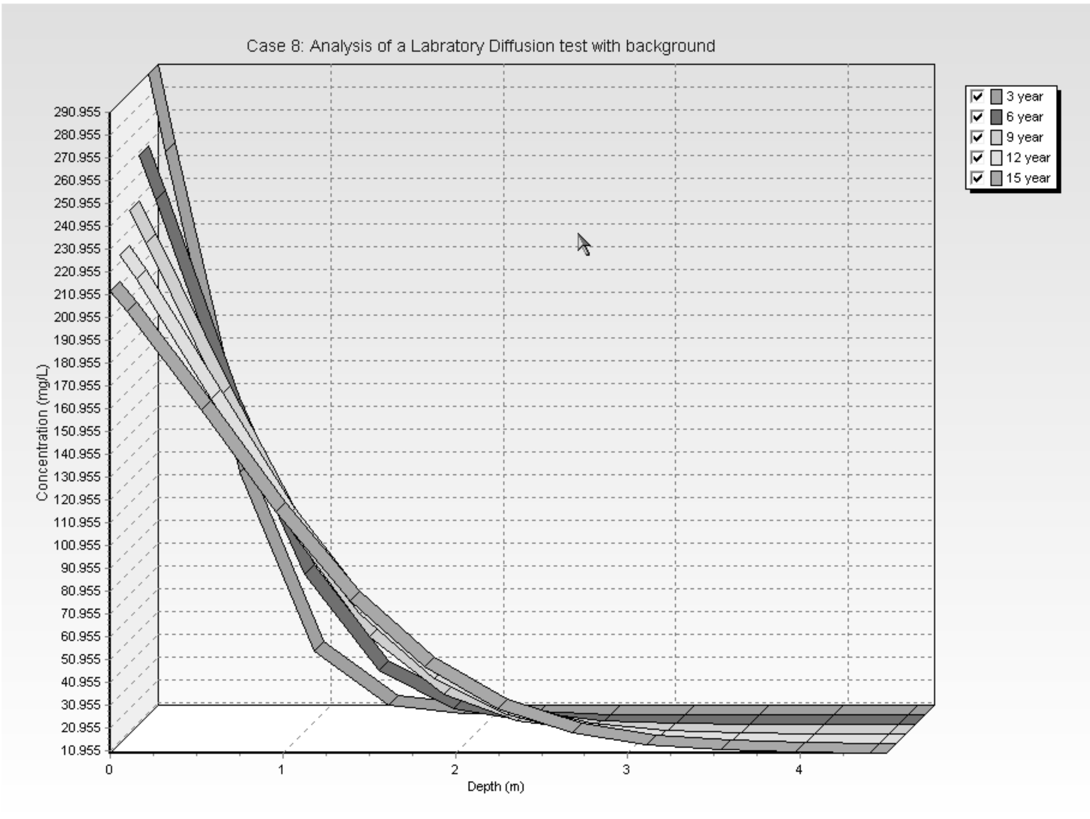
POLLUTEv7 Examples



Example Summary

All the examples in this appendix have been stored in the Examples project, shown below. When reviewing these examples, you can either use the models in the Examples project or create a new project and create the models using the New Model button. In the examples below, it is assumed that the models in the Examples project are being used.

Model #	Title
1	Case 1: Subtitle D Landfill with constant source concentration
2	Case 2: Pure diffusion - specified surface and base concentrations
3	Case 3: Advective diffusive transport, Constant source, Base aquifer
4	Case 4: Finite mass, leachate collection, base aquifer
5	Case 5: Hydraulic trap, Finite mass, leachate collection, base aquifer
6	Case 6: 1m thick liner, 3m fractured till, finite mass, sorption
7	Case 7: Lateral migration in fractured rock
8	Case 8: Analysis of a Labratory Diffusion test with background
9	Case 9: Freundlich Non-linear sorption in a lab diffusion test
10	Case 10: Time-varying velocity; termination of leachate collection
11	Case 11: Variable source concentration history
12	Case 12: POLLUTE vs Analytical solution --single fracture
13	Case 13: Comparison with an analytical method.
14	Case 14: Landfill with Primary and Secondary Leachate Collection
15	Case 15: Landfill with Primary and Secondary Leachate Collection with Failure.
16	Case 16: Monte Carlo Simulation
17	Case 17. Landfill with composite primary and clay secondary liners.
18	Case 18: Phase Change in Secondary Leachate Collection System
19	Case 19: Multiphase Diffusion Test by Buss et al.
20	Case 20: Sensitivity Analysis

Case 1

Shows how to create a **Subtitle D** landfill with a composite liner and constant concentration source. The flow through the composite liner is calculated using a leakage rate calculation as proposed by Giroud et. al. (1992).

Case 2

Shows the case of **pure diffusion** with constant source and base concentrations.

Case 3

Edits the previously entered data in Case 2 to include **advective transport and fixed outflow** in the base stratum.

Case 4

Shows how to add a **finite mass source with leachate collection** to Case 3. Also shows how to calculate the **Reference Height of Leachate** and the **Volume of Leachate Collected**. Uses the **automatic search** for the peak concentration.

Case 5

Illustrates use of the program to model a **hydraulic trap**, using essentially the same data as in Case 4.

Case 6

This case has a 1 m thick compacted clay liner underlain by a 3 m thick **fractured till layer**. The source is **finite mass** with a **leachate collection system**, and the base is an **aquifer with fixed outflow**. Different sorption in the liner and the fractured till is also considered.

Case 7

The lateral migration of a **radioactive contaminant** is modelled, in a **fractured porous rock** with a single set of parallel fractures. The base of the porous rock is assumed to extend to a considerable distance from the source and is represented by an **infinite thickness boundary condition**. This example illustrates the case where the default integration is not adequate. The **maximum sublayer thickness** feature is also used in this example.

Case 8

Uses an **Initial Concentration Profile** in analyzing a laboratory **diffusion test for Potassium.** The specimen consists of a 4.5 cm thick clay sample with a background concentration of Potassium of 10 mg/L. In this example the Reference Height of Leachate is equal to the actual height of leachate above the sample.

Case 9

Freundlich non-linear sorption is considered in analyzing a laboratory **diffusion test for Phenol.** The sample is a 7 cm thick undisturbed clay, with a 6.5 cm leachate column above for a source.

Case 10

The **Variable Properties** option is used to e**xamine time-varying advective-dispersive transport** from a landfill. A landfill with a finite mass and a leachate collection system with an inward Darcy Velocity (i.e., a **hydraulic trap**) is considered. **The leachate collection system is assumed to begin to fail** after 19 years. After failure of the leachate collection system the leachate mound builds over a 10 year period, causing a reversal in the hydraulic gradient and a loss of the hydraulic trap.

Case 11

This example demonstrates the use of a **time-varying source concentration** and **an initial concentration profile.** A landfill cell is initially filled with fresh water, and no waste is deposited for 7 years. The landfill is situated in a clay with a pore water chloride concentration, during the initial 7 years the chloride from the clay diffuses into the cell water. Between 7 and 10 years the cell is filled with waste and the chloride concentration increases linearly to 2100 mg/L. The source concentration then remains constant between 10 and 13 years. Between 13 and 15 years the source concentration decreases linearly to 1180 mg/L. The source concentration then remains constant between 15 and 19 years.

Case 12

In this example the **results of the program are compared with an analytical solution** developed by Tang et al. (1981). The analysis is for a **single fracture system.** It is shown that the program gives exactly the same results as the analytical solution.

Case 13

The **results of the program are compared to the results obtained by an analytical solution** given by TDAST. The TDAST program was developed by Javandel et al. (1984), and is for a 2-dimensional plane dispersion problems in an infinitely deep porous media. Concentrations obtained by both methods are in close agreement for a dispersion coefficient of 0.01 m^2/a. However, at higher dispersion coefficients, for example 5 or 10 m^2/a, the methods are not in agreement. This is because for the geometry and time frame considered in this problem, a 2-dimensional solution is required and POLLUTEv7 considers only 1-dimensional migration in the layer below the source.

Case 14

In this example a landfill with **primary and secondary leachate collection systems** is modelled using the **Passive Sink** option. The secondary leachate collection system is simulated using a passive sink to model outflow from the collection system. The landfill contains a finite mass of a conservative species, and is underlain by an aquifer with fixed outflow.

Case 15

The model of Case 14 is extended to incorporate **failure of the primary leachate collection system** after 20 years. This failure is modelled using the Variable Properties special feature. The use of the **Variable Properties and Passive Sink** features together is illustrated in this example.

Case 16

This example illustrates the use of the **Monte Carlo simulation** feature, in conjunction with the **Variable Properties and Passive Sink** features. The landfill model used in Case 15 is modified to **simulate uncertainty in the time of failure** of the primary leachate collection system. In this example the failure time is given a triangular distribution, with a minimum of 15 years, a mode of 25 years, and a maximum of 50 years.

Case 17

This example demonstrates how to create a landfill with a c**omposite primary liner, primary and secondary leachate collection systems, and a compacted clay secondary liner.**

Case 18

A **phase change** in the secondary leachate collection system is modelled using the **Phase Change** special feature. The phase change occurs in the secondary leachate collection system at the interface between the unsaturated and saturated zones, assumed to be .2 and .1 metres thick respectively. The landfill contains a constant concentration of DCM, which experiences biological decay in the landfill, primary and secondary liners, and the aquifer.

Case 19

In this example a **multiphase diffusion test** performed by Buss et al. (1995) is modelled. This test involved the migration of toluene from a ‘constant’ source through a 0.1 cm thick HDPE geomembrane, a 18.2 cm thick airspace and into a 12.3 cm water reservoir (assumed to be well mixed).

Case 20

This example uses the same date as Case 16 for Monte Carlo simulation, except a **Sensitivity Analysis** is performed. In this example the failure time has a minimum of 15 years and a maximum of 50 years.

Case 1: Subtitle D Landfill

Description

This example illustrates the use of the program to model a U.S. RCRA Subtitle D landfill. The landfill consists of a composite liner and a primary leachate collection system. The composite liner is composed of a 60 mil (1.5 mm) geomembrane in good contact with a 0.9 m thick compacted clay liner. Small holes with an area of 0.1 cm^2 and a frequency of 1 per acre (2.5 per hectare) are assumed for the geomembrane. The method proposed by Giroud et al (1992) is used to calculate the flow (leakage) through the composite liner, these calculations are performed automatically by the program.

The landfill has a length (L) of 200 m in the direction parallel to groundwater flow in the underlying aquifer. Consideration is being given to a volatile organic contaminant with an initial source concentration of 1500 µg/L, which is assumed to remain constant with time over the time period being examined in this example. The leachate head on the composite liner is assumed to be constant at 0.3 m. The flow in the aquifer must be established based on hydrogeologic data and is represented in terms of the horizontal Darcy velocity (the "Base Outflow Velocity") in the aquifer at the down-gradient edge of the landfill.

The parameters used for this example are listed below:

Property		Value	Units
Geomembrane Contact		Good	-
Geomembrane Holes		Circles	-
Hole Area		0.1	cm^2
Hole Frequency		1	/acre
Source Concentration	c_o	1500	µg/L
Source Type		Constant	-
Landfill Length	L	200	m
Leachate Head on Liner		0.3	m
Geomembrane Thickness		60	mil
Geomembrane Diffusion Coef.		3.0×10^{-5}	m^2/a
Clay Thickness	H_s	0.9	m
Clay Diffusion Coef.	D	0.02	m^2/a
Distribution Coefficient	K_d	0.5	mL/g
Soil Porosity	n	0.35	-
Dry Density		1.9	g/cm^3
Aquifer Thickness	h	3.0	m
Aquifer Porosity	n_b	0.3	-
Base Outflow Velocity	v_b	10	m/a

For more information regarding:

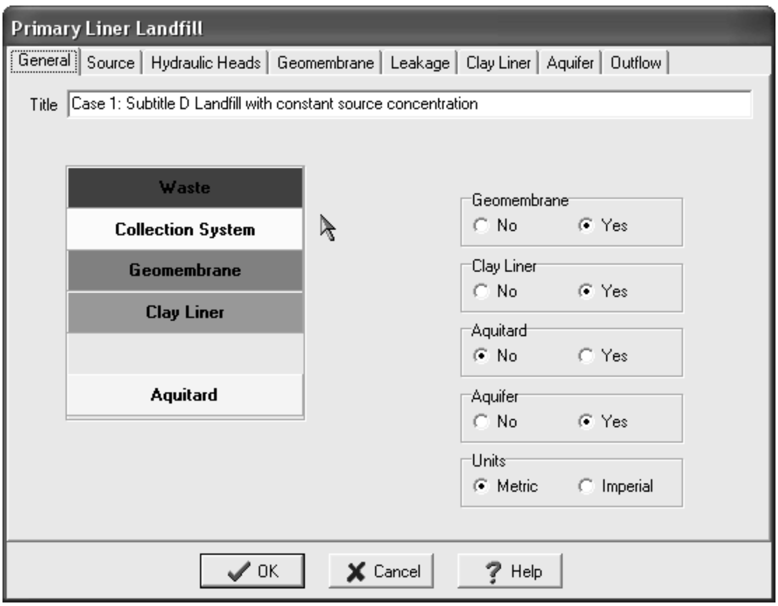
- Leakage through composite liners - see Giroud et al (1992).
- Diffusion through geomembranes - see Hughes and Monteleone, (1987); Lord et al (1988).
- Diffusion, sorption, and effective porosity in clays (D, K_d, n) - see Rowe et al (1988)
- Modelling, hydrogeology, and engineering interaction - see Rowe (1992), Rowe et al, 1994.
- Theory used - see Rowe and Booker (1985, 1991), Rowe et al (1994).

Data Entry

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 1 and open the model by double clicking on it in the model list. After the model is displayed, click on any layer to display the Primary Liner Landfill form below.

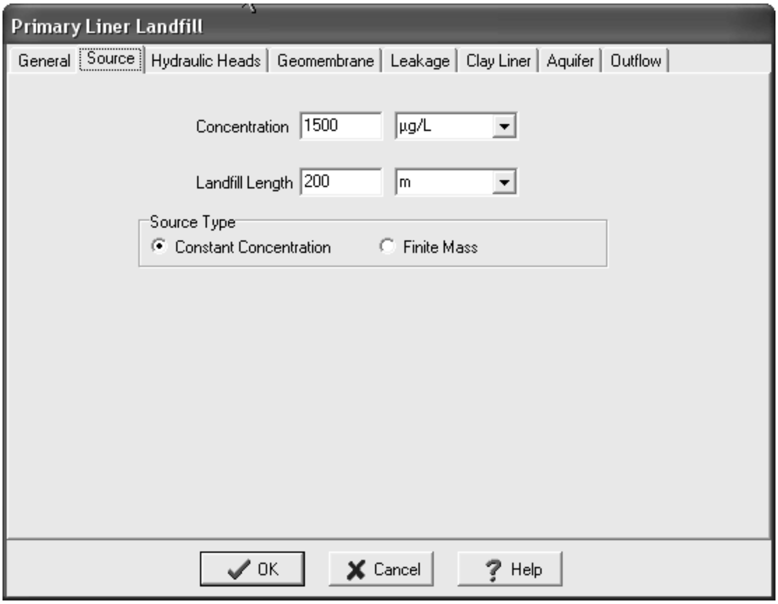
Model Parameters

On the General tab, the title and layers present in the model are specified as shown above. In this example there is a geomembrane, clay liner and aquifer.

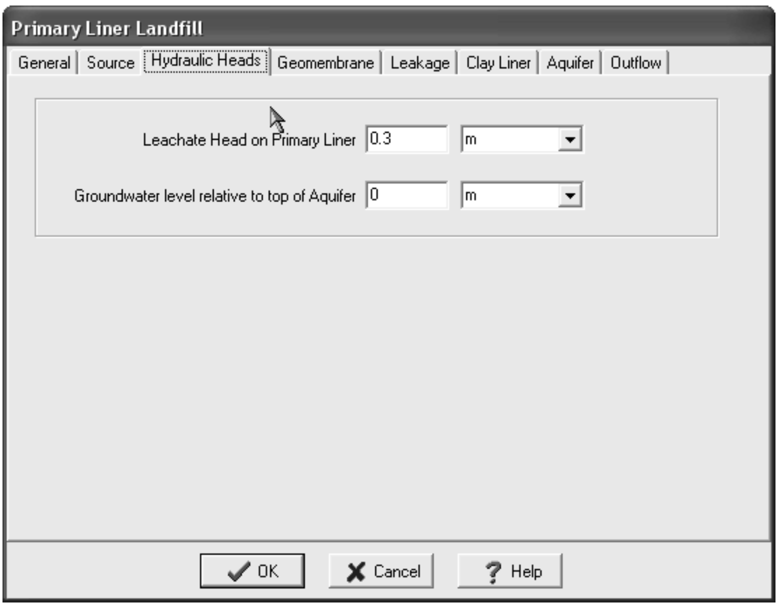


On the Source tab shown on the next page, the Source Type, Source Concentration and Landfill Length are specified. In this example, the source type is constant concentration. If the source type was finite mass additional information for the source would need to be entered as discussed in Case 4.

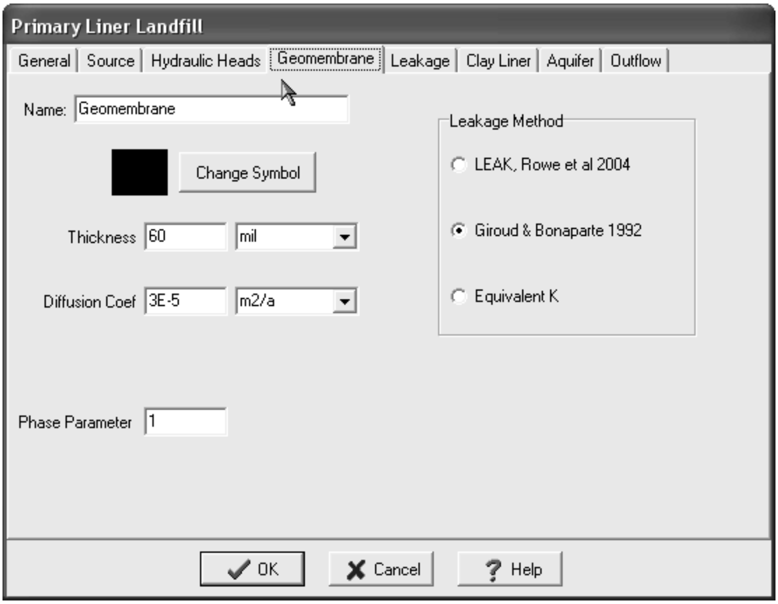
Case 1: Subtitle D Landfill with Constant Concentration



The Hydraulic Heads tab, shown below, is used to specify the leachate head on the primary liner and the groundwater level relative to the top of the aquifer. These heads are used to calculate the Darcy velocity through the liner.



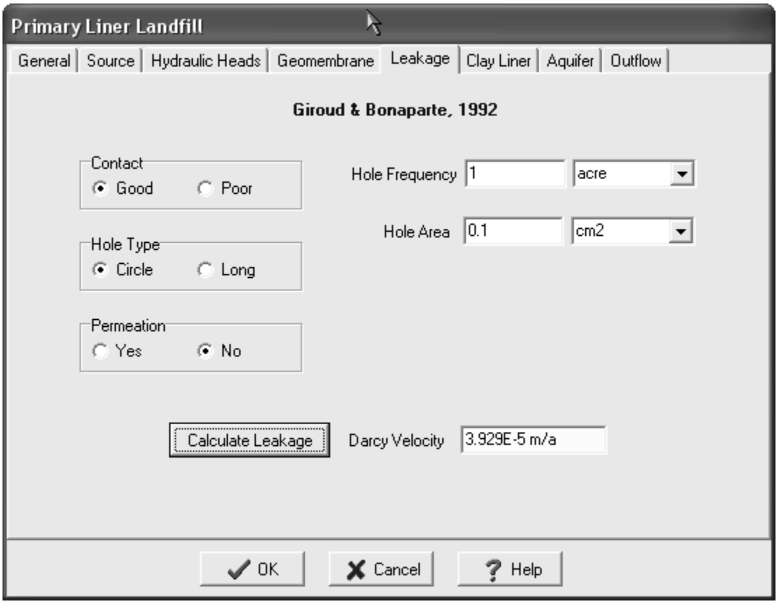
On the Geomembrane tab shown below, the Name, Thickness, Diffusion Coefficient, Phase Parameter, and method to calculate the leakage through the geomembrane is specified. If the method is Rowe et. al. 2004 or Giroud & Bonaparte 1992, an additional tab will be displayed to enter the hole parameters. If the method is equivalent K, then the Hydraulic Conductivity of the geomembrane can be entered on this tab. In this example the leakage method used is Giroud & Bonaparte 1992.



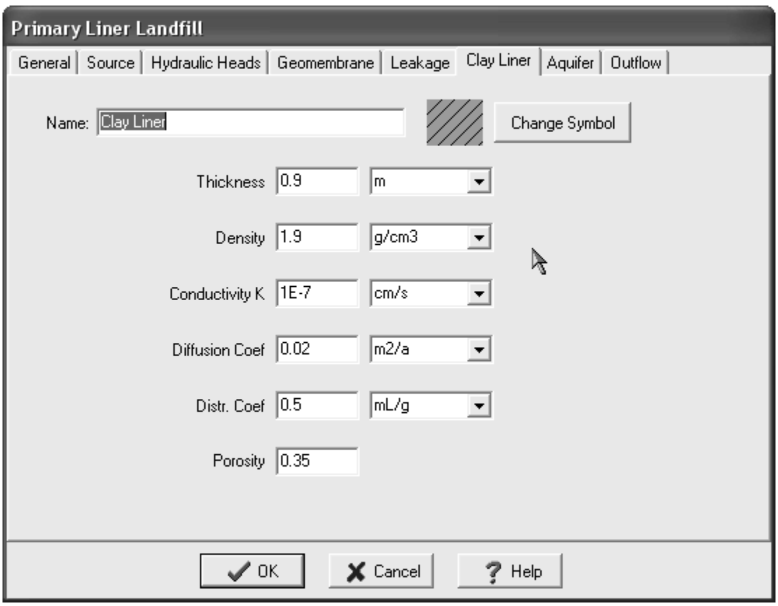
The parameters for the holes in the geomembrane are specified on the Leakage tab shown on the next page. These parameters include the Type of Contact, Hole Type, Use of Permeation, and Hole Frequency. If the type of holes is Circles then the Hole Area can be specified, if the type is Long then the Hole Length and Width can be specified.

At the bottom of the tab, the Calculate Leakage button can be used to calculate and display the Darcy velocity (leakage) through the primary liner .In this example the calculated Darcy velocity is 3.929×10^{-5} m/a

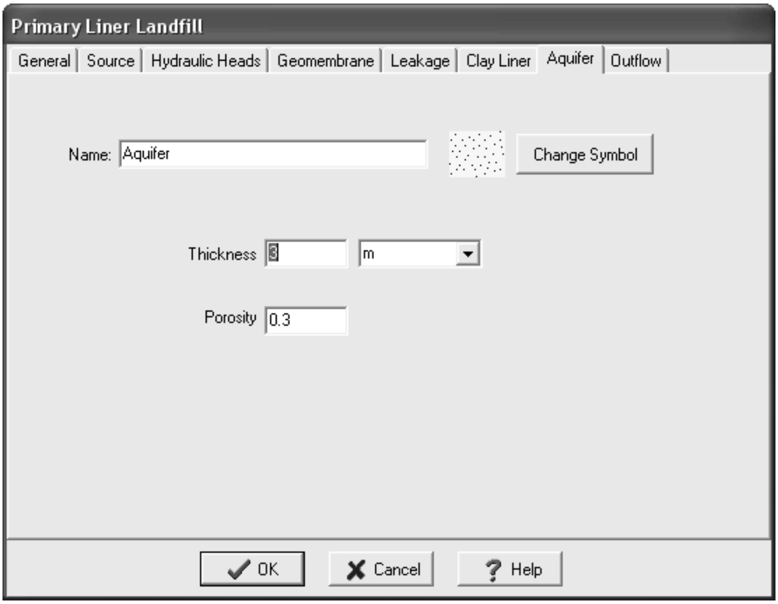
Case 1: Subtitle D Landfill with Constant Concentration



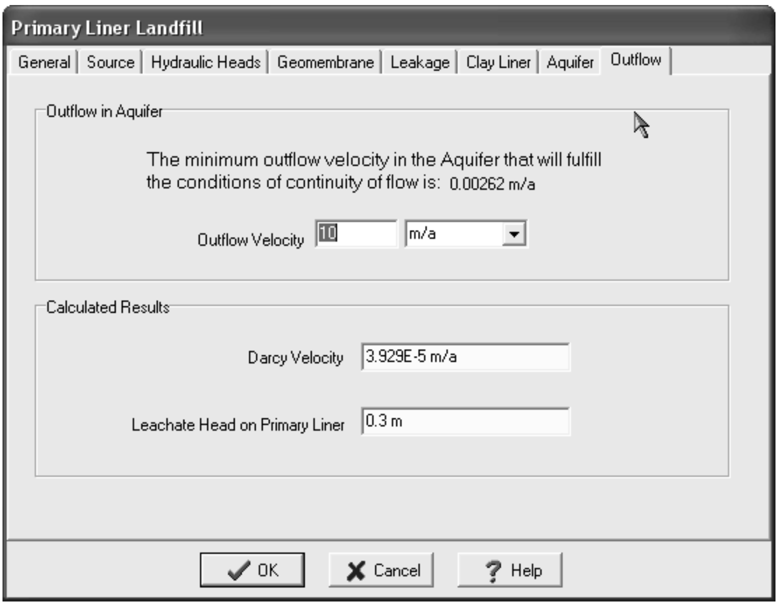
The Clay Liner tab below is used to specify the properties of the clay liner below the geomembrane. These properties include the Name, Symbol, Thickness, Density, Hydraulic Conductivity, Diffusion Coefficient, Distribution Coefficient, and Porosity.



The Aquifer tab, shown below, is used to specify the Name, Symbol, Thickness and Porosity of the Aquifer.

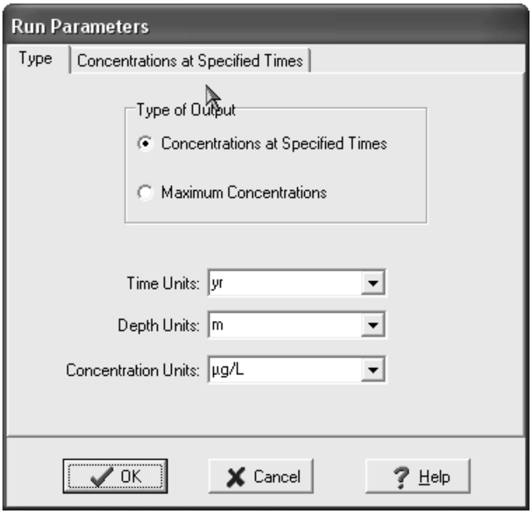


The last tab is used to specify the Outflow Rate in the Aquifer. This rate should be at greater than or equal to the minimum calculated by the program. In this example, the minimum is 0.00262 m/a.

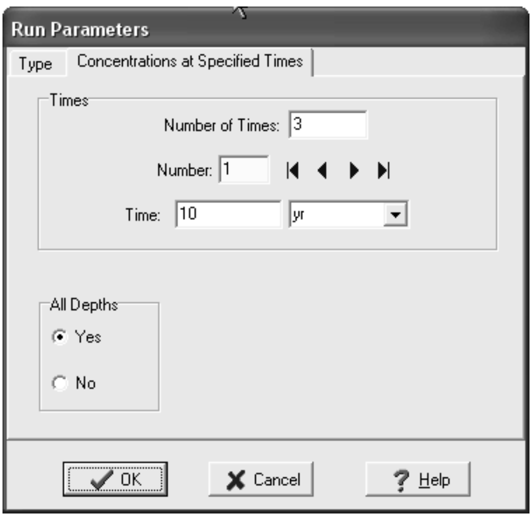


Run Parameters

To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The Run Parameters form below will be displayed. The Type tab is used to specify the Type of Output and the units for the output. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found.



The Concentrations at Specified Times tab is used to specify the times and depths to calculate the concentrations.



Model Execution

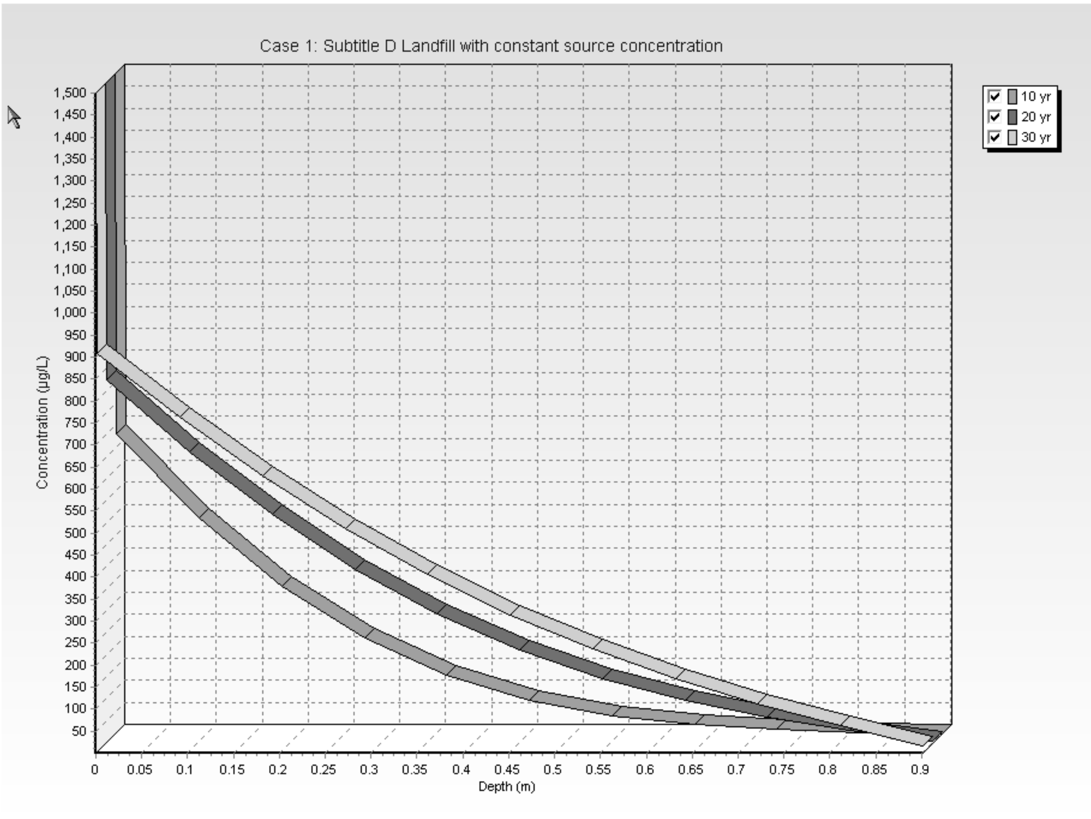
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 1: Subtitle D Landfill with constant source concentration

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 3.929E-5 m/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	3E-5 m2/a	1	0 cm3/g	950 kg/m3
Clay Liner	0.9 m	10	0.02 m2/a	0.35	0.5 mL/g	1.9 g/cm3

Boundary Conditions

Contant Concentration
Source Concentration = 1500 µg/L

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 3 m
Base Porosity = 0.3
Base Outflow Velocity = 10 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth m	Concentration µg/L
10	0.000E+00	1.500E+03

	1.524E-03	6.823E+02
	9.152E-02	4.917E+02
	1.815E-01	3.370E+02
	2.715E-01	2.190E+02
	3.615E-01	1.345E+02
	4.515E-01	7.798E+01
	5.415E-01	4.254E+01
	6.315E-01	2.176E+01
	7.215E-01	1.028E+01
	8.115E-01	4.107E+00
	9.015E-01	3.970E-01
20	0.000E+00	1.500E+03
	1.524E-03	8.259E+02
	9.152E-02	6.636E+02
	1.815E-01	5.198E+02
	2.715E-01	3.966E+02
	3.615E-01	2.942E+02
	4.515E-01	2.117E+02
	5.415E-01	1.471E+02
	6.315E-01	9.768E+01
	7.215E-01	6.006E+01
	8.115E-01	3.082E+01
	9.015E-01	6.430E+00
30	0.000E+00	1.500E+03
	1.524E-03	9.082E+02
	9.152E-02	7.636E+02
	1.815E-01	6.309E+02
	2.715E-01	5.115E+02
	3.615E-01	4.062E+02
	4.515E-01	3.148E+02
	5.415E-01	2.365E+02
	6.315E-01	1.698E+02
	7.215E-01	1.126E+02
	8.115E-01	6.246E+01
	9.015E-01	1.675E+01

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other

Case 2: Pure Diffusion

Description

This example illustrates the use of the program for the simple case of pure diffusion of a conservative species (i.e., no sorption). The hydrogeology is comprised of a 4 m thick layer with a constant contaminant concentration source at the top, and an underlying aquifer at the base. There is a sufficiently high flushing velocity in the aquifer that the concentration at the bottom of the layer can be assumed to be zero and the aquifer is not explicitly modelled. The following parameters are assumed for the example:

Property		Value	Units
Darcy Velocity	v_a	0.0	m/a
Diffusion Coefficient	D	0.01	m^2/a
Distribution Coefficient	K_d	0.0	cm^3/g
Soil Porosity	n	0.4	-
Dry Density		1.5	g/cm^3
Soil Layer Thickness	H	4.0	m
Number of Sub-layers		4	-
Source Concentration	c_o	1.0	g/L
Base Concentration	c_b	0.0	g/L
Times of Interest	t	10, 50, 100	a
		150, 200	a

Data Entry

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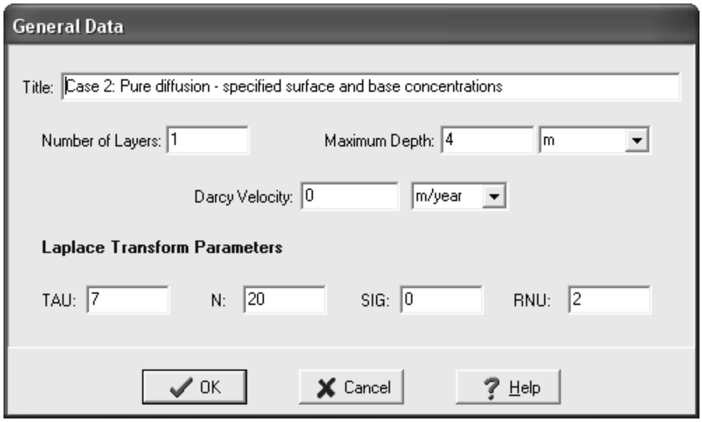
*S*tart the POLLUTEv7 program and open the Examples project. Select Case 2 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

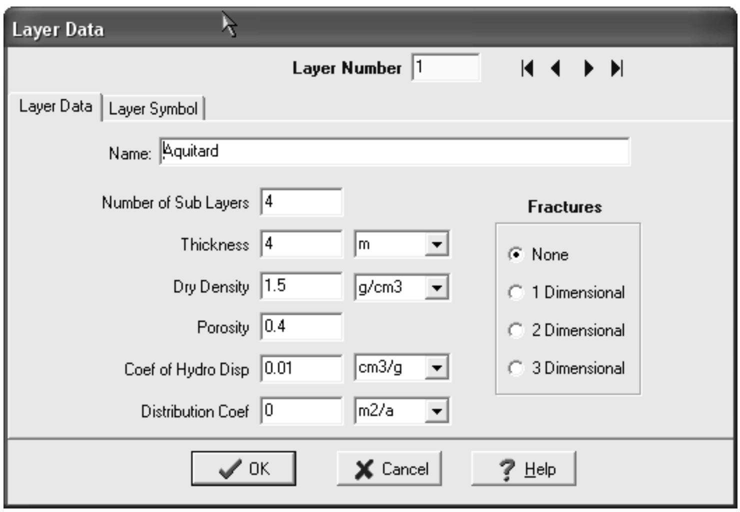
To edit the general model data either click on the title or select the General Data menu item from the Data Entry menu. On the General Data form on the next page the Title, Number of Layers, Maximum Depth, Darcy velocity, and Laplace Transform parameters can be specified.. In this example there will only be one layer and since it is for diffusion only the Darcy velocity is zero.

