User Manual

Draft Version

March 2011 (updated)

Table of Contents

1.0 Introduction

CALMIM (California Landfill Methane Inventory Model) is a field-validated 1-dimensional transport and oxidation model that calculates annual site-specific landfill methane emissions based on the major processes that control emissions:

- Surface area and properties of the daily, intermediate, and final cover materials,
- The % of surface area for each cover type with engineered gas recovery, and
- Seasonal methane oxidation in each cover type as controlled by climatic factors.

The driving force for emissions is the methane concentration gradient through each cover type coupled with typical annual soil moisture and temperature profiles which control methane transport and microbial methane oxidation over an annual cycle. CALMIM is an IPCC (Intergovernmental Panel on Climate Change) Tier III model for methane emissions from solid waste disposal sites[1].

The climate-related factors (meteorology and soil microclimate) are automatically accessed based on the site location and physical properties of the cover materials. This model is intended to be user-friendly with a series of input boxes where the user enters basic information on the areas and properties of daily, intermediate, and final cover materials, as well as the % surface area for each cover type with engineered gas recovery (either vertical wells or horizontal collectors).

CALMIM calculates daily emissions for each cover type which are summed to provide an annual total for the site, both in units of g methane/square meter/day (g CH_4 m^{-2} d^{-1}) and for the site as a whole. Taking into consideration recent literature which indicates that first order kinetic models for theoretical methane generation do not match field measurements for landfill methane emissions, CALMIM is the first landfill methane emissions model *which does not rely on a first order model for methane generation based on the mass of waste in place*.

CALMIM was developed during 2007-2010 with supporting laboratory studies and field validation under the auspices of the California Energy Commission PIER (Public Interest Energy Research) Program. CALMIM is JAVA-based, freely available to users, and is intended to be the first step in the development of improved science-based models which have been field-validated and can be internationally applied to landfill methane emissions inclusive of seasonal methane oxidation.

The project team consisted of

- J. Bogner (Landfills +, Inc. and University of Illinois, Chicago)
- K. Spokas (USDA-ARS, St. Paul, MN), and
- J. Chanton (Florida State University, Tallahassee, FL).

[1] IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*. IPCC/ IGES, Hayama, Japan. http:/ / www.ipcc-nggip.iges.or.jp/ public/ 2006gl/ ppd.htm.

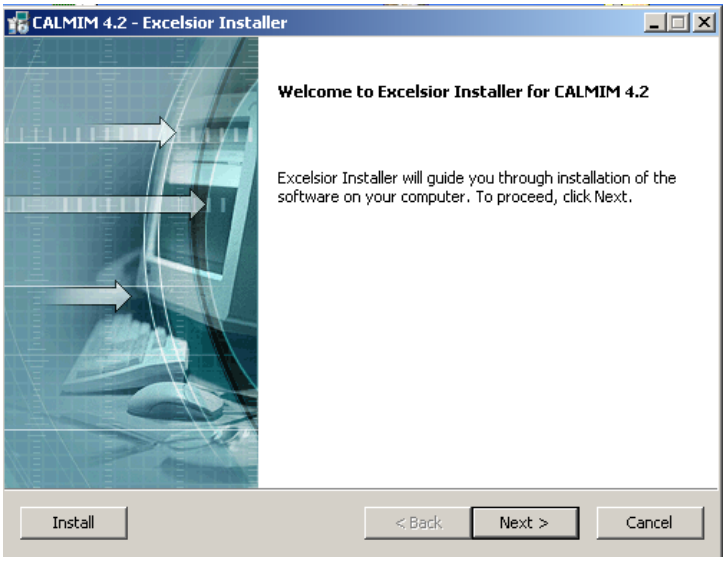
2.0 Installation Guide

This section will describe the installation of the CALMIM model.

CALMIM uses the Excelsior Installer from the JET family of Java pre-compiler programs. The program is distributed via a setup program (CALMIM-setup.exe) as shown below:

This program is available for download from (http://calmim.lmem.us) or on a distribution CD available through the California Energy Commission (PIER).

The user should double click on the icon and the following initial window is displayed:

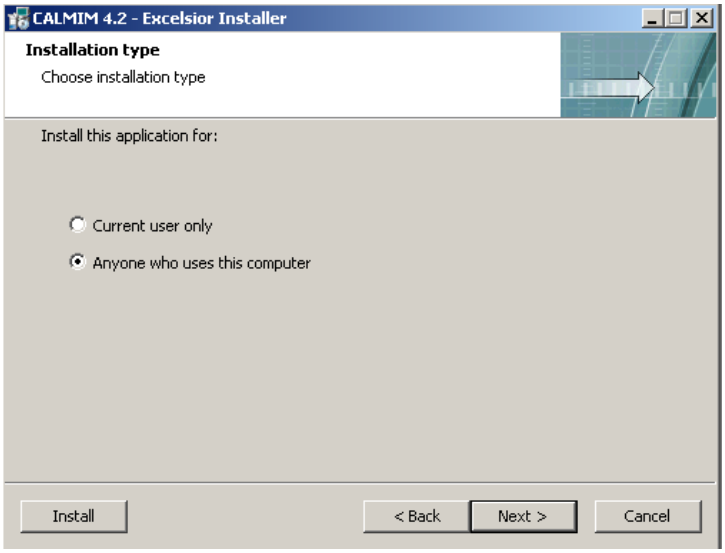


The user can use the “Install” button to use all program defaults (for file location, associations, and directories); or the user can use the Back and Next buttons to navigate through the installation wizard (as described in the next section) to customize the installation of the program.

2.1 Installation Type

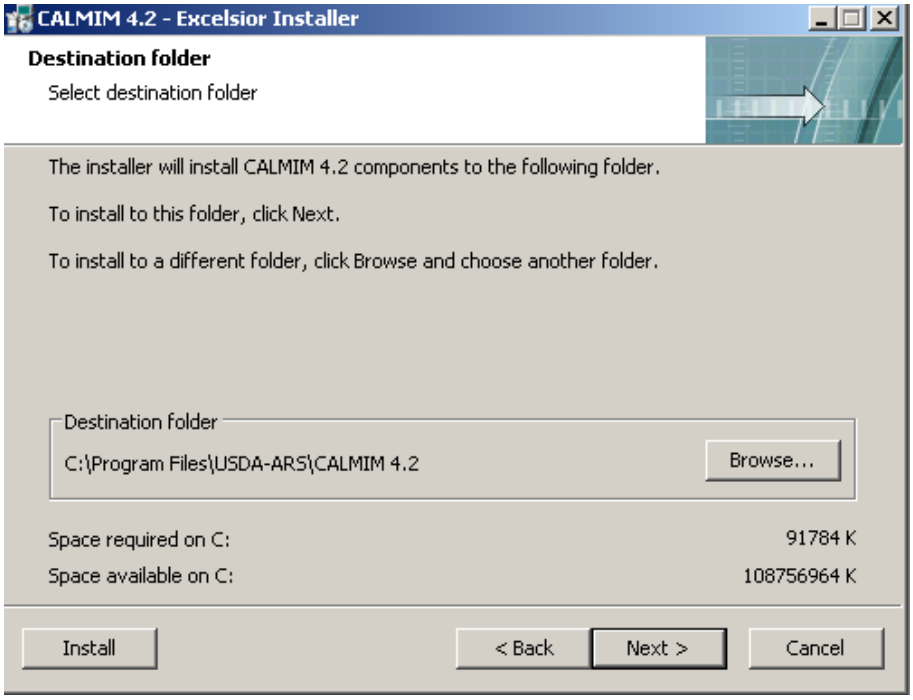
On the first screen, the user can select to install the program solely for the current user or for all the users of the computer system.

The default option is for all users to have access to the program. This option is toggled by the associated buttons on the form. Once the user has made the selection, the “Next” button moves to the next window of the installation wizard.



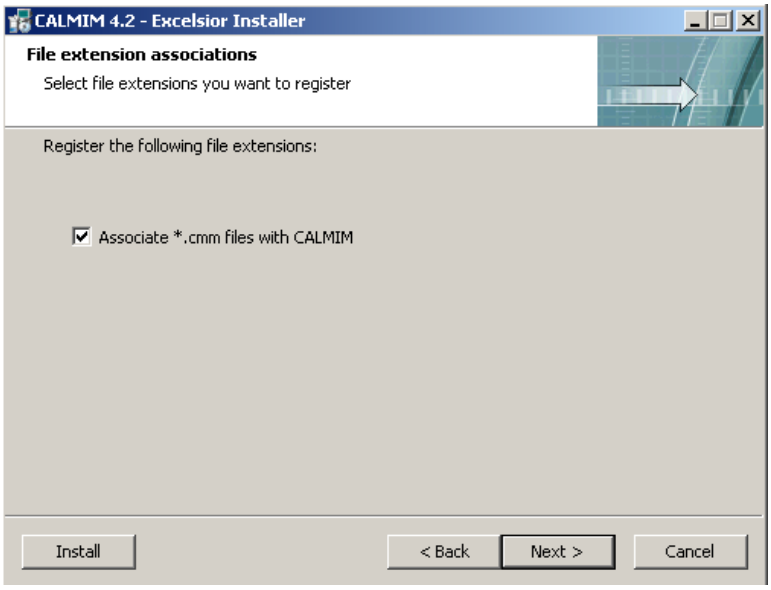
2.2 Program File Location

The next screen allows the user to alter the default file locations for the model directory (default is shown in the Destination folder box). The user can customize this selection by pressing the "Browse" button. After the user has selected the directory for the folder, the user should press the "Next" button for the next panel in the wizard.



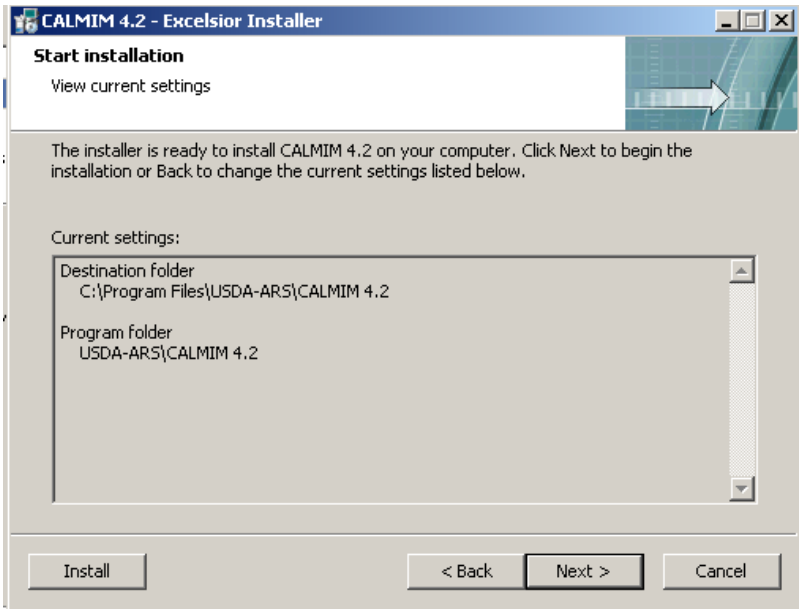
2.3 File Extension Association

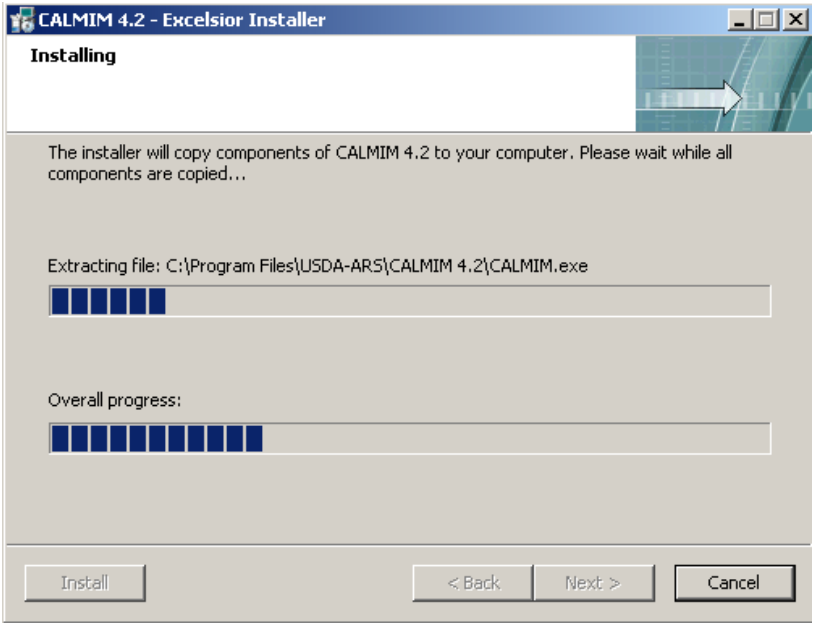
The next panel allows the user to associate the CALMIM profile filenames to be associated with the CALMIM program. This option is either enabled or disabled through the checkbox. The advantage to this association is if the profile filename is double clicked, will cause the computer to open the CALMIM model. Selecting “Next” takes the user to the next panel.



2.4 Installation Progress Window

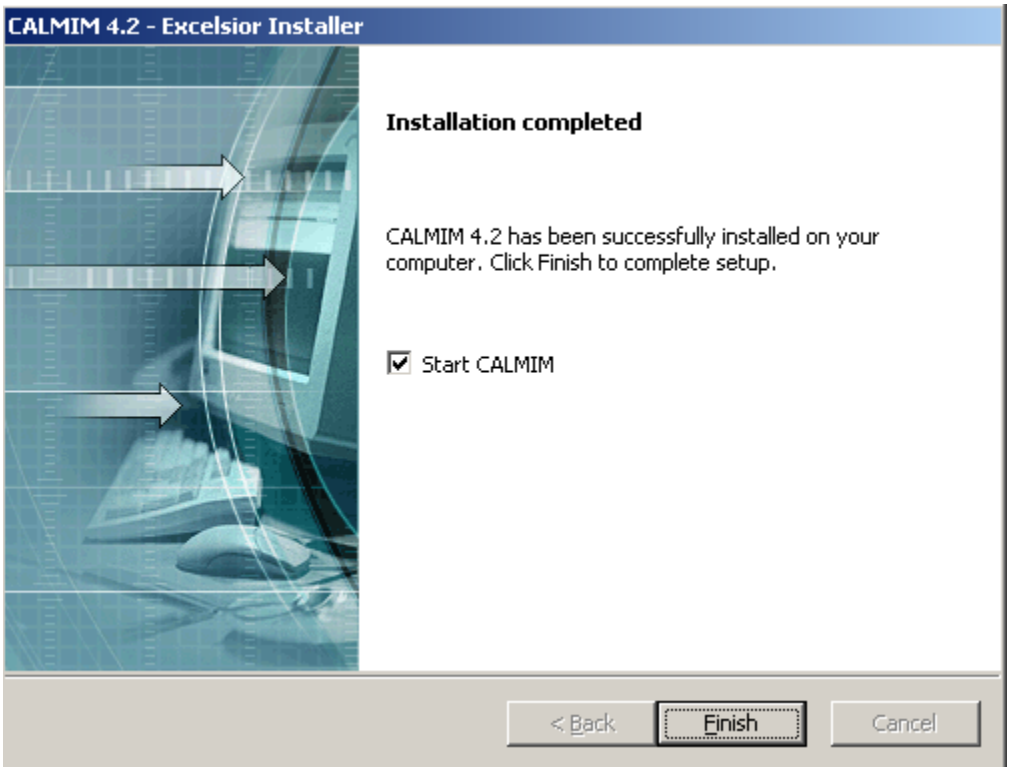
After the selections are made the program installs according to the selected preferences.



