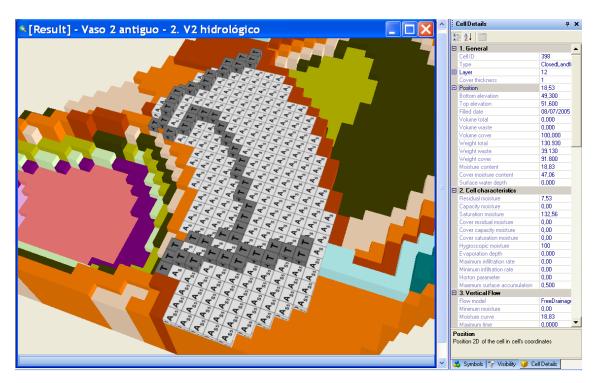


Figure 46. Example of consultation of results in the graphic viewer

The information shown in the *Cells details* tab can be organized in two different ways: in alphabetical order or grouped by categories. The parameters shown in each category are listed below.

### General.

- Cell identification number (Cell ID)
- Cell Type.
- Layer to which the cell belongs.
  - Layer thickness: data in m.





- Cover thickness: data in m.
- Cell Position: horizontal position of the cell in coordinates expressed as a number of cells.
  - X: position of the cell in the X axis of the terrain model.
  - Y: position of the cell in the Y axis of the terrain model.
- Bottom elevation: in absolute coordinates, data in m.
- Top elevation: in absolute coordinates, data in m
- Filled date: date the cell was created
- Total volume: data in m<sup>3</sup>.
- Total volume of waste in the cell (Waste volume): data in m<sup>3</sup>.
- Total cover volume in the cell (Cover volume): data in m<sup>3</sup>.
- Total weight: data in kg in dry weight.
- Waste weight in the cell (Waste weight): data in kg in dry weight.
- Cover weight in the cell (Cover weight): data in kg in dry weight.
- Moisture content of waste in the cell (Moisture content): data in percentage in dry weight.
- Cover moisture content of the cell (Cover moisture content): data in percentage in dry weight.
- Depth of the water accumulated on the surface (Surface water depth): data in m.

#### Cell characteristics.

- Residual moisture of waste in the cell (Residual moisture): data in percentage in dry weight.
- Field capacity moisture of waste in the cell (Capacity moisture): data in percentage in dry weight.
- Saturation moisture of waste in the cell (Saturation moisture): data in percentage in dry weight.
- Residual moisture of the cover in the cell (Cover residual moisture): data in percentage in dry weight.
- Field capacity moisture of the cover in the cell (Cover capacity moisture): data in percentage in dry weight.
- Saturation moisture of the cover in the cell (Cover saturation moisture): data in percentage in dry weight.





- Hygroscopic moisture (wilting point) as a percentage of residual moisture (Hygroscopic moisture): data in percentage.
- Evaporation depth: data in m.
- Maximum infiltration rate: data in mm/h.
- Minimum infiltration rate: data in mm/h.
- Horton parameter: rate of decline in infiltration capacity. Data in h<sup>-1</sup>.
- Maximum accumulation of water-depth on the surface (Maximum surface accumulation): data in m.
- Moisture Hydrolysis Curve: points which define the curve relating moisture to hydrolysis.

#### Vertical flow.

- Vertical Flow Model which currently applies (Flow model).
- Minimum moisture: data in percentage in dry weight.
- Value of the moisture curve that currently applies (Moisture curve value): data in percentage in dry weight.
- Maximum gradient time for the slow flow (Maximum gradient time): data in d.
- Time of vertical flow (Time): data in d.
- Maximum saturation thickness for the slow flow (Maximum saturation thickness): data in m.
- Saturation thickness for the slow flow (Thickness): data in m.
- Maximum gradient time for preferential flow (Preferential maximum gradient time): data in d.
- Modified time for vertical preferential flow (Preferential time): data in d.
- Maximum saturation thickness for preferential channels (Preferential maximum thickness): data in m.
- Saturation thickness for preferential channels (Preferential thickness): data in m.
- Drain operated full in the last hour (Is drain full): true or false data

## • Composition of the solid (Composition solid)

- Non-accessible carbon: data in kg in dry weight
- Readily biodegradable carbon: data in kg in dry weight
- Slowly biodegradable carbon: data in kg in dry weight
- Non-biodegradable carbon: data in kg in dry weight