Case 2: Pure Diffusion



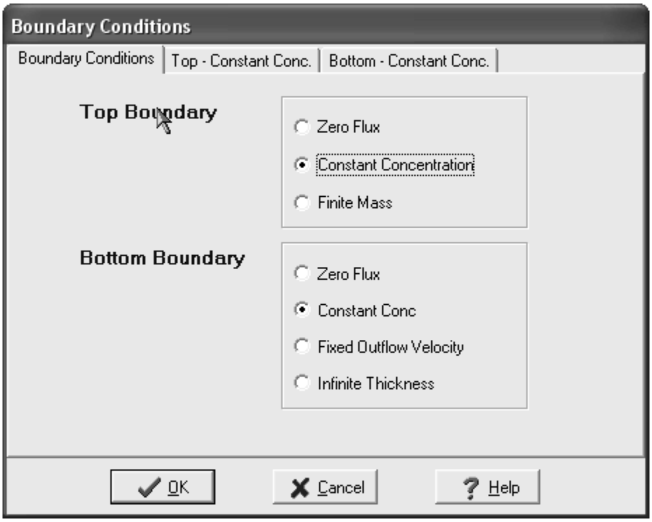
Layer Data

The data for the layer can be specified by either clicking on the layer or by selecting the Layer Data menu item from the Data Entry menu. On the Layer Data form shown below, the data and symbol for the layer can be specified. In this example, the diffusion coefficient of 0.01 is specified for the layer.



Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. On the Boundary Conditions form below the top and bottom boundary conditions can be specified. In this example, the top boundary has a constant concentration of 1 and the bottom boundary has a constant concentration of 0.



Run Parameters

To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The Run Parameters form is the same as shown in Case 1. In this example, the concentrations will be calculated at 5 times: 10, 50, 100, 150, and 200 years.

Model Execution

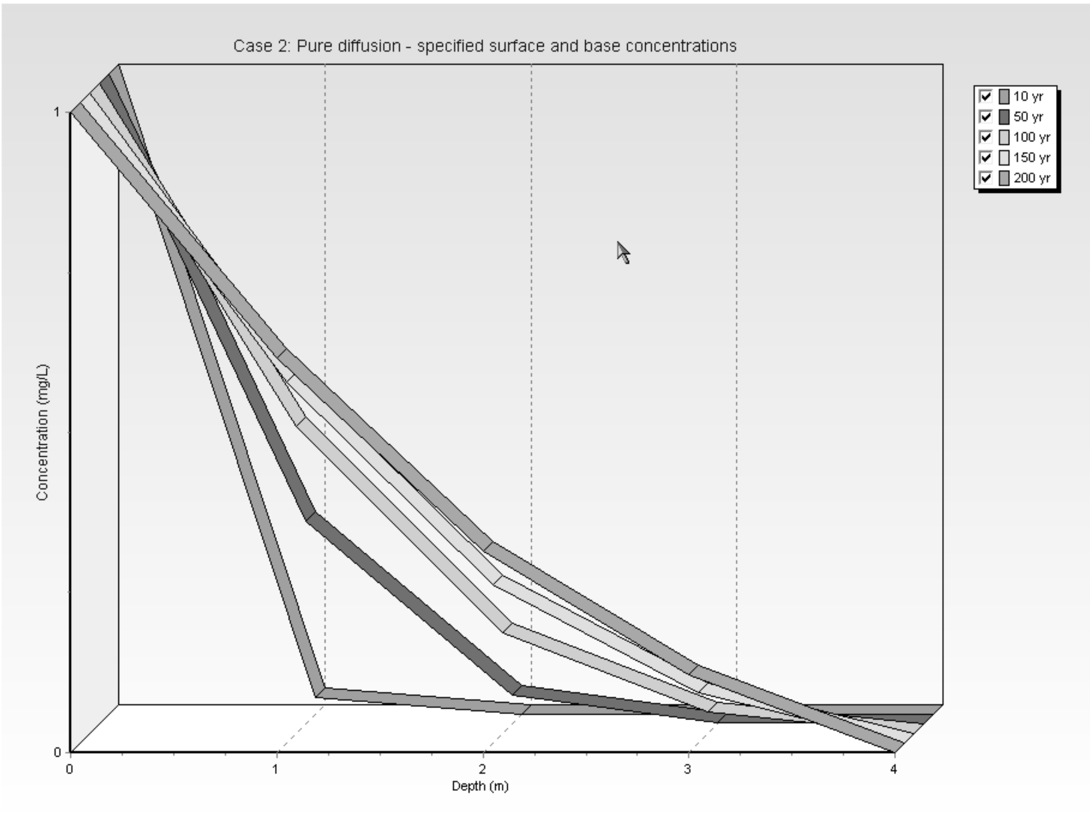
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 2: Pure diffusion - specified surface and base concentrations

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Aquitard	4 m	4	0.01 cm3/g	0.4	0 m2/a	1.5 g/cm3

Boundary Conditions

Contant Concentration
Source Concentration = 1 mg/L

Contant Concentration Bottom Boundary
Base Concentration = 0 mg/L

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth m	Concentration mg/L
10	0.000E+00	1.000E+00
	1.000E+00	2.535E-02
	2.000E+00	7.744E-06
	3.000E+00	2.011E-11
	4.000E+00	0.000E+00

50	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 3.173E-01 4.550E-02 2.699E-03 0.000E+00
100	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 4.795E-01 1.573E-01 3.349E-02 0.000E+00
150	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 5.636E-01 2.477E-01 7.937E-02 0.000E+00
200	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 6.166E-01 3.146E-01 1.212E-01 0.000E+00

Case 3: Advective Diffusive Transport

Description

In this example the input data file from Case 2 will be edited to include advective transport and a permeable base stratum (aquifer) with a fixed outflow. The hydrogeology is comprised of a 4 m thick aquitard layer with a constant contaminant concentration in the landfill source at the top, and a 20 m thick underlying aquifer at the base.

Although the aquifer is 20 m thick it is generally unrealistic to model dilution (mixing) of contaminant through the full thickness. The actual thickness that should be modelled depends on the hydrogeologic conditions, the length of monitoring screens, and the local regulations. In this example dilution (mixing) of the contaminant will only be considered in the upper 3m of the aquifer, and hence the aquifer thickness used is h = 3 m.

Since the aquifer (i.e., the contaminant receptor) is being modelled as a boundary condition the actual deposit thickness that is explicitly modelled is the 4 m thick aquitard, and the concentration given in the output at the 4 m depth is the concentration in the upper 3 m of the aquifer. It is assumed that this is uniformly distributed in the 3 m and that no contaminant moved lower than 3 m into the aquifer (if the aquifer thickness, h, were to be increased, the concentration in the aquifer would drop).

In the underlying aquifer the inflow of water beneath the up gradient edge of the landfill is given by a Darcy velocity of 20 m/a.

The "base velocity" is the outflow velocity beneath the down-gradient edge of the landfill and corresponds to the inflow velocity (20 m/a) at the up gradient edge plus the inflow from the landfill.

Based on continuity of flow the initial flow in the aquifer, q_{in}, is given by the inflow velocity (v_{in} = 20 m/a in this example) multiplied by the thickness of the aquifer being considered (h = 3 m in this example) and the width of the landfill (the landfill dimension perpendicular to the direction of groundwater flow, W = 300 m in this example), thus:

$$q_{in} = v_{in} * h * W = 20 * 3 * 300 = 18000 \text{ m}^2/\text{a}$$

The flow into the aquifer from the landfill, q_a, is the downward Darcy velocity (v_a = 0.1 m/a in this case) multiplied by the length (L = 200 m) and width (W = 300 m) of the landfill, thus:

$$q_a = v_a * L * W = 0.1 * 200 * 300 = 6000 \text{ m}^3/\text{a}$$

Hence the outflow at the down-gradient edge of the landfill is:

$$q_{out} = q_{in} + q_a = 18000 + 6000 = 24000 \text{ m}^3/\text{a}$$

And the "Base Outflow Velocity", v_b, is the outflow divided by the width of the landfill (W = 300 m) and the thickness of the aquifer being considered (h = 3 m), therefore:

$$v_b = q_{out} / (W * h) = 24000 / (3 * 300) = 26.67 \text{ m/a}$$

The following parameter are assumed for the example:

Property		**Value**	**Units**
Darcy Velocity	v_a	0.1	m/a
Diffusion Coefficient	D	0.01	m^2/a
Distribution CoefficientK_d		0.0	cm^3/g
Soil Porosity	n	0.4	-
Dry Density		1.5	g/cm^3
Soil Layer Thickness	H	4.0	m
Number of Sub-layers		4	-
Source Concentration	c_o	1.0	g/L
Landfill Length	L	200.0	m
Landfill Width	W	300.0	m
Thickness of Aquifer	h	3.0	m
Porosity of Aquifer	n_b	0.3	-
Base Outflow Velocity	v_b	26.67	m/a
Times of Interest	t	10, 50, 100	a
		150, 200	a

The landfill length (L) is measured in the direction parallel to groundwater flow. And the landfill width (W) is the direction perpendicular to groundwater flow, since this is not a 3D analysis this parameter has no effect on the results.

Warning: The evaluation of the base flow velocity, v_b, requires consideration of the local hydrogeology and the potential effect of the proposed landfill on flow conditions. For some situations, the aquitard has sufficiently low hydraulic conductivity and the aquifer has sufficiently high transmissivity that simple hand continuity calculations as indicated above are appropriate. In other cases some more sophisticated flow models may be required. The parameters used in any modelling should be selected by a hydrogeologist/engineer with sufficient knowledge and experience to understand the existing flow system and the flow system that is likely to exist after the landfill construction.

Note: The concentration at 4 m is the concentration at the bottom of the aquitard and in the 3 m thick aquifer part of the aquifer beneath the landfill. This example was selected to have a downward flow (v_a = 0.1 m/a) so large that advection controls and in fact for the constant source boundary condition it is possible to calculate the peak impact in the aquifer from a simple hand calculation, viz.

$$c_{max} = q_a * c_o / q_{out} = 6000 * 1 / 24000 = 0.25 \text{ g/L}$$

[As an exercise the user may wish to repeat the calculation for v_a = 0.005 m/a, v_b = 20.34 m/a. Based on the simple hand calculation above, this would give c_{max} = 0.0164 g/L = 16.4 mg/L.]

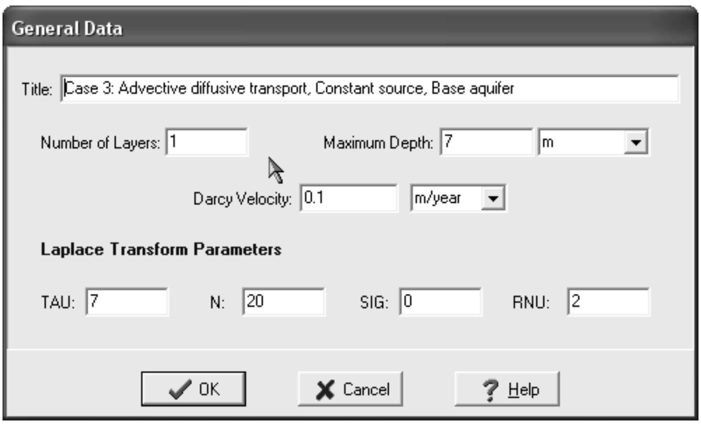
Data Entry

l

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 3 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

To edit the Darcy velocity either click on the title or select the General Data menu item from the Data Entry menu. On the General Data form below the Darcy velocity of 0.1 m/a can be specified.

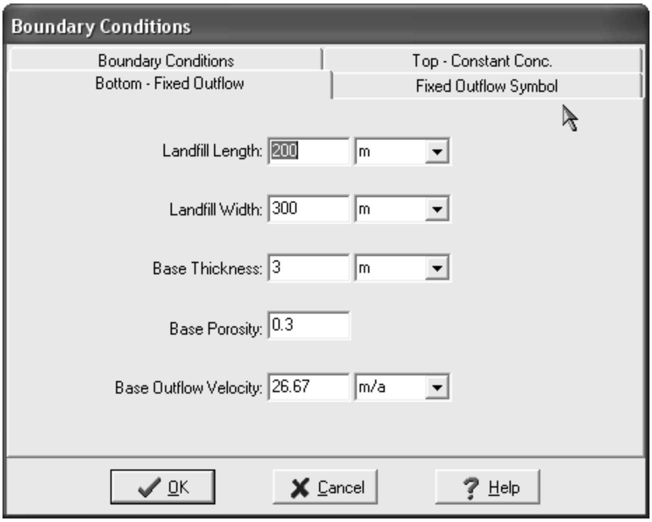


Layer Data

The layer data for this model is the same as that in Case 2.

Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a constant concentration of 1 and the bottom boundary is represented as an aquifer with a fixed outflow velocity as shown on the Boundary Condition form below.



Run Parameters

The run parameters for this model is the same as that in Case 2.

Model Execution

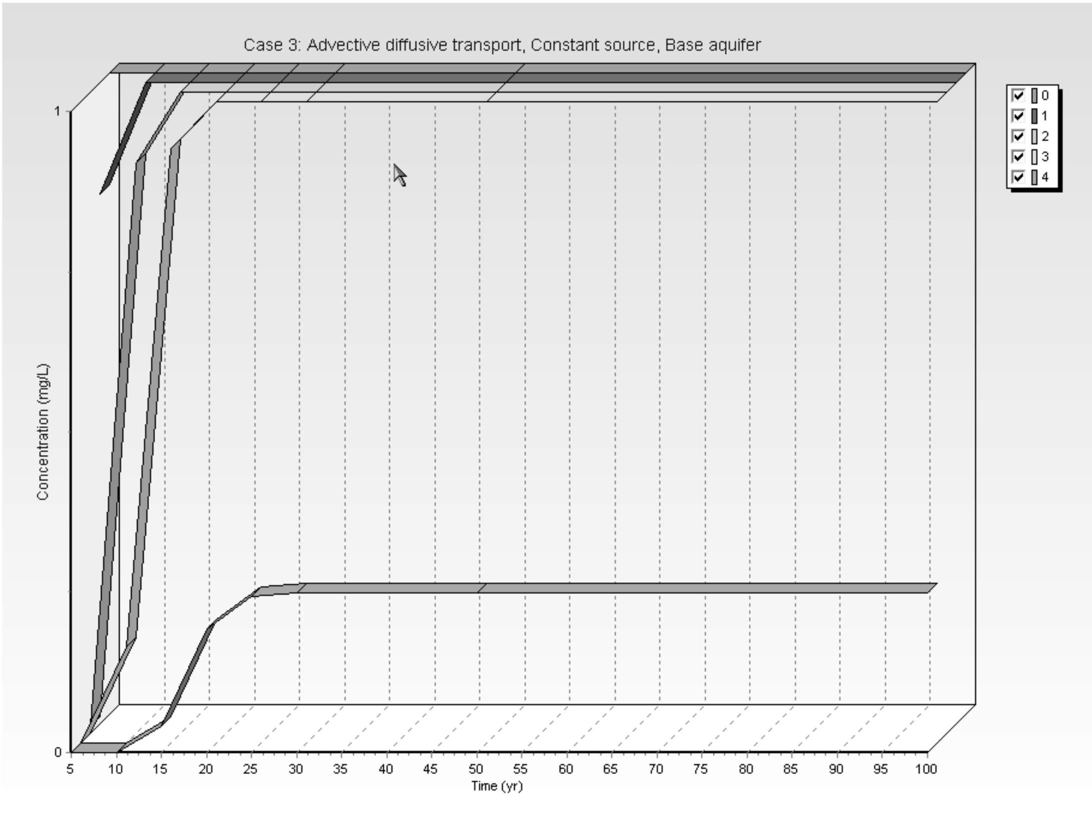
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Time

The Concentration vs. Time chart below can be displayed by pressing the Concentration vs Time button on the Output toolbar or selecting the Concentration vs Time menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 3: Advective diffusive transport, Constant source, Base aquifer

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0.1 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Aquitard	4 m	4	0.01 cm3/g	0.4	0 m2/a	1.5 g/cm3

Boundary Conditions

Contant Concentration
Source Concentration = 1 mg/L

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 300 m
Base Thickness = 3 m
Base Porosity = 0.3
Base Outflow Velocity = 26.67 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth m	Concentration mg/L
5	0.000E+00	1.000E+00
	1.000E+00	8.257E-01

	2.000E+00 3.000E+00 4.000E+00	1.116E-02 2.255E-08 6.655E-11
10	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 9.998E-01 8.892E-01 1.490E-01 2.805E-05
15	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 1.000E+00 9.995E-01 9.271E-01 4.101E-02
20	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 1.000E+00 1.000E+00 9.994E-01 1.930E-01
25	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 1.000E+00 1.000E+00 1.000E+00 2.426E-01
30	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 1.000E+00 1.000E+00 1.000E+00 2.491E-01
50	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 1.000E+00 1.000E+00 1.000E+00 2.500E-01
100	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.000E+00 1.000E+00 1.000E+00 1.000E+00 2.500E-01

Case 4: Finite Mass Source

Description

In this example the input data file from Case 3 will be edited to include a source with a finite mass of waste and a leachate collection system. The hydrogeology is comprised of a 4 m thick layer with a finite mass source at the top, and an underlying aquifer at the base with fixed outflow as discussed in Case 3. All of the parameters are the same as in Case 3, except the vertical Darcy velocity will be 0.03 m/a, the horizontal inflow velocity will be 4 m/a and there will be a finite mass top boundary condition. The finite mass top boundary condition requires the input of the Reference Height of Leachate (H_r), Rate of Increase in Concentration (C_r), and the Volume of Leachate Collected (Q_c).

It is assumed in this example that the waste has an average thickness of 6.25 m and a density of 600 kg/m^3, and that chloride represents 0.2% of the total mass of the waste. Thus, the total mass of chloride per unit area of the landfill (m_{tc}) is calculated by multiplying the proportion of chloride by the density of the waste and the thickness of the waste.

$$\text{i.e.} \quad m_{tc} = 0.002 * 600 * 6.25 \text{ kg/m}^2$$

A peak concentration (c_o) for chloride of 1000 mg/L (i..e., 1 kg/m^3) is assumed. The Reference Height of Leachate is then:

$$H_r = m_{tc} / c_o = 0.002 * 600 * 6.25 / 1 = 7.5 \text{ m}$$

If the peak concentration is reached relatively early in the life of the landfill and the analysis starts at this time, then there will be no increase in concentration with time. The Rate of Increase in Concentration (C_r) would then be zero.

The Volume of Leachate (Q_c) collected is equal to the difference between the infiltration through the cover (q_o = 0.3 m/a here) and the exfiltration through the base (v_a = 0.03 m/a here), and is given by:

$$Q_r = q_o - v_a = 0.3 - 0.3 = 0.27 \text{ m/a}$$

In this example the inflow in the aquifer at the up gradient edge of the landfill will be 4 m/a and the outflow at the down gradient edge (v_b) is then:

$$v_b = (v_b(in)*h*W + v_a*L*W)/(h*W) = v_a(in) + v_a*L/h = 4 + 0.03*200/3 = 6 \text{ m/a}$$

The following parameters are assumed for the example:

Property		**Value**	**Units**
Darcy Velocity	v_a	0.03	m/a
Diffusion Coefficient	D	0.01	m^2/a
Distribution Coefficient	K_d	0.0	cm^3/g
Soil Porosity	n	0.4	-
Dry Density		1.5	g/cm^3
Soil Layer Thickness	H	4.0	m
Number of Sub-layers		4	-
Source Concentration	c_o	1000.0	mg/L
Rate of Increase in c_o	c_r	0.0	mg/L/a
Ref. Height of Leachate	H_r	7.5	m
Volume Collected	Q_c	0.27	m/a
Landfill Length	L	200.0	m
Landfill Width	W	300.0	m
Thickness of Aquifer	h	3.0	m
Porosity of Aquifer	n_b	0.3	-
Base Outflow Velocity	v_b	6.0	m/a
Upper and Lower Time Limits		25, 400	a

The landfill length is measured in the direction parallel to groundwater flow. And the landfill width is the direction perpendicular to groundwater flow, since this is not a 3D analysis this parameter has no effect on the results.

Data Entry

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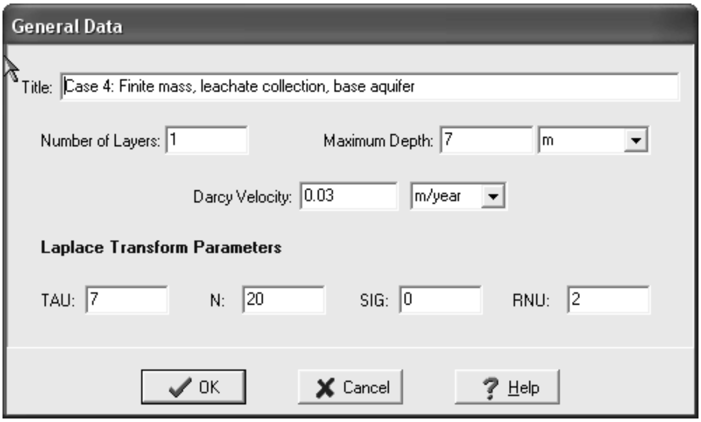
*S*tart the POLLUTEv7 program and open the Examples project. Select Case 4 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

The general data for this example is the same as in Case 3, except for the Darcy velocity. To edit the Darcy velocity either click on the title or select the General Data menu item from the Data Entry menu. On the General Data form below the Darcy velocity of 0.03 m/a can be specified.

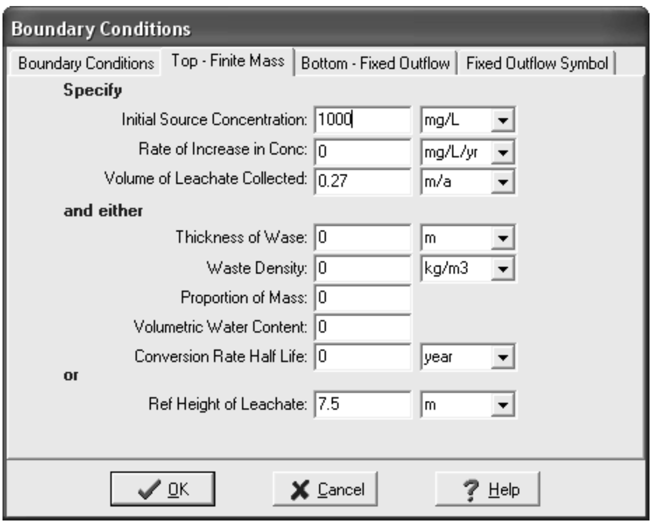


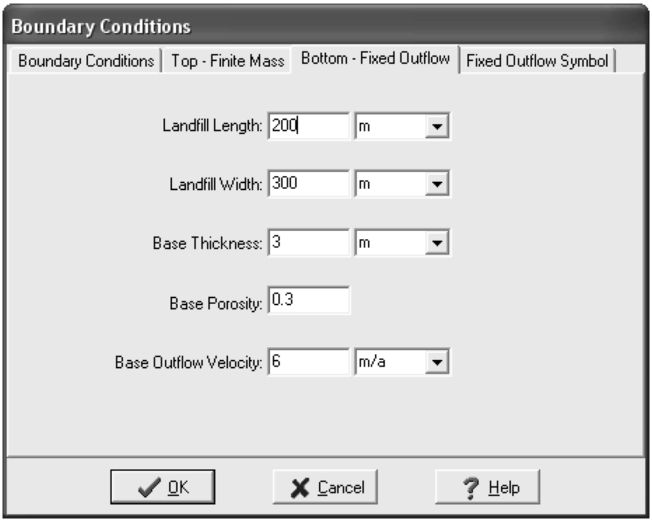
Layer Data

The layer data for this model is the same as that in Case 3.

Boundary Conditions

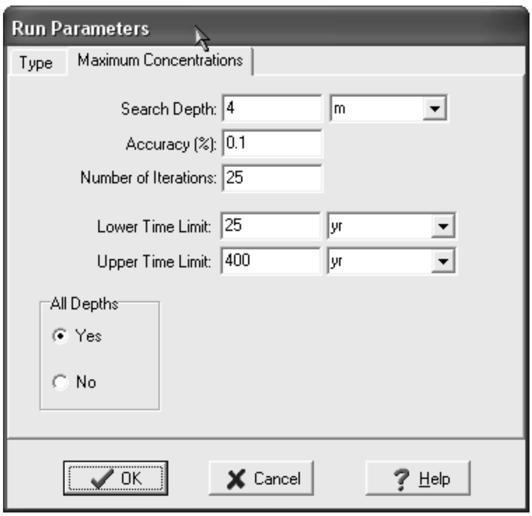
The boundary conditions for the model are the can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented as an aquifer with a fixed outflow velocity as shown on the Boundary Condition forms below.





Run Parameters

The run parameters for this model can be specified by selecting the Run menu item from the Execute menu or pressing the Run button on the toolbar. In this example the automatic search for the peak base concentration option is going to be used. The search depth will be 4 m (the bottom of the layer) and the lower and upper time limits will be 25 and 400 years.



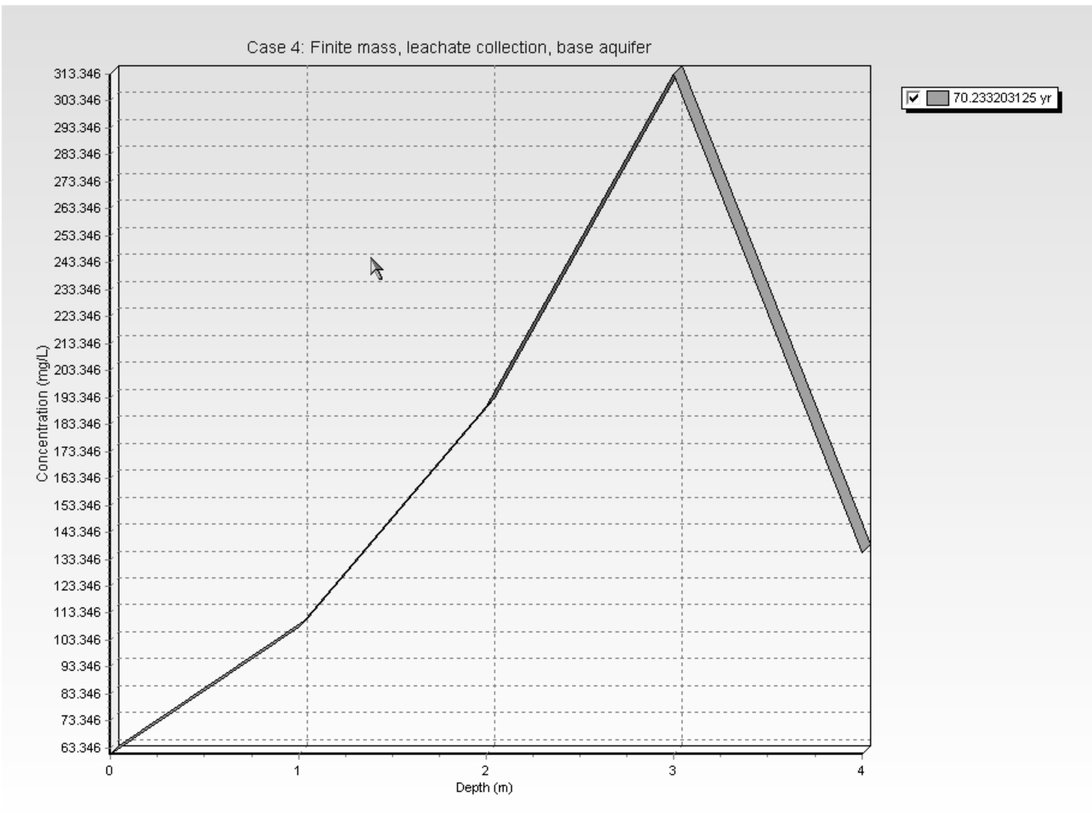
Provided the initial estimate for these time limits are reasonable the program will find the maximum even if it lies outside these limits. The default values for the Accuracy and Maximum number of Search Attempts should prove sufficient for this *example and most other problems.*

Model Execution

To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.



Concentration vs Depth

The Concentration vs. Depth chart on the previous page can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.

Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar. ***The maximum concentration in the aquifer in this example is 136 mg/L. This peak occurs at 70 years.***

Case 4: Finite mass, leachate collection, base aquifer

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0.03 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Aquitard	4 m	4	0.01 cm3/g	0.4	0 m2/a	1.5 g/cm3

Boundary Conditions

Finite Mass Top Boundary
Initial Concentration = 1000 mg/L
Rate of Increase = 0 mg/L/yr
Volume of Leachate Collected = 0.27 m/a
Thickness of Waste = 0 m
Waste Density = 0 kg/m3
Proportion of Mass = 0
Volumetric Water Content = 0
Conversion Rate Half Life = 0 year
Reference Height of Leachate = 7.5 m

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 300 m
Base Thickness = 3 m
Base Porosity = 0.3
Base Outflow Velocity = 6 m/a

Laplace Transform Parameters

Maximum Base Concentration Parameters

Depth to Search = 4 m
Lower Time Limit = 25 yr
Upper Time Limit = 400 yr
Base Concentration Accuracy = 0.1
Maximum Search Attempts = 25

Maximum Base Concentration and Time of Occurrence

Time yr	Depth m	Concentration mg/L	Preceeding Time	Preceeding Concentration	Exceeding Time	Exceeding Concentration
7.0233E+01	0.0000E+00	6.1040E+01				
	1.0000E+00	1.0820E+02				
	2.0000E+00	1.8998E+02				
	3.0000E+00	3.1335E+02				
	4.0000E+00	1.3589E+02	6.8517E+01	1.3550E+02	7.1949E+01	1.3548E+02

Number of Search Attempts = 5

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this computer program. The user accepts full responsibility for assessing the validity and applicability of the results obtained with this program for any specific case.

Case 5: Hydraulic Trap - Finite Mass Source

Description

This illustrates the use of the program for the case where there is a hydraulic trap (i.e., flow is into the landfill). The parameters are essentially the same as in Case 4, (where there was a finite mass source with a leachate collection system and a fixed outflow base) except that the Darcy velocity has been changed and the base aquifer is now assumed to be only 1 m thick with a porosity of 0.35 and is underlain by a low permeability layer. We also now choose to ignore the width of the landfill and take W = 1 m. This is the same as modelling a 1 m strip through the landfill. This width, W, has no effect on the results.