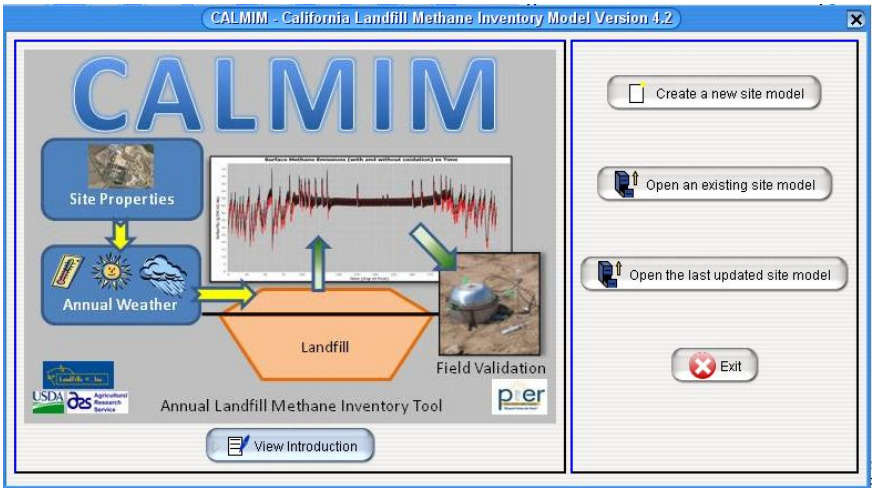


2.5 Installation Completed

The following dialog box is shown once the installation has completed. The user can immediately start the model by leaving the checkbox enabled.



3.0 Main Screen



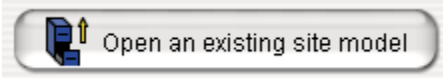
The main screen has five available options:

1. **View Introduction** 

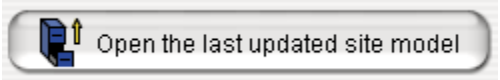
This button will display introductory material (not as in-depth as Chapter 1 of this manual).

2. **Create a new site model** 

This button launches a new input wizard to collect information on the landfill site to be modeled. This is the starting point for new sites and new users without previously saved profiles.

3. **Open an existing site model** 

This button opens a previous saved file (See Chapter 4.?)

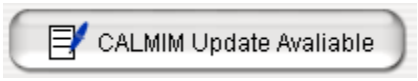
4. **Open the last updated site model** 

This button opens the last modeled site (last run) of the CALMIM model.

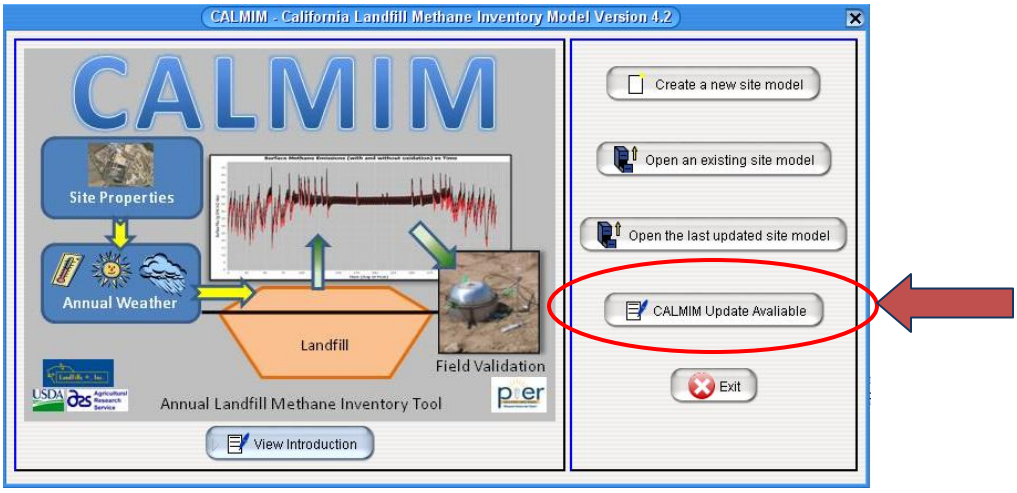
5. **Exit** 

This button will exit the program.

3.1 Update availability



If the user has a connection to the internet, an automatic check will be run each time CALMIM starts to determine if there is an update available. If there is an update available, an additional button will be displayed on the main menu as shown below:



When the user selects this button, you will be taken to the main webpage for CALMIM distribution. The user can download and install the updated version.

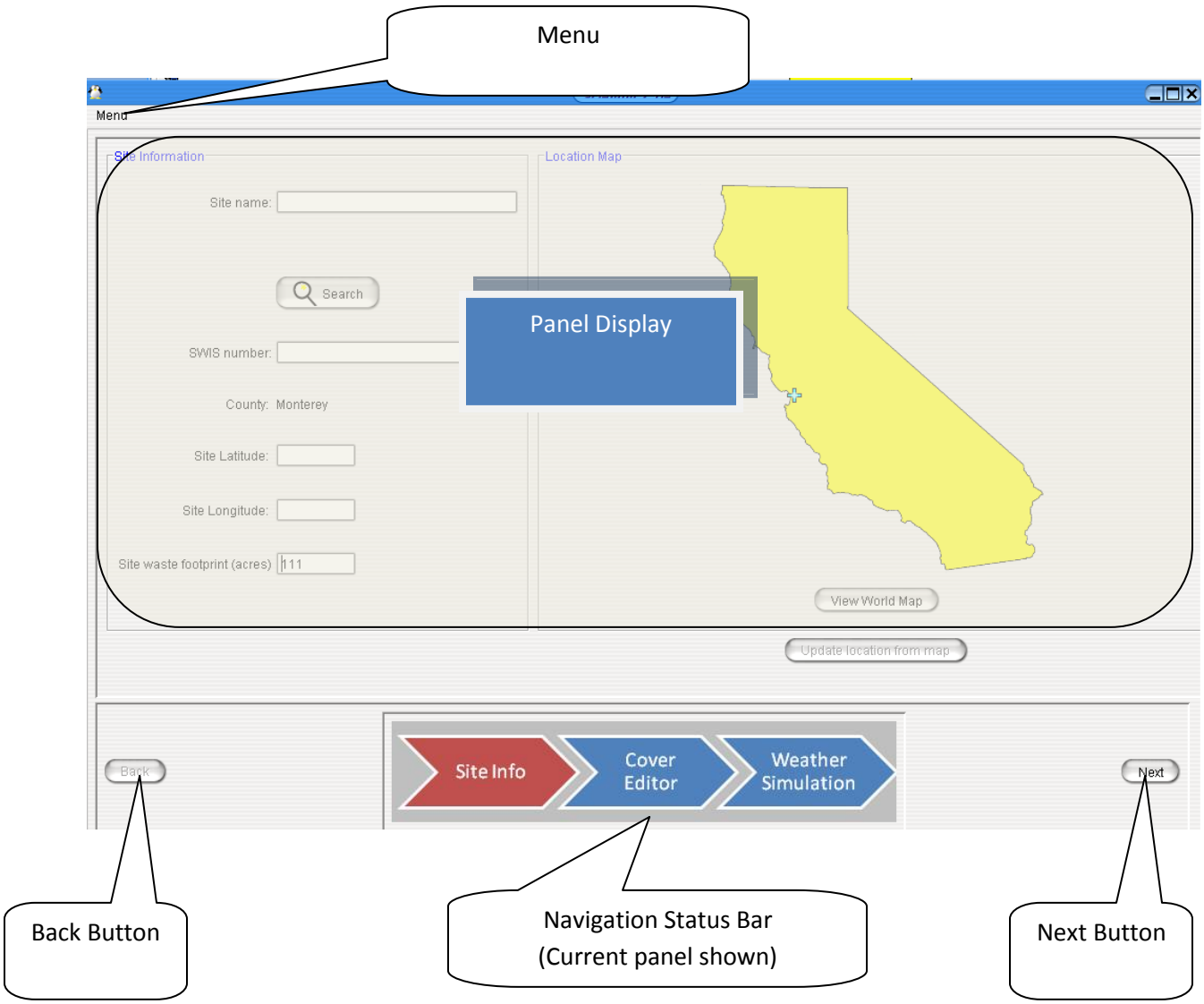
Note:

IMPORTANT! Please remove (uninstall) the current version before installing any updates.

This warning will also be displayed by the installer program.

[Please see ***Installation Guide (Section 2)*** for further information]

4.0 Main Wizard Window



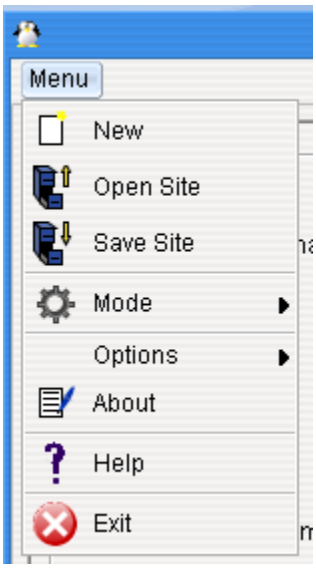
Menu – displays the menu for the program, which is described on the next page.

Back button – Allows the user to navigate backwards in the wizard screens. This button is enabled once the user has advanced to the next panel (Cover Editor).

Next button – Allows the user to move to the next panel in the wizard screens.

Navigation status bar – Displays the current page of the wizard (in red) as well as where the user is in the panel order.

Menu:



Menu Options:

New –

Opens a new site

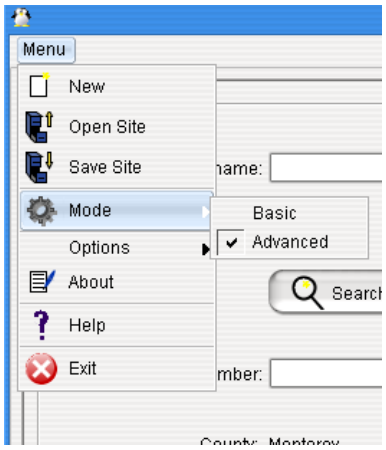
Open Site –

Opens dialog box to open a previously saved site. The CALMIM profile files are saved with a *.CMM extension.

Save Site –

Opens dialog box to save current site profile file (.CMM).

Mode –



This option allows the user to select the basic or advanced user levels. The advanced mode is used as to toggle whether the irrigation editor is displayed in the Weather display panel (see Section 7). This is the sole feature that is enabled or disabled with this option.

5.0 Site Properties Panel

The required information about the landfill site to be modeled is included on this panel. There are inputs for a site name, latitude, longitude, and site footprint. All of these inputs are required for each site.

5.0.1 *Latitude*

The latitude of the site is entered in this text box. The latitude is positive for North of the equator and negative for locations South of the equator. For example, the latitude for Sydney Australia (33^{o} 55' South) would be entered as -33.92 and for Chicago, IL (USA; 41^{o} 51' North) would be +42.85.

5.0.2. *Longitude*

The longitude of the site is entered in this textbox. East is entered as positive values and West longitudes are negative values. For example, the longitude for Sydney, Australia (151^{o} 17' East) would be entered as +151.28 and for Chicago, IL (USA; 87^{o} 41' West) would be -87.68.

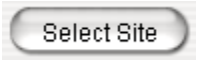
5.0.3. *Site Footprint*

This entry is the total size of the waste footprint in acres. This is area represents the area at the site where there is currently waste deposited, and not the total size or permitted size of the landfill site.

5. 1 SWIS Database Search 

By entering a part of the name in the site name box and then by pressing “Enter” or the search button, the program will attempt to locate the site in the SWIS database included with the CALMIM model (http://www.calrecycle.ca.gov/SWFAcilities/Directory/).

The model will display a pop up box:

The user can select the site from the pull-down box and then click on the “Select Site” button 

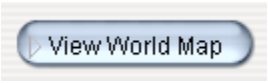
. The program will automatically populate the corresponding text boxes with the latitude, longitude, and waste footprint if available in the SWIS records. The user will then be returned to the main wizard.

If none of the listed sites are the desired site, please select “Cancel” and the program will return to the wizard. At this point, the user could either modify the search or continue by manually entering the required data.

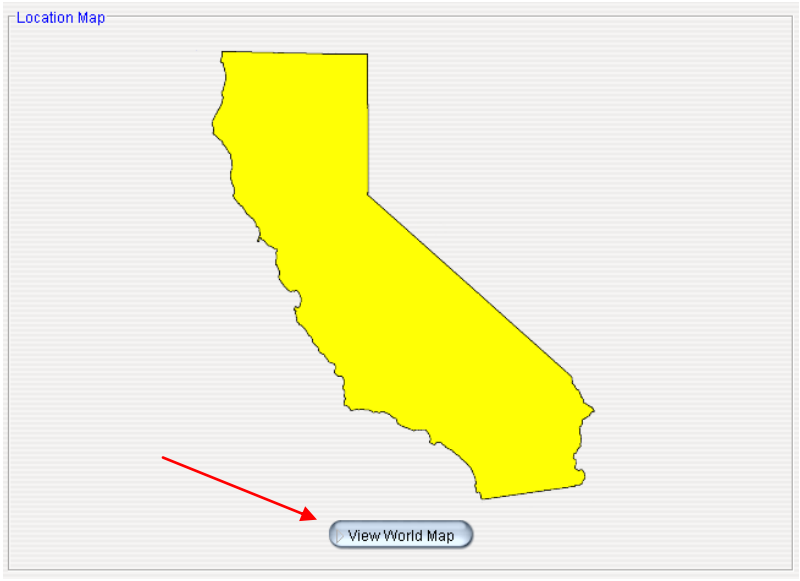
If the site is not found, the model will display a warning box notifying the user that the site was not located in the database.