- Non-accessible hydrogen: data in kg in dry weight
- Readily biodegradable hydrogen: data in kg in dry weight
- Slowly biodegradable hydrogen: data in kg in dry weight
- Non-biodegradable hydrogen: data in kg in dry weight
- Non-accessible oxygen: data in kg in dry weight
- Readily biodegradable oxygen: data in kg in dry weight
- Slowly biodegradable oxygen: data in kg in dry weight
- Non-biodegradable oxygen: data in kg in dry weight
- Non-accessible nitrogen: data in kg in dry weight
- Readily biodegradable nitrogen: data in kg in dry weight
- Slowly biodegradable nitrogen: data in kg in dry weight
- Non-biodegradable nitrogen: data in kg in dry weight
- Non-accessible sulphur: data in kg in dry weight
- Readily biodegradable sulphur: data in kg in dry weight
- Slowly biodegradable sulphur: data in kg in dry weight
- Non-biodegradable sulphur): data in kg in dry weight

## • Dissolved components (Composition dissolved).

- Intermediate carbon: data in kg.
- Intermediate hydrogen: data in kg.
- Intermediate oxygen: data in kg.
- Acetate: data in kg.
- Dissolved ammonia nitrogen: data in kg.
- Dissolved hydrogen sulphide: data in kg.
- Dissolved carbon dioxide: data in kg.
- Dissolved hydrogen: data in kg.
- Dissolved methane: data in kg.
- Dissolved nitrogen: data in kg.
- Dissolved oxygen: data in kg.
- Non-biodegradable carbon: data in kg.
- Non-biodegradable hydrogen: data in kg.
- Non-biodegradable oxygen: data in kg.
- Non-biodegradable nitrogen: data in kg.
- Non-biodegradable sulphur: data in kg.





## Composition of the gas mix (Composition gases).

- Carbon dioxide: data in kg.

- Hydrogen: data in kg.

Methane: data in kg.

Oxygen: data in kg.

Nitrogen: data in kg.

#### Settlements.

- Settlement coefficient through compression (Compression ratio: nondimensional data.
- Ratio mass loss/settlement (Mass loss ratio): non-dimensional data.
- Average overload pressure: data in kg/m².
- Maximum overload pressure: data in kg/m<sup>2</sup>.
- Accumulated primary settlement (Primary settlement): data in m.
- Remaining primary settlement: data in m.
- Secondary settlement: data in m.
- Remaining secondary settlement: data in m.
- Apparent specific weight of the cell (Apparent specific weight): data in kg/m³ in dry weight.

#### Various.

- Last hour of surface recirculation.

## 4.4 Other results of the simulation

Within each simulation there are three folders which contain information about the simulation. The *Cells* folder contains the results of the cells selected in the *Trace Cells* simulation tab; in the *Leachate collection types* folder there is information about each leachate collection system defined by the user in the model and the *Leachate Streams* folder contains the results of other leachate flows which are calculated in the model.

#### 4.4.1 Cells folder

In this folder the cells selected in the *Trace Cells* simulation tab appear. Click the right-hand button on each cell and select the *View in grid* option, where a window will appear with the series of results you require when you click the button. The





results which can be consulted in this window, for each day of simulation are the following:

- Day.
- Waste dry weight: data in kg in dry weight.
- Apparent specific weight of the cell (Apparent specific weight): data in kg/m<sup>3</sup>.
- Bottom elevation of the cell (Bottom elevation): data in m.
- Top elevation of the cell (Top elevation): data in m.
- Residual moisture: data in percentage in dry weight
- Saturation moisture: data in percentage in dry weight.
- Accumulated water-depth on the surface (Surface water-depth): data in m.
- Moisture content of the cover (Cover moisture content): data in percentage in dry weight.
- Moisture content: data in percentage in dry weight, corresponding to the complete cell if it is Soil or Closed Soil type, or the waste part if it is Landfill or Closed Landfill.
- Horizontal hydraulic conductivity: data in m/s, corresponding to the complete cell if it is Soil or Closed Soil type, or the waste part if it is Landfill or Closed Landfill
- Vertical hydraulic conductivity: data in m/s, corresponding to the complete cell if it is Soil or Closed Soil type, or the waste part if it is Landfill or Closed Landfill
- Preferential channels fraction: data in percentage.
- Vertical flow model: type of vertical flow model which currently applies.
- Minimum moisture: data in percentage in dry weight.
- Value of the moisture curve that currently applies (Moisture curve value): data in percentage in dry weight.
- Modified time for the slow vertical flow (Vertical flow time): data in d.
- Maximum gradient time for the slow vertical flow (Maximum gradient time): data in d.
- Maximum saturation thickness for slow vertical flow (Maximum saturation thickness): data in m.
- Parameter  $\beta$  (Beta): of the slow vertical flow which currently applies. Non-dimensional data.
- Saturation thickness for the slow flow (Saturation thickness): data in m.
- Saturation elevation: data in m.
- Modified time for the preferential vertical flow (Preferential vertical flow time):
   data in days