The calculation and values for the Reference Height of Leachate is the same as in Case 4. Again it is assumed that the average infiltration through the cover, (q_o) is 0.3 m/a. For this example the Darcy velocity (v_a) into the base of the landfill is assumed to be -0.001 m/a. The negative value for the Darcy velocity implies that the flow is upward. Neglecting the small volume of groundwater collected the average Volume of Leachate Collected (Q_c) is:

$$Q_c = q_o = 0.3 \text{ m/a}$$

In this example the inflow in the aquifer at the up gradient edge of the landfill will be 4 m/a and the outflow at the down gradient edge (v_b) is then:

$$v_b = v_b(\text{in}) + v_a{*}L/h = 4 - 200{*}0.001 = 3.8 \text{ m/a}$$

The following parameters are assumed for the example:

Property		**Value**	**Units**
Darcy Velocity	v_a	-0.001	m/a
Diffusion Coefficient	D	0.01	m^2/a
Distribution CoefficientK		0.0	cm^3/g
Soil Porosity	n	0.4	-
Dry Density		1.5	g/cm^3
Soil Layer Thickness	H	4.0	m
Number of Sub-layers		4	-
Source Concentration	c_o	1000.0	mg/L
Rate of Increase in c_o	c_r	0.0	mg/L/a
Ref. Height of Leachate	H_r	7.5	m
Volume Collected	Q_c	0.3	m/a
Landfill Length	L	200.0	m

Landfill Width	W	1.0	m
Thickness of Aquifer	h	1.0	m
Porosity of Aquifer	n_b	0.35	-

Data Entry

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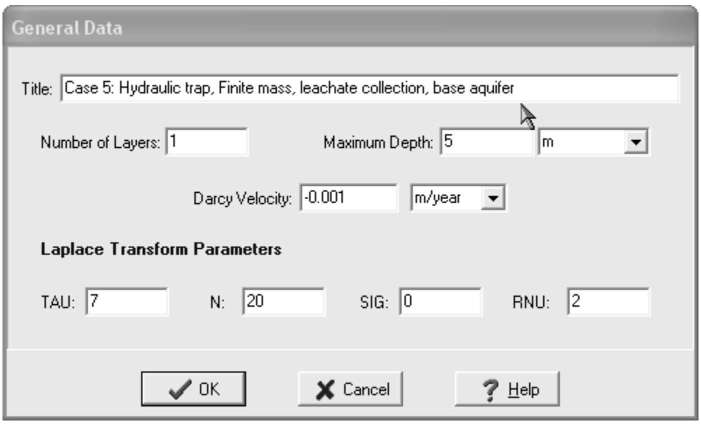
*S*tart the POLLUTEv7 program and open the Examples project. Select Case 5 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

The general data for this example is the same as in Case 4, except for the Darcy velocity. To edit the Darcy velocity either click on the title or select the General Data menu item from the Data Entry menu. On the General Data form below the Darcy velocity of -0.001 m/a can be specified.

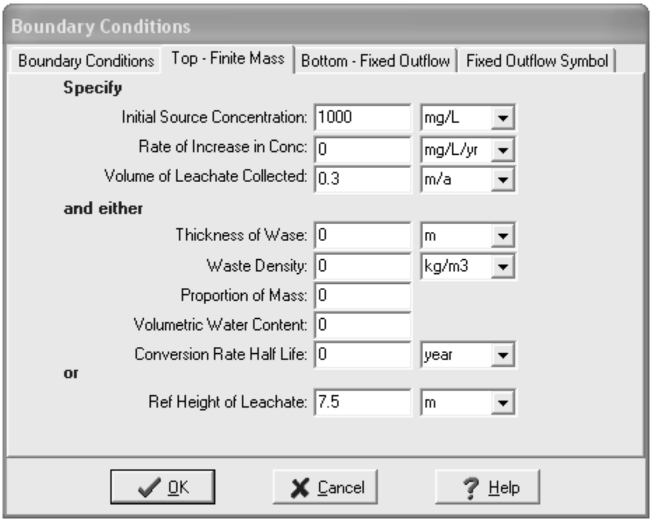


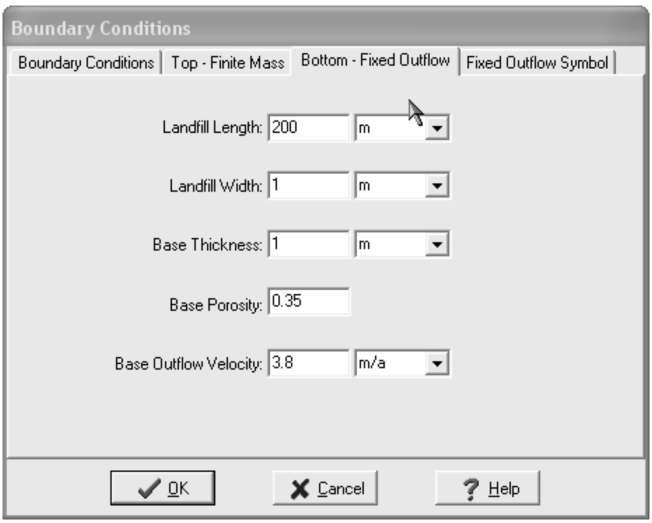
Layer Data

The layer data for this model is the same as that in Case 4.

Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented as an aquifer with a fixed outflow velocity as shown on the Boundary Condition forms below.





Run Parameters

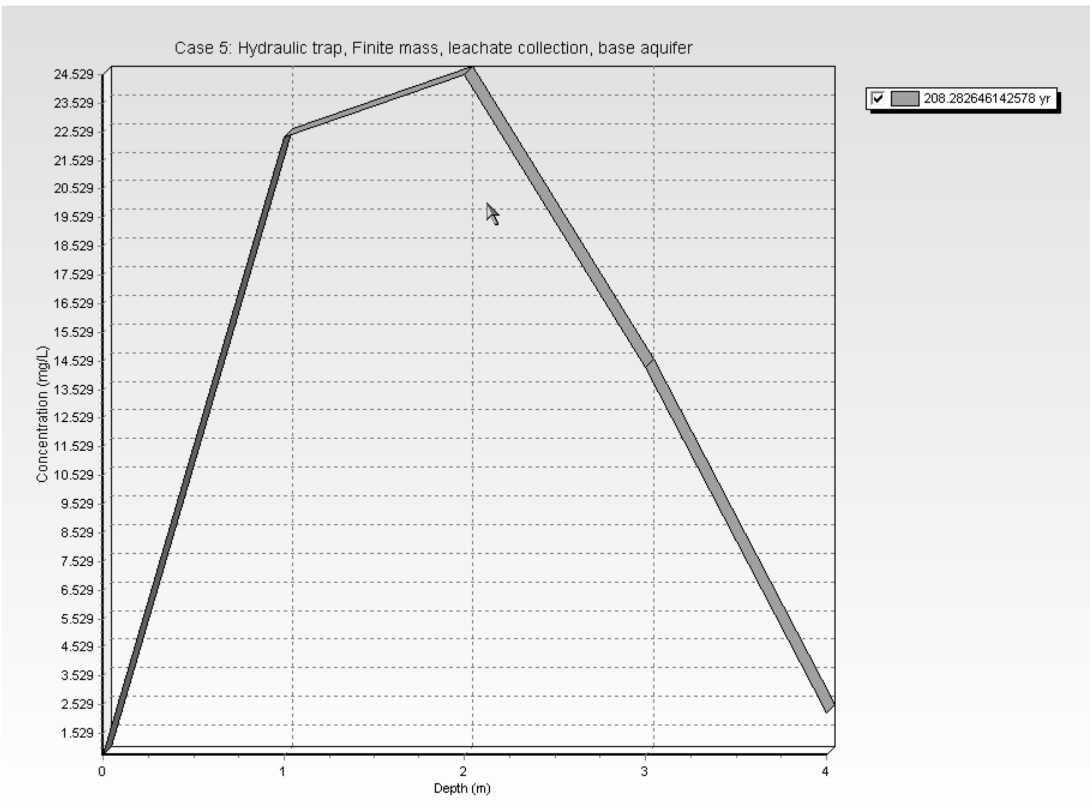
The run parameters for this model are the same as in Case 4.

Model Execution

To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.



Concentration vs Depth

The Concentration vs. Depth chart on the previous can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.

Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar. **The peak at 2008 years was found, even though the upper time limit specified by the user was 400 years.**

Case 5: Hydraulic trap, Finite mass, leachate collection, base aquifer

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = -0.001 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Aquitard	4 m	4	0.01 cm3/g	0.4	0 m2/a	1.5 g/cm3

Finite Mass Top Boundary
Initial Concentration = 1000 mg/L
Rate of Increase = 0 mg/L/yr
Volume of Leachate Collected = 0.3 m/a
Thickness of Waste = 0 m
Waste Density = 0 kg/m3
Proportion of Mass = 0
Volumetric Water Content = 0
Conversion Rate Half Life = 0 year
Reference Height of Leachate = 7.5 m

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.35
Base Outflow Velocity = 3.8 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Maximum Base Concentration Parameters

Depth to Search = 4 m
Lower Time Limit = 25 year
Upper Time Limit = 400 year
Base Concentration Accuracy = 0.01
Maximum Search Attempts = 25

Maximum Base Concentration and Time of Occurrence

Time yr	Depth m	Concentration mg/L	Preceeding Time	Preceeding Concentration	Exceeding Time	Exceeding Concentration
2.0828E+02	0.0000E+00	7.7427E-01				
	1.0000E+00	2.2363E+01				
	2.0000E+00	2.4529E+01				
	3.0000E+00	1.4300E+01				
	4.0000E+00	2.2199E+00	2.0800E+02	2.2199E+00	2.0857E+02	2.2198E+00

Number of Search Attempts = 8

NOTICE

The peak concentration in the aquifer at the down gradient edge of the landfill is only about 2 mg/L, compared to the initial source concentration of 1000 mg/L. This peak is reached after 208 years. Thus with a working hydraulic trap some contaminant reaches the base aquifer despite the inward gradient, however for this diffusion coefficient and combination of parameters the impact is negligible.

Case 6: Fractured Layer and Sorption

Description

This example illustrates the use of the program for the case where one of the layers are fractured and there is and sorption of the contaminant species. The “barrier” consists of a 1 m thick compacted clay layer overlying a 3 m thick fractured till. A reactive species (i.e., one that will sorb on to the clay) is modelled in this case. The same finite mass source and leachate collection system is used as in the previous examples.

A Darcy velocity (v_a) of 0.02 m/a through the deposit and an infiltration through the cover (q_o) of 0.3 m/a are assumed. The Volume of Leachate Collected (Q_c) is then given by:

$$Q_c = q_o - v_a = 0.3 - 0.02 = 0.28 \text{ m/a}$$

As in the previous examples the inflow in the aquifer at the up gradient edge of the landfill is 4 m/a. The outflow (v_b) at the down gradient edge of the landfill is then:

$$v_b = 4 + 200*0.02 = 8 \text{ m/a}$$

The following parameters are defined for this example:

Property		**Value**	**Units**
Darcy Velocity	v_a	0.02	m/a
Diffusion Coefficient	D	0.01	m^2/a
Distribution Coefficient	K_d	1.5	cm^3/g
Soil Porosity	n	0.4	-
Dry Density		2.0	g/cm^3
Soil Liner Thickness	H_L	1.0	m
Number of Sub-layers		1	-
Fractured Till Thickness	H_T	3.0	m
Number of Sub-layers		1	-
Fracture spacing in x direction	$2H_1$	1.0	m
Fracture opening in x “	$2h_1$	10	μm
Fracture spacing in y direction	$2H_2$	1.0	m
Fracture opening in y “	$2h_2$	10	μm
Dispersion along fractures	D_f	0.06	m^2/a
Fracture Distribution Coefficient	K_f	0.0	cm^3/g

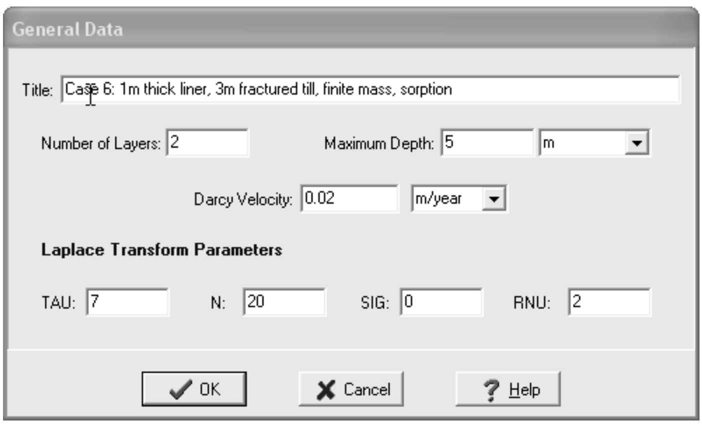
Property		Value	Units
Matrix Diffusion Coefficient	D_m	0.01	m^2/a
Matrix Distribution Coefficient	K_m	1.5	cm^3/g
Matrix Porosity	n_m	0.4	-
Dry Density of Matrix		2.0	g/cm^3
Source Concentration	c_o	1000	mg/L
Rate of Increase in Conc.	c_r	0.0	mg/L/a
Reference Height of Leachate	H_r	7.5	m
Volume of Leachate Collected	Q_c	0.28	m/a
Landfill Length	L	200.0	m
Landfill Width	W	1.0	m
Aquifer Thickness	h	1.0	m
Aquifer Porosity	n_b	0.35	-
Base Outflow Velocity	v_b	8.0	m/a
Lower and Upper Time Limits		20, 300	a

Data Entry

Start the POLLUTEv7 program and open the Examples project. Select Case 6 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

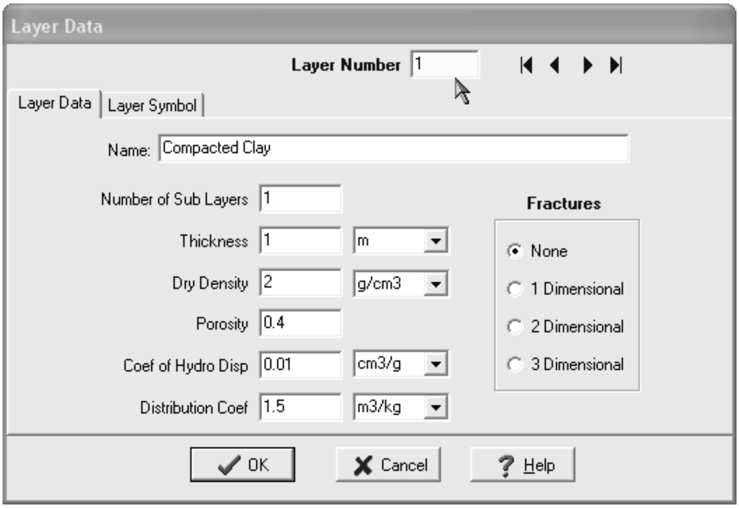
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. On the General Data form the Darcy velocity of 0.02 m/a and the number of layers of 2 can be specified.

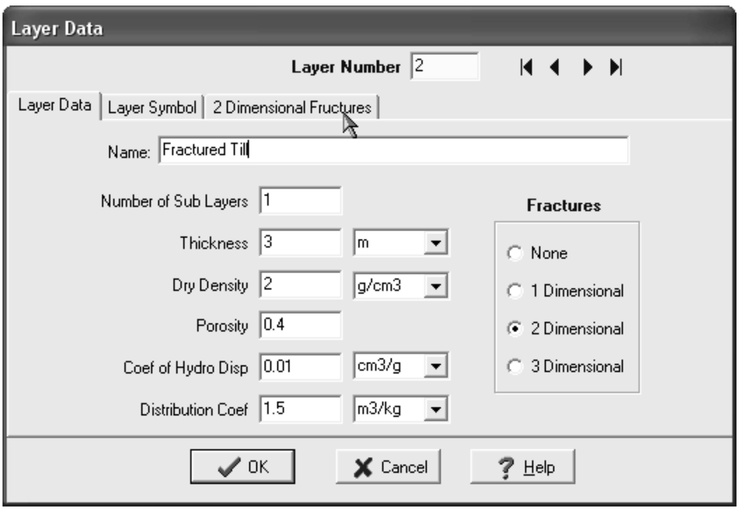


Layer Data

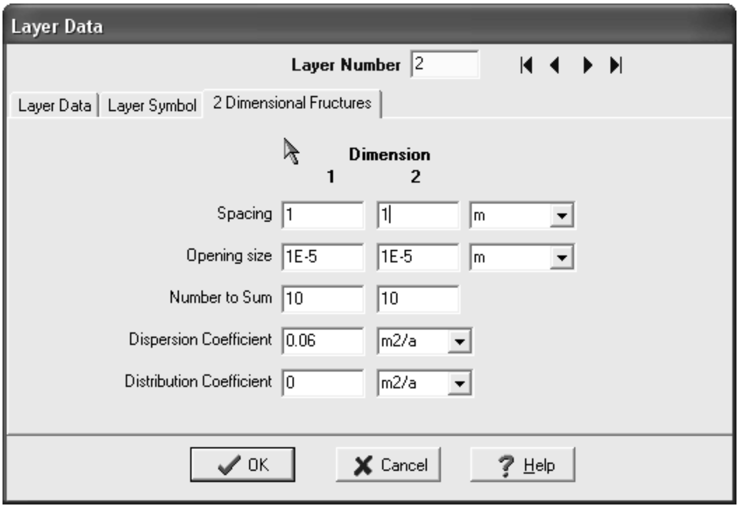
The layer data for the two layers can be specified by either clicking on the layers or selecting the Layer Data menu item from the Data Entry menu. On this form the current layer number can be selected using the arrows at the top of the form. The first layer in this model is a compacted clay with no fractures.



To enter the data for the second layer, click on the Next button at the top of the form. The second layer is a fractured till with 2 dimensional fractures.

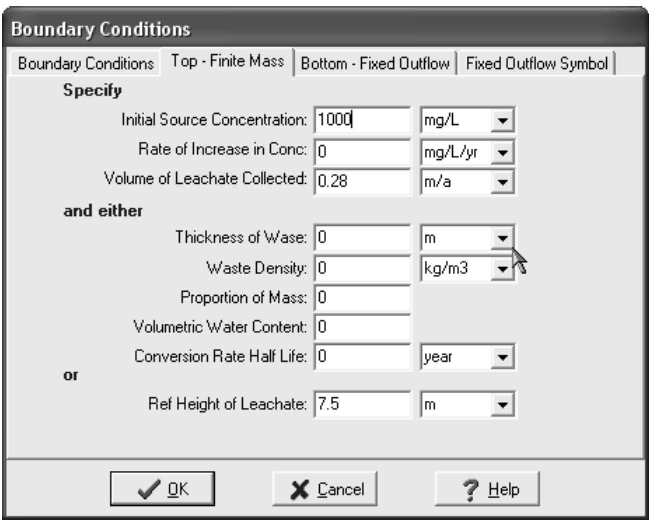


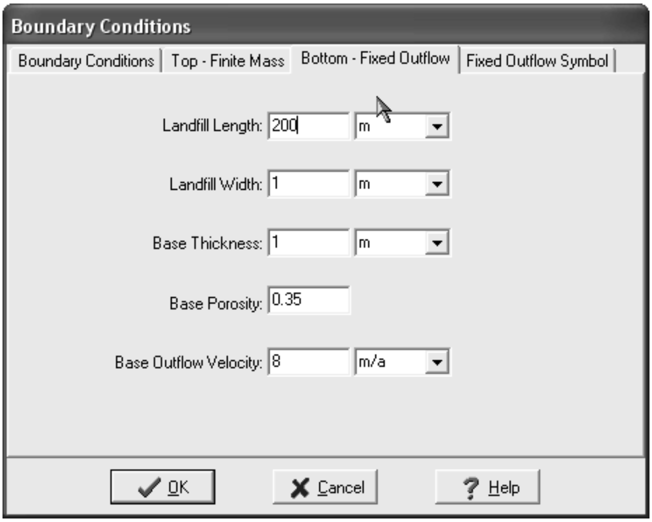
On the Fracture tab, the parameters for the two sets of fractures can be specified. The x and y directions for a 2-dimensional fracture system refer to two sets of vertical fractures which are approximately perpendicular to each other. Fracture opening size is the gap between the walls of the fractures in m for metric units.



Boundary Conditions

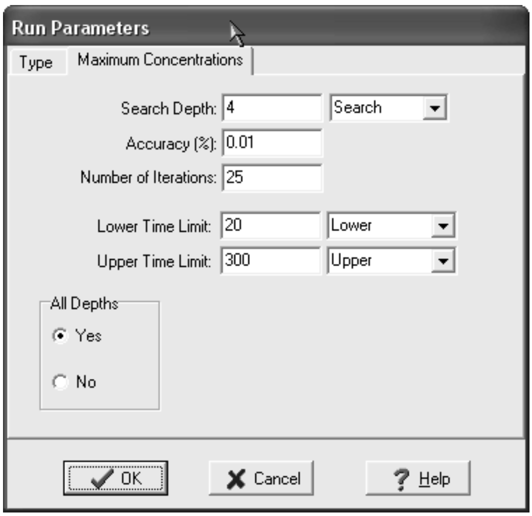
The boundary conditions for the model are the can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented as an aquifer with a fixed outflow velocity as shown on the Boundary Condition forms below.





Run Parameters

The run parameters for this model can be specified by selecting the Run Parameters menu item from the Data Entry menu. On the Run Parameters form below, the parameters for searching for the maximum concentration can be specified.



Model Execution

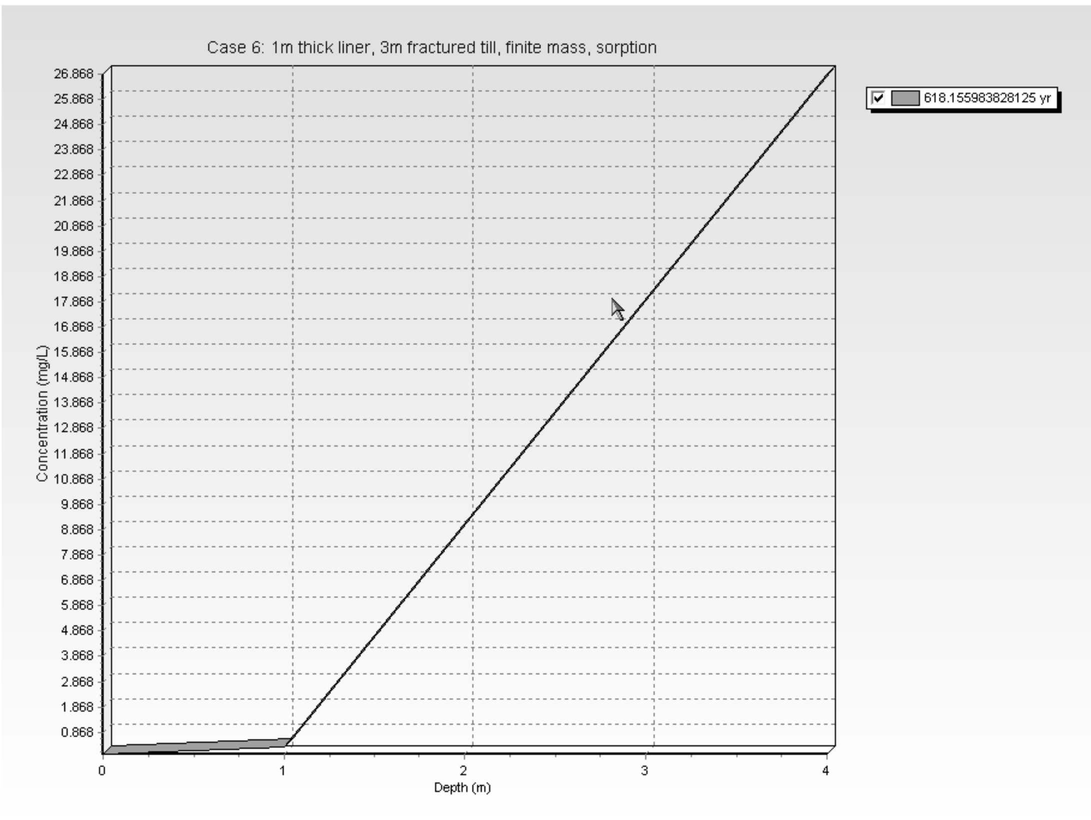
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar. The peak concentration occurred at 618 years, which is outside the lower and upper time limits specified. In this example the program was able to find the peak since the bounds were reasonably close to the peak time of occurrence.

Case 6: 1m thick liner, 3m fractured till, finite mass, sorption

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0.02 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Compacted Clay	1 m	1	0.01 cm3/g	0.4	1.5 m3/kg	2 g/cm3
Fractured Till	3 m	1	0.01 cm3/g	0.4	1.5 m3/kg	2 g/cm3

Layer	Fracture Spacing 1	Opening Size 1	Number 1	Fracture Spacing 2	Opening Size 2	Number 2	Fracture Spacing 3	Opening Size 3	Number 3
Fractured Till	1 m	1E-5 m	10	1 m	1E-5 m	10			

Layer	Dispersion Coefficient in Fractures	Distribution Coefficient in Fractures	Fracture Porosity	Retardation Coefficient in Matrix
Fractured Till	0.06 m2/a	0 m2/a	2.0000E-05	8.5000E+00

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 1000 mg/L
Rate of Increase = 0 mg/L/yr
Volume of Leachate Collected = 0.28 m/a
Thickness of Waste = 0 m
Waste Density = 0 kg/m3
Proportion of Mass = 0
Volumetric Water Content = 0

Conversion Rate Half Life = 0 year
Reference Height of Leachate = 7.5 m

Fixed Outflow Bottom Boundary

Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.35
Base Outflow Velocity = 8 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Maximum Base Concentration Parameters

Depth to Search = 4 Search
Lower Time Limit = 20 Lower
Upper Time Limit = 300 Upper
Base Concentration Accuracy = 0.01
Maximum Search Attempts = 25

Maximum Base Concentration and Time of Occurrence

Time yr	Depth m	Concentration mg/L	Preceeding Time	Preceeding Concentration	Exceeding Time	Exceeding Concentration
6.1816E+02	0.0000E+00	1.7644E-03				
	1.0000E+00	2.9323E-01				
	4.0000E+00	2.6868E+01	6.1770E+02	2.6868E+01	6.1861E+02	2.6869E+01

Number of Search Attempts = 10

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No

Case 7: Fractured Rock and Radioactive Decay

Description

This example illustrates the use of the program for lateral migration of a radioactive contaminant in a fractured porous rock with a single set of parallel fractures. It considers advective-dispersive transport along the fractures and diffusion into the rock matrix. The deposit is assumed to extend a considerable distance from the source (effectively an infinite distance) but we are only interested here in what happens over the first 50 m after 30 years..

It is assumed that the source concentration, c_o, is 1 unit and that the half life of the radioactive species is 100 years. The source is considered to have a sufficiently large supply that there is no significant change in source concentration due to mass movement into the rock. However the source does experience radioactive decay.

This example is also being used to illustrate the **Maximum Sublayer Thickness Special Feature**, for specifying sublayer thicknesses that are greater than 5 units.

The following parameters are defined for this example:

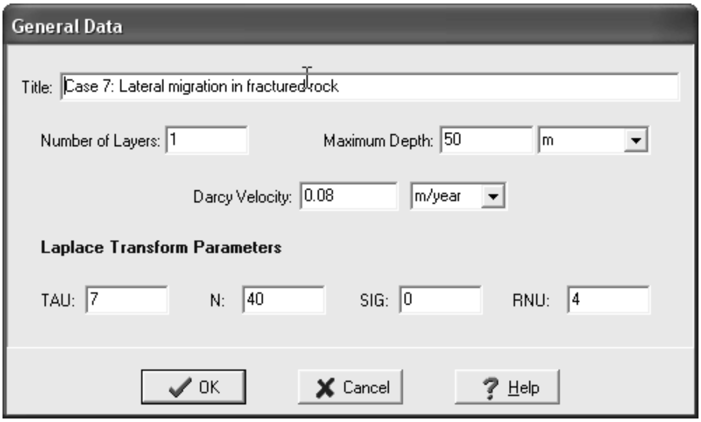
Property		Value	Units
Darcy Velocity	v_a	0.08	m/a
Matrix Diffusion Coefficient	D_m	0.0018	m^2/a
Matrix Distribution Coefficient	K_m	0.0	cm^3/g
Matrix Porosity	n_m	0.05	-
Matrix Dry Density		2.0	g/cm^3
Fractured Rock Thickness	H_T	50	m
Number of Sub-layers		5	-
Fracture spacing	$2H_1$	0.05	m
Fracture opening	$2h_1$	10	µm
Dispersion along fractures	D_f	6.0	m^2/a
Fracture Distribution Coefficient	K_f	0.0	cm^3/g
Source Concentration	c_0	1.0	unit
Half life of contaminant		100	a
Time period of interest		30	a

Data Entry

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 7 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

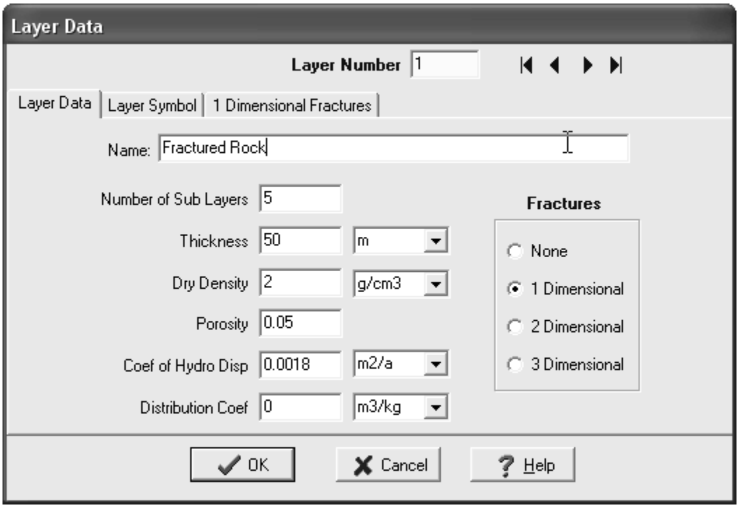
General Data

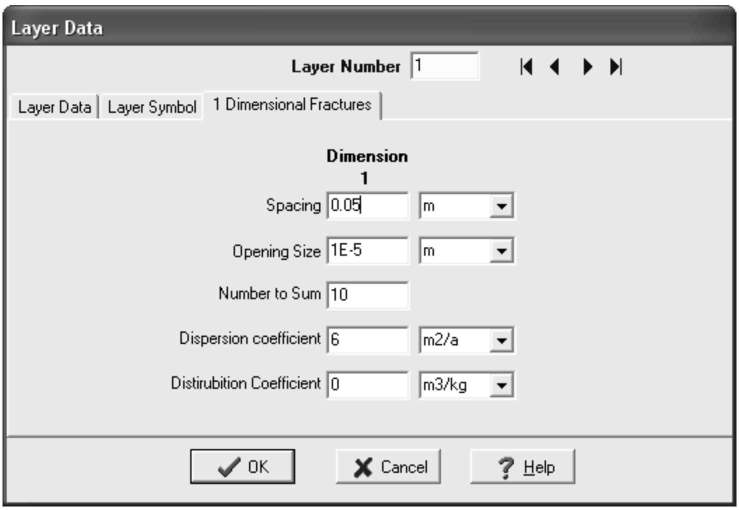
The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. On the General Data form below, the integration parameters for the Laplace Transform have been increased for this example. These parameters will need to be adjusted if the output shows that the default parameters are insufficient.



Layer Data

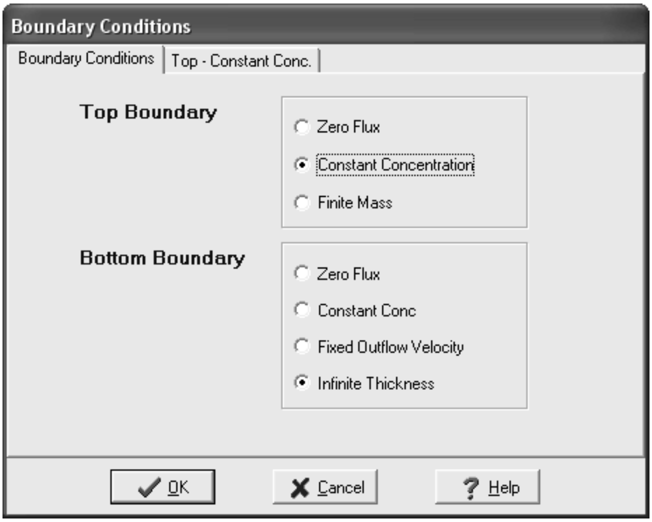
The layer data for the layer can be specified by either clicking on the layer or selecting the Layer Data menu item from the Data Entry menu. On this form the data for the layer and fracture can be added as below.





Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a constant concentration and the bottom boundary is represented as a layer with infinite thickness, as shown on the Boundary Condition forms below. For the Infinite Thickness boundary condition, the properties of the last layer in the Layer Data are assumed to extend infinitely.



Run Parameters

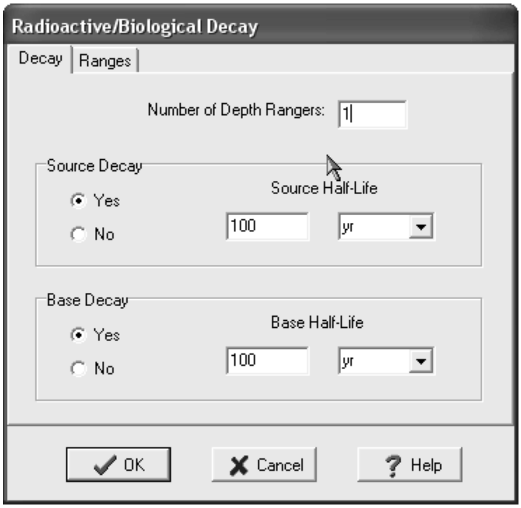
To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. In this example the concentrations will be calculated at a time of 30 years and at 4 depths: 10, 30, 40, and 50 m.