5.2 Map Options

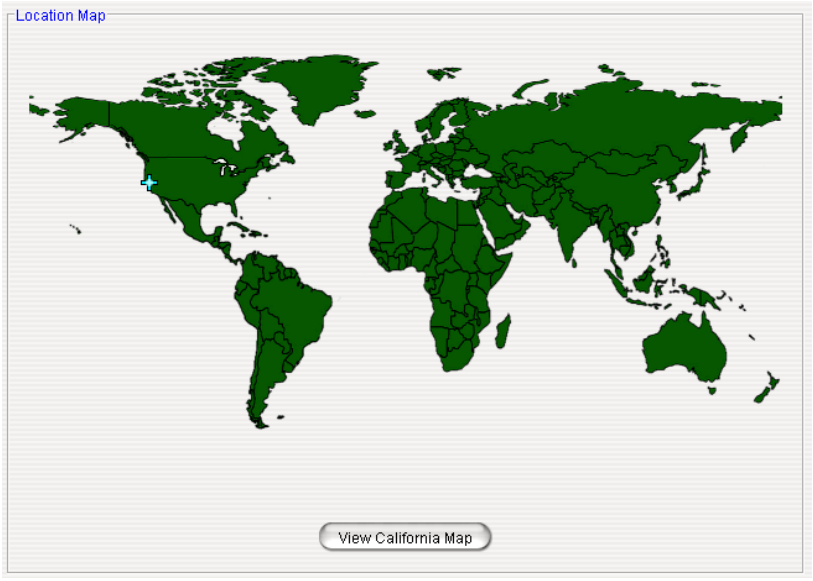
The map is set for locations in California (see Map Panel in Site Information panel above). However, if the user wished to enter a location outside of California, the user can select the "View World Map" button:



This button is located at the bottom of the Location Map panel as shown below.



If this button is selected, the model will change to the world view:



To return to the California map, the user can select the 

button.

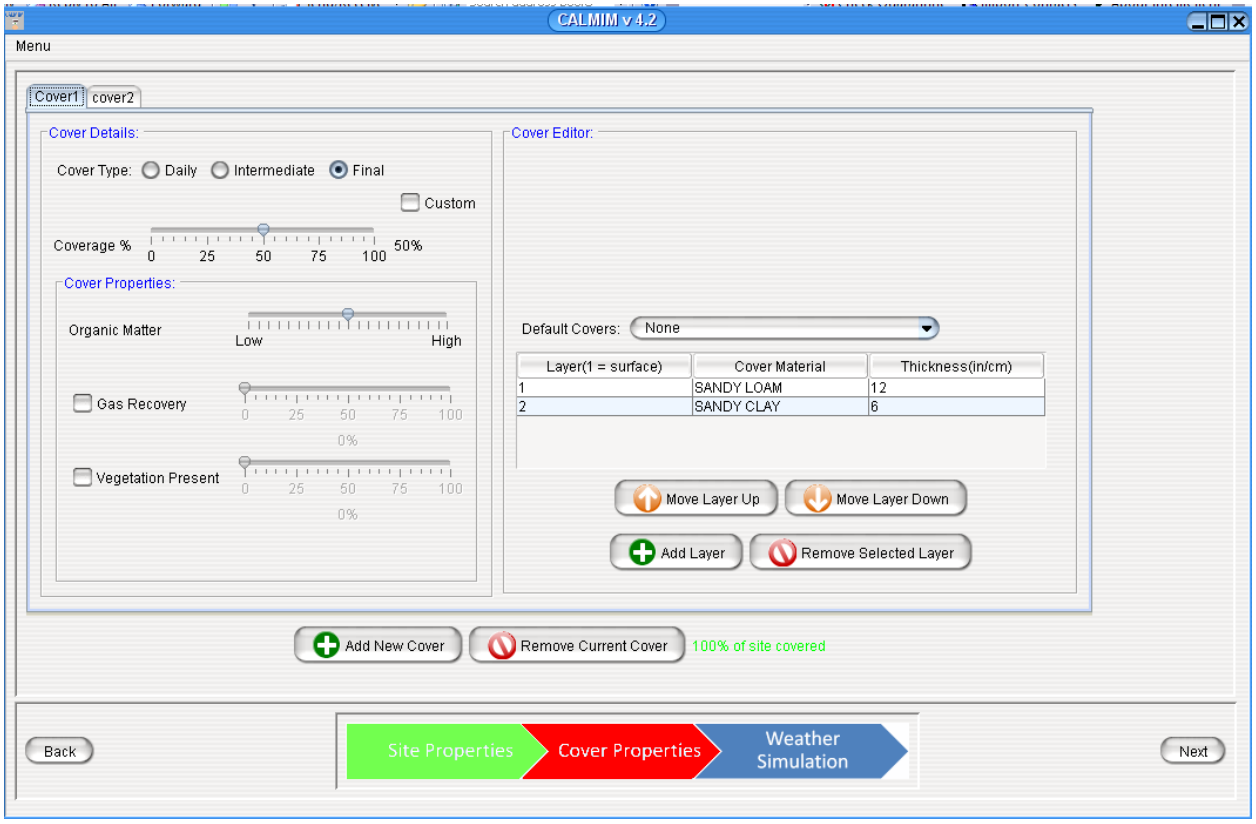
5.2.1 Location Selection from Maps

By clicking any location on the map, and then corresponding clicking the button:

The user can populate the latitude and longitude locations from the world map (or California map) into the respective text boxes for latitude and longitude.

For non-California locations, the user must enter a site name and the corresponding waste footprint (site footprint), before continuing to the next panel.

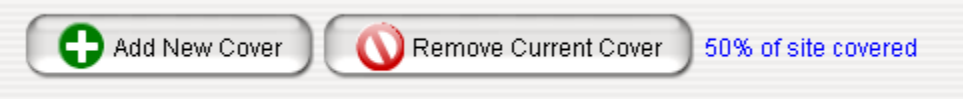
6.0 Cover Editor Panel



This panel allows the user to customize up to 10 different covers for the site.

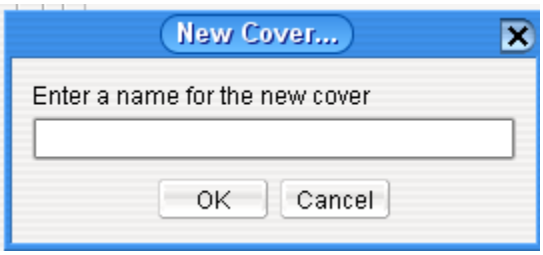
6.1 Cover Tabs

There are two main buttons to add or delete covers from the model:

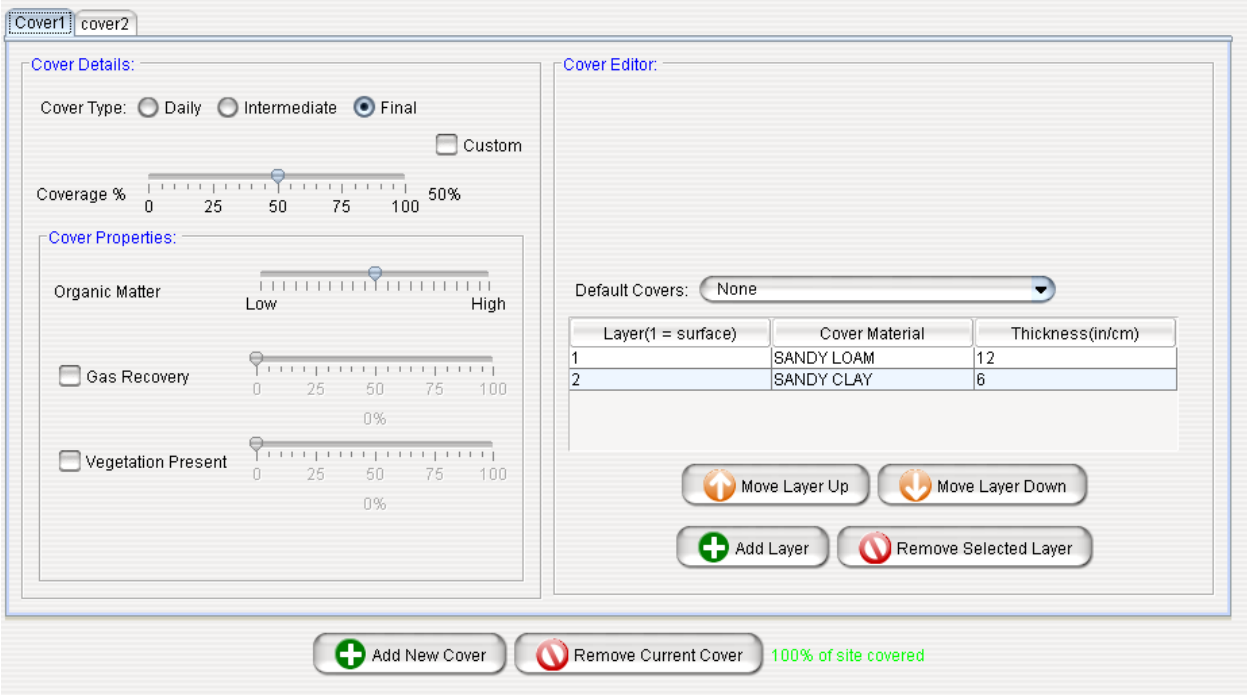


1. ***Add New Cover button*** 

   The user should use this button to add a new cover to the model. The program will prompt the user for a name for the cover as shown below:



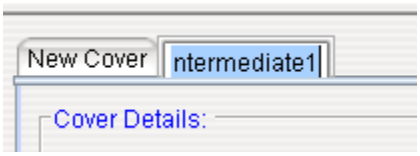
   The name should be descriptive enough for the user to identify the cover in the output, for example “Intermediate1” or similar. This new cover will then appear as a tab as shown in the figure below.



The user can switch between cover types by clicking on the respective tabs.

Renaming Cover Tabs

By double clicking on the tabs, the user can rename the various cover tabs. This will highlight the tab to allow a new cover name to be entered. Up to 10 different covers can be entered per model run.

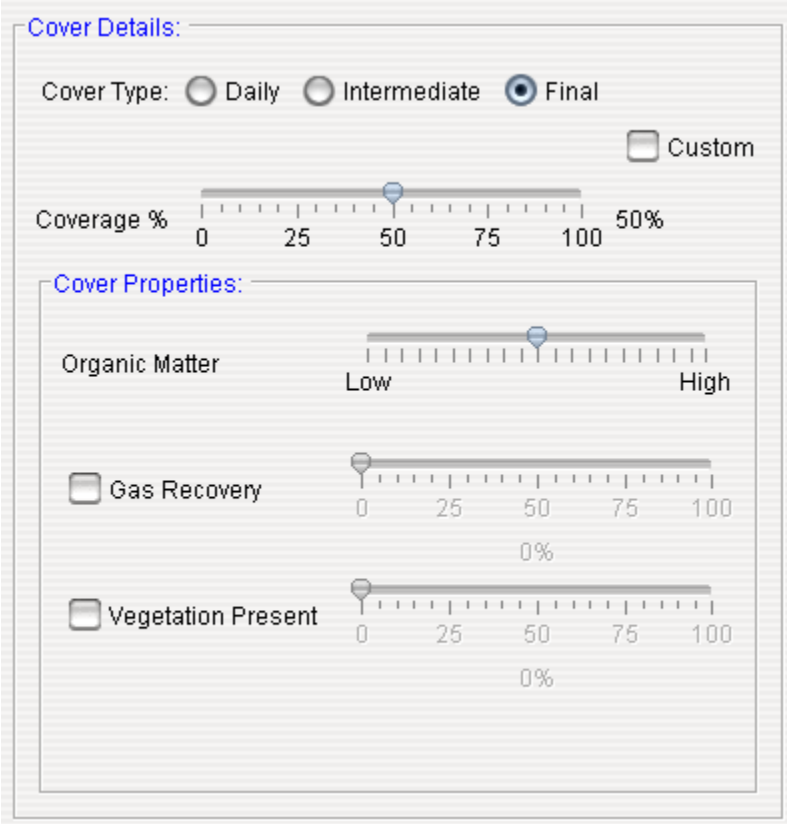


2. ***Remove Current Cover*** 

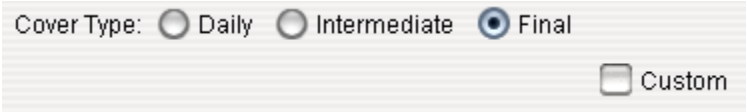
This button will remove the currently selected cover tab. The model will not allow the user to delete the last tab as one model tab is required for the model to run. Before deleting the model will confirm the delete with the user by the dialog box shown below:

The name of the selected cover will appear in the dialog box in place of **Interemdiate1** in the example dialog above.

6.2 Cover Details Section of Panel

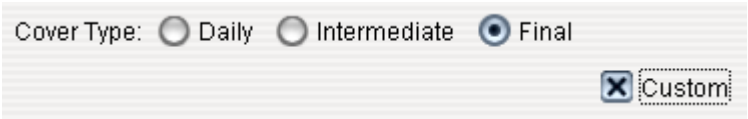


6.1.1 *Cover Type*

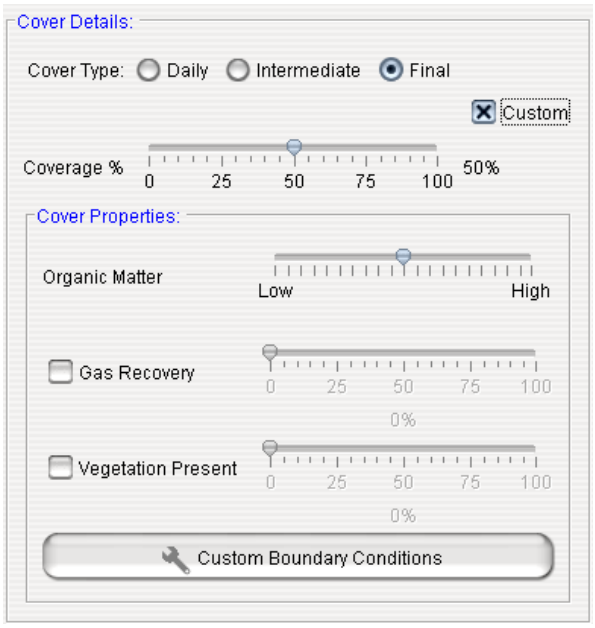


These 3 buttons allow the user to select the basic cover type for any cover. The cover type is used to set the default gas concentrations, default temperature profiles and maximum methane oxidation rate for each type (See Appendix A).