- Preferential maximum gradient time: data in days.
- Maximum saturation thickness for the preferential flow (Preferential maximum saturation thickness): data in m.
- Parameter β for preferential flow (Preferential beta): Non-dimensional data.
- Saturation thickness for the preferential flow (Preferential saturation thickness):
   data in m.
- Saturation elevation for the preferential flow (Preferential saturation elevation):
   data in m.
- Methane in the gas mix (Methane): data in kg.
- Carbon dioxide in the gas mix (Carbon dioxide) : data in kg.
- Oxygen in the gas mix (Oxygen): data in kg.
- Hydrogen in the gas mix (Hydrogen): data in kg.
- Nitrogen in the gas mix (Nitrogen): data in kg.
- Released Methane: data in kg.
- Released Carbon dioxide: data in kg.
- Released Oxygen: data in kg.
- Released Hydrogen: data in kg.
- Released Nitrogen: data in kg.
- Generated Methane: data in kg.
- Generated Carbon dioxide: data in kg.
- Generated Hydrogen: data in kg.
- Average overload pressure: data in kg/m².
- Accumulated primary settlement (Primary settlement): data in m.
- Remaining primary settlement: data in m.
- Secondary settlement. Data in m.
- Remaining secondary settlement: data in m.
- Drain operated full in the last hour (Is drain full): true or false data
- Cna (solid carbon non-accessible): data in kg.
- Crb (solid accessible readily biodegradable carbon): data in kg.
- Csb (solid accessible slowly biodegradable carbon): data in kg.
- Cnb (solid accessible non-biodegradable carbon): data in kg.
- Hna (solid non-accessible hydrogen): data in kg.
- Hrb (solid accessible readily biodegradable hydrogen): data in kg.
- Hsb (solid accessible slowly biodegradable hydrogen): data in kg.





- Hnb (solid accessible non-biodegradable hydrogen): data in kg.
- Ona (solid non-accessible oxygen): data in kg.
- Orb (solid accessible readily biodegradable oxygen): data in kg.
- Osb (solid accessible slowly biodegradable oxygen): data in kg.
- Onb (solid accessible non-biodegradable oxygen): data in kg.
- Nna (solid non-accessible nitrogen): data in kg.
- Nrb (solid accessible readily biodegradable nitrogen): data in kg.
- Nsb (solid accessible slowly biodegradable nitrogen): data in kg.
- Nnb (solid accessible non-biodegradable nitrogen): data in kg.
- Sna (solid non-accessible sulphur): data in kg.
- Srb (solid accessible readily biodegradable sulphur): data in kg.
- Ssb (solid accessible slowly biodegradable sulphur): data in kg.
- Snb (solid accessible non-biodegradable sulphur): data in kg.
- DCcho (dissolved intermediate carbon): data in kg.
- DHcho (dissolved intermediate hydrogen): data in kg.
- DOcho (dissolved intermediate oxygen): data in kg.
- DAC (Dissolved acetate): data in kg.
- DNH3 (Dissolved ammonia nytrogen): data in kg.
- DSH2 (Dissolved hydrogen sulphide): data in kg.
- DCO2 (Dissolved carbon dioxide): data in kg.
- DH2 (Dissolved hydrogen): data in kg.
- DCH4 (Dissolved methane): data in kg.
- DN2 (Dissolved nytrogen): data in kg.
- DO2 (Dissolved oxygen): data in kg.
- DCnb (Dissolved non-biodegradable carbon): data in kg.
- DHnb (Dissolved non-biodegradable hydrogen): data in kg.
- DOnb (Dissolved non-biodegradable oxygen): data in kg.
- DNnb (Dissolved non-biodegradable nitrogen): data in kg.
- DSnb (Dissolved non-biodegradable sulphur): data in kg.