Special Features

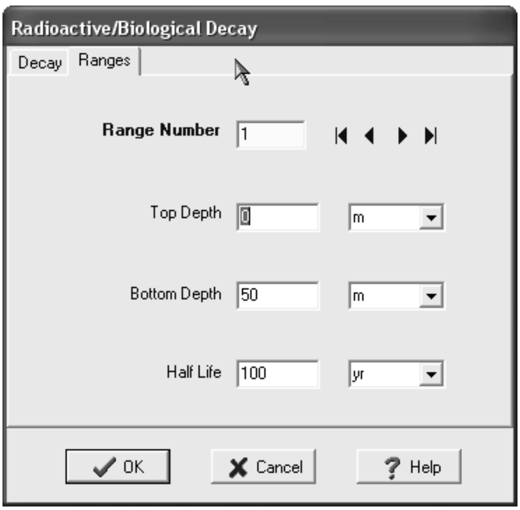
The radioactive decay and maximum sublayer thickness for this example are specified using the Special Features menu.

Radioactive Decay

To specify the radioactive decay, select the Radioactive/Biological Decay menu item from the Special Features form. The Decay tab on the Radioactive/Biological Decay form shown on the next page can be used to specify the source and base decay.



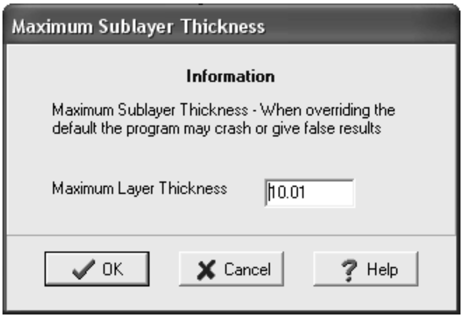
The data for the depth ranges is entered on the Ranges tab, shown below. In this example there is one depth range, corresponding to the entire thickness of the layer, with a half-life of 100 years.



Maximum Sublayer Thickness

The Maximum Sublayer Thickness special feature allows the user to override the default maximum sublayer thickness of 5 units. This maximum is set to avoid problems with exponential overflow which can sometimes occur if the sublayers are too large. When overriding the default you take the risk that the program will crash or give false results - **caveat emptor!.**

To change the maximum sublayer thickness, select the Maximum Sublayer Thickness menu item from the Special Features menu, the Maximum Sublayer Thickness form below will then be displayed. In this example a value of 10.01 is used, each sublayer may be up to 10.01 m thick in this example. The reason for changing this parameter is to allow the calculation of depth at 10 m intervals in the 50 m layer.



Model Execution

To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

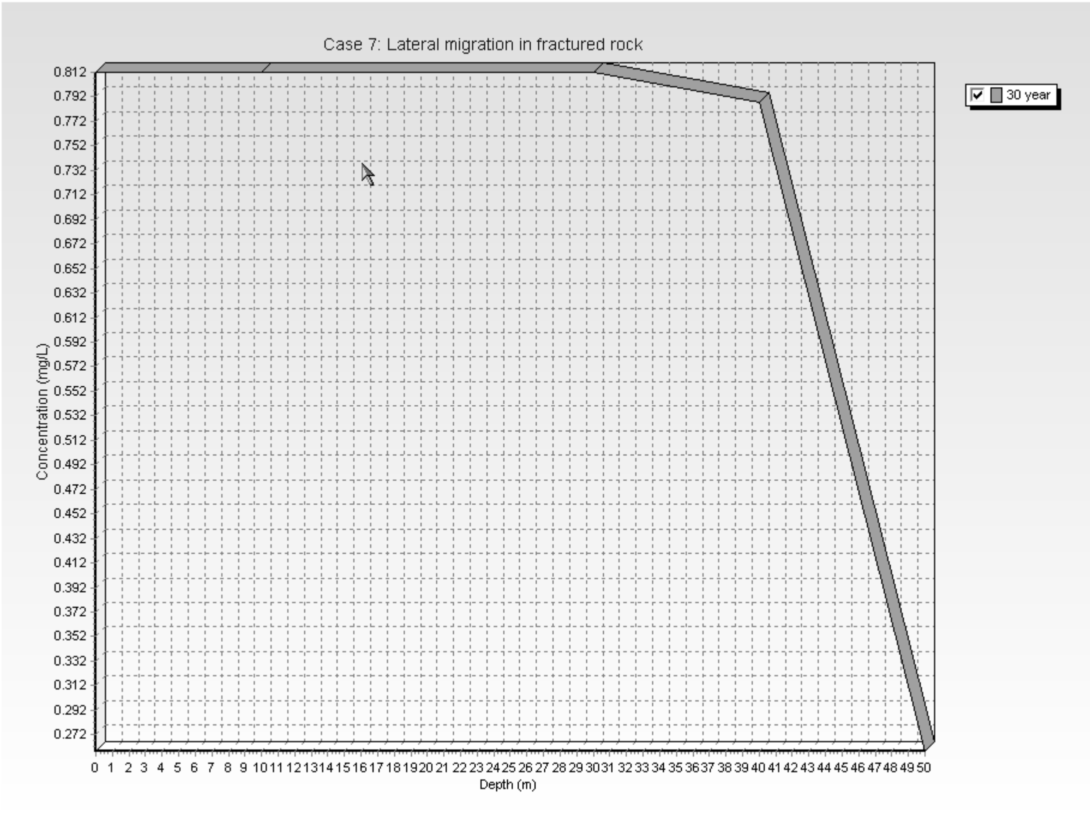
Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart on the next page can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.

Case 7: Fractured Rock and Radioactive Decay



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 7: Lateral migration in fractured rock

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0.08 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Fractured Rock	50 m	5	0.0018 m2/a	0.05	0 m3/kg	2 g/cm3

Layer	Fracture Spacing 1	Opening Size 1	Number 1	Fracture Spacing 2	Opening Size 2	Number 2	Fracture Spacing 3	Opening Size 3	Number 3
Fractured Rock	0.05 m	1E-5 m	10						

Layer	Dispersion Coefficient in Fractures	Distribution Coefficient in Fractures	Fracture Porosity	Retardation Coefficient in Matrix
Fractured Rock	6 m2/a	0 m3/kg	2.0000E-04	1.0000E+00

Boundary Conditions

Contant Concentration
Source Concentration = 1 mg/L

Infinite Thickness Bottom Boundary

RADIOACTIVE OR BIOLOGICAL DECAY

First Order Radioactive or Biological Decay Depth Ranges

Minimum Depth	Maximum Depth	Half Life
0 m	50 m	100 yr

Radioactive or Biological Decay Source Half Life = 100 yr

Radioactive or Biological Decay Base Half Life = 100 yr

Laplace Transform Parameters

TAU = 7 **N** = 40 **SIG** = 0 **RNU** = 4

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
30	0.000E+00	8.123E-01
	1.000E+01	8.123E-01
	3.000E+01	8.123E-01
	4.000E+01	7.881E-01
	5.000E+01	2.588E-01

NOTICE

Case 7: Fractured Rock and Radioactive Decay

Below is the results using the default Laplace Transform parameters. These results are clearly wrong! The other values are correct. We can get the correct value at 50 m by increasing the amount of integration as indicated in the previous output listing.

First Order Radioactive or Biological Decay Depth Ranges

Minimum Depth	Maximum Depth	Half Life
0 m	50 m	100 yr

Radioactive or Biological Decay Source Half Life = 100 yr

Radioactive or Biological Decay Base Half Life = 100 yr

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
30	0.000E+00	8.123E-01
	1.000E+01	8.123E-01
	3.000E+01	8.123E-01
	4.000E+01	7.883E-01
	5.000E+01	-1.384E+02

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this computer program. The user accepts full responsibility for assessing the validity and applicability of the results obtained with this program for any specific case.

Case 8: Diffusion with Initial Concentration Profile

Description

The results of a laboratory diffusion test are analyzed in this example [see Rowe, Caers & Barone, 1988; Barone, Yanful, Quigley & Rowe, 1989]. In this example the diffusion of Potassium in a clay is examined. The clay has an initial background concentration of Potassium of 10 mg/L.

The leachate source has an initial concentration (c_o) of 400 mg/L, and the physical height of the leachate in the reservoir above the soil was 6 cm. At the base of the specimen there was an impermeable barrier (i.e., zero flux).

Following are the parameters used in this example:

Property		Value	Units
Darcy Velocity	v_a	0.0	m/d
Diffusion Coefficient	D	0.648	cm^2/d
Distribution Coefficient	K_d	2.68	cm^3/g
Soil Porosity	n	0.39	-
Dry Density		1.68	g/cm^3
Soil Layer Thickness	H	4.5	cm
Number of Sub-layers		10 -	
Source Concentration	c_o	400.0	mg/L
Ref. Height of Leachate	H_r	6.0	cm
Background Concentration		10.0	mg/L
Times of Interest	t	3, 6, 9	d
		12, 15	d

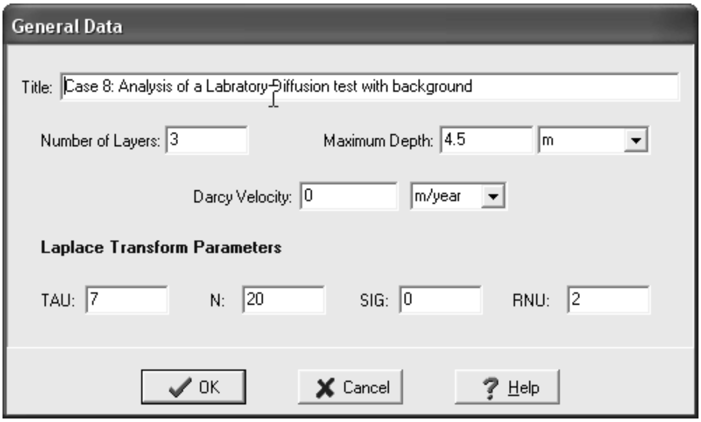
When using an initial concentration profile (eg. background 10 mg/L in this example) the user should have at least three layers, with the top and bottom layer being very thin. In this example layers 1 and 3 are taken to be 0.1 cm thick and layer 2 (the main layer) is taken to be 4.5 - 0.2 = 4.3 cm thick.

Data Entry

Start the POLLUTEv7 program and open the Examples project. Select Case 8 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

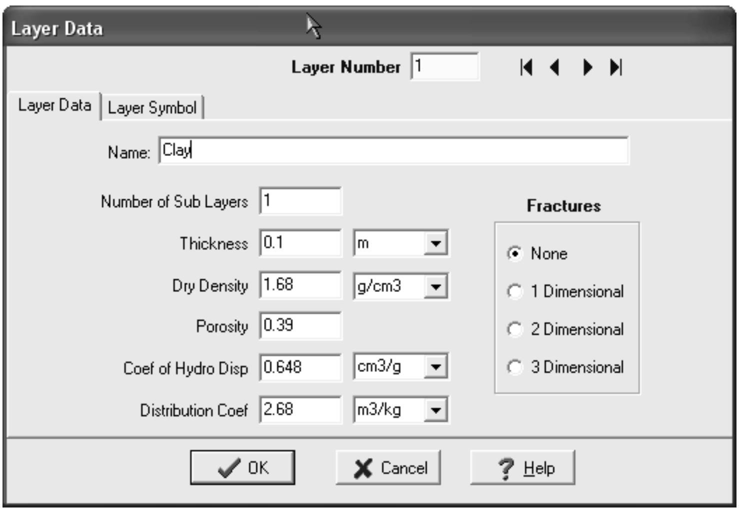
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. On the General Data form below, the Darcy velocity is set to zero for pure diffusion.

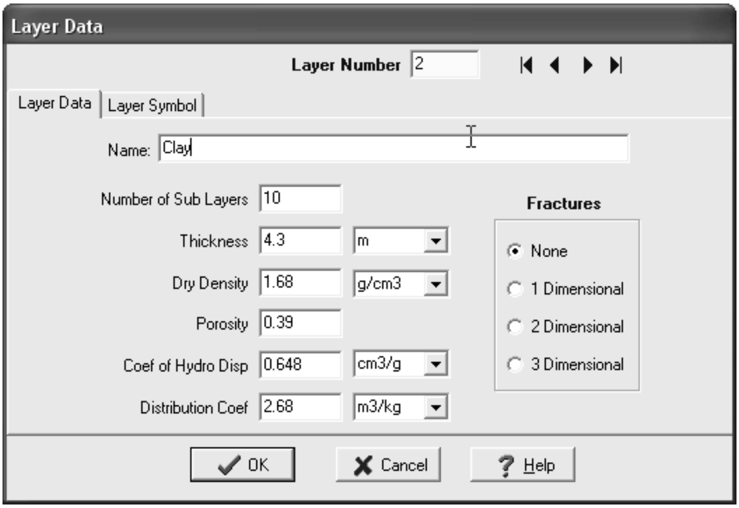


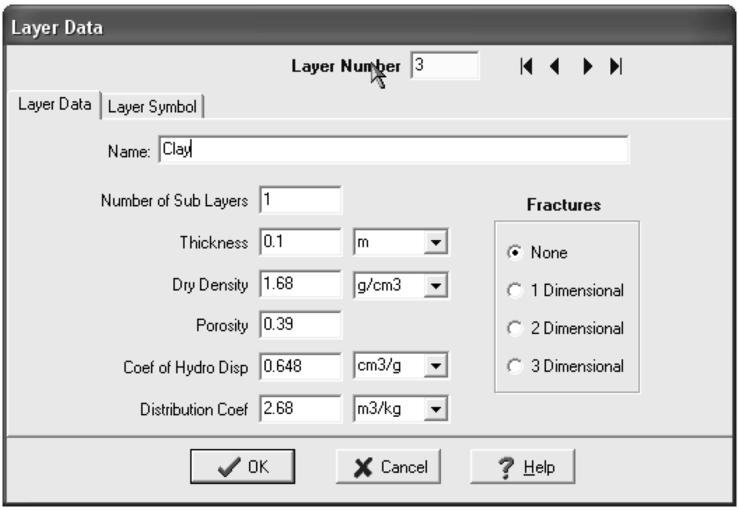
Layer Data

The layer data for the layers can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu. On this form the data for the layers can be added as shown below.



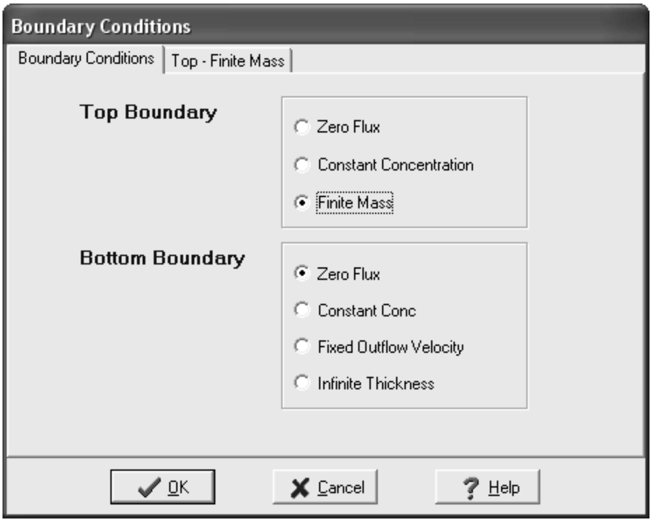
There are no fractures in these layers. For pure diffusion even if there were fractures it should be modelled as if the soil was unfractured, since there would be no flow in the fractures for pure diffusion.

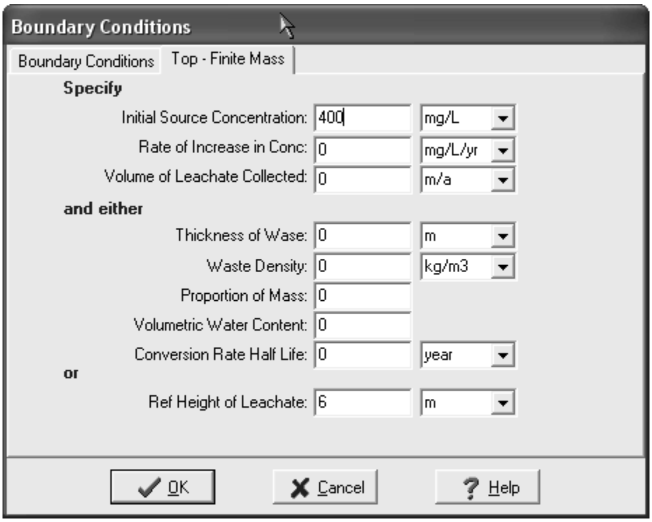




Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented as a zero flux layer, as shown on the Boundary Condition forms on the next page.





Run Parameters

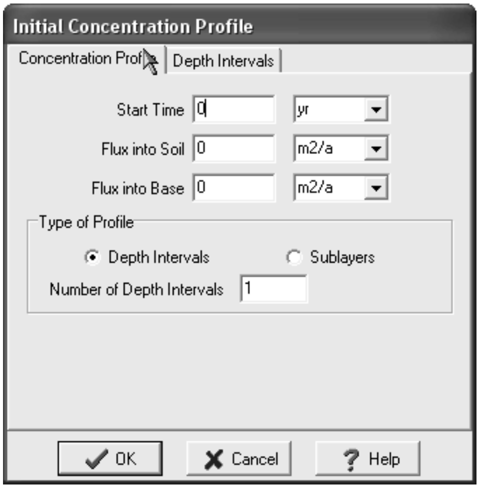
To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. In this example the concentrations will be calculated at 5 times: 3, 6, 9, 12, and 15 years.

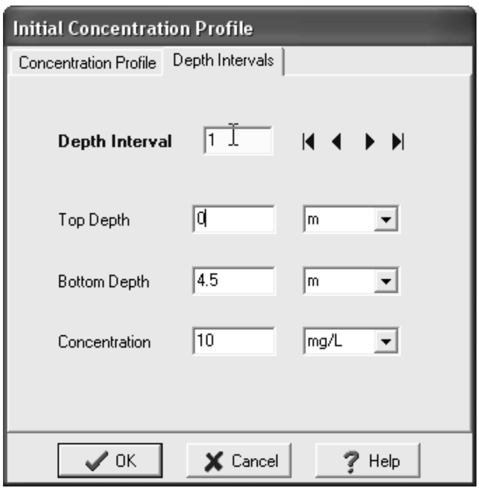
Special Features

The initial concentration profile for this example is specified using the Special Features menu.

Initial Concentration Profile

To specify the initial concentration profile, select the Initial Concentration Profile menu item from the Special Features form. The Concentration Profile tab on the form shown below can be used to specify the type of profile as either Depth Intervals or Sublayers.





Model Execution

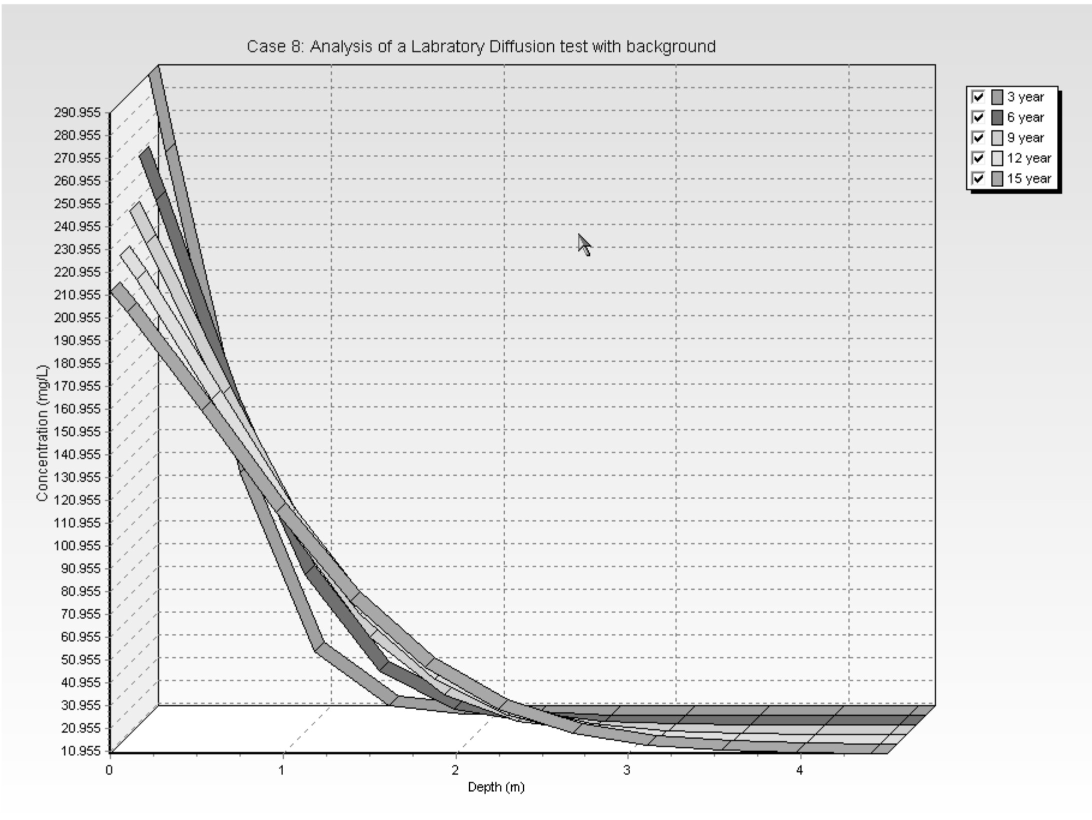
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 8: Analysis of a Labratory Diffusion test with background

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	0.1 m	1	0.648 cm3/g	0.39	2.68 m3/kg	1.68 g/cm3
Clay	4.3 m	10	0.648 cm3/g	0.39	2.68 m3/kg	1.68 g/cm3

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	0.1 m	1	0.648 cm3/g	0.39	2.68 m3/kg	1.68 g/cm3
Clay	4.3 m	10	0.648 cm3/g	0.39	2.68 m3/kg	1.68 g/cm3
Clay	0.1 m	1	0.648 cm3/g	0.39	2.68 m3/kg	1.68 g/cm3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 400 mg/L
Rate of Increase = 0 mg/L/yr
Volume of Leachate Collected = 0 m/a
Thickness of Waste = 0 m
Waste Density = 0 kg/m3
Proportion of Mass = 0
Volumetric Water Content = 0
Conversion Rate Half Life = 0 year
Reference Height of Leachate = 6 m

Flux into Base = 0 m2/a

Case 8: Diffusion with Initial Concentration Profile

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
3	0.000E+00	2.910E+02
	1.000E-01	2.569E+02
	5.300E-01	1.164E+02
	9.600E-01	3.779E+01
	1.390E+00	1.426E+01
	1.820E+00	1.038E+01
	2.250E+00	1.002E+01
	2.680E+00	1.000E+01
	3.110E+00	1.000E+01
	3.540E+00	1.000E+01
	3.970E+00	1.000E+01
	4.400E+00	1.000E+01
	4.500E+00	1.000E+01
6	0.000E+00	2.596E+02
	1.000E-01	2.398E+02
	5.300E-01	1.491E+02
	9.600E-01	7.573E+01
	1.390E+00	3.391E+01
	1.820E+00	1.664E+01
	2.250E+00	1.140E+01
	2.680E+00	1.022E+01
	3.110E+00	1.003E+01
	3.540E+00	1.000E+01
	3.970E+00	1.000E+01
	4.400E+00	1.000E+01
	4.500E+00	1.000E+01
9	0.000E+00	2.394E+02
	1.000E-01	2.253E+02
	5.300E-01	1.586E+02
	9.600E-01	9.690E+01
	1.390E+00	5.273E+01
	1.820E+00	2.758E+01
	2.250E+00	1.602E+01
	2.680E+00	1.172E+01
	3.110E+00	1.040E+01
	3.540E+00	1.008E+01
	3.970E+00	1.001E+01
	4.400E+00	1.000E+01

	4.500E+00	1.000E+01
12	0.000E+00	2.243E+02
	1.000E-01	2.135E+02
	5.300E-01	1.610E+02
	9.600E-01	1.088E+02
	1.390E+00	6.682E+01
	1.820E+00	3.859E+01
	2.250E+00	2.256E+01
	2.680E+00	1.480E+01
	3.110E+00	1.160E+01
	3.540E+00	1.046E+01
	3.970E+00	1.012E+01
	4.400E+00	1.004E+01
	4.500E+00	1.003E+01
15	0.000E+00	2.124E+02
	1.000E-01	2.036E+02
	5.300E-01	1.605E+02
	9.600E-01	1.158E+02
	1.390E+00	7.699E+01
	1.820E+00	4.814E+01
	2.250E+00	2.948E+01
	2.680E+00	1.891E+01
	3.110E+00	1.365E+01
	3.540E+00	1.134E+01
	3.970E+00	1.045E+01
	4.400E+00	1.020E+01
	4.500E+00	1.019E+01

NOTICE

Case 9: Freundlich Non-linear Sorption

Description

In this example a laboratory test is simulated using diffusion and Freundlich non-linear sorption. The sample is a 7 cm thick clay with an impermeable base and a finite mass source of Phenol. The leachate source has an initial concentration (c_o) of 50 mg/L, and the physical height of the leachate in the reservoir above the soil was 6.5 cm. Parameters for the Freundlich isotherm were obtained experimentally from batch tests, these are K_f=2 and =0.628 (see the section on Freundlich Non-linear Sorption in Chapter 4 for a discussion on these parameters).

Following are the parameters used in this example:

Property		**Value**	**Units**
Darcy Velocity	v_a	0.0	cm/hr
Diffusion Coefficient	D	0.019	cm^2/hr
Sorption Coefficient	K_f	2.0	cm^3/g
Sorption Exponent		0.628	-
Soil Porosity	n	0.46	-
Dry Density		1.47	g/cm^3
Soil Layer Thickness	H	7.0	cm
Number of Sub-layers		14	-
Source Concentration	c_o	50.0	mg/L
Ref. Height of Leachate	H_r	6.5	cm
Times of Interest	t	200, 400	hr
		600, 800	hr

When using non-linear sorption the accuracy of the solution is dependent on the number of sub-layers used.

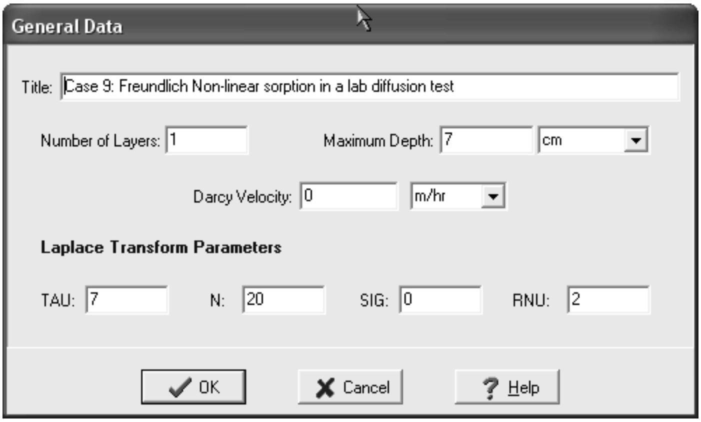
Data Entry

l

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 9 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

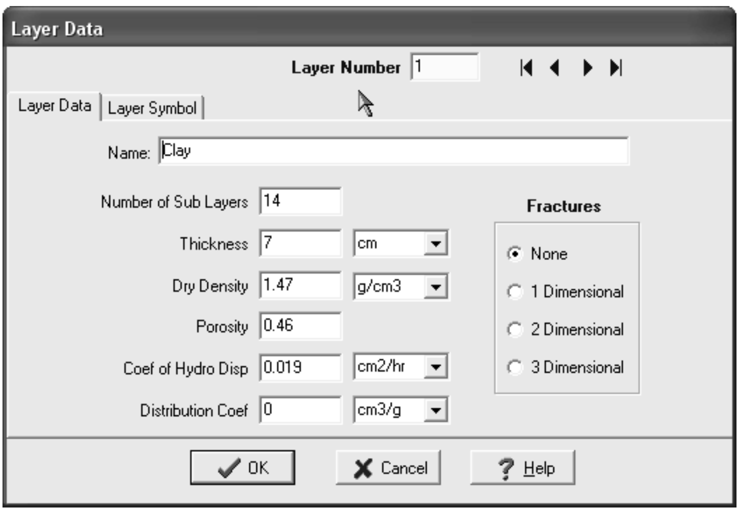
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. On the General Data form below, the Darcy velocity is set to zero for pure diffusion.



Layer Data

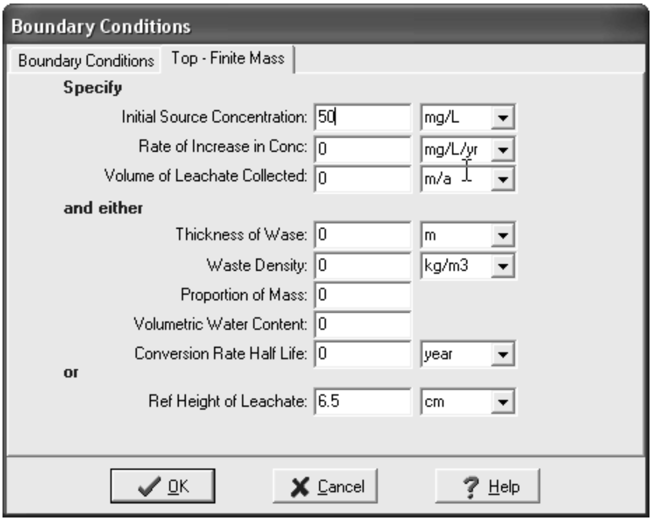
The layer data for the layer can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu. On this form the data for the layer can be added as shown below. When using non-linear sorption the Distribution Coefficient is automatically calculated. The value entered below is ignored by the program.



There are no fractures in the layer. For pure diffusion even if there were fractures it should be modelled as if the soil was unfractured, since there would be no flow in the fractures for pure diffusion through the matrix.

Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented as a zero flux layer, as shown on the Boundary Condition form below.



Run Parameters

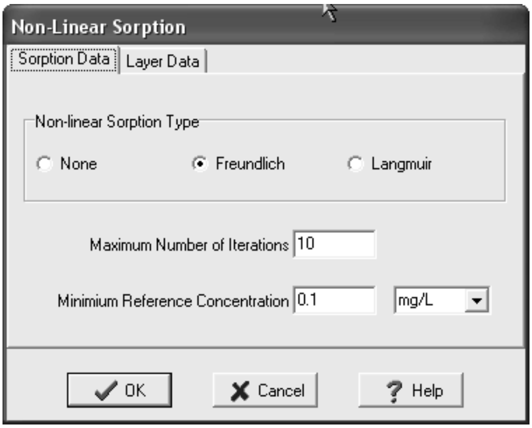
To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. In this example the concentrations will be calculated at 4 times: 200, 400, 600, and 800 years.

Special Features

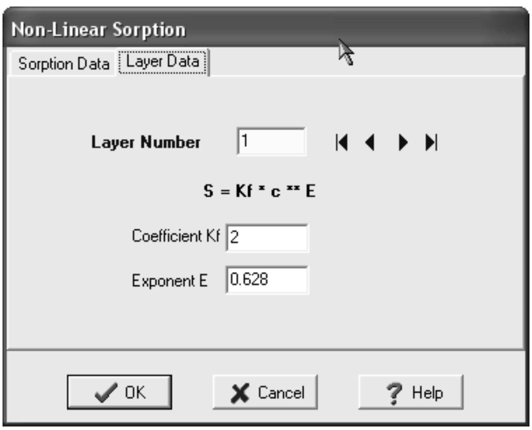
The non-linear sorption for this example is specified using the Special Features menu.

Non-linear Sorption

To specify the Freundlich non-linear sorption, select the Non-linear Sorption menu item from the Special Features form. The Sorption Data tab on the Non-linear Sorption form shown on the next page can be used to specify the type of sorption as either Freundlich or Langmuir.



The Freundlich non-linear sorption parameters are entered on the Layer Data tab shown below. These *parameters are determined experimentally.* The iterative procedure used to determine the distribution coefficient is repeated until either the maximum change in concentrations between iterations is less than 0.1% or the maximum number of iterations is reached. Minimum reference concentration is the minimum value that will be used in calculating the distribution coefficient. If the average concentration in a sub-layer is less than this minimum reference value, then the reference value is used in the calculation of the distribution coefficient (see the section on Freundlich Non-linear Sorption in Chapter 4 for more information).