There is also the selection for a "Custom" cover type, which is selected by checking the Custom checkbox:

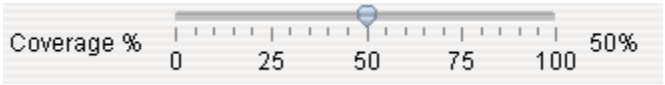


When the custom cover type is selected the model displays the “Custom boundary conditions” button:

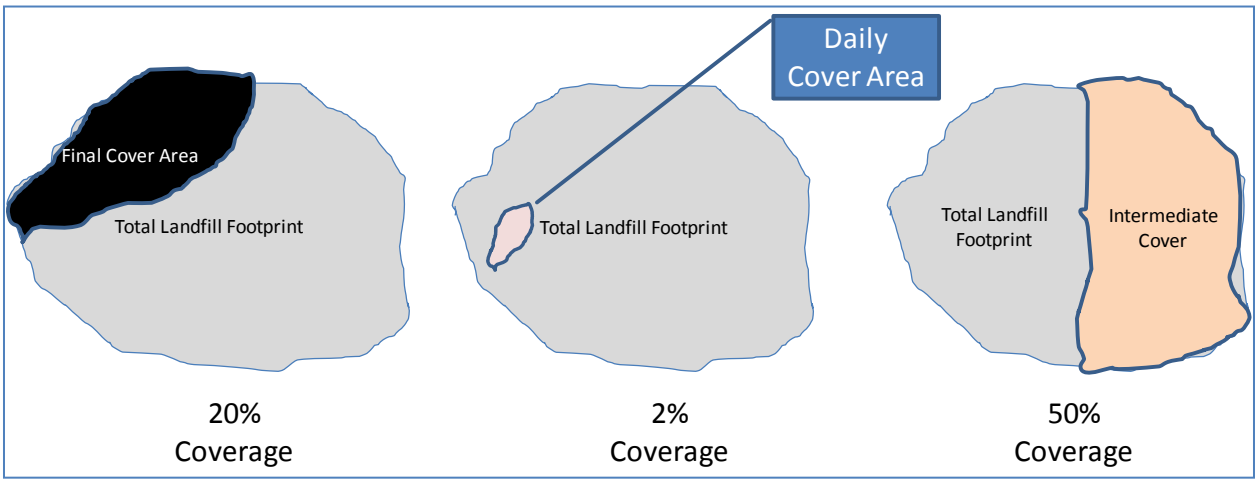


The features of this button are described later (section 6.5)

6.1.2 *Coverage Percentage*



This slider bar allows the user to specify the percentage of landfill area that this cover represents. For example, as shown in the figure below, the percent coverage for different representative areas of the hypothetical landfill:

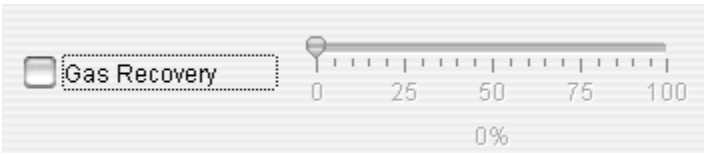


6.1.1 *Cover Properties*

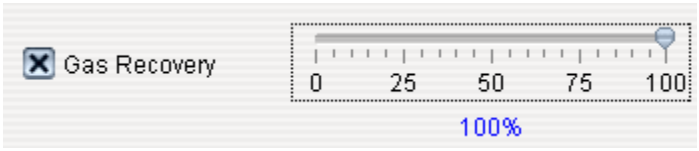
a. Organic matter (slider bar)

This selection controls the amount of organic material that the model uses in the calculation of the soil properties (see below). High Organic material cover materials would be those amended with sewage sludge, compost, wood chips, or other organic wastes. This slider represents 0 to 5% organic matter percentage.

b. Gas Recovery System Information

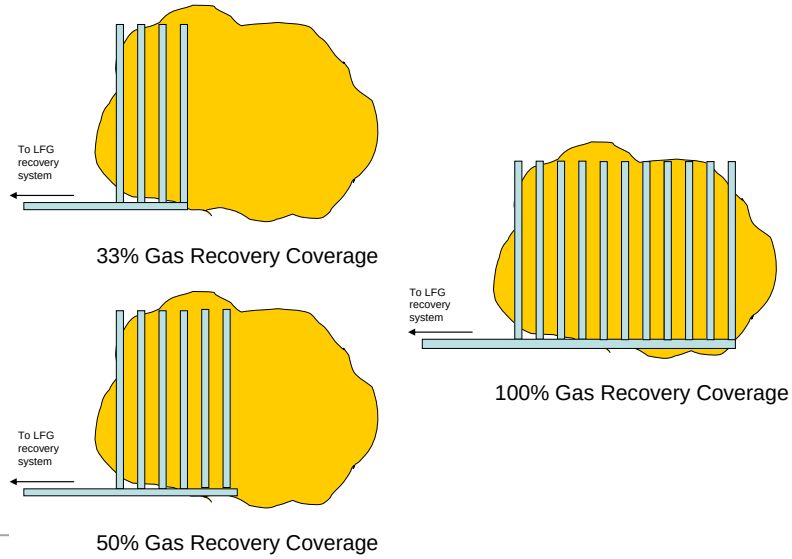


If a gas recovery system is present, the user should select the **Gas Recovery checkbox**, which will enable the gas recovery slider bar as shown below:



NOTE: This percentage is NOT the efficiency of the gas recovery system.
Instead this percentage represents the area coverage of the gas recovery system for this cover.

The user should select the percent of the area for this cover type that has a gas recovery system in place (horizontal, vertical, or combination). The figure below illustrates some examples.

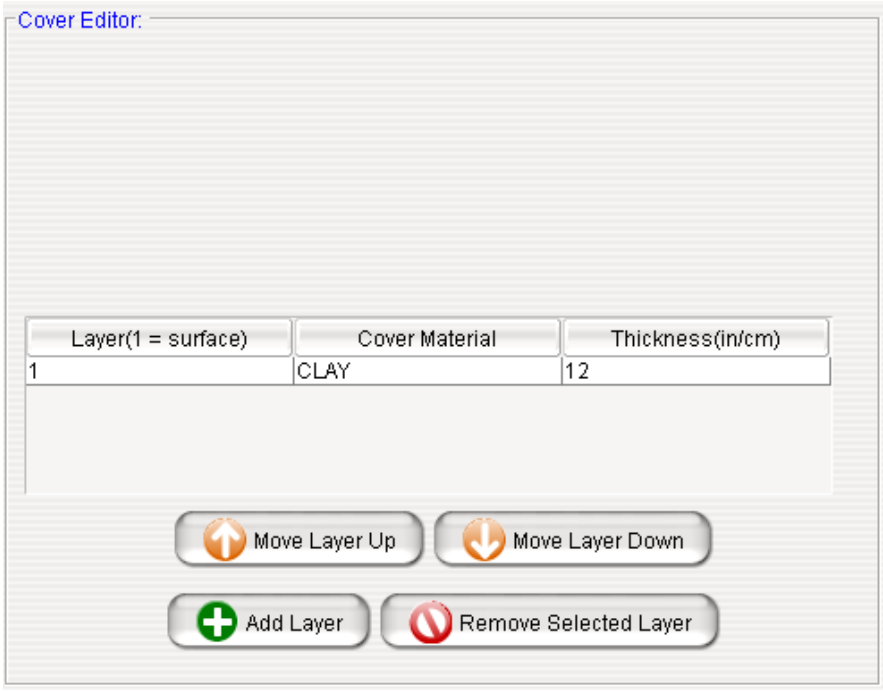


c. Vegetation Present

If there is vegetation present on the cover type, then the user should select the "Vegetation Present" checkbox, which will enable the vegetation present scroll bar.

The user should use the scroll bar to enter the approximate average vegetation coverage for this cover type. This is an estimate for the amount of ground surface that is covered by vegetation.

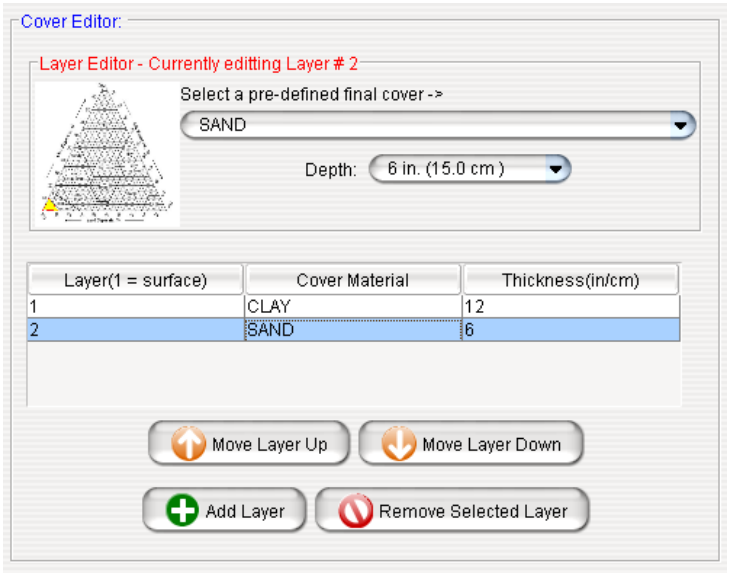
6.2 Cover Editor



6.2.1 Highlighting a layer in the cover editor

To highlight a layer:

Position the mouse over any element (layer number, cover material, or thickness) and press the mouse button. The highlighted layer will appear in blue as shown in the figure below (layer #2 → 6 inch sand layer is selected):



1. **Move Layer Up** 

This option is only functional with two or more layers.

This button moves the selected layer closer to the surface (up).

2. Move Layer Down 

This option is only functional with two or more layers.

This button moves the selected layer closer to the base of the cover (down).

3. Add Layer 

This option adds a new layer (default layer is 6 inches of clay).

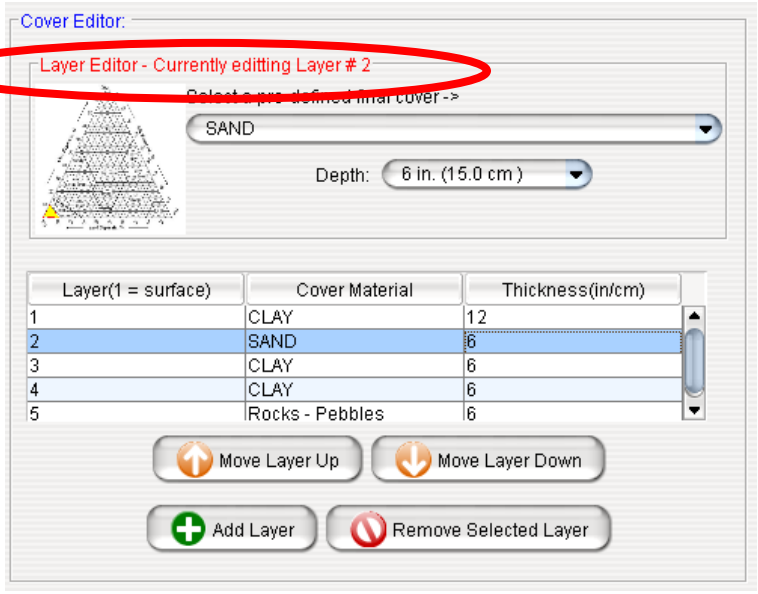
4. Remove Selected Layer 

This button removes the selected (highlighted) layer in the cover editor.

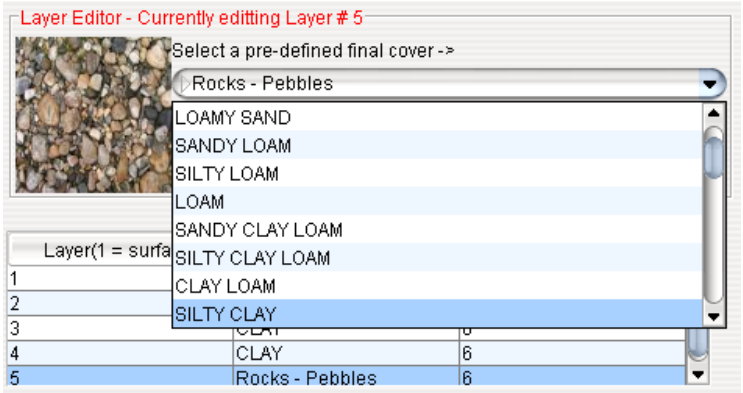
6.2.2 *Cover Layer Editor*

Once a layer is highlighted (see Section 4.2.1), the layer editor becomes visible for that respective layer.

Note: the title bar of the editor indicates which layer you are currently editing. See circled area in figure below.

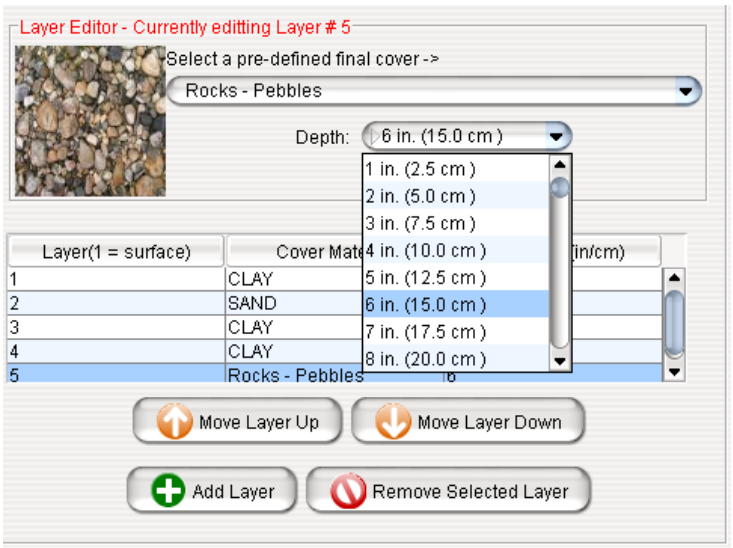


Once the layer editor is enabled by highlighting the respective layer, the user make a selection among the 12 USDA soil texture classifications or among 21 other alternative choices through the pull-down combo box. Choices include various alternative daily cover (ADC) materials and non-soil materials including geomermbranes. The model will display either the section of the textual triangle selected (USDA soil types) or a representative picture of the cover material selected. See Appendix A for the physical properties (default values) for these various materials.



(Combo box for material selection is shown expanded)

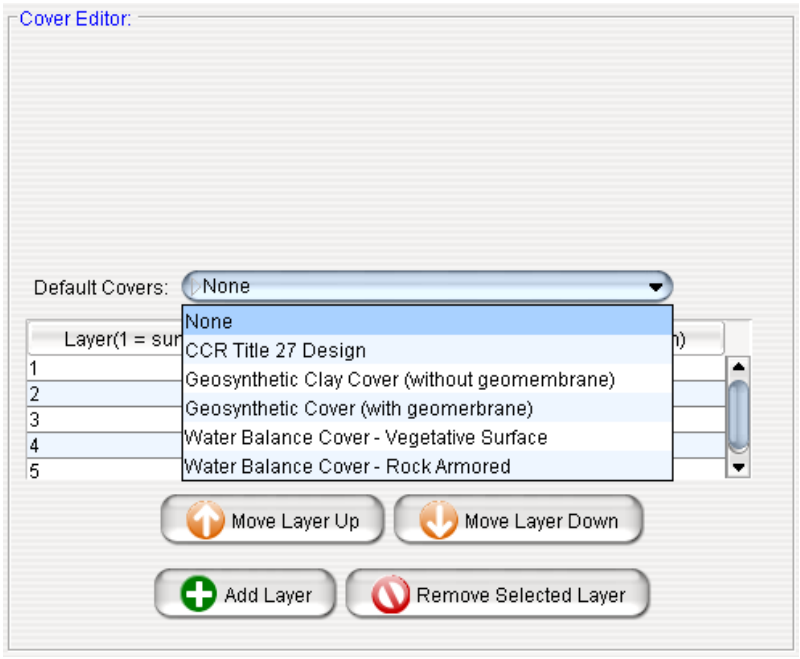
After the material is selected for a layer, the thickness of the layer should be specified with the pull-down combo box as shown in the figure below. The individual upper limit for layer thicknesses is 100 inches (254 cm). Some of the specialized materials have a fixed thickness and the user will not be able to select a different thickness (e.g. geomembranes).