Besides, the daily results corresponding to the different leachate flows in the cells are saved: Available leachate, Collected leachate, Lateral seepage, Bottom leakage, Recirculated leachate, Treated leachate, Surplus leachate and Extracted leachate.

Of all these flow types, the simulation results which are available for each simulated day are the following:





- Volume: data in m<sup>3</sup>.
- Chemical oxygen demand (COD): data in mg O<sub>2</sub>/L.
- Biochemical oxygen demand (BOD): data in mg O<sub>2</sub>/L.
- DCcho (dissolved intermediate carbon): data in kg.
- DHcho (dissolved intermediate hydrogen): data in kg.
- DOcho (dissolved intermediate oxygen): data in kg.
- DAC (Dissolved acetate): data in kg.
- DNH3 (Dissolved ammonia nitrogen): data in kg.
- DSH2 (Dissolved hydrogen sulphide): data in kg.
- DCO2 (Dissolved carbon dioxide): data in kg.
- DH2 (Dissolved hydrogen): data in kg.
- DCH4 (Dissolved methane): data in kg.
- DN2 (Dissolved nytrogen): data in kg.
- DO2 (Dissolved oxygen): data in kg.
- DASH (Dissolved ashes): data in kg.
- DCnb (Dissolved non-biodegradable carbon): data in kg.
- DHnb (Dissolved non-biodegradable hydrogen): data in kg.
- DOnb (Dissolved non- biodegradable oxygen): data in kg.
- DNnb (Dissolved non-biodegradable nitrogen): data in kg.
- DSnb (Dissolved non-biodegradable sulphur): data in kg.

## 4.4.2 Leachate collection types folder

In this folder, the results corresponding to each leachate collection system included in the simulated model are saved.

Click the right-hand button on the cell and select the *Results in grid* option. When you click on the button, a window will appear in which you will see the results listed in the previous section for the different leachate streams.

#### 4.4.3 Leachate streams folder

In this folder, the results corresponding to other global leachate flows in the landfill appear:

- Available leachate.
- Collected leachate.





- Lateral seepage.
- Bottom leakage.
- Recirculated leachate.
- Treated leachate.
- Surplus leachate.
- Leachate extracted from the vertical extraction wells (Extracted leachate).

Click the right-hand button over each type of flow and select the *Results in grid* option. When you click on the button, a window will appear in which you will see the results described in Section 4.4.1.

# 4.5 View current data in graphic format

The program includes a design tool which allows you to graphically analyze the results. The tool is activated in all the options in which the results in "Grid" format can be consulted. The results to be included in the graph should appear in the data window: the button (View current data in graphic format) is then clicked, opening a window with the corresponding graph (see Figure 47).





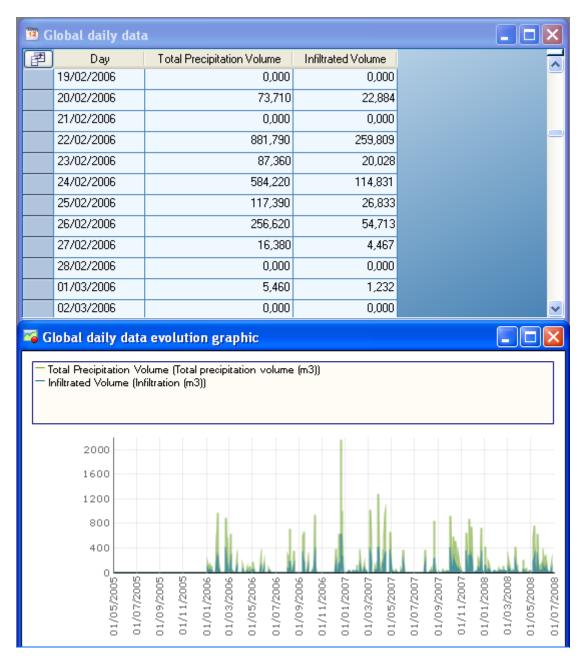


Figure 47. Example of results graphic





# 4.6 Study of results using an external spreadsheet

In the calibration and validation processes, it is convenient to compare simulation results either directly, graphically or mathematically (with deviation calculations, etc.), with the series of field data that are available. In order to do so, the results of the program in all its formats can be exported to an XLS file by clicking on the button (top bar in the main window) where they can be processed externally.