Model Execution

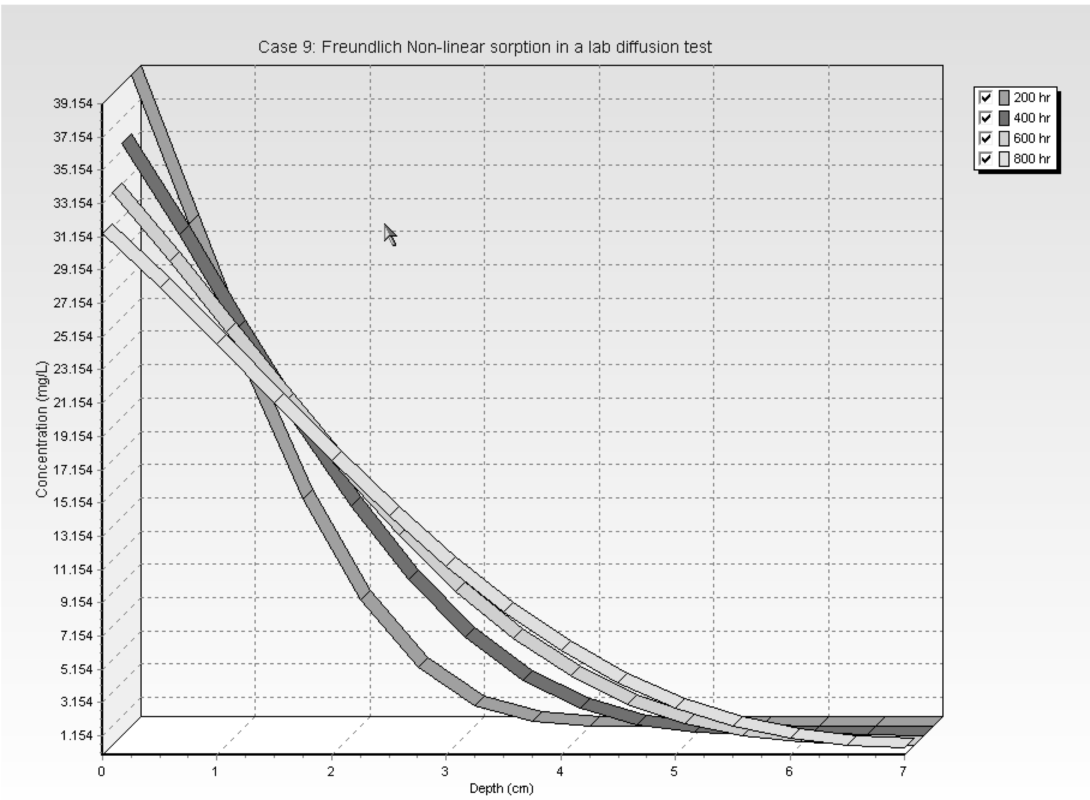
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 9: Freundlich Non-linear sorption in a lab diffusion test

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0 m/hr

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	7 cm	14	0.019 cm2/hr	0.46	0 cm3/g	1.47 g/cm3
			Dispersion			
Clay	7 cm	14	0.019 cm2/hr	0.46	0 cm3/g	1.47 g/cm3

Non-Linear Sorption

Maximum Number of Iterations = 10
Minimum Reference Concentration = 0.1 mg/L
Freundlich Sorption Isotherm S = K * c^E

Layer	K	E
1	2	0.628

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 50 mg/L
Rate of Increase = 0 mg/L/yr
Volume of Leachate Collected = 0 m/a
Thickness of Waste = 0 m
Waste Density = 0 kg/m3
Proportion of Mass = 0
Volumetric Water Content = 0
Conversion Rate Half Life = 0 year

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time hr	Depth cm	Concentration mg/L
200	0.000E+00	3.915E+01
	5.000E-01	3.022E+01
	1.000E+00	2.143E+01
	1.500E+00	1.367E+01
	2.000E+00	7.618E+00
	2.500E+00	3.521E+00
	3.000E+00	1.233E+00
	3.500E+00	2.728E-01
	4.000E+00	3.002E-02
	4.500E+00	1.801E-03
	5.000E+00	6.511E-05
	5.500E+00	1.412E-06
	6.000E+00	1.834E-08
	6.500E+00	1.499E-10
	7.000E+00	5.539E-12

Convergence Check for Non-linear Sorption
0 Iterations. Maximum Change: 0%

400	0.000E+00	3.562E+01
	5.000E-01	3.009E+01
	1.000E+00	2.439E+01
	1.500E+00	1.884E+01
	2.000E+00	1.376E+01
	2.500E+00	9.404E+00
	3.000E+00	5.917E+00
	3.500E+00	3.349E+00
	4.000E+00	1.645E+00
	4.500E+00	6.591E-01
	5.000E+00	1.935E-01
	5.500E+00	3.828E-02
	6.000E+00	5.748E-03
	6.500E+00	6.747E-04
	7.000E+00	1.213E-04

	1.500E+00	2.057E+01
	2.000E+00	1.643E+01
	2.500E+00	1.261E+01
	3.000E+00	9.239E+00
	3.500E+00	6.408E+00
	4.000E+00	4.156E+00
	4.500E+00	2.478E+00
	5.000E+00	1.324E+00
	5.500E+00	6.085E-01
	6.000E+00	2.267E-01
	6.500E+00	6.795E-02
	7.000E+00	3.012E-02

Convergence Check for Non-linear Sorption
0 Iterations. Maximum Change: 0%

800	0.000E+00	3.136E+01
	5.000E-01	2.812E+01
	1.000E+00	2.469E+01
	1.500E+00	2.119E+01
	2.000E+00	1.772E+01
	2.500E+00	1.441E+01
	3.000E+00	1.135E+01
	3.500E+00	8.617E+00
	4.000E+00	6.273E+00
	4.500E+00	4.347E+00
	5.000E+00	2.841E+00
	5.500E+00	1.736E+00
	6.000E+00	9.974E-01
	6.500E+00	5.794E-01
	7.000E+00	4.451E-01

Convergence Check for Non-linear Sorption
0 Iterations. Maximum Change: 0%

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this

Case 10: Time-varying Transport

Description

This example illustrates the use of the programs to study time-varying rates of advective-dispersive transport from a landfill, using the Variable Properties special feature. The landfill contains a finite mass of a conservative species, and has a leachate collection system. Initially there is an inward hydraulic gradient causing a hydraulic trap. After 20 years the collection of leachate is terminated and the leachate mound begins to build reaching it's maximum height after another 10 years. The increased leachate mound causes a reversal in the hydraulic gradient, that results in a reversal of the Darcy velocity and the loss of the hydraulic trap.

The analysis starts at time zero which corresponds to the completion of the landfill and the development of a peak leachate concentration (c_o) of 1000 mg/L. It is assumed that the average waste thickness is 6.25 m with a density of 600 kg/m3, and that the contaminant represents 0.2% of the total mass of the waste. Thus the total mass of contaminant per unit area of landfill is:

$$m_{tc} = 0.002 * 600 = 6.25 \text{ kg/m}^2$$

The Reference Height of Leachate (H_r) is then calculated by dividing the total mass of contaminant per unit area (m_{tc}) by the contaminant concentration (c_o).

$$H_r = (0.002 * 600 * 6.25) / 1 = 7.5 \text{ m}$$

It is also assumed that the peak concentration in the landfill is reached relatively early in the life of the landfill, and that the analysis starts at this time. Consequently there is no increase in concentration with time and the Rate of Increase in Concentration (c_r) with time is zero.

The average infiltration through the cover (q_o) is assumed to be 0.3 m/a. If the average exfiltration through the base of the landfill is v_a (which varies with time), then the Volume of Leachate Collected is:

$$Q_c = q_o - v_a = 0.3 - v_a$$

In this example the landfill is situated in a 4 m thick clay, which in underlain by an aquifer. The landfill is assumed to be 200 m long in the direction parallel to the groundwater flow in the aquifer. At the up gradient edge of the landfill the inflow in the aquifer is given by a Darcy velocity of 2 m/a. The outflow Darcy velocity at the down gradient edge of the landfill (v_b) is assumed to be 2 m/a from years 0 to 20, then increasing between 20 and 30 years according to the relationship:

Case 10: Time-varying Advective-dispersive Transport

$$vb = 2 + 200 * v_a$$

After 30 years the outflow Darcy velocity (v_b) is 6.2 m/a.

When using the Variable Properties special feature it is possible to independently specify the diffusion coefficient (Dm) and the dispersivity (). In this example the dispersivity is assumed to be zero for inward flow (i.e., $v_a < 0$), and is 0.4 m for outward flow (i.e., $v_a > 0$). The coefficient of hydrodynamic dispersion (D) is then calculated by:

$$D = D_m + \alpha * v_a/n$$

where n is the porosity, in this example 0.4.

Following are the parameters used in this example:

Property		**Value**	**Units**
Darcy Velocity	v_a	variable	m/a
Diffusion Coefficient	D	0.02	m^2/a
Distribution Coefficient	K_d	0.0	cm^3/g
Dispersivity ($v_a < 0$)		0.0	m
Dispersivity ($v_a > 0$)		0.4	m
Soil Porosity	n	0.4	-
Dry Density		1.5	g/cm^3
Soil Layer Thickness	H	4.0	m
Number of Sub-layers		12	-
Source Concentration	c_o	1000	mg/L
Ref. Height of Leachate	H_r	7.5	m
Volume of Leachate Collected	Q_c	variable	m/a
Landfill Length	L	200.0	m
Landfill Width	W	1.0	m
Aquifer Thickness	h	1.0	m
Aquifer Porosity	n_b	0.3	-
Aquifer Outflow Velocity	v_b	variable	m/a

When using the Variable Properties special feature the accuracy of the solution is dependent on the number of sub-layers used.

This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Variable Properties option. The example is not a prescription for modelling contaminant migration during operation and failure of a landfill. Each landfill has its own unique characteristics and no general prescription can be made. The Variable Properties option should only by used by someone with the hydrogeologic and engineering background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation.

Data Entry

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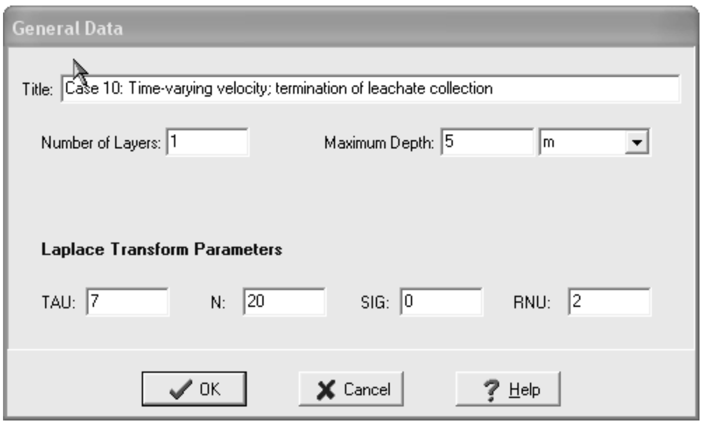
*S*tart the POLLUTEv7 program and open the Examples project. Select Case 10 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

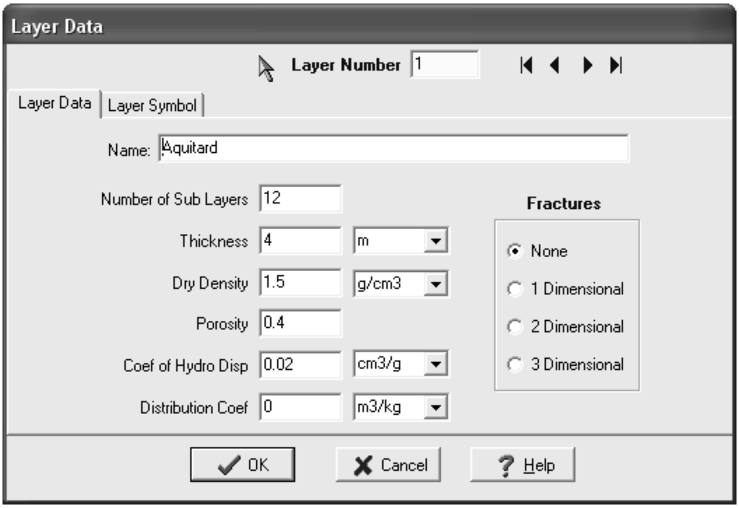
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. In the General Data form below, the Darcy velocity can be specified if the Time-varying Properties special feature is used. Any Darcy velocity entered will be ignored.



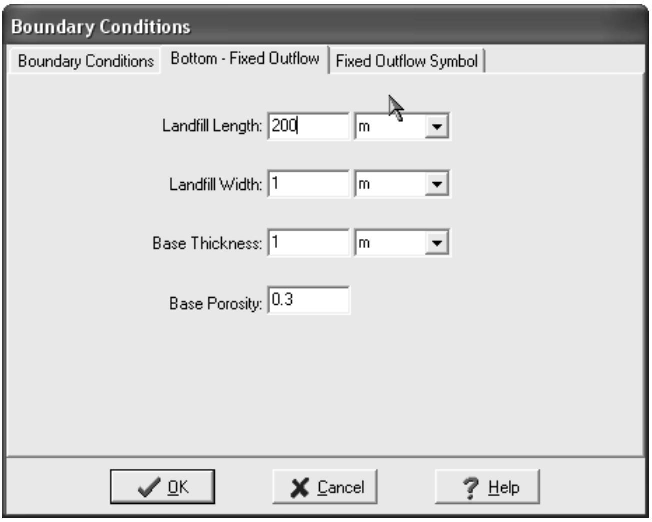
Layer Data

The layer data for the layer can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu. On this form the data for the layer can be added as shown below.



Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented by a fixed outflow aquifer, as shown on the Boundary Condition form below. If the Time-varying Properties special feature has been selected, the Mass tab will not be shown and the source parameters will be entered in the Time-Varying Properties form. If the Time-varying Properties special feature has not been selected yet, any parameters entered on the Finite Mass tab will be ignored.



Run Parameters

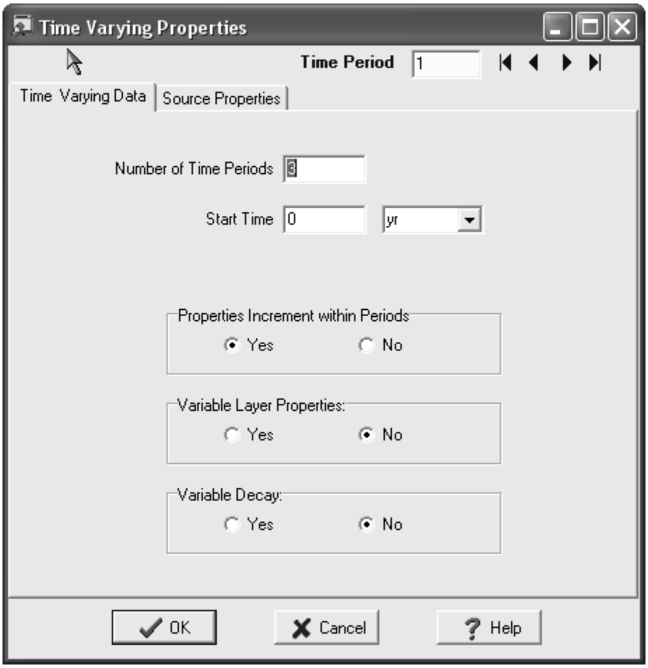
To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. When the time-varying properties special feature is used the times to calculate the concentrations are specified in the Time-Varying Properties form. In this example the concentrations will be calculated at 5 depths: 0, 1, 2, 3, and 4 m.

Special Features

The time-varying properties for this example is specified using the Special Features menu.

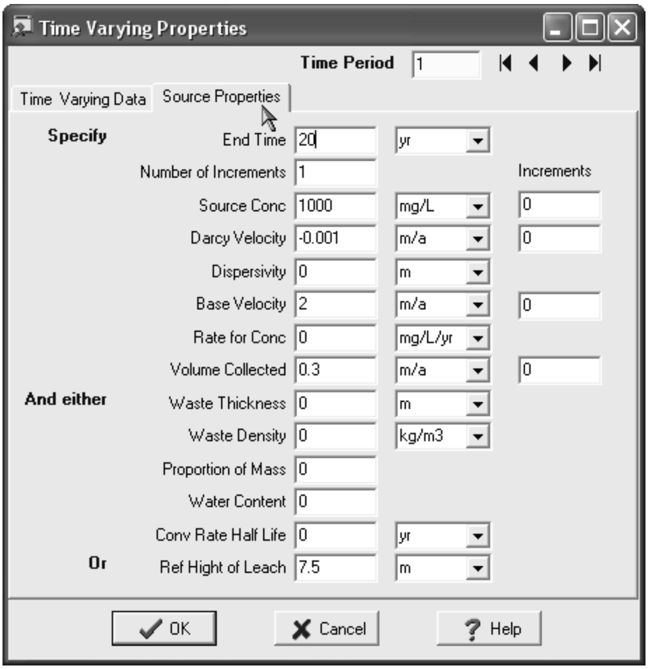
Time-Varying Properties

To specify the time-varying properties, select the Time-Varying Properties menu item from the Special Features form. The Time-Varying Data tab on the Time-Varying Properties form shown below can be used to specify the number of time periods and whether there are variable layer properties and variable decay. In this example there are 3 time periods viz. 0 to 20 years, 20 to 30 years, and 30 to 130 years.



Time Period 1

The data for each time period is specified on the Source Properties tab shown below. In the first time period, specifying only one time increment means that the concentrations will only be calculated at the end time (i.e., 20 years). A negative Darcy velocity indicates the flow is upwards.Since the first time period corresponds to an operating leachate collection system and there is no additional mass entering the landfill; there is no increase in source concentration, Darcy velocity, Volume of Leachate Collected, or Base velocity.

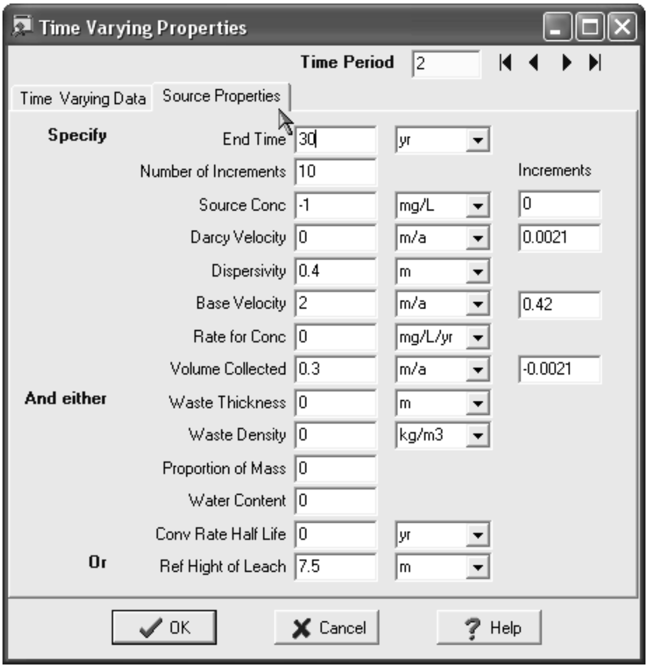


Time Period 2

The data for time period two can be specified by pressing the next button at the top of the form. This time period is from 20 to 30 years and is shown on the next page.Between the years 20 and 30 the velocities increase linearly with time, this will be approximated by a series of incremental increase at 1 year intervals. Thus there are 10 increments starting at year 21 and ending at year 30. Specifying the source concentration as -1 causes the calculated concentration at the end of the previous period to be used as the concentration at the beginning of this period.

The Darcy velocity and dispersivity are the values at the beginning of the time period. When operation of the leachate collection system is terminated the leachate mound begins to rise causing the Darcy velocity to reverse direction and become positive. A positive Darcy velocity results in the dispersivity becoming 0.4.

*The increment in Darcy velocity represents the change for each one year increment. Assuming the infiltration through the cover is constant the increment in the volume of leachate collected will be equal and opposite to the increment in the Darcy velocity. The increment in the base velocity is equal to the increment in the Darcy velocity multiplied by the length of the landfill (i.e., 0.0021 * 200 = 0.42 m/a).*

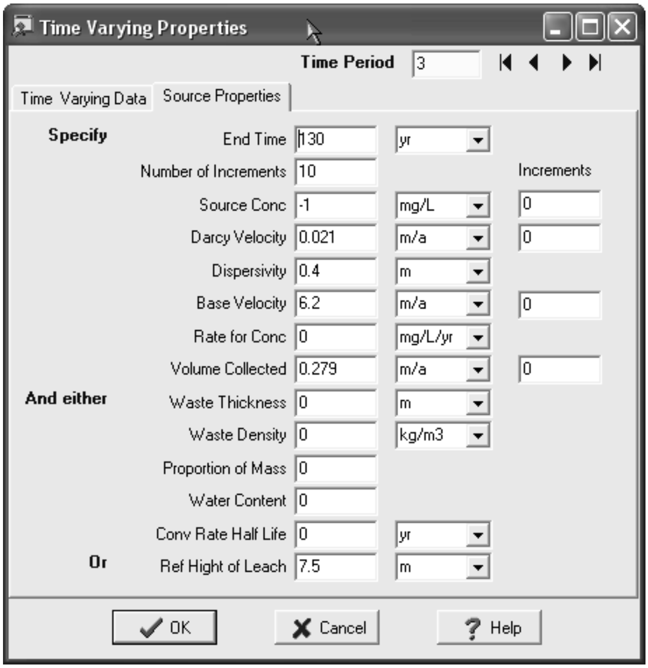


Time Period 3

The data for time period three should be entered next, this time period is from 30 to 130 years and is shown on the next page. During the 100 years between 30 and 130 years the velocities remain constant. By specifying 10 increments the concentrations will be calculated and listed every 10 years during this period. The Darcy velocity is the resulting velocity from the build-up of leachate after the failure of the leachate collection system.

Since the leachate collection has completely failed by the start of this time period and the leachate mound has fully developed, there is no further increase in the velocities. Note that there will still be some leachate collected by the toe drains, which are assumed to be functioning even though the leachate collection system has failed.

The volume of leachate collected by the toe drains is equal to the infiltration through the cover minus the downward Darcy velocity (i.e., 0.3 - 0.021 = 0.279 m/a). And the base velocity is equal to the inflow plus the Darcy velocity times the landfill length (i.e., 2 + 200*0.021 = 6.2 m/a).



Model Execution

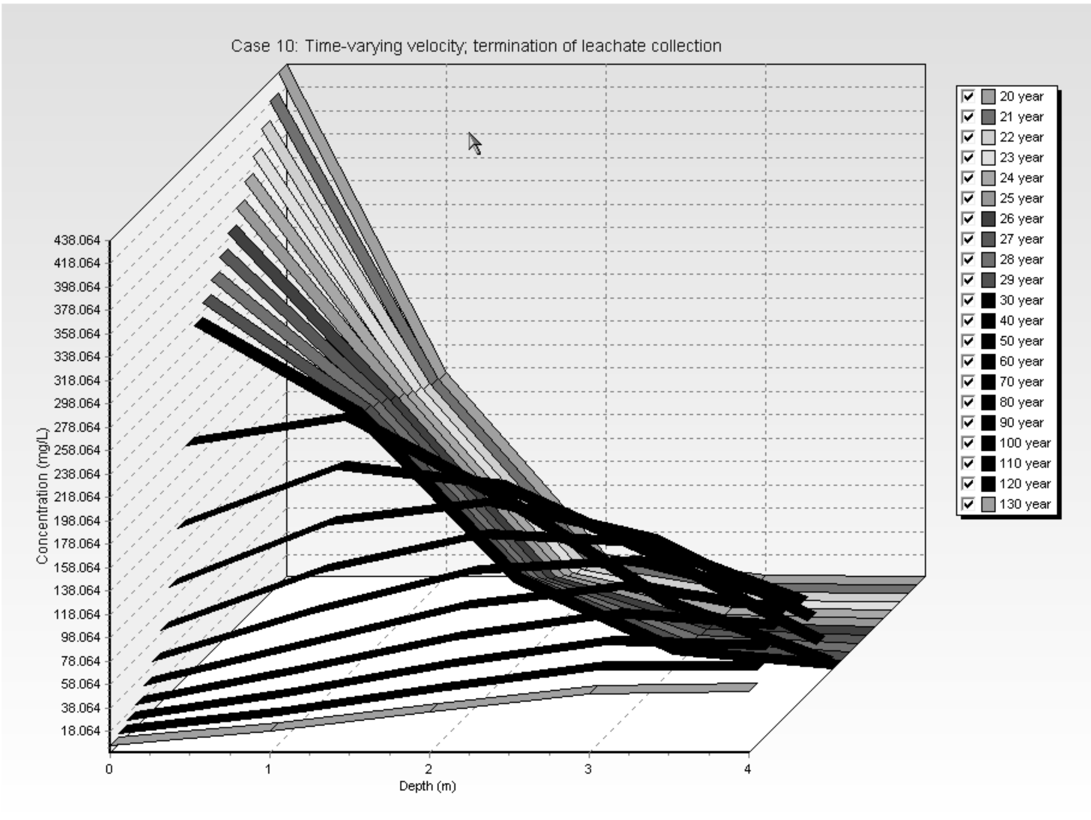
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 10: Time-varying velocity; termination of leachate collection

THE VARIABLE VELOCITY AND/OR CONCENTRATION OPTION HAS BEEN USED
NOTE THAT THE ACCURACY OF THE CALCULATIONS WITH THIS OPTION WILL DEPEND ON THE NUMBER OF SUBLAYERS USED

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Aquitard	4 m	12	0.02 cm3/g	0.4	0 m3/kg	1.5 g/cm3

Boundary Conditions

Finite Mass Top Boundary

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.3

VARIATION IN PROPERTIES WITH TIME:

TIME PERIODS WITH THE SAME SOURCE AND VELOCITY

Period	Start Time	No. of Steps	Time Step	Source Conc	Rate of Change	Height of Leachate	Volume Collected
1	0 yr	1	20 yr	1000 mg/L	0	7.5 m	0.3 m/a
2	20 yr	10	1 yr	-1 mg/L	0	7.5 m	0.3 m/a
3	30 yr	10	10 yr	-1 mg/L	0	7.5 m	0.279 m/a

Case 10: Time-varying Advective-dispersive Transport

Period	Start Time	End Time	Darcy Velocity	Dispersivity	Base Velocity
1	0 yr	20 yr	-0.001 m/a	0 m	2 m/a
2	20 yr	30 yr	0 m/a	0.4 m	2 m/a
3	30 yr	130 yr	0.021 m/a	0.4 m	6.2 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
20	0.000E+00	4.381E+02
	1.000E+00	1.739E+02
	2.000E+00	1.858E+01
	3.000E+00	5.903E-01
	4.000E+00	2.130E-03
21	0.000E+00	4.208E+02
	1.000E+00	1.762E+02
	2.000E+00	2.094E+01
	3.000E+00	7.799E-01
	4.000E+00	3.240E-03
22	0.000E+00	4.042E+02
	1.000E+00	1.794E+02
	2.000E+00	2.391E+01
	[illegible]	[illegible]
	4.000E+00	1.416E-01
29	0.000E+00	3.052E+02
	1.000E+00	2.118E+02
	2.000E+00	6.485E+01
	3.000E+00	9.011E+00
	4.000E+00	2.393E-01
30	0.000E+00	2.933E+02
	1.000E+00	2.155E+02
	2.000E+00	7.342E+01
	2.000E+00	3.190E+01
	4.000E+00	3.955E-01
40	0.000E+00	1.977E+02
	1.000E+00	2.196E+02
	2.000E+00	1.465E+02
	3.000E+00	6.029E+01
	4.000E+00	1.003E+01
50	0.000E+00	1.339E+02
	1.000E+00	1.842E+02
	2.000E+00	1.687E+02
	3.000E+00	1.063E+02
	4.000E+00	3.505E+01
60	0.000E+00	9.098E+01
	1.000E+00	1.449E+02
	[illegible]	[illegible]

	3.000E+00 4.000E+00	1.298E+02 6.300E+01
70	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	6.198E+01 1.106E+02 1.405E+02 1.336E+02 8.275E+01
80	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	4.233E+01 8.308E+01 1.169E+02 1.253E+02 9.140E+01
90	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	2.897E+01 6.184E+01 9.440E+01 1.108E+02 9.078E+01
100	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.986E+01 4.577E+01 7.479E+01 9.434E+01 8.407E+01
110	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	1.365E+01 3.377E+01 5.845E+01 7.812E+01 7.417E+01
120	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	9.400E+00 2.486E+01 4.523E+01 6.338E+01 6.318E+01
130	0.000E+00 1.000E+00 2.000E+00 3.000E+00 4.000E+00	6.486E+00 1.828E+01 3.473E+01 5.061E+01 5.243E+01

Case 11: Time-varying Source Concentration

Description

In this example there is a time-varying source concentration history and diffusive transport of a conservative species (i.e., no sorption) from a landfill. Time zero corresponds to the excavation of a landfill cell, the cell then filled quickly with water to a depth of 6 m. No waste was added to the cell for 7 years. The landfill is situated in a clay that contains chloride in its pore water at a concentration of 120 mg/L. During the 7 years that the cell contained water the chloride began to diffused out of the clay pore water and into the cell water. Between the years 7 and 10, waste was added to the cell and the source concentration of chloride increased linearly with time reaching a peak value at year 10 of 2100 mg/L. The source concentration of chloride then remained relatively constant between the years 10 and 13. During the years 13 to 15 the source concentration decreased linearly with time to a value of 1180 mg/L at year 15. The source concentration then remained relatively constant again from years 15 to 19. This example will calculate the predicted chloride distribution with depth at year 19.

There is no leachate collection system in the landfill, and the water level in the waste corresponds to the natural water level. The hydraulic gradient is zero, and hence the Darcy velocity is zero. And the clay is sufficiently thick that it can be assumed to be infinite for the time period under consideration.

When using the Variable Properties special feature it is possible to independently specify the diffusion coefficient (Dm) and the dispersivity (). In this example the dispersivity is assumed to be zero since there is no flow. Clearly if there is no flow then the value of the dispersivity is not relevant since the coefficient of hydrodynamic dispersion (D) is then calculated by:

$$D = D_m + \alpha * v_a /n$$

The Reference Height of Leachate for this example is the same as the depth of water in the cell (i.e., 6 m). In this example the source concentration is assigned specific values at various times by setting the value of the Reference Height of Leachate very large. Setting the Reference Height of Leachate very large will ensure that the source concentration remains constant during that time interval.

Following are the parameters used in this example:

Property		Value	Units
Darcy Velocity	v_a	0.0	m/a
Diffusion Coefficient	D_m	0.00663	m^2/a
Distribution Coefficient	K_d	0.0	cm^3/g
Dispersivity		0.0	m
Soil Porosity	n	0.37	-

Property		Value	Units
Dry Density		1.6	g/cm^3
Soil Layer Thickness		infinite	m
Thickness of Interest	H	1.5	m
Number of Sub- layers		15	-
Source Concentration	c_o	variable	mg/L
Reference Height of Leachate	H_r	6.0	m
Volume of Leachate Collected	Q_c	0.0	m/a

When using the Variable Properties special feature the accuracy of the solution is dependent on the number of sub-layers used.

This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Variable Properties option. The example is not a prescription for modelling contaminant migration from a landfill. Each landfill has its own unique characteristics and no general prescription can be made. The Variable Properties option should only by used by someone with the hydrogeologic and engineering background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation.

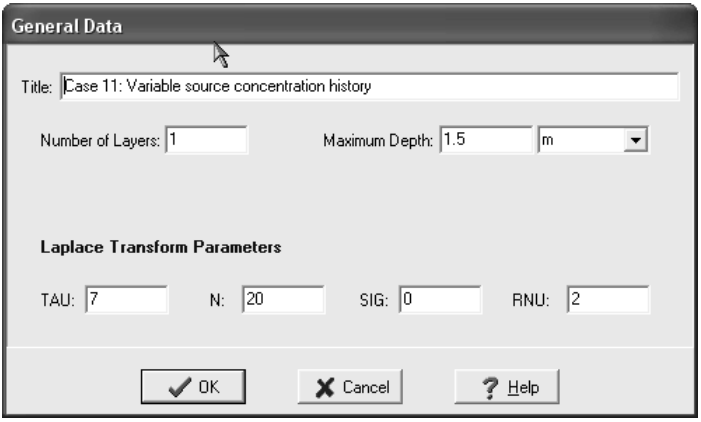
Data Entry

l

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 11 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

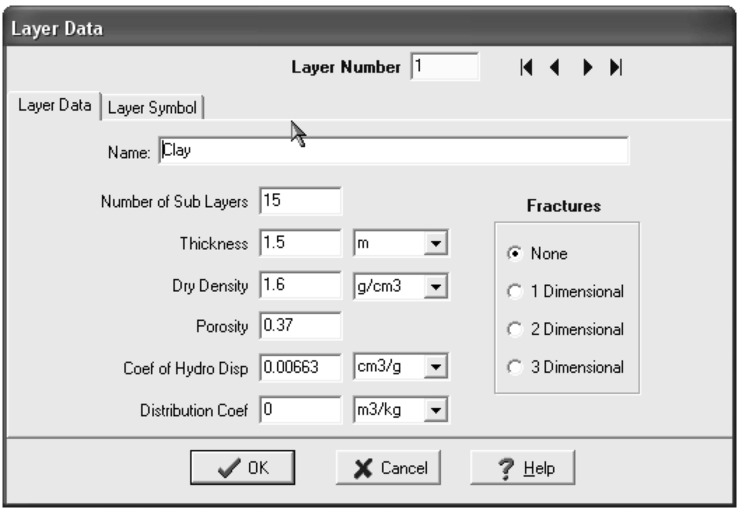
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. In the General Data form on the next page, the Darcy velocity can not be specified if the Time-varying Properties special feature is used. Any Darcy velocity entered will be ignored.



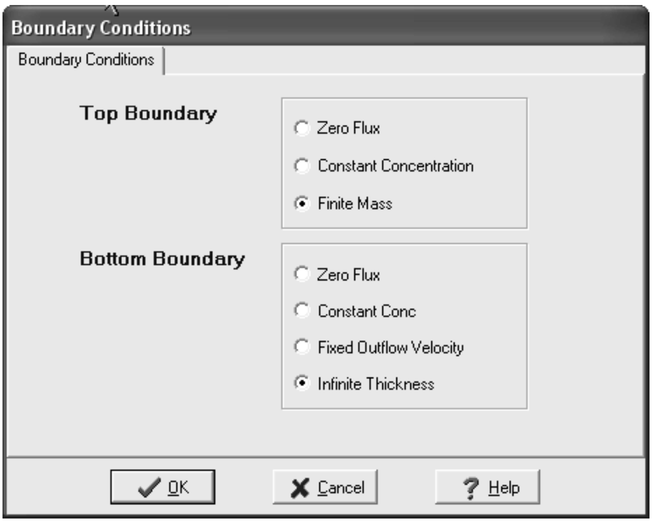
Layer Data

The layer data for the layer can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu. On this form the data for the layer can be added as shown below. Although the clay layer is assumed to be infinite, the concentrations for only the top 1.5 m will be calculated. This is the depth interval where the contaminant plume is expected.



Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented by a layer of infinite thickness, as shown on the Boundary Condition form below. If the Time-varying Properties special feature has been selected, the Finite Mass tab will not be shown and the source parameters will be entered in the Time-Varying Properties form. If the Time-varying Properties special feature has not been selected yet, any parameters entered on the Finite Mass tab will be ignored.



Run Parameters

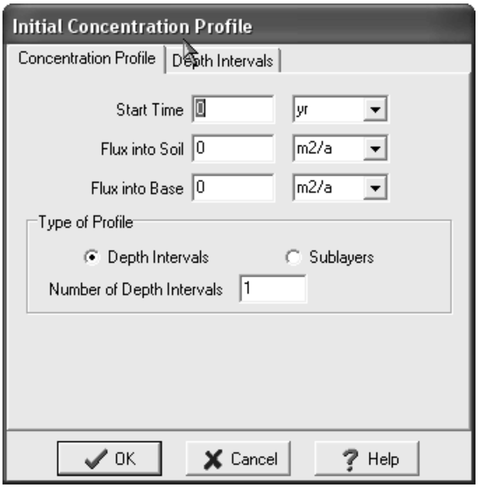
To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. When the time-varying properties special feature is used the times to calculate the concentrations are specified in the Time-Varying Properties form.

Special Features

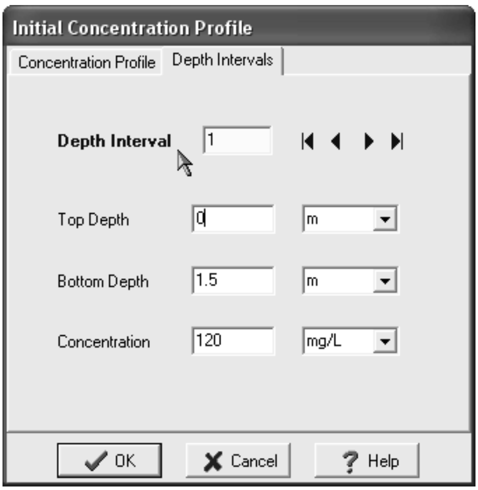
The initial concentration profile and time-varying properties for this example are specified using the Special Features menu.

Initial Concentration Profile

To specify the initial concentration profile, select the Initial Concentration Profile menu item from the Special Features form. The Concentration Profile tab on the form shown on the next page can be used to specify the type of profile as either Depth Intervals or Sublayers. The concentration profile can be specified as a constant for given depth intervals or as a different value for every sublayer.

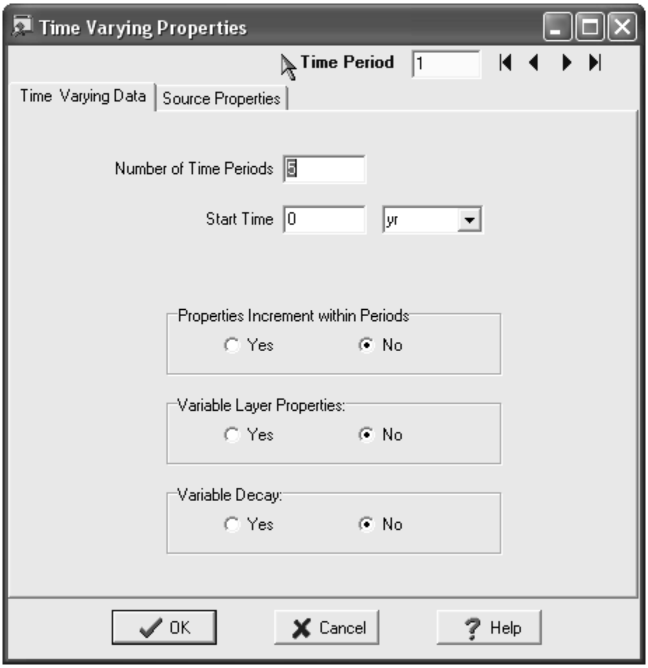


In this example the background concentration is uniform with depth, and can be specified as a constant 120 mg/L over 1 depth interval.



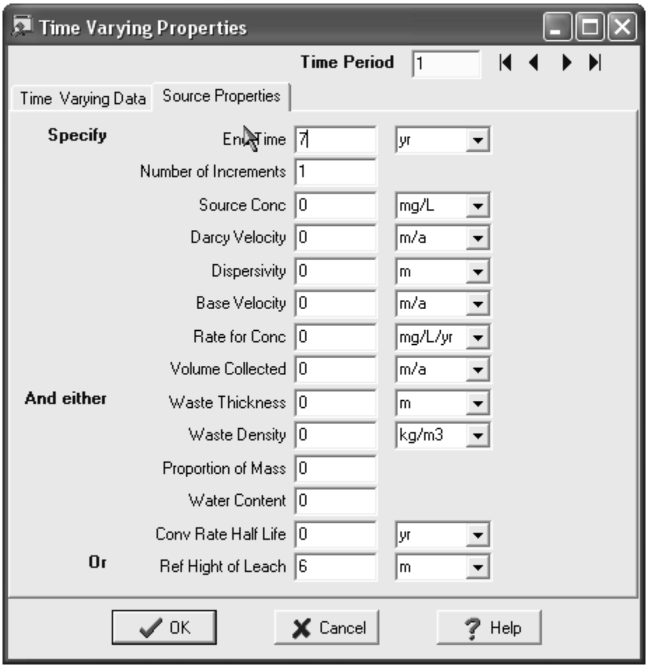
Time-Varying Properties

To specify the time-varying properties, select the Time-Varying Properties menu item from the Special Features form. The Time-Varying Data tab on the Time-Varying Properties form shown below can be used to specify the number of time periods and whether there are variable layer properties and variable decay. In this example there are 5 time periods viz. 0 to 7 years, 7 to 10 years, 10 to 13 years, 13 to 15 years, and 15 to 19 years.



Time Period 1

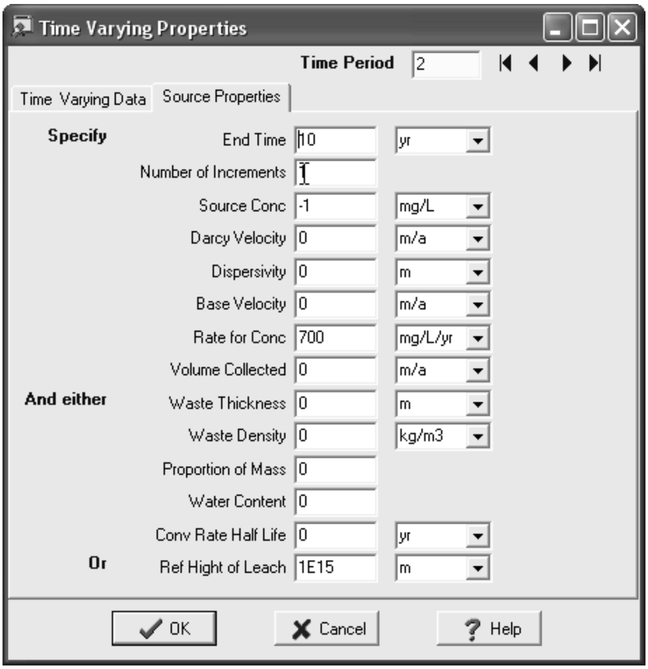
The data for each time period is specified on the Source Properties tab shown on the next page. In the first time period, specifying only one time increment means that the concentrations will only be calculated at the end time (i.e., 7 years).The beginning source concentration is zero, since fresh water is initially filling the cell.



Time Period 2

The data for time period two can be specified by clicking on the next arrow at the top of the form. This time period is from 7 to 10 years, and is shown below. Between the years 7 and 10 the source concentration increase linearly with time at a rate of 700 mg/L per year.

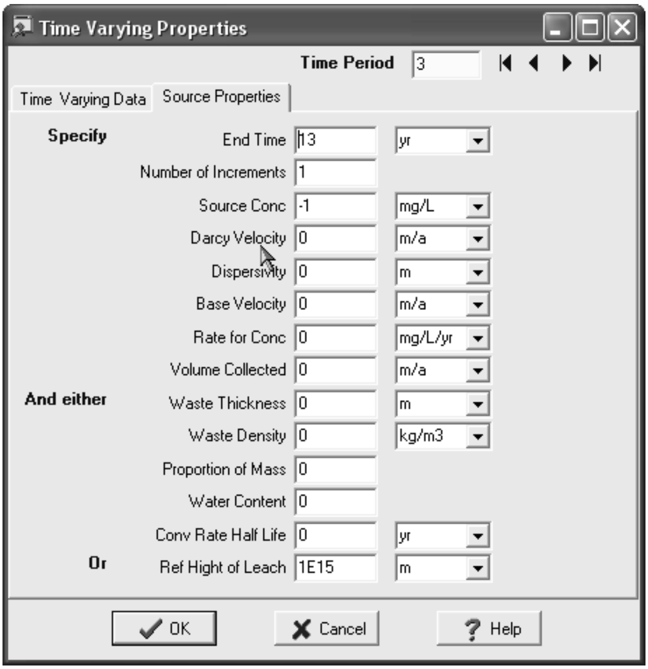
Only one time increment is necessary, since we are not interested in calculating the concentrations at any intermediate times. Specifying the source concentration as -1 causes the calculated concentration at the end of the previous period to be used as the concentration at the beginning of this period. The Leachate Reference Height is set very high in order to ignore the effects of source depletion.



Time Period 3

Next the data for time period three should be entered, this time period is from 10 to 13 years, and is shown below. During the 3 years between 10 and 13 years the source concentration remains constant.

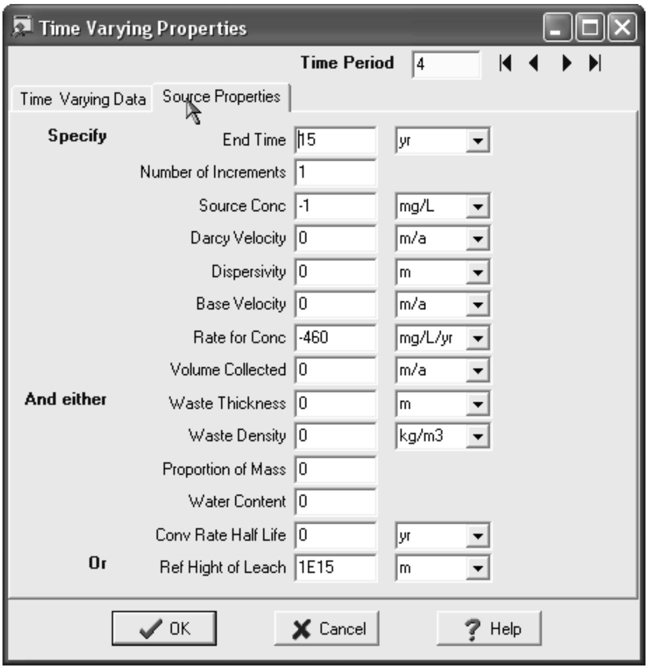
Specifying the beginning concentration as -1 indicates to use the calculated concentration at the end of the previous time period as the concentration at the start of this time period. The Leachate Reference Height is set very high in order to ignore the effects of source depletion.



Time Period 4

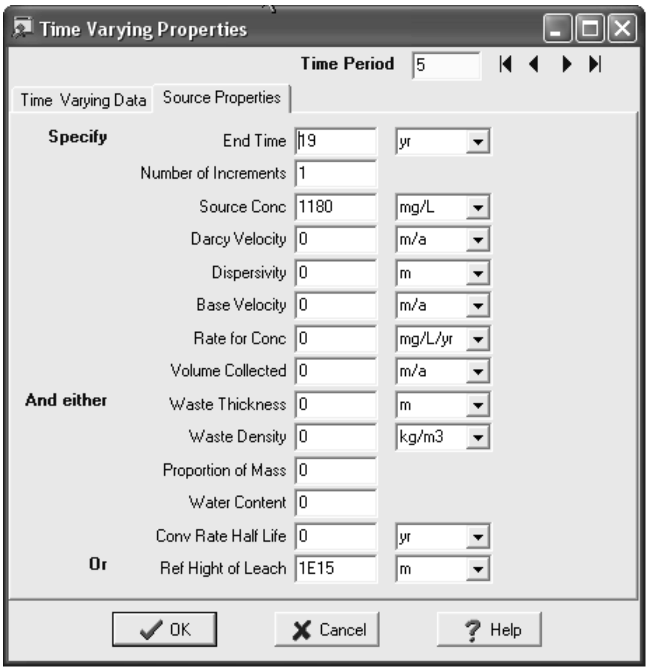
Next the data for time period four should be entered as shown on the form below, this time period is from 13 to 15 years. Between the years 13 and 15 the source concentration decreases linearly with time at the rate of 460 mg/L per year.

Specifying the beginning concentration as -1 indicates to use the calculated concentration at the end of the previous time period as the concentration at the start of this time period. The Leachate Reference Height is set very high in order to ignore the effects of source depletion.



Time Period 5

Data for the last time period should be entered, this time period is from 15 to 19 years. For the 4 years between 15 and 19 the source concentration is assumed to remain constant at 1180 mg/L. The Leachate Reference Height is set very high in order to ignore the effects of depletion of the source.



Model Execution

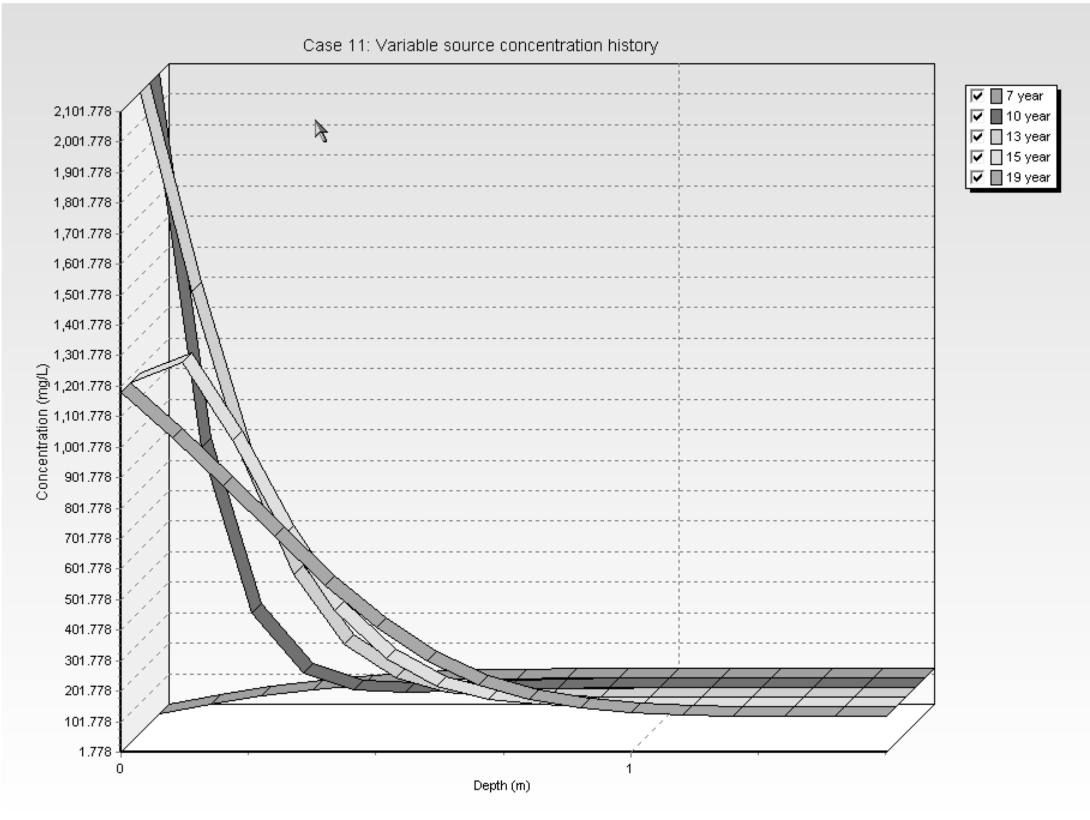
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 11: Variable source concentration history

THE VARIABLE VELOCITY AND/OR CONCENTRATION OPTION HAS BEEN USED
NOTE THAT THE ACCURACY OF THE CALCULATIONS WITH THIS OPTION WILL DEPEND ON THE NUMBER OF SUBLAYERS USED

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	1.5 m	15	0.00663 cm3/g	0.37	0 m3/kg	1.6 g/cm3

Boundary Conditions

Finite Mass Top Boundary

Infinite Thickness Bottom Boundary

INITIAL CONCENTRATION PROFILE

Time = 0 yr
Flux into Soil = 0 m2/a
Flux into Base = 0 m2/a

Top Depth	Bottom Depth	Concentration
0 m	1.5 m	120 mg/L

VARIATION IN PROPERTIES WITH TIME:

TIME PERIODS WITH THE SAME SOURCE AND VELOCITY

Period	Start Time	No. of Steps	Time Step	Source Conc	Rate of Change	Height of Leachate	Volume Collected
1	0 yr	1	7 yr	0 mg/L	0	6 m	0 m/a
2	7 yr	1	3 yr	-1 mg/L	700	1E15 m	0 m/a
3	10 yr	1	3 yr	-1 mg/L	0	1E15 m	0 m/a
4	13 yr	1	2 yr	-1 mg/L	-460	1E15 m	0 m/a
5	15 yr	1	4 yr	1180 mg/L	0	1E15 m	0 m/a

Case 11: Time-varying Source Concentration with Background

Period	Start Time	End Time	Darcy Velocity	Dispersivity	Base Velocity
1	0 yr	7 yr	0 m/a	0 m	0 m/a
2	7 yr	10 yr	0 m/a	0 m	0 m/a
3	10 yr	13 yr	0 m/a	0 m	0 m/a
4	13 yr	15 yr	0 m/a	0 m	0 m/a
5	15 yr	19 yr	0 m/a	0 m	0 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
7	0.000E+00	1.778E+00
	1.000E-01	3.201E+01
	2.000E-01	5.930E+01
	3.000E-01	8.141E+01
	4.000E-01	9.749E+01
	5.000E-01	1.080E+02
	6.000E-01	1.142E+02
	7.000E-01	1.174E+02
	8.000E-01	1.190E+02
	9.000E-01	1.196E+02
	1.000E+00	1.199E+02
	1.100E+00	1.200E+02
	1.200E+00	1.200E+02
	1.300E+00	1.200E+02
	1.400E+00	1.200E+02
	1.500E+00	1.200E+02
10	0.000E+00	2.102E+03
	1.000E-01	9.048E+02
	2.000E-01	3.644E+02
	3.000E-01	1.653E+02
	4.000E-01	1.107E+02
	5.000E-01	1.042E+02
	6.000E-01	1.086E+02
	7.000E-01	1.134E+02
	8.000E-01	1.165E+02
	9.000E-01	1.183E+02
	1.000E+00	1.192E+02
	1.100E+00	1.197E+02
	1.200E+00	1.199E+02
	1.300E+00	1.200E+02
	1.400E+00	1.200E+02
	1.500E+00	1.200E+02
13	0.000E+00	2.102E+03
	1.000E-01	1.449E+03
	2.000E-01	9.023E+02
	3.000E-01	5.194E+02
	4.000E-01	2.937E+02
	5.000E-01	1.816E+02
	6.000E-01	1.351E+02

	6.000E-01	1.351E+02
	7.000E-01	1.198E+02
	8.000E-01	1.166E+02
	9.000E-01	1.171E+02
	1.000E+00	1.182E+02
	1.100E+00	1.190E+02
	1.200E+00	1.195E+02
	1.300E+00	1.198E+02
	1.400E+00	1.199E+02
	1.500E+00	1.200E+02
15	0.000E+00	1.182E+03
	1.000E-01	1.247E+03
	2.000E-01	9.934E+02
	3.000E-01	6.826E+02
	4.000E-01	4.355E+02
	5.000E-01	2.763E+02
	6.000E-01	1.879E+02
	7.000E-01	1.448E+02
	8.000E-01	1.267E+02
	9.000E-01	1.203E+02
	1.000E+00	1.188E+02
	1.100E+00	1.188E+02
	1.200E+00	1.192E+02
	1.300E+00	1.196E+02
	1.400E+00	1.198E+02
	1.500E+00	1.199E+02
19	0.000E+00	1.180E+03
	1.000E-01	1.030E+03
	2.000E-01	8.730E+02
	3.000E-01	7.092E+02
	4.000E-01	5.501E+02
	5.000E-01	4.104E+02
	6.000E-01	3.005E+02
	7.000E-01	2.232E+02
	8.000E-01	1.740E+02
	9.000E-01	1.457E+02
	1.000E+00	1.310E+02
	1.100E+00	1.240E+02
	1.200E+00	1.211E+02
	1.300E+00	1.200E+02
	1.400E+00	1.198E+02
	1.500E+00	1.198E+02

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this computer program. The user accepts full responsibility for assessing the validity and applicability of the results obtained with this program for any specific case.

Case 12: POLLUTE vs. Analytical Solution

Description

The results obtained from POLLUTE are compared to those obtained by an analytical solution developed by Tang et al. (1981) for a single fracture system. A conservative contaminant is considered with a constant source concentration of 1. The fractures are 10 µm wide, have a groundwater (seepage) velocity along the fracture of 730 m/a, a dispersivity of zero, and a diffusion coefficient along the fractures of 0.077 m^2/a. In this comparison the fracture spacing is 1 m. Because of the very low matrix diffusion coefficient there is no interaction between fractures over the time frame considered, thus the same result would be obtained if the fracture spacing were increased to 10 m. The Darcy velocity, which occurs along the fractures, can be calculated by multiplying the fractures per m times the fracture width times the seepage velocity:

$$v_a = 10x10^{-6} * 1 * 730 = 0.73x10^{-2}$$

A porosity of 0.05 and tortuosity (the ratio of effective diffusion coefficient to the molecular diffusion coefficient in water) of 0.0000983 were assumed for the matrix material. The matrix diffusion coefficient is then given by multiplying the fracture diffusion coefficient and the tortuosity:

$$D_m = 0.077 * 0.0000983 = 7.5691x10^{-6}$$

The following parameters are defined for this example:

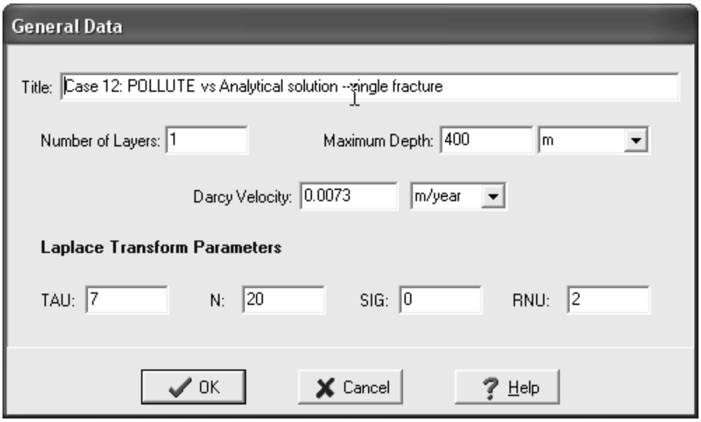
Property		Value	Units
Darcy Velocity	v_a	0.73E-2	m/a
Soil Thickness	H	400.0	m
Number of Sub-layers		4	-
Fracture spacing	$2H_1$	1.0	m
Fracture opening	$2h_1$	10E-6	m
Dispersion along fractures	D_f	0.077	m^2/a
Fracture Distribution Coef.	K_f	0.0	cm^3/g
Matrix Diffusion Coefficient	D_m	7.57E-6	m^2/a
Matrix Distribution Coef.	K_m	1.0	cm^3/g
Matrix Porosity	n_m	0.05	-
Dry Density of Matrix		0.0	g/cm^3
Source Concentration	c_o	1.0	mg/L

Data Entry

Start the POLLUTEv7 program and open the Examples project. Select Case 12 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

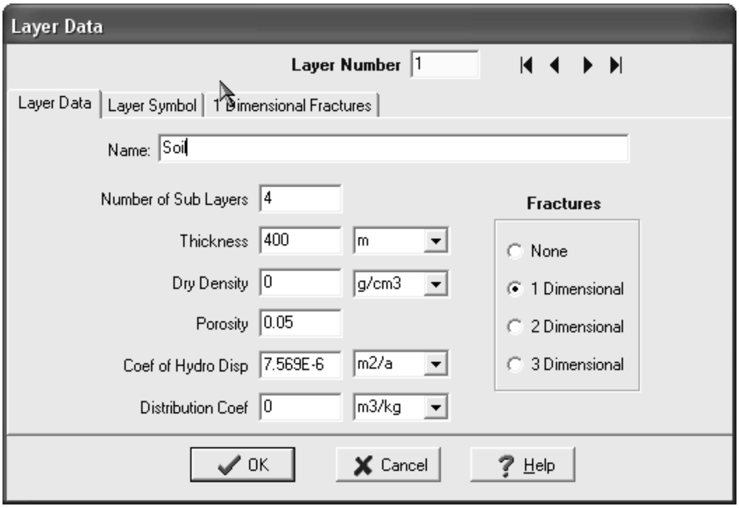
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. In the General Data form on the next page, the Darcy velocity can be specified as 0.73×10^{-2}.

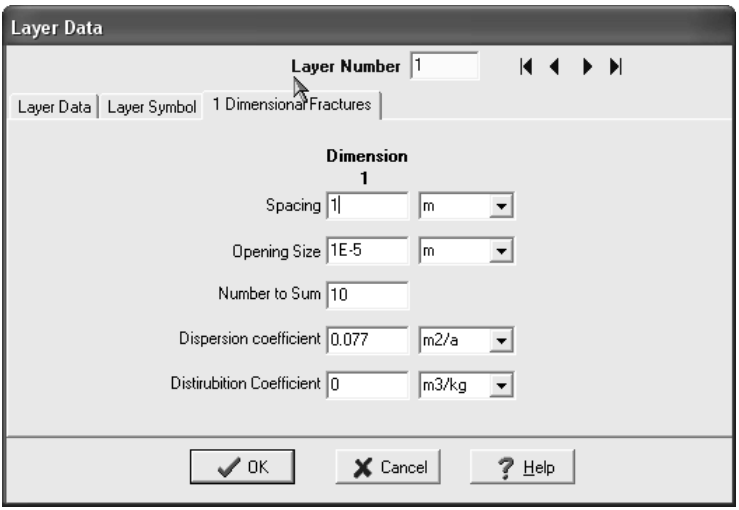


Layer Data

The layer data for the layer can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu. On this form, shown on the next page, the data for the layer can be added.

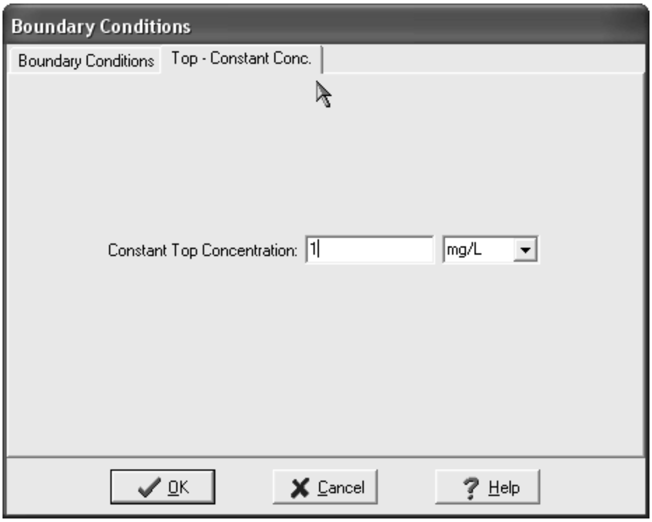


On the Fractures tab, the data for the one dimensional fractures can be specified. The fracture opening size is the gap between the walls of the fracture.



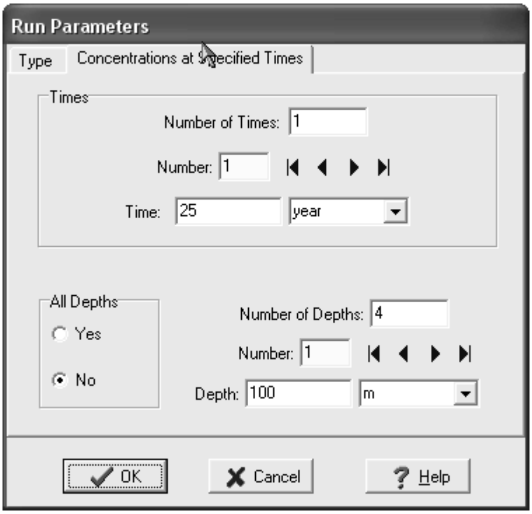
Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a constant concentration and the bottom boundary is represented by a layer of infinite thickness, as shown on the Boundary Condition form below.



Run Parameters

To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The Run Parameters form on the next page will be displayed. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. In this example the concentrations will be calculated at 25 years and at 4 depths: 100, 200, 300, and 400 m.

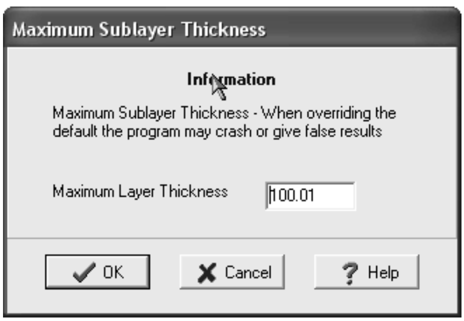


Special Features

The maximum sublayer thickness for this example can be specified using the Special Features menu.

Maximum Sublayer Thickness

The default maximum sublayer thickness is 5 depth units. This maximum is set to avoid problems with exponential overflow, which can sometimes occur if the sublayers are too thick. To override the default maximum sublayer thickness the Maximum Sublayer Thickness feature is used, **when over riding this default the user takes the chance that the program will "crash" or give false results - caveat emptor.**



To specify the maximum sublayer thickness select the Maximum Sublayer Thickness menu item from the Special Features menu, the Maximum Sublayer Thickness form on the previous page will be shown. By specifying the maximum sublayer thickness as 100.01 the sublayers can be up to 100.01 units thick. In this example the sublayers are 100 units thick.

Model Execution

To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

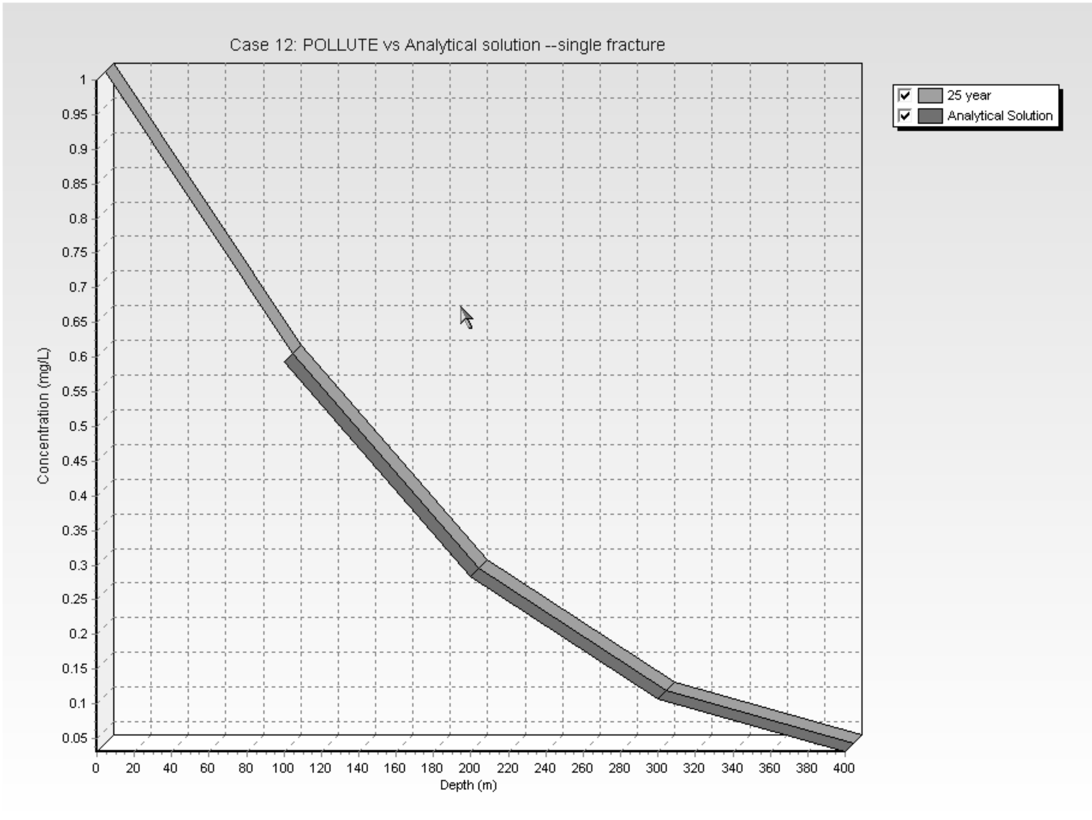
Output Comparison

The calculated concentrations from the POLLUTE program and the analytical solution by Tang et al. (1981) are listed below. Both solutions give identical results.