(Combo box for thickness selection is shown expanded)

6.4 Default final cover types (only for Final Cover types)

When the user selects the final cover type, an additional pull-down combo box is displayed with the 5 default California final cover types.



The details of these final cover types are given in Table 6.1 below.

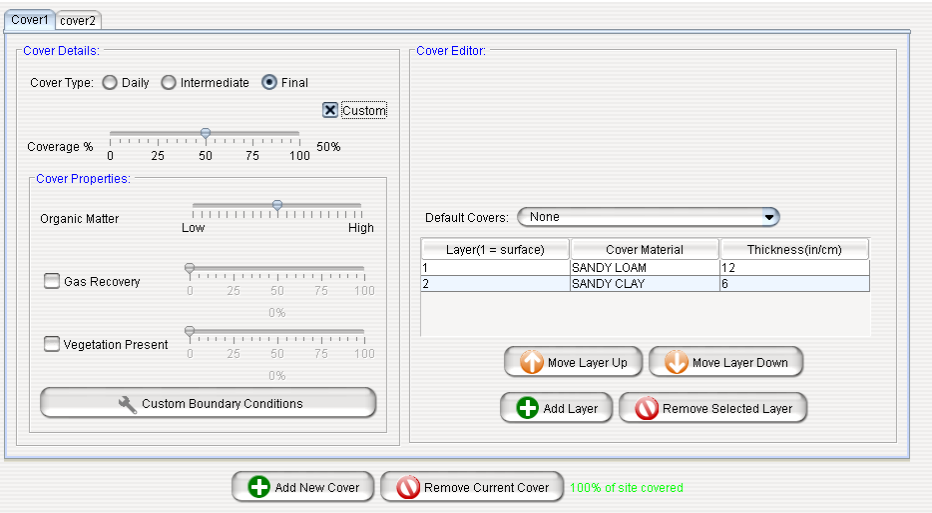
Table 6.1. Settings for Default Final Cover Types

Layer	*CCR Title 27*	*Geosynthetic Clay (without geomembrane)*	*Geosynthetic Cover (with geomembrane)*	*Water Balance (Vegetation Surface)*	*Water Balance (rock armored)*
1	Loam (12 inches)	Loam (12 inches)	Loam (12 inches)	Loam (12 inches)	Rocks/Boulders (6 inches)
2	Clay (12 inches)	Clay (40 inches)	HDPE geomembrane (1 inch*)	Silty Clay Loam (36 inches)	Loam (12 inches)
3	Silty Clay Loam (24 inches)	Silty Clay Loam (12 inches)	Silty Clay Loam (24 inches)		Silty Clay Loam (36 inches)
Vegetation (%)	50	50	50	50	0

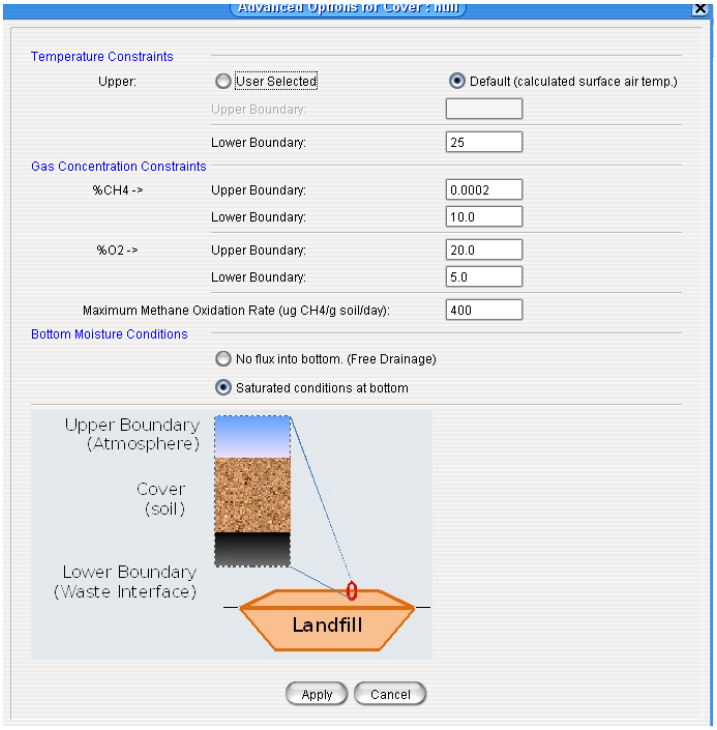
Notes: * indicates the required minimum thickness in the program

6.5 *Custom boundary conditions*

If the "Custom" checkbox is selected, then the user can override the existing default boundary conditions for a given cover type (daily, intermediate, or final; See Appendix 1). The "**Custom Boundary Conditions**" button will be displayed in the cover editor panel as shown below:



When the user clicks on the "Custom Boundary Conditions" button, the dialog box below is displayed.



These options allow the user to change the boundary conditions for the modeling, including:

- Temperature profile (upper and lower temperatures)
  - Atmosphere (Air temperature)
    - Fixed or simulated air temperature
  - Cover interface (top of refuse beneath the cover)

- Gas concentration profiles for methane:
  - Ground surface (atmosphere)
  - Cover interface (top of refuse beneath the cover)

- Gas concentration profile for oxygen
  - Ground surface (atmosphere)
  - Cover interface (top of refuse beneath the cover)

- Maximum oxidation rate

- Bottom moisture conditions
  - Saturated or free drainage

Temperature profile (upper and lower temperatures)

The upper limit can be a user selected constant value (User Selected) or the variable air temperature from the weather simulation.

The lower boundary is held constant at the designated set point.

Gas Concentrations:

Both the concentration of methane and oxygen are specified (in percent by volume) for the upper boundary (atmosphere) and the lower boundary (at the base of cover – cover/waste interface)

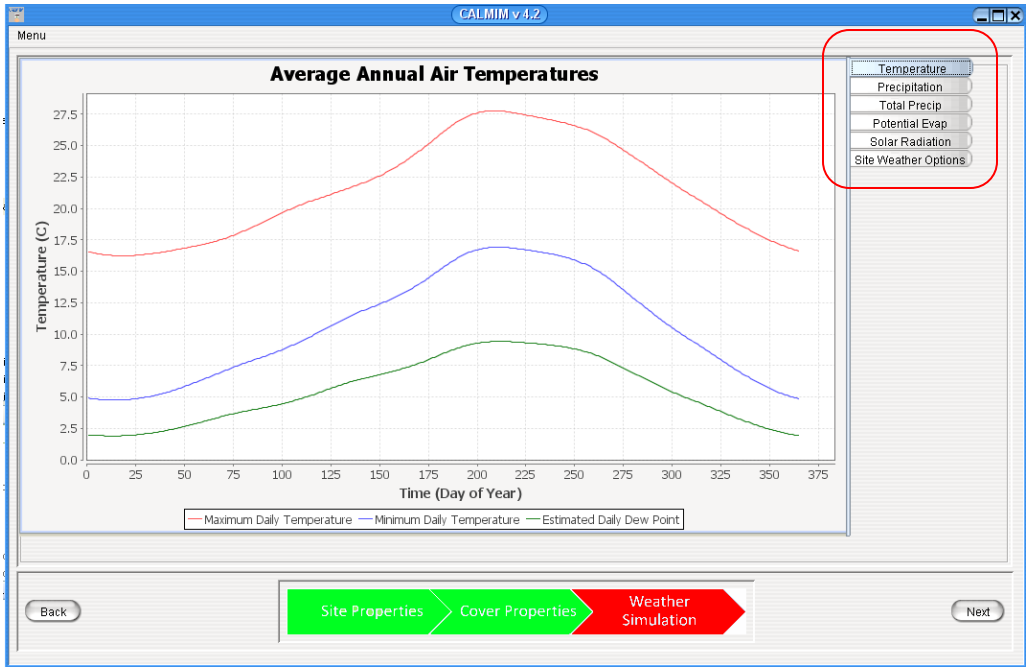
Bottom Moisture Conditions:

Saturated condition at the bottom of the cover is the default boundary condition, since the field state of the cover at the waste/soil interface is typically saturated due to the high humidity of the landfill gas.

However, the user could change this to a free drainage condition.

The upper moisture condition is controlled by the simulated weather (either evaporation or precipitation).

7.0 Weather Simulation Screen



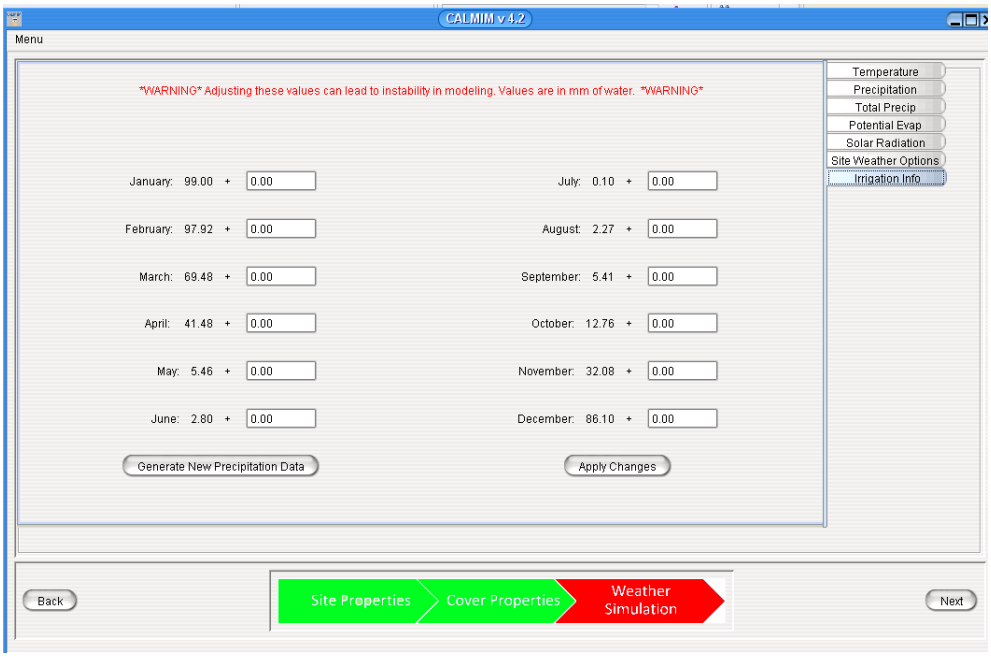
The weather simulation panel displays the results of the weather simulation for the site. The different graphs can be viewed by selecting the respective tabs on the right hand side of the graphs (see circled tabs above).

The graphical libraries used in this program are from JFreeChart
(http://www.jfree.org/index.html)
and the user is encouraged to visit the webpage
(http://www.jfree.org/jfreechart/api/javadoc/index.html)
for further information on the available graph options.

7.1 *Irrigation Info Tab (Advanced Mode Only)*

The ”Irrigation Info” 

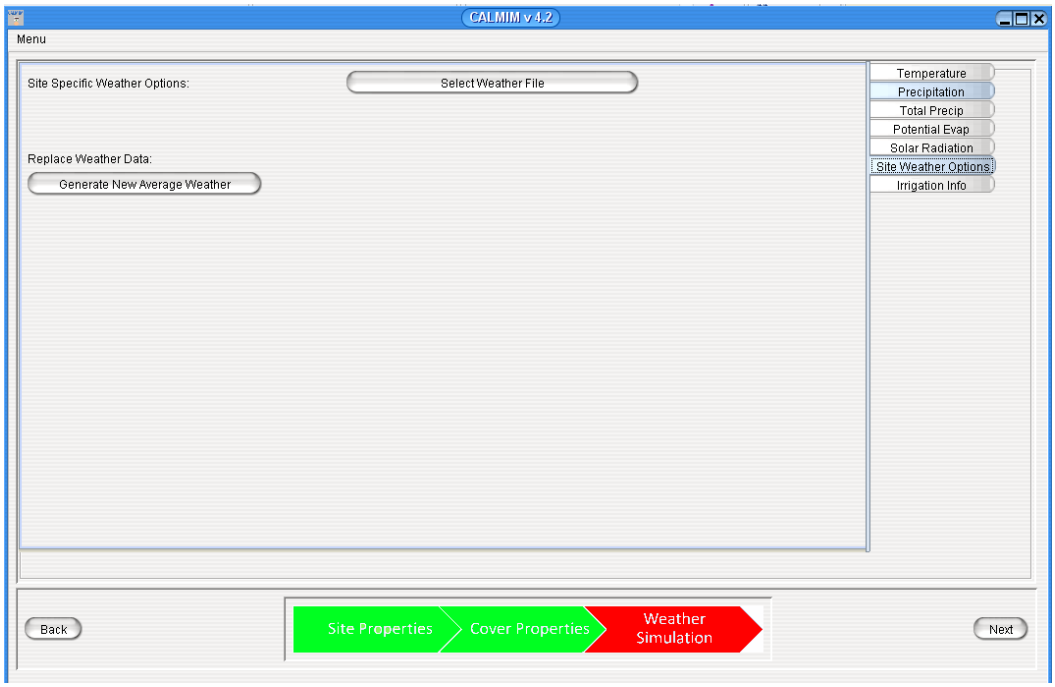
is only displayed when the user is in advanced mode (See Menu Options – Section 4). The irrigation tab allows the user to enter monthly irrigation totals (in mm of water) :



The user should input the total monthly amounts of irrigation water (in mm of water) for the month in the respective textbox, and then select “Apply Changes” to apply the new irrigation amounts. The model will display the new monthly totals and highlight those in green which were updated.

The other button (“Generate New Precipitation Data”) generates a new set of precipitation data, if the user made a serious mistake in entering data and wants to start over.