Depth (m)	POLLUTE (mg/L)	Analytical Solution (mg/L)
100	0.5930	0.5930
200	0.2838	0.2838
300	0.1069	0.1069
400	0.0311	0.0311

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 12: POLLUTE vs Analytical solution --single fracture

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 0.0073 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Soil	400 m	4	7.569E-6 m2/a	0.05	0 m3/kg	0 g/cm3

Layer	Fracture Spacing 1	Opening Size 1	Number 1	Fracture Spacing 2	Opening Size 2	Number 2	Fracture Spacing 3	Opening Size 3	Number 3
Soil	1 m	1E-5 m	10						

Layer	Dispersion Coefficient in Fractures	Distribution Coefficient in Fractures	Fracture Porosity	Retardation Coefficient in Matrix
Soil	0.077 m2/a	0 m3/kg	1.0000E-05	1.0000E+00

Boundary Conditions

Boundary Conditions

Contant Concentration
Source Concentration = 1 mg/L

Infinite Thickness Bottom Boundary

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
25	0.000E+00	1.000E+00
	1.000E+02	5.930E-01
	2.000E+02	2.838E-01
	3.000E+02	1.069E-01
	4.000E+02	3.111E-02

Case 13: Comparison with Analytical Method

Description

In this example the results of POLLUTE are compared to those obtained by the analytical solution given by TDAST. TDAST is a computer program for 2-D plane dispersion in an infinitely deep porous media, developed by Javandel et al. (1984). An infinitely thick layer is considered, however for comparison purposes the calculations will be restricted to the first 10 m. Below the layer the bottom boundary is assumed to extend to infinity and have the same properties as the layer above. The following parameters are assumed for the example:

Property		**Value**	**Units**
Darcy Velocity	v_a	1.0	m/a
Diffusion Coefficient	D	0.01	m^2/a
Distribution Coefficient	K_d	0.0	cm^3/g
Soil Porosity	n	1.0	-
Dry Density		0.0	g/cm^3
Soil Layer Thickness	H	10.0	m
Number of Sub-layers		20	-
Source Concentration	c_o	1.0	g/L
Times of Interest	t	4	a

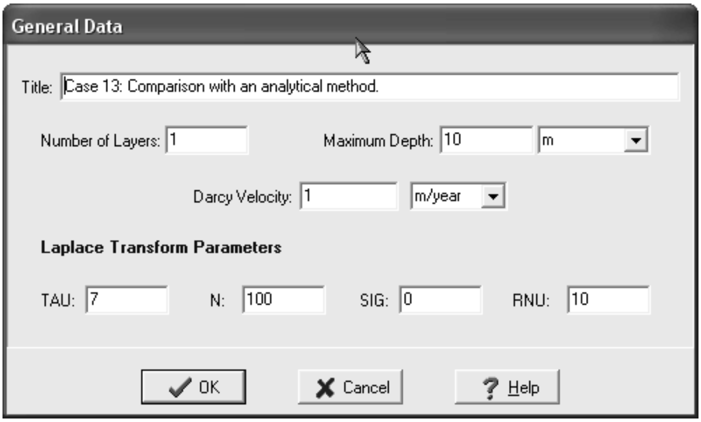
Data Entry

l

Start the POLLUTEv7 program and open the Examples project. Select Case 13 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

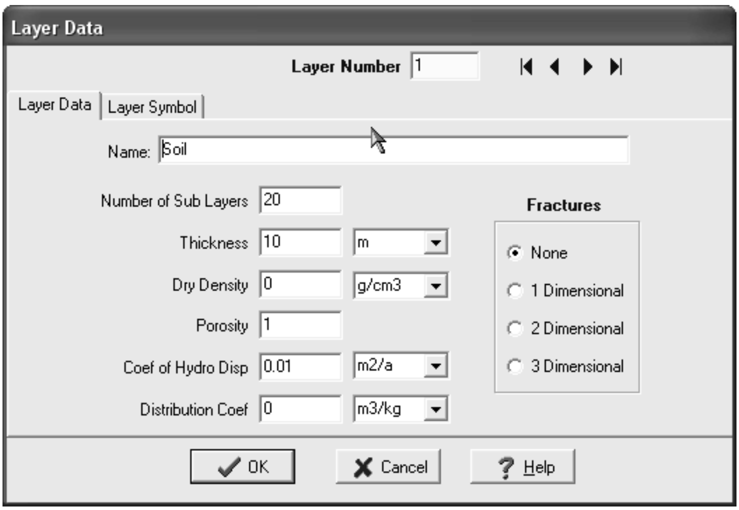
General Data

The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. The General Data form on the next page will be displayed. In this example there is one layer and the Darcy velocity is 1 m/a.



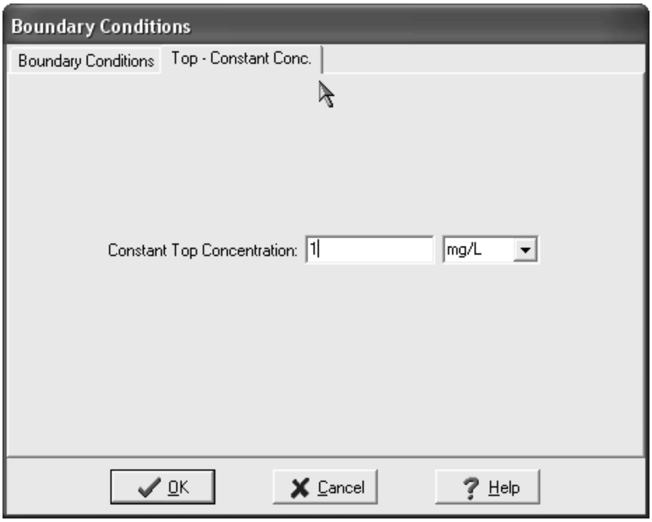
Layer Data

The layer data for the layer can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu. When there is no sorption (i.e., the distribution coefficient is zero) the dry density is not used and can be specified as zero.



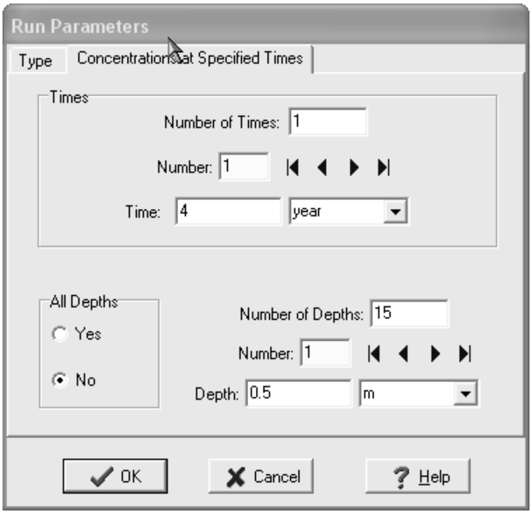
Boundary Conditions

The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a constant concentration and the bottom boundary is represented by a layer of infinite thickness, as shown on the Boundary Condition form below.



Run Parameters

To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The Run Parameters form on the next page will be displayed. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. In this example the concentrations will be calculated at 4 years and at 14 depths from 0.5 to 10 m.



Model Execution

To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

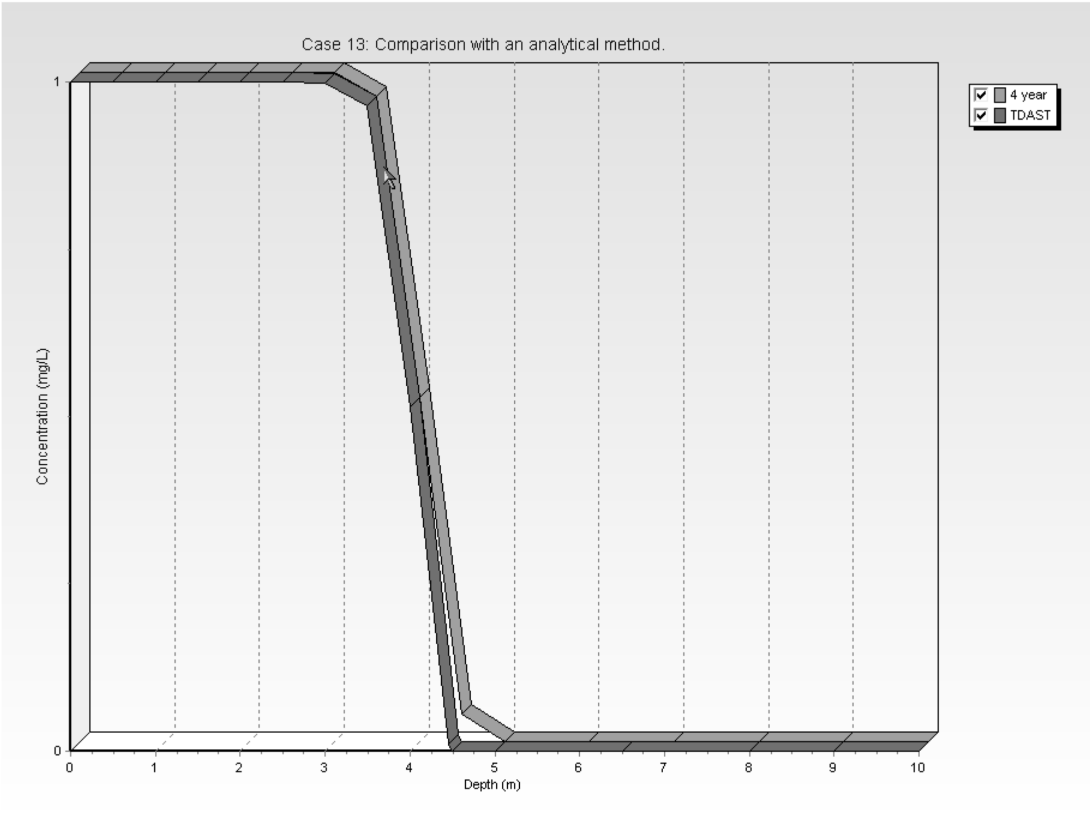
Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart on the next page can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.

Case 13: Comparison with Analytical Method



The results of the POLLUTE program are compared to those obtained by the TDAST program in the figure below. Concentrations obtained by both methods are in close agreement for a dispersion coefficient of 0.01 m2/a. However, it should be noted that at higher values of dispersion coefficient, for example 5 or 10 m^2/a, the POLLUTE program will not give the same result as TDAST. This is because POLLUTE considers only 1-dimensional migration in the layer below the source, whereas TDAST considers 2-dimensional migration.

Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 13: Comparison with an analytical method.

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 1 m/year

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Soil	10 m	20	0.01 m2/a	1	0 m3/kg	0 g/cm3

Boundary Conditions

Contant Concentration
Source Concentration = 1 mg/L

Infinite Thickness Bottom Boundary

Laplace Transform Parameters

TAU = 7 **N** = 100 **SIG** = 0 **RNU** = 10

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
4	0.000E+00	1.000E+00
	5.000E-01	1.000E+00
	1.000E+00	1.000E+00
	1.500E+00	1.000E+00
	2.000E+00	1.000E+00
	2.500E+00	1.000E+00

	3.000E+00	9.998E-01
	3.500E+00	9.646E-01
	4.000E+00	5.141E-01
	4.500E+00	4.133E-02
	5.000E+00	2.277E-04
	6.000E+00	1.928E-09
	7.000E+00	1.927E-09
	8.000E+00	1.927E-09
	9.000E+00	1.927E-09
	1.000E+01	1.927E-09

Case 14: Primary and Secondary Collection

Description

In this example a landfill with both a primary and a secondary leachate collection system is modelled using the Passive Sink special feature. The landfill contains a finite mass of a conservative contaminant species, and is underlain by an aquifer with fixed outflow. A passive sink is used to model the secondary leachate collection system, which is assumed to be composed of a 0.3 m thick granular layer. The Darcy velocity is assumed to be 0.01 m/a downward from the landfill to the secondary leachate collection system, and 0.0 m/a between the secondary leachate collection system and the aquifer (i.e., the water table is assumed to be at the base of the secondary leachate collection system).

The analysis starts at time zero which corresponds to the completion of the landfill and the development of a peak leachate concentration (c_o) of 1000 mg/L. It is assumed that the average waste thickness is 6.25 m with a density of 600 kg/m3, and that the contaminant represents 0.2% of the total mass of the waste. Thus the total mass of contaminant per unit area of landfill is:

$$m_{tc} = 0.002 * 600 * 6.25 = 7.5 \text{ kg/m}^2$$

The Reference Height of Leachate (H_r) is then calculated by dividing the total mass of contaminant per unit area (m_{tc}) by the contaminant concentration (c_o).

$$H_r = 0.002 * 600 * 6.25 / 1 = 7.5 \text{ m}$$

It is also assumed that the peak concentration in the landfill is reached relatively early in the life of the landfill, and that the analysis starts at this time. Consequently there is no increase in concentration with time and the Rate of Increase in Concentration (c_r) with time is zero.

The average infiltration through the cover (q_o) is assumed to be 0.3 m/a. If the average exfiltration through the base of the landfill (v_a) is 0.01 m/a, then the Volume of Leachate Collected is:

$$Q_c = q_o - v_a = 0.3 - 0.01 = 0.29 \text{ m/a}$$

The strata beneath the landfill consists of a 1 m clay layer, a 0.3 m granular layer (i.e., secondary leachate collection system), a 2 m aquitard layer, underlain by a 1 m thick aquifer. The landfill is assumed to be 200 m long in the direction parallel to the groundwater flow in the aquifer. At the up gradient edge of the landfill the inflow in the aquifer is given by a Darcy velocity of 4 m/a.

The outflow Darcy velocity at the down gradient edge of the landfill (v_b) is then by multiplying the landfill length (200 m) by the Darcy velocity below the secondary leachate collection system (0.0 m/a) and adding the inflow, viz:

$$v_b = 4 + 200 / 1 * v_a = 4 \text{ m/a}$$

When using the Passive Sink Properties special feature the deposit is divided into layers which can have vertical and horizontal flows In the example 3 layers are necessary, the first is from the base of the landfill to the top of the secondary leachate collection system, the second is the secondary leachate collection system, and the third is from the base of the secondary leachate collection system to the aquifer. In the first layer there is a vertical downwards Darcy velocity of 0.01 m/a and no horizontal flow. The second layer has a horizontal flow which is equal to the difference in Darcy velocity between the layers above and below, multiplied by the landfill length and divided by the layer thickness, viz:

$$v_s = (v_{a1} - v_{a2}) * L / h = (0.01 - 0.0) * 200 / 0.3 = 6.67 \text{ m/a}$$

In the third layer there is no vertical or horizontal advective flow, there will however still be diffusive flow.

Following are the parameters used in this example:

Property		**Value**	**Units**
Darcy Velocity	v_a	variable	m/a
Sink Outflow Velocity	v_s	variable	m/a
Diffusion Coefficient	D	variable	m^2/a
Distribution Coefficient	K_d	0.0	cm^3/g
Soil Porosity	n	0.4	-
Granular Layer Porosity	n	0.3	-
Dry Density		1.5	g/cm^3
Layer 1 Thickness	H	1.0	m
Layer 2 Thickness	H	0.3	m
Layer 3 Thickness	H	2.0	m
Source Concentration	c_o	1000	mg/L
Ref. Height of Leachate	H_r	7.5	m
Vol. of Leachate Collected	Q_c	0.29	m/a
Landfill Length	L	200.0	m
Landfill Width	W	1.0	m
Aquifer Thickness	h	1.0	m
Aquifer Porosity	n_b	0.3	-
Aquifer Outflow Velocity	v_b	4.0	m/a

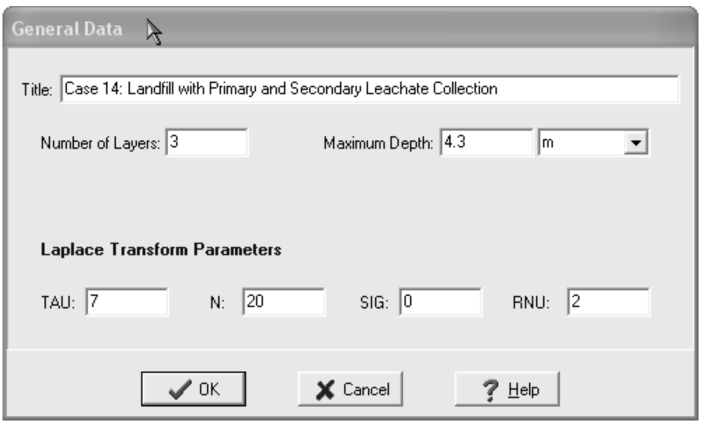
This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Passive Sink option. The example is not a prescription for modelling contaminant migration during operation of a landfill. Each landfill has its own unique characteristics and no general prescription can be made. The Passive Sink option should only by used by someone with the hydrogeotechnical background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation.

Data Entry

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 14 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

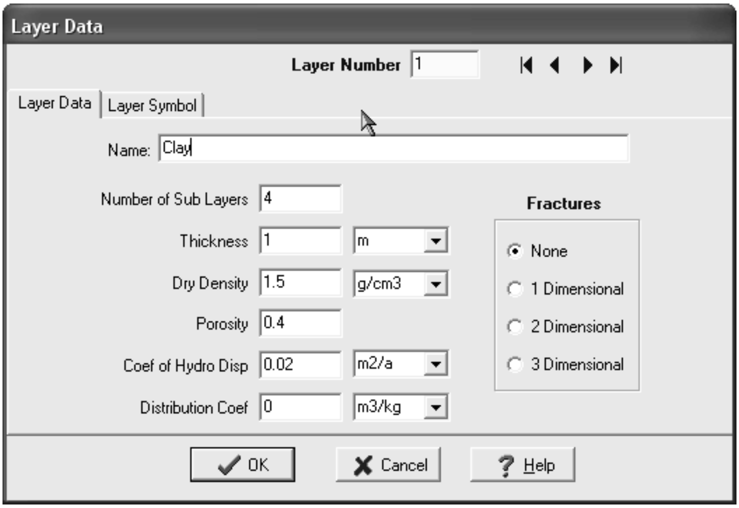
The general data for this example can be specified by either clicking on the title or selecting the General Data menu item from the Data Entry menu. The General Data form on the next page will be displayed. In this example the Darcy velocity will be ignored, the Darcy velocity will be read during the input of the Passive Sink parameters. After the Passive Sink special feature has been selected the Darcy velocity will no longer appear in the General Data form.



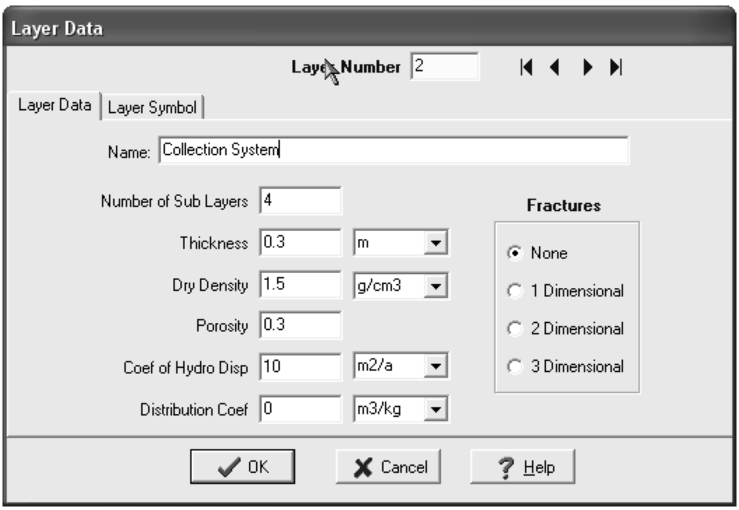
Layer Data

The layer data for the 3 layers can be specified by either clicking on a layer or selecting the Layer Data menu item from the Data Entry menu.

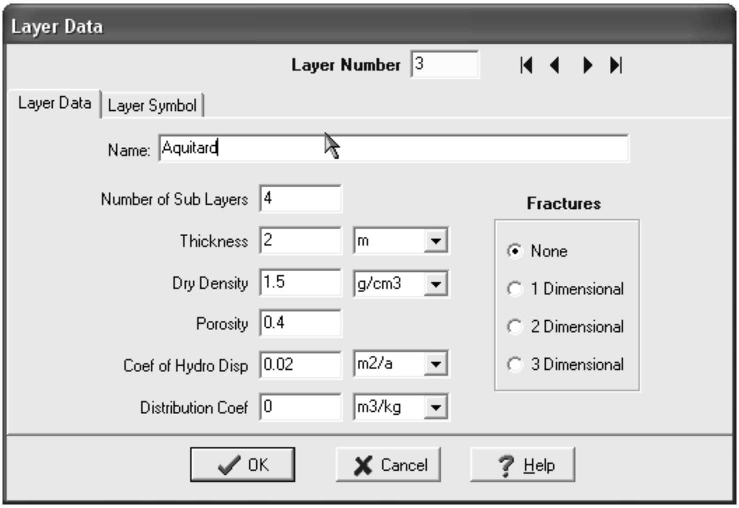
Layer 1



Layer 2

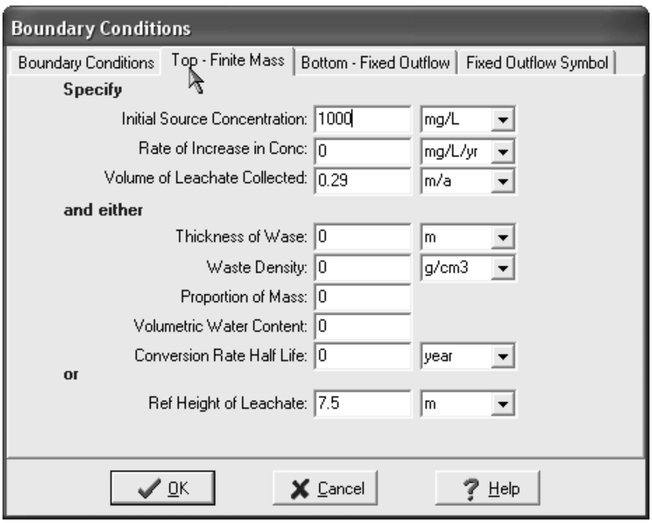


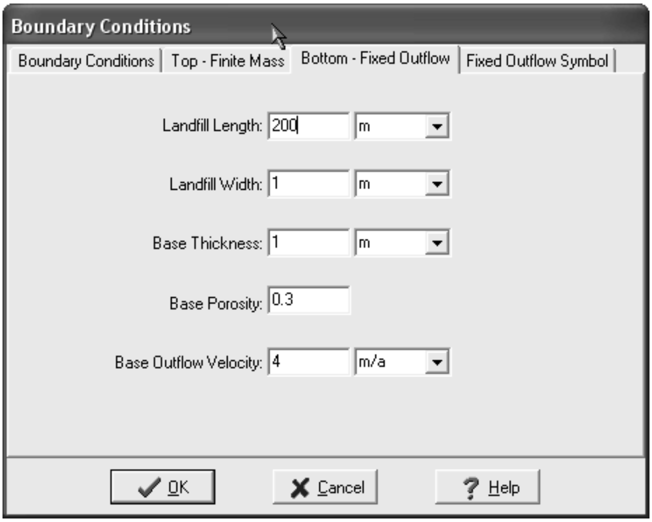
Layer 3



Boundary Conditions

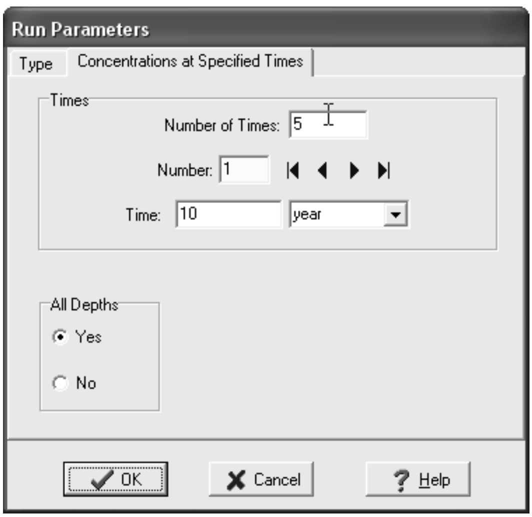
The boundary conditions for the model can be specified by either clicking on the top or bottom boundary or selecting the Boundary Conditions menu item from the Data Entry menu. In this example, the top boundary has a finite mass and the bottom boundary is represented by a fixed outflow aquifer, as shown on the Boundary Condition forms below.





Run Parameters

To set the times and depths to calculate the concentrations, select the Run Parameters menu item from the Data Entry menu. The Run Parameters form below will be displayed. The concentrations can either be calculated at specified times or the time of the maximum concentration can be found. In this example the concentrations will be calculated at 10, 25, 50, 100, and 150 years.

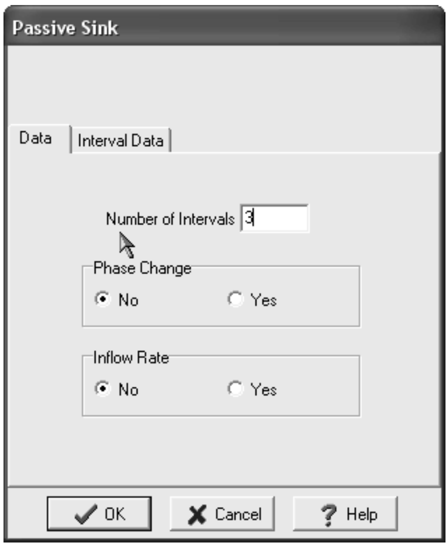


Special Features

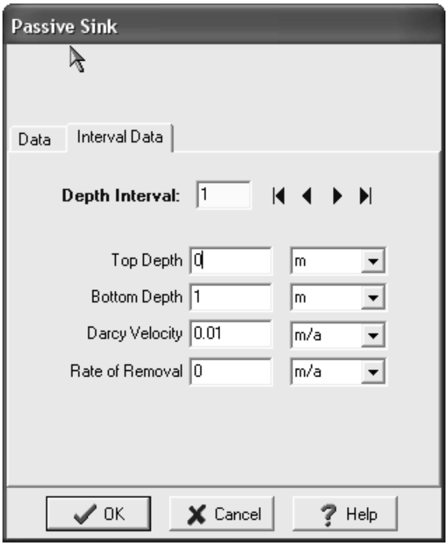
The passive sink data for this model can be entered using the Passive Sink menu item in the Special Features menu.

Passive Sink

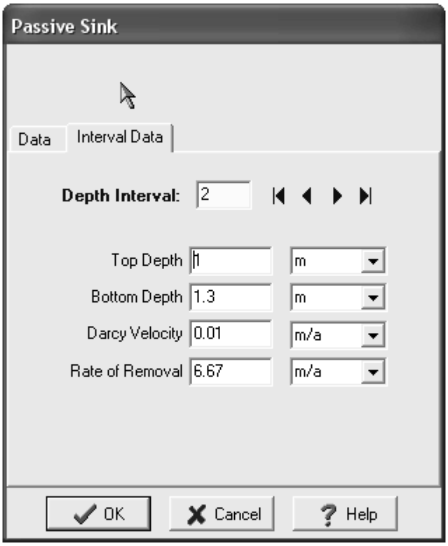
When the Passive Sink menu item is selected the Passive Sink form below will be displayed. On the Data tab the number of depths and whether there is a phase change or inflow can be specified. In this example there are 3 depth intervals. The first depth interval is for the clay liner, the second for the secondary leachate collection system, and the third for the aquitard.



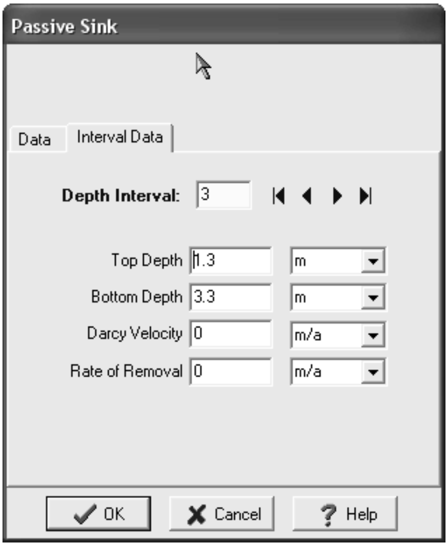
Sink Interval 1



Sink Interval 2



Sink Interval 3



Model Execution

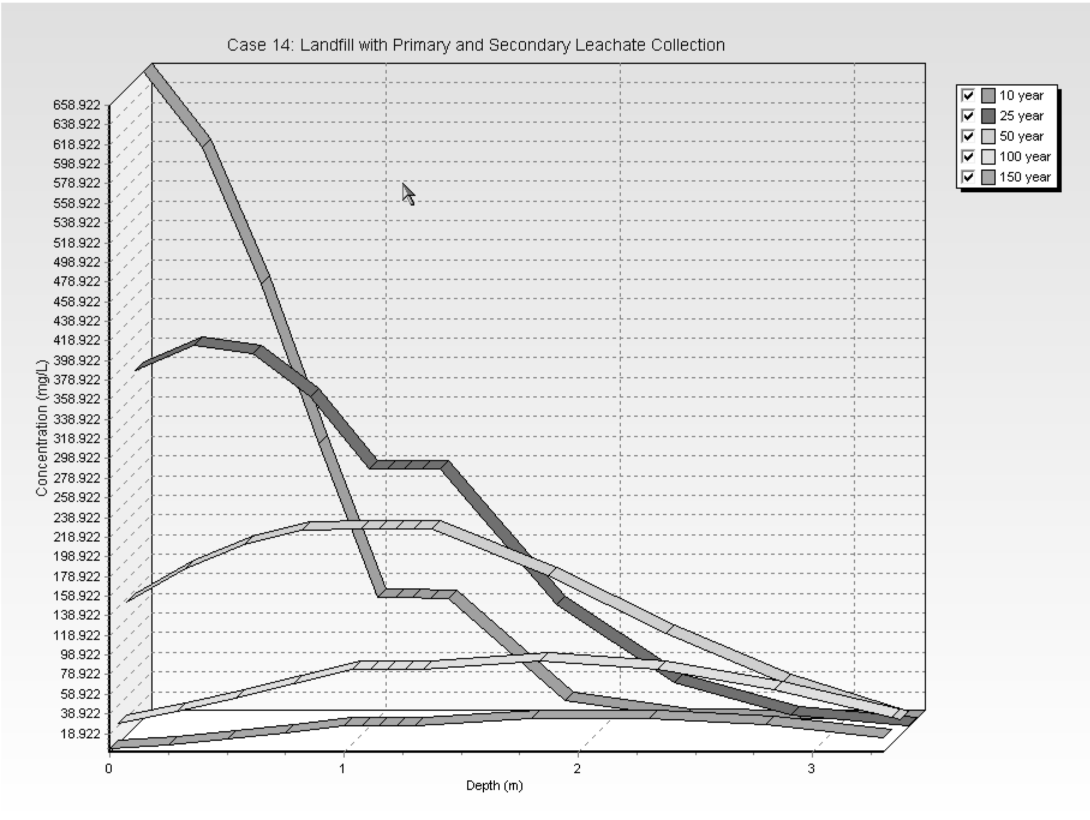
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 14: Landfill with Primary and Secondary Leachate Collection

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	1 m	4	0.02 m2/a	0.4	0 m3/kg	1.5 g/cm3
Collection System	0.3 m	4	10 m2/a	0.3	0 m3/kg	1.5 g/cm3
Aquitard	2 m	4	0.02 m2/a	0.4	0 m3/kg	1.5 g/cm3

Boundary Conditions

Finite Mass Top Boundary
Initial Concentration = 1000 mg/L
Rate of Increase = 0 mg/L/yr
Volume of Leachate Collected = 0.29 m/a
Thickness of Waste = 0 m
Waste Density = 0 g/cm3
Proportion of Mass = 0
Volumetric Water Content = 0
Conversion Rate Half Life = 0 year
Reference Height of Leachate = 7.5 m

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.3
Base Outflow Velocity = 4 m/a

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow
1	0 m	1 m	0.01 m/a	0 m/a
	1 m	1.3 m	0.01 m/a	6.67 m/a
	1.3 m	3.3 m	0 m/a	0 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time year	Depth m	Concentration mg/L
10	0.000E+00	6.589E+02
	2.500E-01	5.818E+02
	5.000E-01	4.425E+02
	7.500E-01	2.803E+02
	1.000E+00	1.231E+02
	1.075E+00	1.230E+02
	1.150E+00	1.229E+02
	1.225E+00	1.228E+02
	1.300E+00	1.228E+02
	1.800E+00	1.873E+01
	2.300E+00	1.587E+00
	2.800E+00	7.432E-02
	3.300E+00	5.162E-04
25	0.000E+00	3.627E+02
	2.500E-01	3.891E+02
	5.000E-01	3.801E+02
	7.500E-01	3.364E+02
	1.000E+00	2.632E+02
	1.075E+00	2.631E+02
	1.150E+00	2.631E+02
	1.225E+00	2.630E+02
	1.300E+00	2.630E+02
	1.800E+00	1.245E+02
	2.300E+00	4.525E+01
	2.800E+00	1.254E+01
	3.300E+00	1.337E+00
50	0.000E+00	1.363E+02
	2.500E-01	1.698E+02
	5.000E-01	1.948E+02
	7.500E-01	2.086E+02
	1.000E+00	2.097E+02
	1.075E+00	2.097E+02
	1.150E+00	2.098E+02
	1.225E+00	2.098E+02
	1.300E+00	2.098E+02
	1.800E+00	1.627E+02
	2.300E+00	1.040E+02
	2.800E+00	5.353E+01
	3.300E+00	1.598E+01
100	0.000E+00	2.019E+01
	2.500E-01	3.310E+01
	5.000E-01	4.699E+01
	7.500E-01	6.133E+01
	1.000E+00	7.553E+01
	1.075E+00	7.554E+01
	1.150E+00	7.556E+01
	1.225E+00	7.558E+01
	1.300E+00	7.560E+01
	1.800E+00	8.454E+01
	2.300E+00	7.584E+01
	2.800E+00	5.456E+01
	3.300E+00	2.635E+01

150	0.000E+00	3.300E+00
	2.500E-01	7.810E+00
	5.000E-01	1.322E+01
	7.500E-01	1.948E+01
	1.000E+00	2.649E+01
	1.075E+00	2.649E+01
	1.150E+00	2.650E+01
	1.225E+00	2.651E+01
	1.300E+00	2.652E+01
	1.800E+00	3.452E+01
	2.300E+00	3.469E+01
	2.800E+00	2.753E+01
	3.300E+00	1.491E+01

NOTICE

Case 15: Leachate Collection with Failure

Description

This example is similar to case 14 except the failure of the primary leachate collection system is also modelled using the Variable Properties special feature. Prior to the failure of the primary leachate collection system there is a downward Darcy velocity of 0.01 m/a between the landfill and the secondary leachate collection system. The primary leachate collection system is assumed to fail between 20 and 30 years, causing the leachate mound in the landfill to rise resulting in an increase in the Darcy velocity. After 30 years the collection system has completely failed and the Darcy velocity is now assumed to be 0.1 m/a.