7.2 Site Weather Options Tab

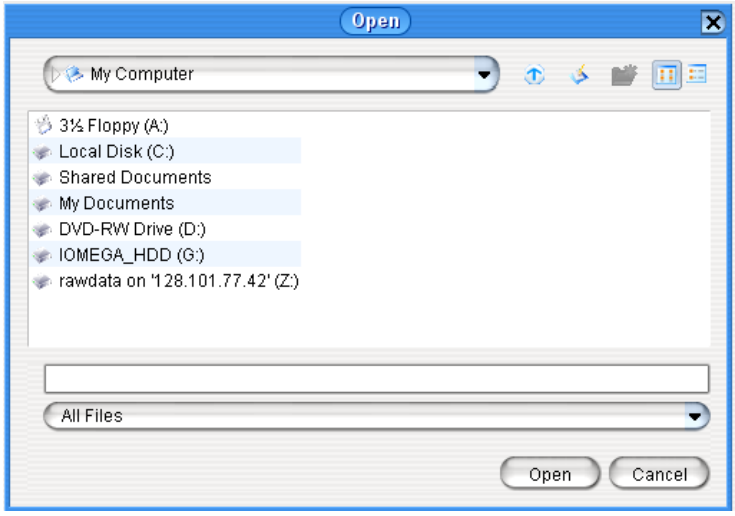


The model has the capability to utilize actual site weather data to improve the estimate over the estimated weather data. In order to load the weather data into the model the file format need to bea comma spaced value (CSV) file with the following (no header rows):

<day of year>, <maximum air temp>, <minimum air temp>, <Precipitation>

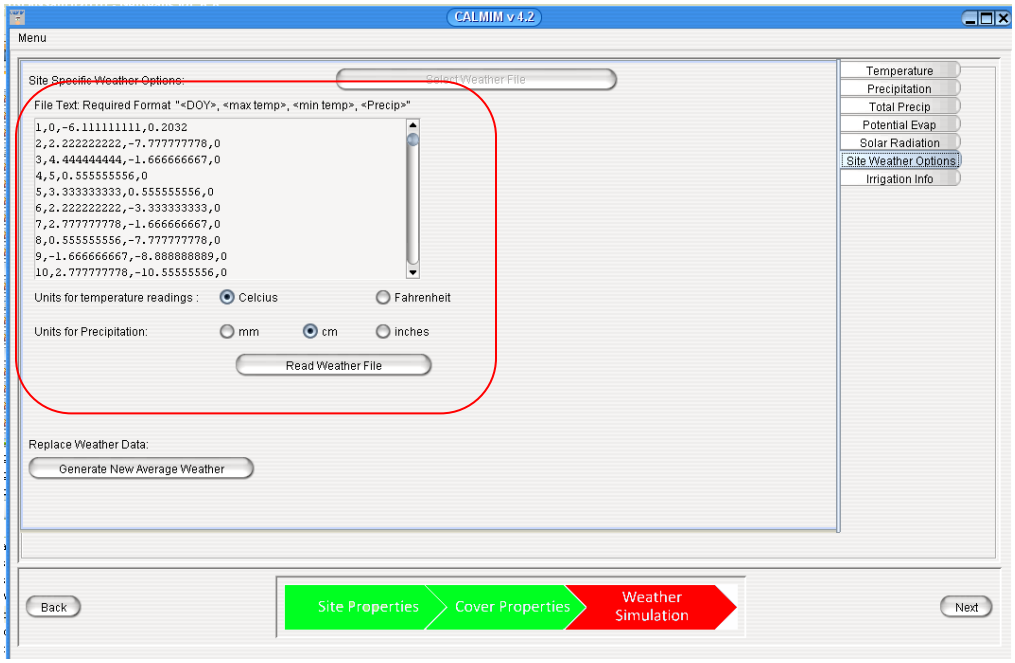
The user selects the 

button to open a file dialog as the one shown below:



The user will select the weather file from the proper location.

After the file is selected, the program will display the weather file in the scrollable text box and request the corresponding units of the temperature and precipitation data. This input is provided through the dialog shown in the figure below.



After selecting the correct units, the user should click on the 

button to load the selected file into the program.

The program will save the respected weather data with the model save file; if the user wants to reprocess using the same weather data as before. The user can also use the tabs to view the imported weather data by clicking on the tabs for the various weather graphs (Section 7.0).

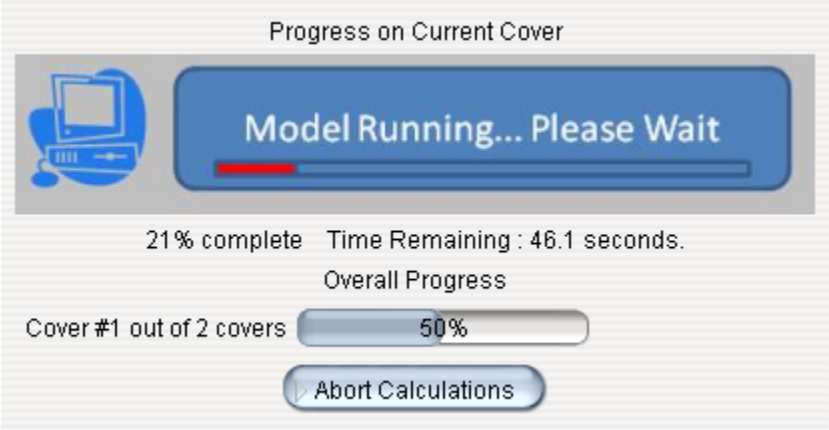
Note:
The model will use the generated average weather data for any missing dates in the data file.

The loaded weather data can be deleted by clicking on the

button to regenerate the average climatic data set.

8.0 Model Calculation Screen

While the model is calculating the following screen is displayed:

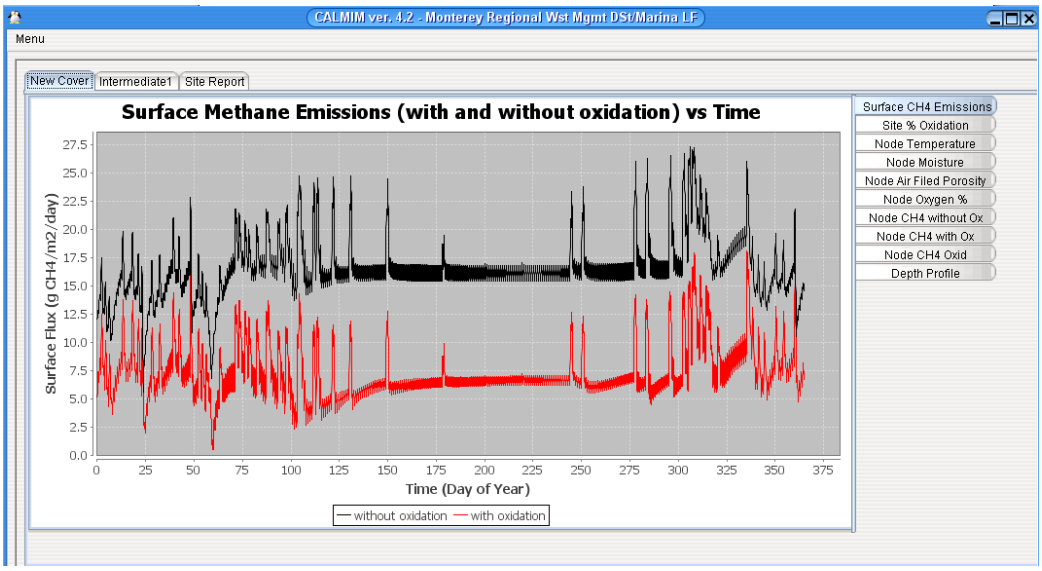


This dialog box displays the current progress of where the model's calculations are for the current cover along with the estimated time remaining. It is important to note that the time remaining only applies to the current cover and not the entire model run.

The progress bar shows the current progress on the total number of covers. The abort calculation button allows you to abort the run and exit the program. No intermediate data from the calculations are stored. The model could be restarted by using the "**Open the last updated site model"** (page 3) to restart the model.

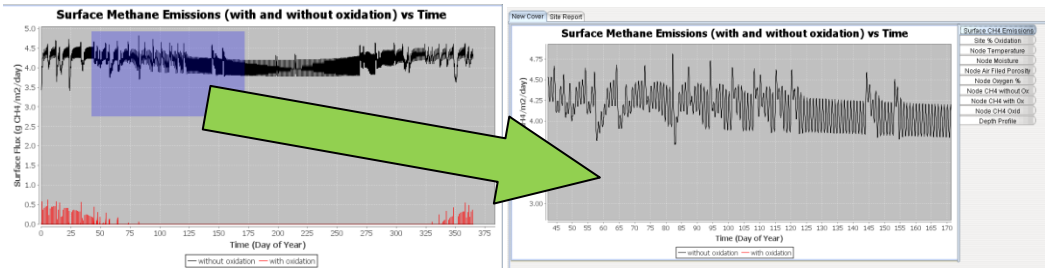
9.0 Final Results Screen

After the model has completed the calculations, the final screen is displayed:

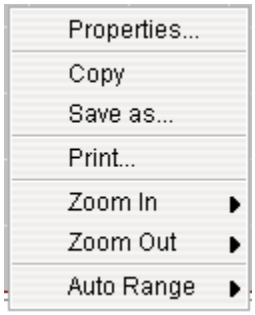


Each of these graphs will be described individually in the following pages. The user can navigate through the various cover types by selecting the corresponding tab panel. In addition, there is a "Site Report" tab, which summarizes the results for the site.

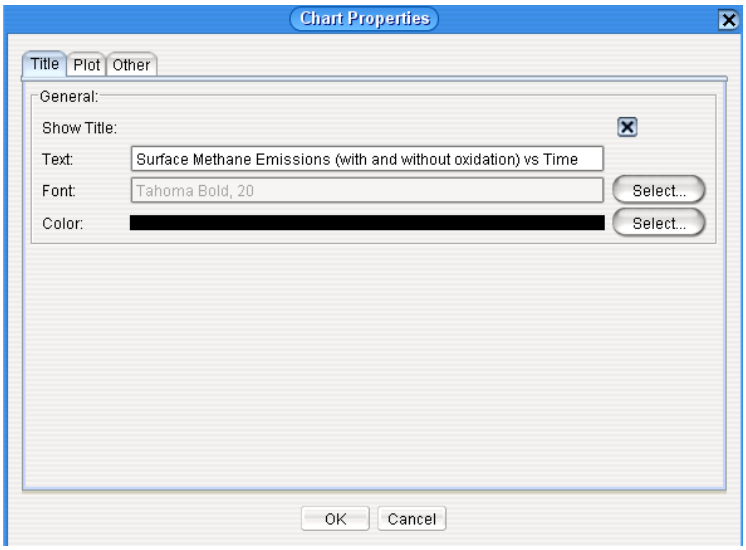
The left mouse button can be used to click and drag a zoom-in area of interest as shown below with the purple region being zoomed to the size of the graph in the right after release of the left mouse button.



For each of the graphs the user can press the right mouse button on the graph to display the option menu for the figure:



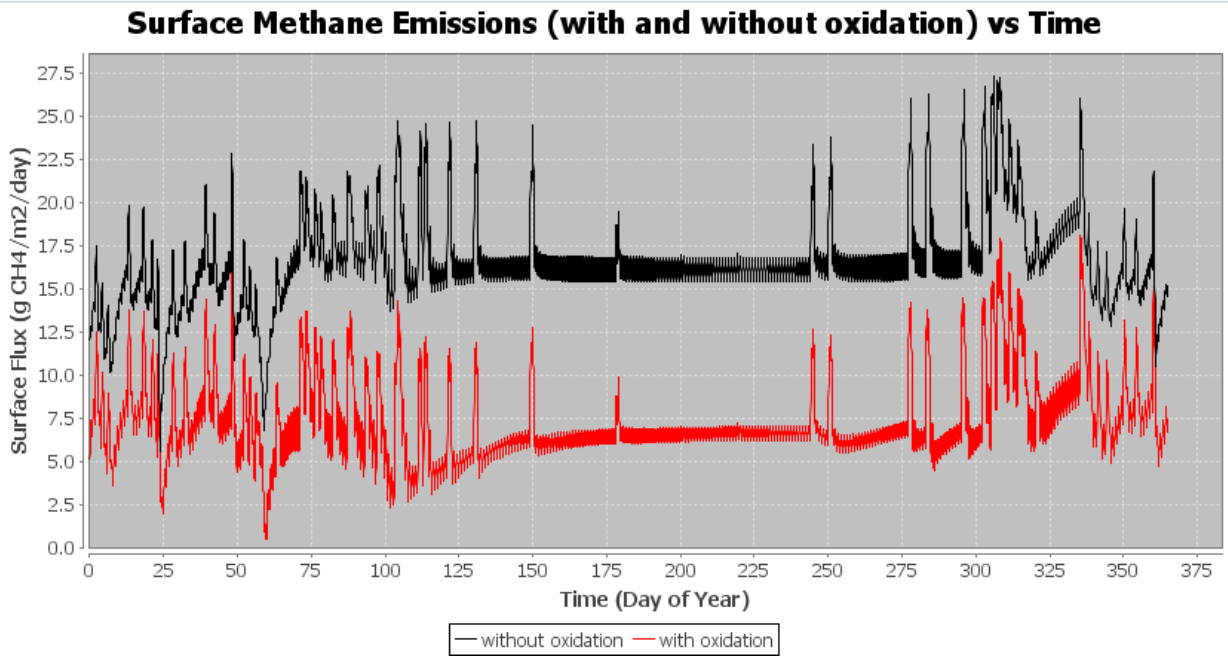
Selecting "Properties…" brings up the properties screen, where the user can change and alter the appearance of the graphs.



The "Save as" and "Print" functions will allow the particular graph to be saved or printed for future reference.

The graphical libraries used in this program are from JFreeChart
(http://www.jfree.org/index.html)
and the user is encouraged to visit the webpage
(http://www.jfree.org/jfreechart/api/javadoc/index.html)
for further information on the available graph options.

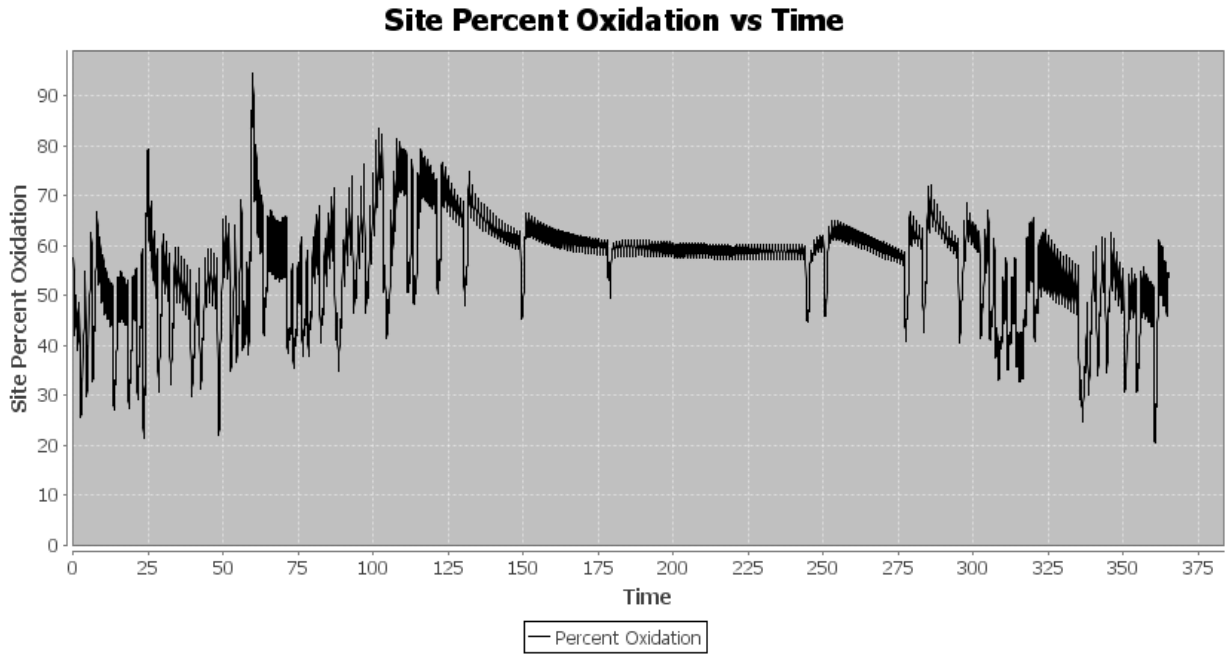
Surface CH4 Emissions *-Predicted Surface Methane Emissions for this Cover*



This graph displays the variable surface emissions both without oxidation (black line) and with methane oxidation (red line) included in the calculations.

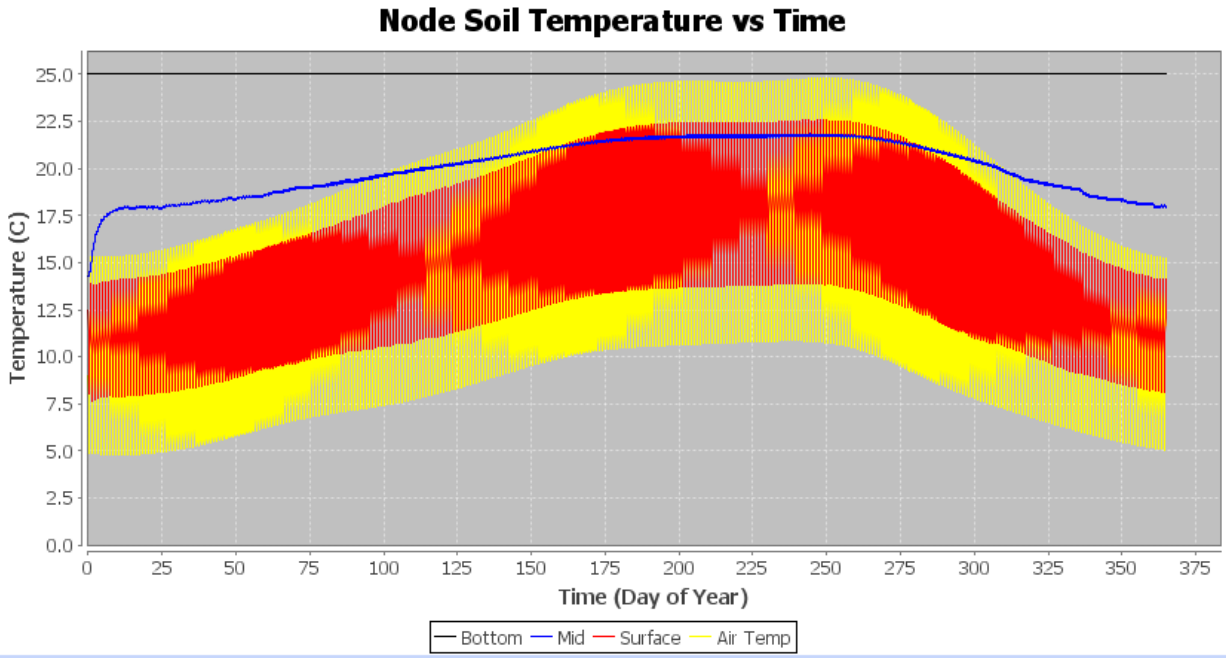
The graph clearly shows the high variability that the model estimates as a result of the variable soil moisture and temperature within the cover soil and how this impacts both the gas diffusion and microbial methane oxidation. These impacts can be further seen in the following graphs.

Site % Oxidation ***-Predicted Percent Oxidation for this Particular Cover***



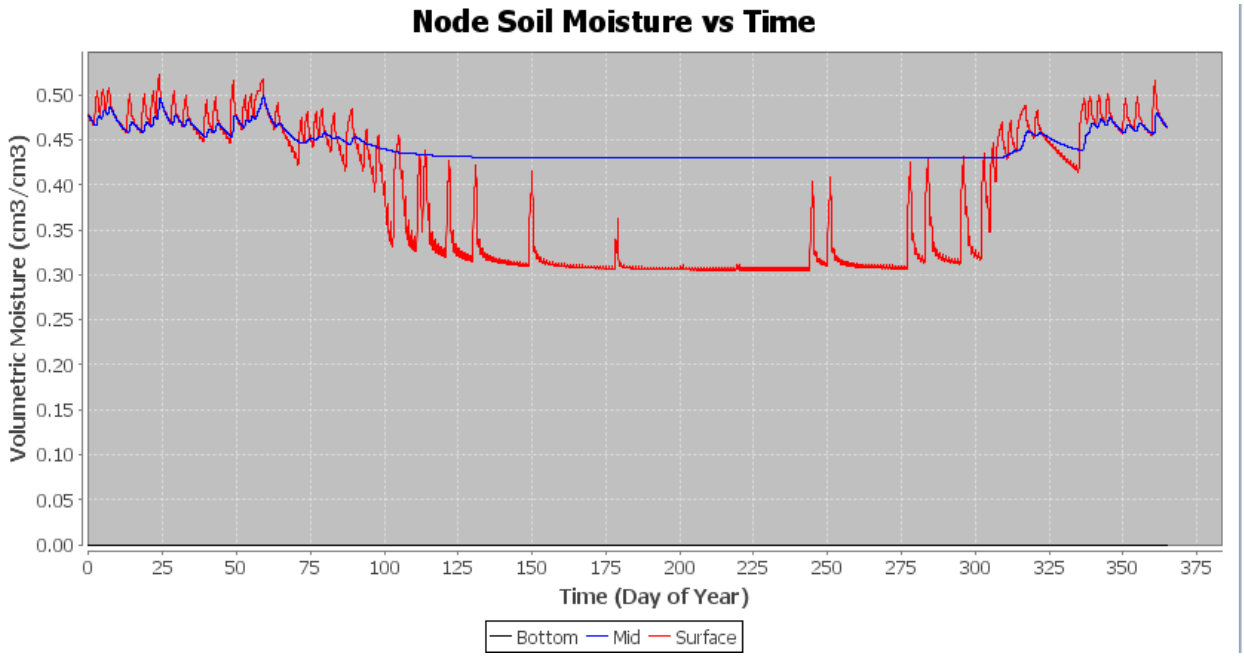
This graph illustrates the calculated percent oxidation as a result of the variable temperature and soil moisture conditions in the landfill cover materials. This is the net total effect from comparing with and without surface emission values.

Node Temperature ***-Predicted Temperature of each Node***



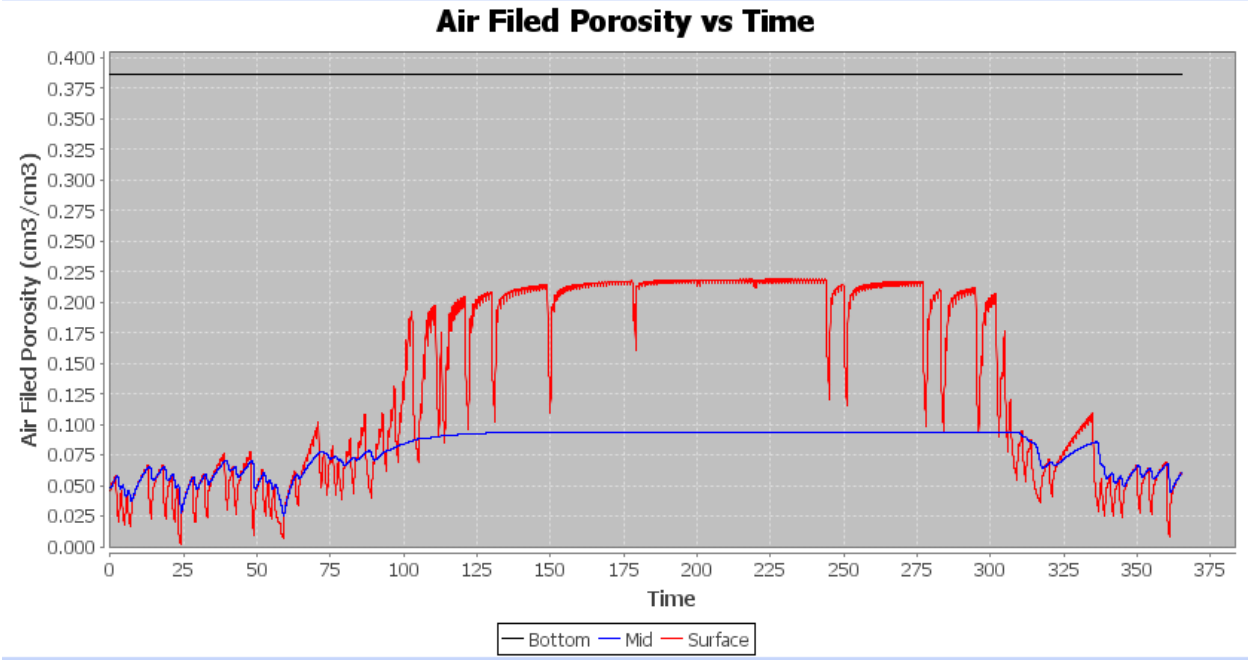
This graph illustrates the surface, mid and bottom node results for soil temperature of these 3 respective depths through the cover.

Node Moisture ***-Predicted Soil Moisture (volumetric) of each Node***



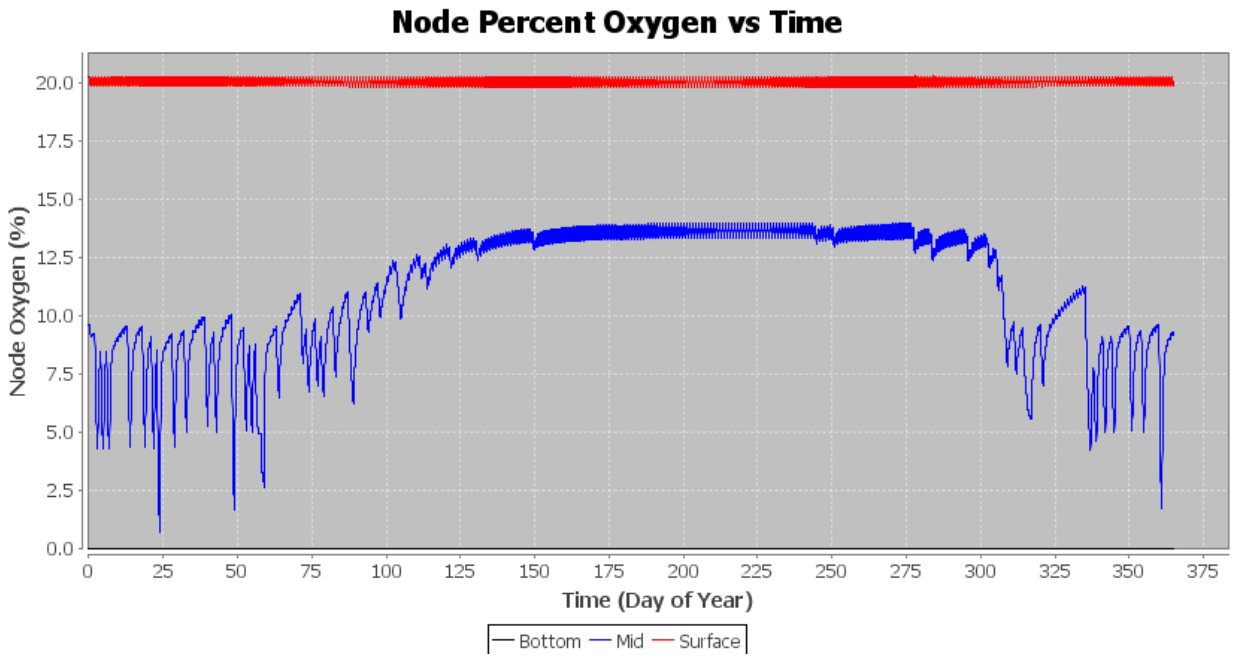
This graph illustrates the surface, mid and bottom node results for soil moisture of these 3 respective depths through the cover.

Node Air Filed Porosity ***-Predicted Air-Filled Porosity of each Node***



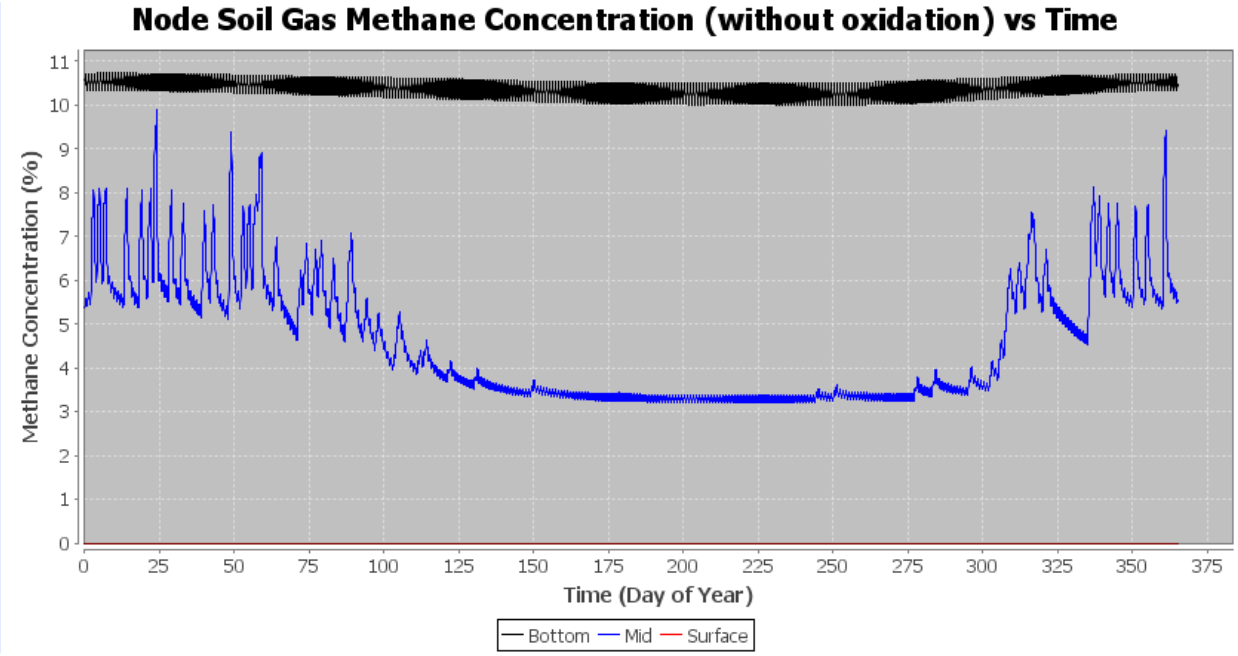
This graph illustrates the surface, mid and bottom node alterations in air-filled porosity as a function of the fluctuating soil moisture conditions.

Node Oxygen % ***- Oxygen Concentration within each Node***



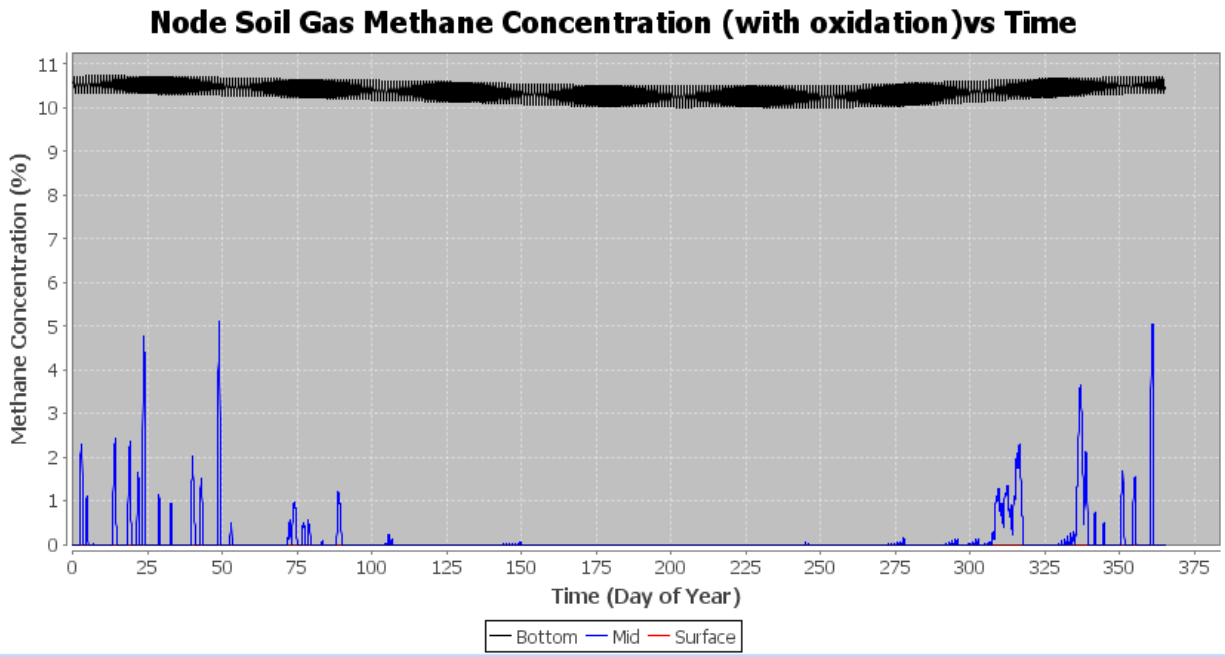
This graph illustrates the surface, mid and bottom node results for oxygen concentrations of these 3 respective depths through the cover.

Node CH4 without Ox ***- Methane Concentration within each Node without Methane Oxidation***



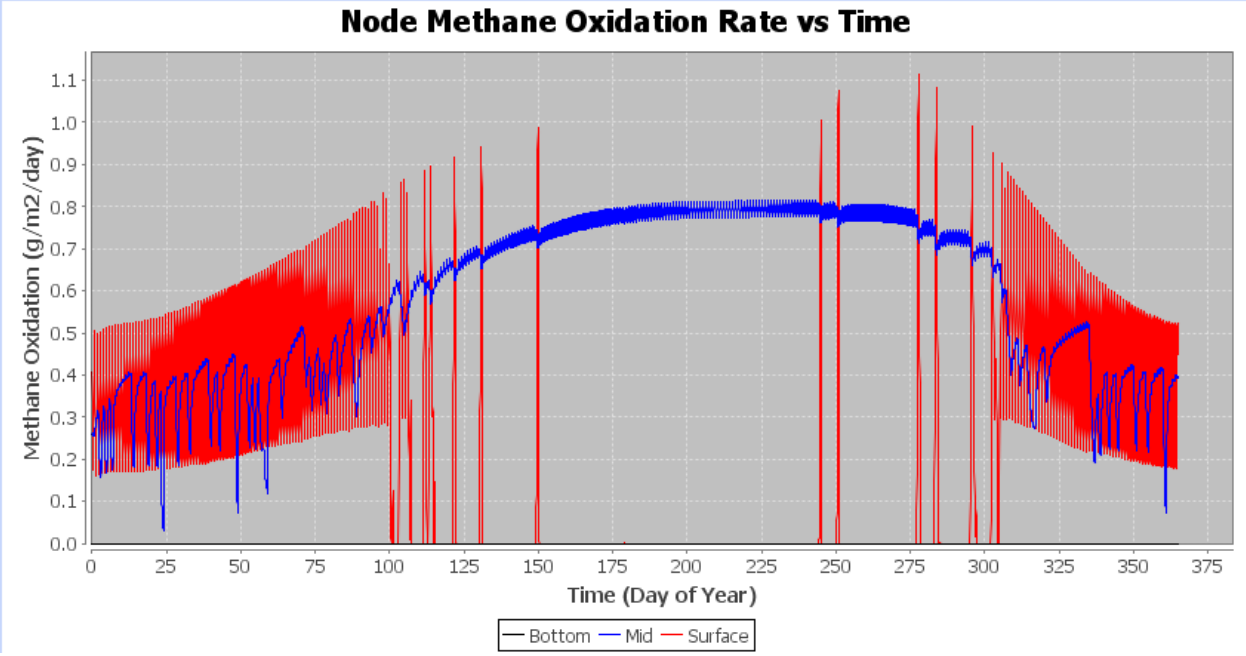
This graph illustrates the surface, mid and bottom node results for methane concentrations at these 3 nodes without methane oxidation.

Node CH4 with Ox - ***Methane Concentration within each Node with Methane Oxidation***



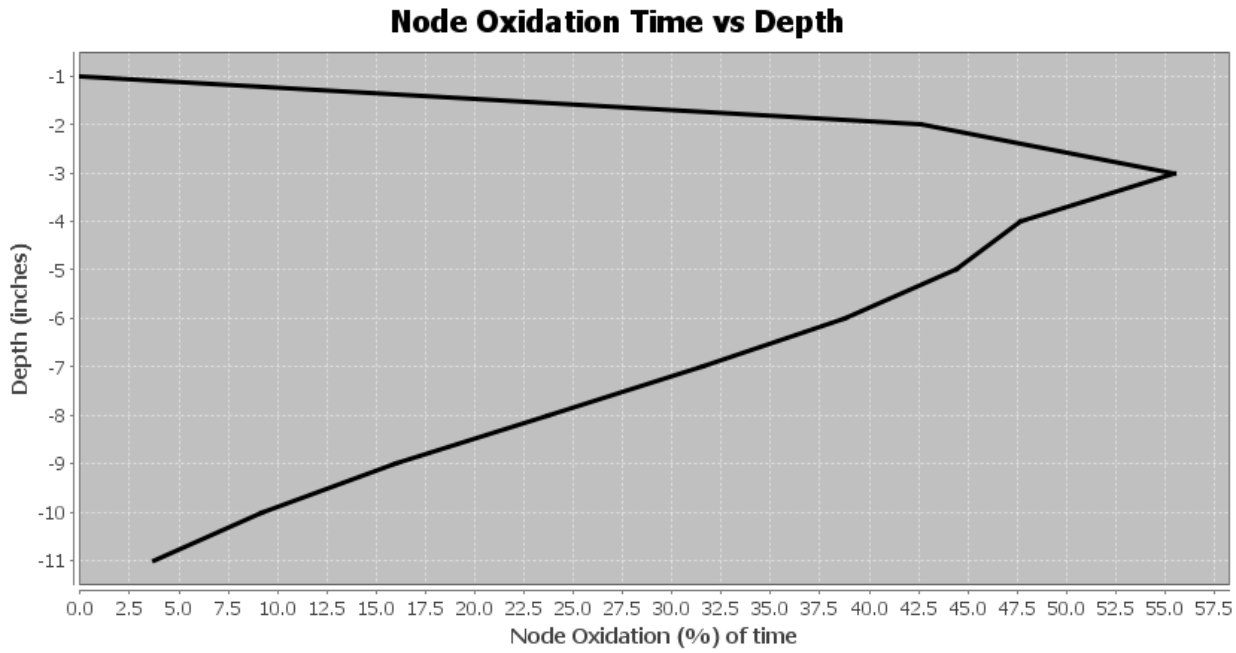
This graph illustrates the surface, mid and bottom node results for methane concentrations with methane oxidation. Note the drastic difference in methane concentrations between the with and without methane oxidation scenarios. Also note how variable the methane concentration is in the middle layer of this particular cover.

Node CH4 Oxid ***- Percent Oxidation within each Node***



This graph illustrates the total methane oxidation occurring per node (grams CH4/m2/day). Note that this is per node and not the methane surface emission.

Depth Profile - ***Depth Profile of Methane Oxidation***



This graph illustrates the percentage of time that the respective layer is capable of oxidizing methane at that respective depth.

Appendix A

Default boundary conditions for different cover types

Table A1. Default conditions for selected cover types.

Cover Type	Lower Temperature Boundary Condition (^{o}C)	Lower Methane Boundary Condition (% vol)	Lower Oxygen Boundary Condition (% vol)
Daily	25	0.30	5
Intermediate	35	45	1
Final	40	55	0

Appendix B

Default Material Properties in Model

	Sand (%)	Silt (%)	Clay (%)	Soil ?	Bulk Density (g/cm3)	SatConductivity (kg/m3)	Volunteric Moisture (33 kPa)	Volumetric Moisture (1500 kPa)	Beta (Campbell)	Total Porosity (33 kPa)
Soil Materials										
SAND	93.6	3.06	3.34	true	1.63	0.002703	0.091	0.039	2.01	0.386
SANDY CLAY	93.6	3.06	3.34	true	1.44	0.000176	0.231	0.113	10.21	0.455
LOAMY SAND	82.74	9.66	7.6	true	1.58	0.001760	0.116	0.051	2.86	0.402
SANDY LOAM	65.6	22.5	11.9	true	1.53	0.000763	0.139	0.062	4.29	0.422
SILTY LOAM	21.8	62.7	15.5	true	1.28	0.000137	0.276	0.125	6.86	0.518
LOAM	42.9	39.5	17.6	true	1.40	0.000292	0.223	0.102	6.26	0.474
SANDY CLAY LOAM	60.1	11.3	28.6	true	1.47	0.000356	0.2	0.095	7.42	0.445
SILTY CLAY LOAM	9	55	36	true	1.24	0.000052	0.321	0.151	10.36	0.532
CLAY LOAM	34.7	30.3	35	true	1.35	0.000125	0.264	0.125	8.94	0.489
SILTY CLAY	9.3	43.89	46.81	true	1.28	0.000031	0.312	0.15	13.00	0.517
CLAY	10	25	65	true	1.26	0.000034	0.351	0.172	14.20	0.524
SILT	7.96	63.62	5.41	true	1.16	0.000106	0.332	0.149	6.72	0.564
Rocks - Pebbles	93.6	3.06	3.34	true	1.63	0.002703	0.091	0.039	2.01	0.386
Rocks - Boulders (large)	95.6	2.06	2.34	true	2.01	0.003100	0.071	0.019	2.01	0.245
ADC Foundry Sands	90	5	5	true	1.63	0.003703	0.1	0.04	3.00	0.39
ADC Dredged Materials	7.96	63.62	5.41	true	1.16	0.000106	0.332	0.149	6.72	0.564
ADC Ash	21.8	62.7	15.5	true	1.28	0.000137	0.276	0.125	6.86	0.518
ADC Contaminated Soils (clay)	10	25	65	true	1.26	0.000034	0.351	0.172	14.20	0.524
ADC Contaminated Soils (sand)	90	5	5	true	1.63	0.003703	0.1	0.04	3.00	0.39
ADC Contaminated Soils (general - loam)	42.9	39.5	17.6	true	1.40	0.000292	0.223	0.102	6.26	0.474
ADC Tire Shreds [small <2 in (50 mm)]	90	5	5	true	1.08	0.051300	0.19	0.06	2.00	0.51
ADC Tire Shreds [large >2 in (50 mm)]	90	5	5	true	1.63	0.003703	0.1	0.04	3.00	0.39
ADC Wood Chips (all)	90	5	5	true	1.08	0.081300	0.22	0.06	2.00	0.33
ADC sludge	10	80	10	true	1.20	0.001060	0.452	0.15	8.70	0.564
ADC Energy Resource Exploration and Production Wastes	42.9	39.5	17.6	true	1.40	0.000292	0.223	0.102	6.26	0.474
ADC Composted Organic Materials	42.9	39.5	17.6	true	1.40	0.000292	0.223	0.102	6.26	0.474
Non-Soil Materials										
Geomembrane (HDPE)	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524
Geomembrane (LDPE)	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524
Geomembrane (EDPM)	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524
Geotextile (woven)	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524
ADC Spray Applied Cement Products	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524
ADC Spray Applied Foams	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524
ADC Temporary Tarp	10	25	65	false	1.26	0.000034	0.351	0.172	14.20	0.524

Appendix C

Geomembrane notes

Average K_{sat} for a HDPE geomembrane is around 4 x 10^{-13} m/sec (Narejo and Memon, 1995; Giroud and Badu-Tweneboah, 1992). For the geomembrane node (1 inch thick = 2.54 cm), the effective hydraulic conductivity is calculated by the following formula:

where B is the thickness of the geomembrane in cm (=2.54*mils/1000). Factors that affect the gas diffusion coefficient (D_{GEOM}) are temperature, permeability of polymer to the respective gas, and the crystallinity of polymer (Moisan, 1980; Billingham 1990). As seen in the Table A2 (below) the diffusion coefficient is typically six orders of magnitude smaller for the geomembrane than for the soil (Rowe and Rimal, 2008).

Table A2. Diffusion Coefficients for various materials.

Material	**Diffusion Coefficient ($m^2 sec^{-1}$)**
Gravel	6×10^{-10}
GT	6×10^{-10}
Sand	3×10^{-10}
Geomembrane	2.1×10^{-15}
Geomembrane (exposed to leachate)	2.1×10^{-15}
Geomembrane (exposed to water)	2.5×10^{-16}
Geosynthetic clay liner (GCL)	1×10^{-10}

References:

Billingham, N. C. (1990). “Physical phenomena in the oxidation and stabilization of polymers.” Oxidation inhibition in organic materials, J. Pospisil and P. P. Klemchuk, eds., Vol. II, CRC Press, Boca Raton, Fla.

Giroud J.P., Badu-Tweneboah.,K (1992) "Rate of Leakage through a composite liner due to Geomembrane Defects" Geotextiles and Geomembranes, 11(1) Elsevier Science Publishers Ltd, England.

Moisan, J. Y. (1980). “Diffusion des additifs du polyethylene. I. Influence de la nature du diffusant.” Eur. Polym. J., 16, 979-987.

Narejo,D.B and Memon,G.Q (1995), "Compatibility of Geosynthetic clay liners with three Pennsylvania municipal solid waste leachates", Geosynthetics International, 2(5), 889-892.

Rowe, R.K. and S. Rimal, 2008. Aging of HDPE Geomembrane in Three Composite Landfill Liner Configurations Journal of Geotechnical and Geoenvironmental Engineering, Vol. 134, No. 7 906-916.

Refernces for SolarCalc usage:

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