As in case 14 the landfill contains a finite mass of a conservative species, and is underlain by an aquifer with fixed outflow. A passive sink is used to model the secondary leachate collection system, which is assumed to be composed of a 0.3 m thick granular layer. The Darcy velocity is assumed to be initially 0.01 m/a downward from the landfill to the secondary leachate collection system, and 0.0 m/a between the secondary leachate collection system and the aquifer (i.e., the water table is assumed to be at the base of the secondary leachate collection system).

The analysis starts at time zero which corresponds to the completion of the landfill and the development of a peak leachate concentration (c_o) of 1000 mg/L. As in example 14 the Reference Height of Leachate is 7.5 m, and the Rate of Increase in Concentration is zero.

The average infiltration through the cover (q_o) is assumed to be 0.3 m/a. If the average exfiltration through the base of the landfill v_a (which varies with time), then the Volume of Leachate Collected is:

$$Q_c = q_o - v_a = 0.3 - v_a$$

The strata beneath the landfill, landfill dimensions, and aquifer characteristics are the same as in example 14.

Passive sink layers are divided the same as in example 14, except that the Darcy velocity in the first layer and the outflow in the second layer will be variable. The Darcy velocity in the first layer will be 0.01 m/a between 0 and 20 years, then will increase linearly between 20 and 30 years to 0.1 m/a, and then will be 0.1 m/a.

In the second layer the horizontal outflow is equal to the difference in Darcy velocity between the layers above and below, multiplied by the landfill length and divided by the layer thickness, viz:

$$v_s = (v_{a2} - v_{a1}) * 200/0.3 \text{ m/a}$$

In the third layer there is no vertical or horizontal advective flow, there will however still be diffusive flow.

When using the Variable Properties special feature with the Passive special feature it is possible to specify the Darcy velocities in both features. The Darcy velocity used by POLLUTE will be the result from the multiplication of the two velocities. For most practical applications, it is recommended that the Darcy velocity be entered as 1.0 in one of the features, and then the actual value entered in the other feature. In this example the Darcy velocity is entered as 1.0 in the Variable Properties special feature, and the actual values are entered in the Passive Sink special feature.

Using the Variable Properties special feature the dispersivity can also be specified, in this example it is assumed to be 0.4 since there is outward flow from the landfill.

Following are the parameters used in this example:

Property		Value	Units
Darcy Velocity	v_a	variable	m/a
Sink Outflow Velocity	v_s	variable	m/a
Diffusion Coefficient	D	0.02	m^2/a
Dispersivity		0.4	m
Distribution Coefficient	K_d	0.0	cm^3/g
Soil Porosity	n	0.4	-
Granular Layer Porosity	n	0.3	-
Dry Density		1.5	g/cm^3
Layer 1 Thickness	H	1.0	m
Layer 2 Thickness	H	0.3	m
Layer 3 Thickness	H	2.0	m
Source Concentration	c_o	1000	mg/L
Ref. Height of Leachate	H_r	7.5	m
Vol. of Leachate Collected	Q_c	variable	m/a
Landfill Length	L	200.0	m
Landfill Width	W	1.0	m
Aquifer Thickness	h	1.0	m
Aquifer Porosity	n_b	0.3	-
Aquifer Outflow Velocity	v_b	4.0	m/a

When using the Variable Properties special feature the accuracy of the results is dependent on the number of sublayers used.

This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Variable Properties and Passive Sink option. The example is not a prescription for modelling contaminant migration during operation of a landfill. Each landfill has its own unique characteristics and no general prescription can be made. These options should only by used by someone with the hydrogeologic and engineering background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation.

Data Entry

*S*tart the POLLUTEv7 program and open the Examples project. Select Case 15 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

The general data for this example is the same as for Case 14, except that the title is different.

Layer Data

The layer data for this example is the same as for Case 14.

Boundary Conditions

The boundary conditions for this example is the same as for Case 14.

Run Parameters

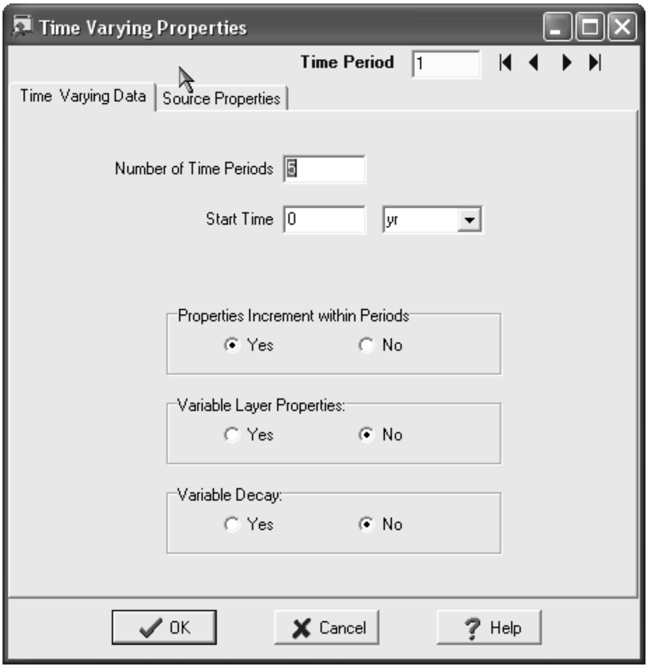
The run parameters for this example is the same as for Case 14.

Special Features

The time-varying data and passive sink data for this model can be entered using the Time-varying Data and Passive Sink menu items in the Special Features menu.

Time-varying Data

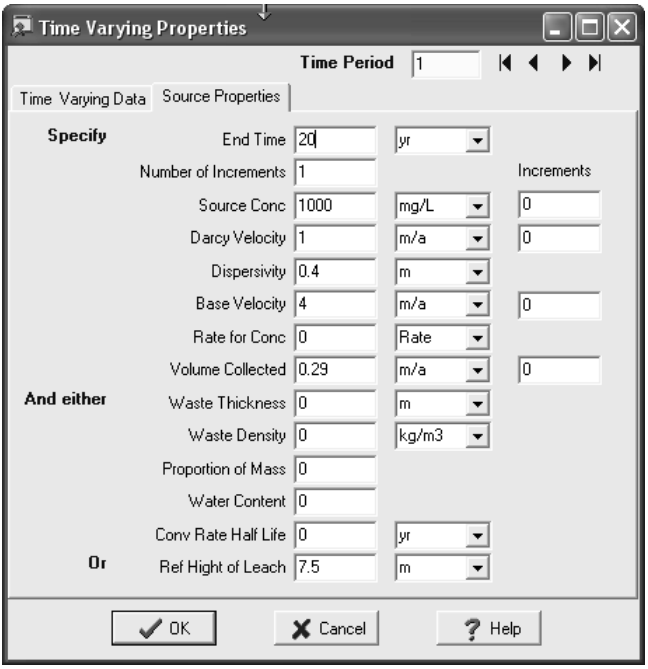
To specify the time-varying properties, select the Time-Varying Properties menu item from the Special Features form. The Time-Varying Data tab on the Time-Varying Properties form shown below can be used to specify the number of time periods and whether there are variable layer properties and variable decay. In this example there are 5 time periods.



Case 15: Leachate Collection with Failure

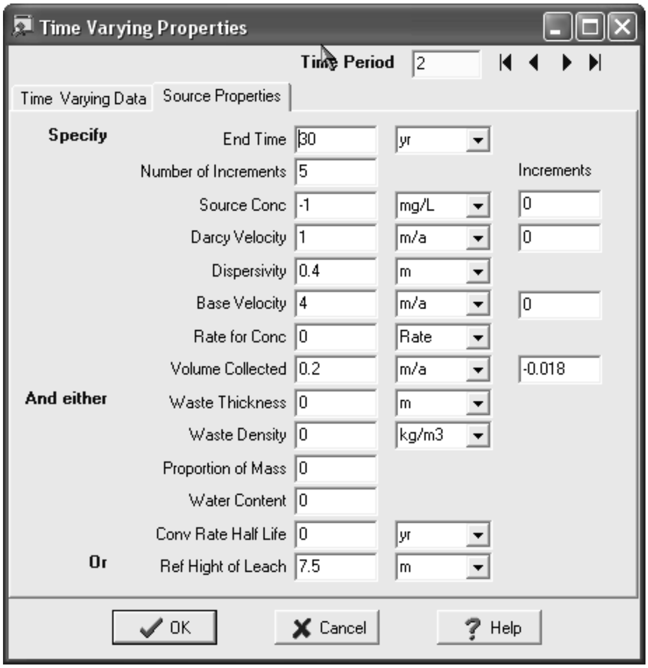
Time Period 1

The data for each time period is specified on the Source Properties tab shown on the next page. In the first time period, specifying only one time increment means that the concentrations will only be calculated at the end time (i.e., 20 years). The Darcy velocity is set to one here and will be entered in the Passive Sink option. Since this is the first time period the primary leachate collection system is still functioning and there is no increase in any of the above parameters.



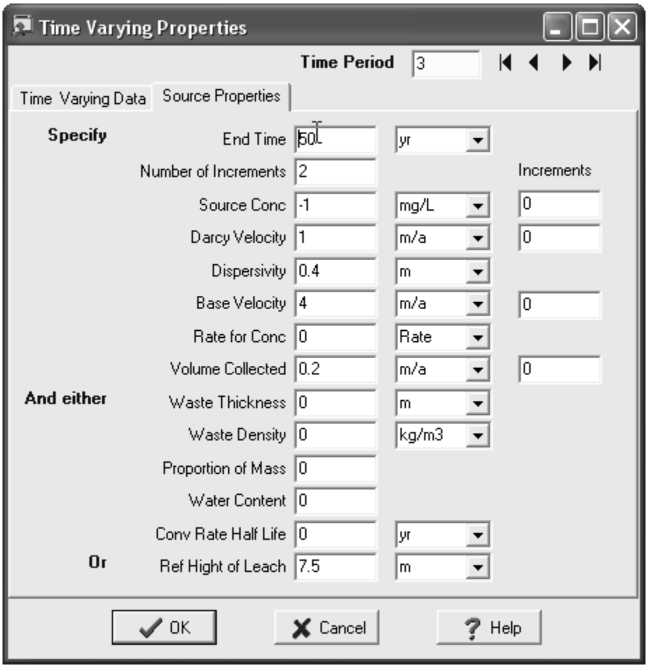
Time Period 2

The data for the second time period, from 20 to 30 years, can be specified by pressing the next arrow at the top of the form. The increment in the Leachate collected results from the increasing Darcy velocity during this period. This increase in Darcy velocity will be taken into account in the Passive Sink option.



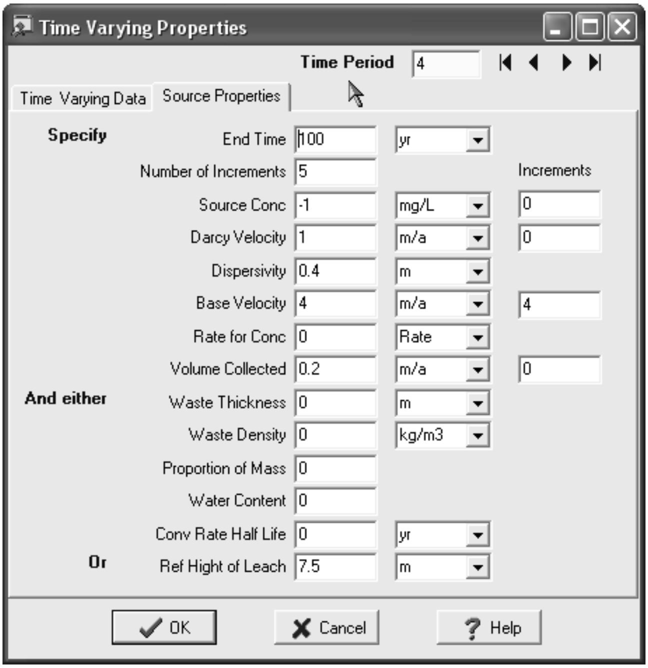
Time Period 3

Next the data for time period three from 30 to 50 years must now be entered.. Two increments are used to calculate the concentrations at 40 and 50 years. At this point the primary leachate collection system has completely failed and there is no further increase in the Darcy velocity. The Volume of Leachate collected is now equal to the infiltration through the cover 0.3 m/a minus the final Darcy velocity 0.1 m/a.



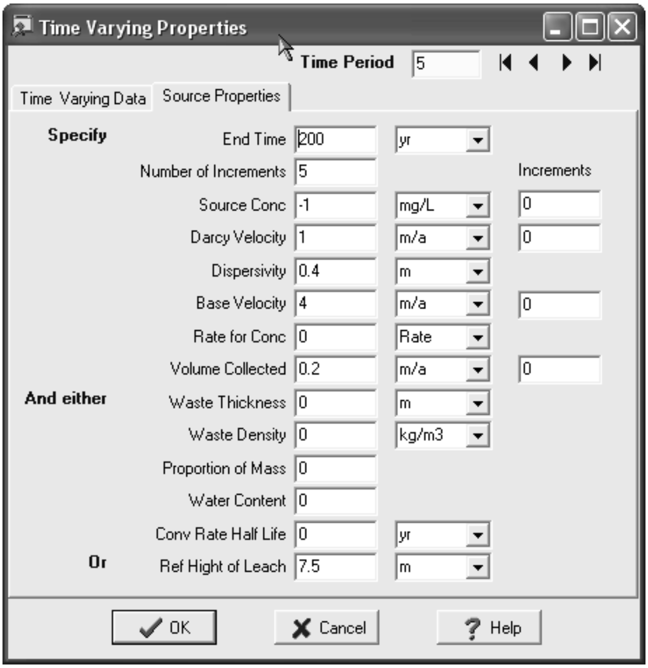
Time Period 4

The data for time period four should now be entered. Five increments are used to calculate the concentrations at 60, 70, 80, 90, and 100 years.



Time Period 5

Finally the data for time period five is entered.. Five increments are used to calculate the concentrations at 120, 140, 160, 180, and 200 years.



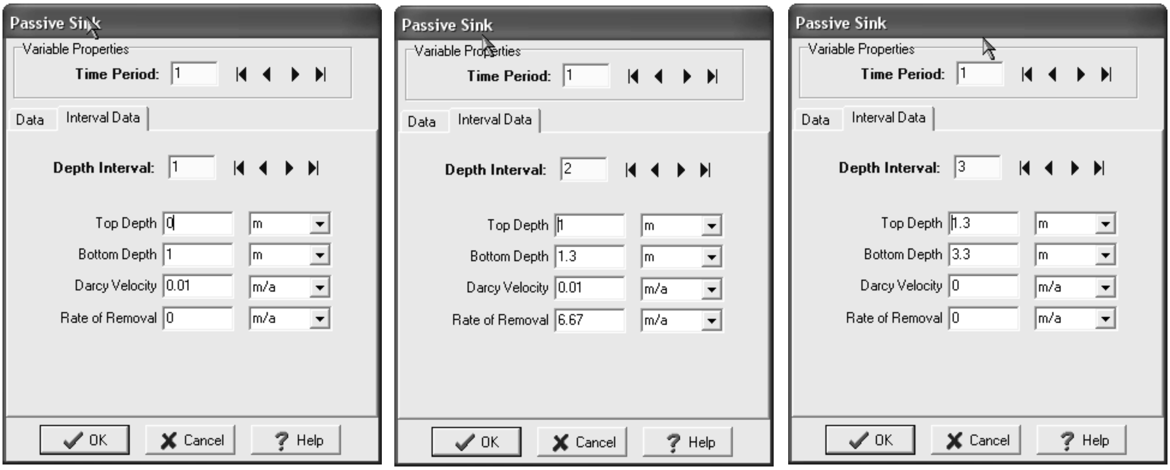
Passive Sink

When the Passive Sink menu item is selected the Passive Sink form on the next page will be displayed. On the Data tab the number of depths and whether there is a phase change or inflow can be specified. In this example there are 3 depth intervals. The first depth interval is for the clay liner, the second for the secondary leachate collection system, and the third for the aquitard.

When the Time-varying Properties special feature is also used, the current time period is displayed and controlled at the top of the form. The passive sink data must be entered for each time period.

Time Period 1

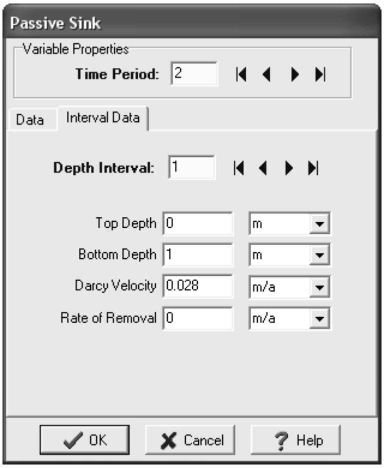
The first time period corresponds from 0 to 20 years. For this time period the data for the 3 passive sink depth intervals can be entered on the Interval tab as shown below.

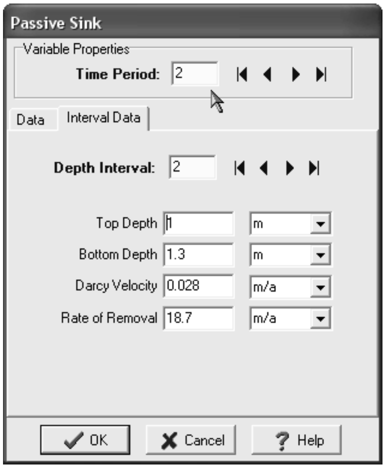


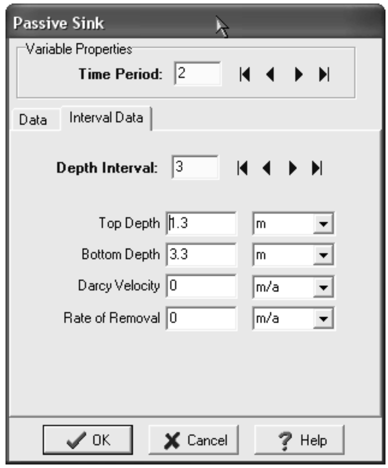
Time Period 2

The first time period corresponds from 20 to 30 years. For this time period the data for the 3 passive sink depth intervals can be entered on the Interval tab as shown on the next page. There is an increase in the Darcy velocity during this time period due to the failure of the primary leachate collection system. This will also result in a proportional increase in the Outflow velocity of the secondary leachate collection system as shown.

Case 15: Leachate Collection with Failure

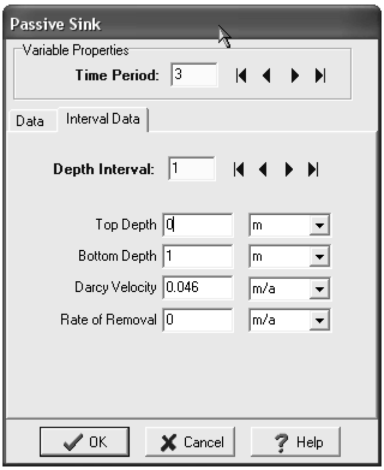


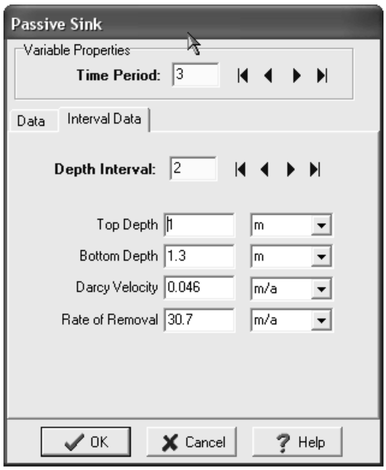


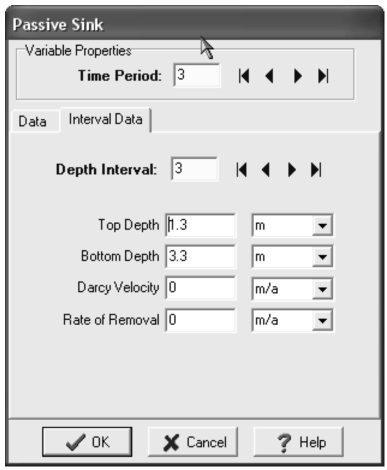


Time Period 3

The first time period corresponds from 30 to 50 years. For this time period the data for the 3 passive sink depth intervals can be entered on the Interval tab as shown below.

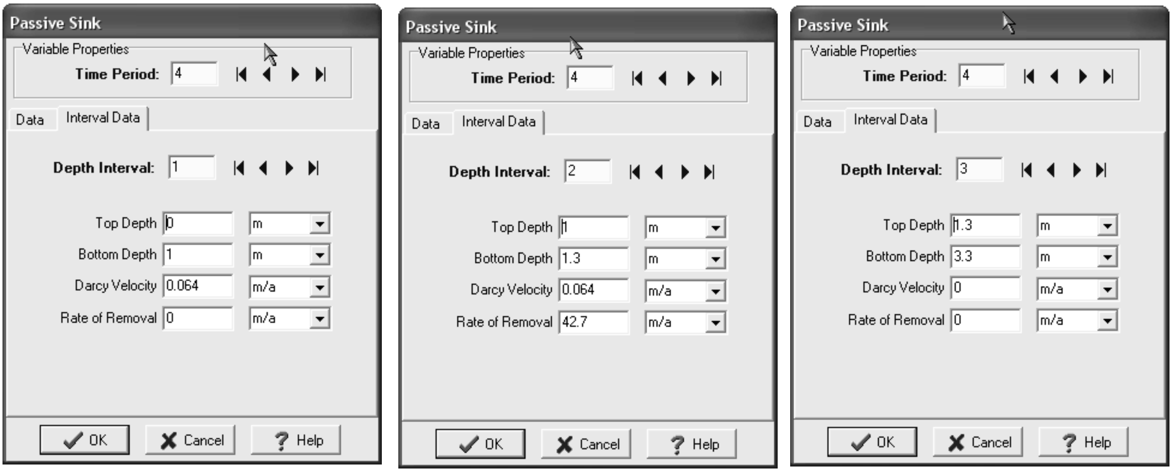






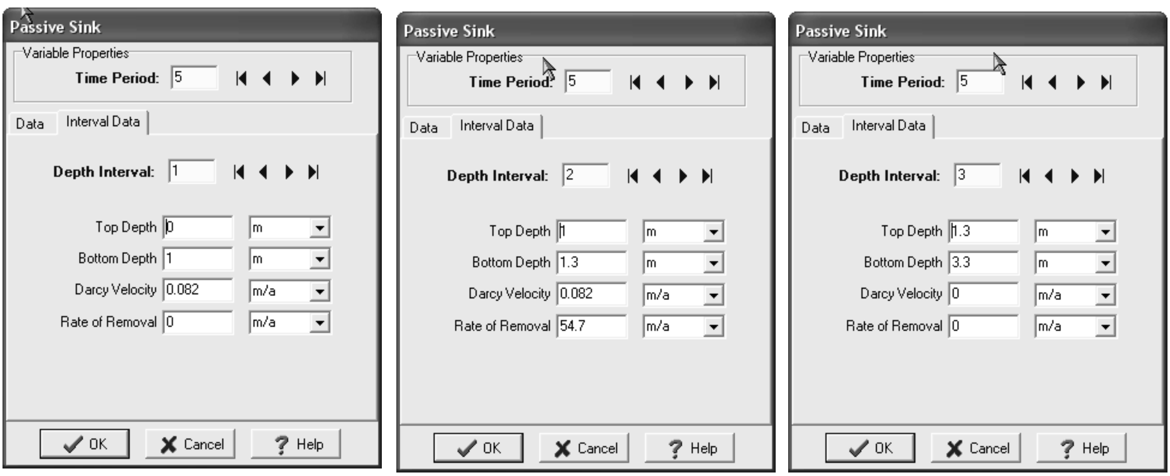
Time Period 4

The first time period corresponds from 50 to 100 years. For this time period the data for the 3 passive sink depth intervals can be entered on the Interval tab as shown below.



Time Period 5

The first time period corresponds from 100 to 200 years. For this time period the data for the 3 passive sink depth intervals can be entered on the Interval tab as shown below.



Model Execution

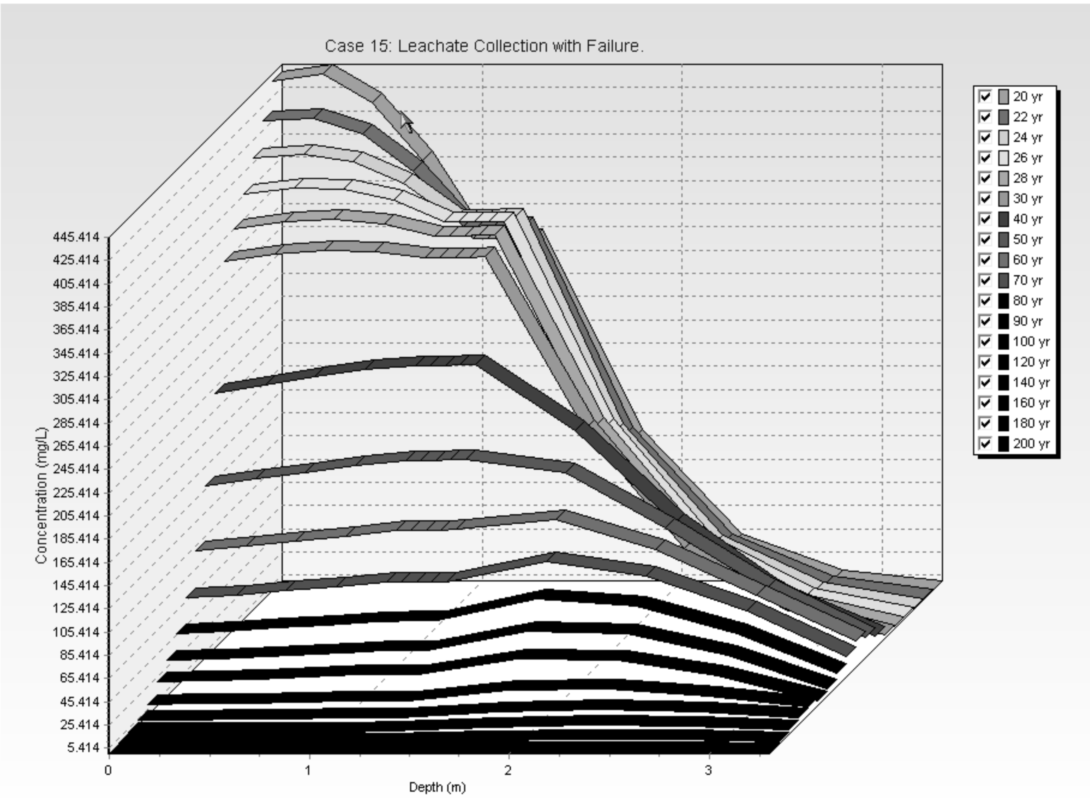
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 15: Leachate Collection with Failure.

THE VARIABLE VELOCITY AND/OR CONCENTRATION OPTION HAS BEEN USED
NOTE THAT THE ACCURACY OF THE CALCULATIONS WITH THIS OPTION WILL DEPEND ON THE NUMBER OF SUBLAYERS USED

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	1 m	4	0.02 m2/a	0.4	0 mL/g	1.5 g/cm3
Collection System	0.3 m	4	10 m2/a	0.3	0 mL/g	1.5 g/cm3
Aquitard	2 m	4	0.02 m2/a	0.4	0 mL/g	1.5 g/cm3

Boundary Conditions

Finite Mass Top Boundary

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.3

VARIATION IN PROPERTIES WITH TIME:

TIME PERIODS WITH THE SAME SOURCE AND VELOCITY

Period	Start Time	No. of Steps	Time Step	Source Conc	Rate of Change	Height of Leachate	Volume Collected
1	0 yr	1	20 yr	1000 mg/L	0	7.5 m	0.29 m/a
2	20 yr	5	2 yr	-1 mg/L	0	7.5 m	0.2 m/a
3	30 yr	2	10 yr	-1 mg/L	0	7.5 m	0.2 m/a
4	50 yr	5	10 yr	-1 mg/L	0	7.5 m	0.2 m/a
5	100 yr	5	20 yr	-1 mg/L	0	7.5 m	0.2 m/a

Period	Start Time	End Time	Darcy Velocity	Dispersivity	Base Velocity
1	0 yr	20 yr	1 m/a	0.4 m	4 m/a
2	20 yr	30 yr	1 m/a	0.4 m	4 m/a
3	30 yr	50 yr	1 m/a	0.4 m	4 m/a
4	50 yr	100 yr	1 m/a	0.4 m	4 m/a
5	100 yr	200 yr	1 m/a	0.4 m	4 m/a

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow
1	0 m	1 m	0.01 m/a	0 m/a
	1 m	1.3 m	0.01 m/a	6.67 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
2	0 m	1 m	0.028 m/a	0 m/a
	1 m	1.3 m	0.028 m/a	18.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
3	0 m	1 m	0.046 m/a	0 m/a
	1 m	1.3 m	0.046 m/a	30.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
4	0 m	1 m	0.064 m/a	0 m/a
	1 m	1.3 m	0.064 m/a	42.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
5	0 m	1 m	0.082 m/a	0 m/a
	1 m	1.3 m	0.082 m/a	54.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
6	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
7	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
8	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
9	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
10	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
11	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
12	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a

13	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
14	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
15	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
16	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
17	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
18	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth m	Concentration mg/L
20	0.000E+00	4.395E+02
	2.500E-01	4.454E+02
	5.000E-01	4.211E+02
	7.500E-01	3.712E+02
	1.000E+00	3.033E+02
	1.075E+00	3.033E+02
	1.150E+00	3.032E+02
	1.225E+00	3.032E+02
	1.300E+00	3.032E+02
	1.800E+00	1.307E+02
	2.300E+00	4.108E+01
	2.800E+00	9.391E+00
	3.300E+00	7.095E-01
22	0.000E+00	4.137E+02
	2.500E-01	4.158E+02
	5.000E-01	4.017E+02
	7.500E-01	3.701E+02
	1.000E+00	3.224E+02
	1.075E+00	3.223E+02
	1.150E+00	3.223E+02
	1.225E+00	3.224E+02
	1.300E+00	3.225E+02
	1.800E+00	1.411E+02

	7.500E-01	3.701E+02
	1.000E+00	3.224E+02
	1.075E+00	3.223E+02
	1.150E+00	3.223E+02
	1.225E+00	3.224E+02
	1.300E+00	3.225E+02
	1.800E+00	1.411E+02
	2.300E+00	4.899E+01
	2.800E+00	1.236E+01
	3.300E+00	1.062E+00
24	0.000E+00	3.895E+02
	2.500E-01	3.927E+02
	5.000E-01	3.861E+02
	7.500E-01	3.679E+02
	1.000E+00	3.372E+02
	1.075E+00	3.371E+02
	1.150E+00	3.372E+02
	1.225E+00	3.373E+02
	1.300E+00	3.376E+02
	1.800E+00	1.530E+02
	2.300E+00	5.647E+01
	2.800E+00	1.551E+01
	3.300E+00	1.518E+00
26	0.000E+00	3.667E+02
	2.500E-01	3.717E+02
	5.000E-01	3.705E+02
	7.500E-01	3.614E+02
	1.000E+00	3.426E+02
	1.075E+00	3.426E+02
	1.150E+00	3.427E+02
	1.225E+00	3.430E+02
	1.300E+00	3.434E+02
	1.800E+00	1.645E+02
	2.300E+00	6.390E+01
	2.800E+00	1.875E+01
	3.300E+00	2.077E+00
28	0.000E+00	3.454E+02
	2.500E-01	3.512E+02
	5.000E-01	3.531E+02
	7.500E-01	3.497E+02
	1.000E+00	3.388E+02
	1.075E+00	3.388E+02
	1.150E+00	3.390E+02
	1.225E+00	3.394E+02
	1.300E+00	3.399E+02
	1.800E+00	1.741E+02
	2.300E+00	7.118E+01
	2.800E+00	2.208E+01
	3.300E+00	2.737E+00
30	0.000E+00	3.253E+02
	2.500E-01	3.312E+02
	5.000E-01	3.345E+02
	7.500E-01	3.341E+02
	1.000E+00	3.282E+02
	1.075E+00	3.282E+02
	1.150E+00	3.285E+02
	1.225E+00	3.289E+02
	1.300E+00	3.296E+02

	1.300E+00	3.296E+02
	1.800E+00	1.808E+02
	2.300E+00	7.803E+01
	2.800E+00	2.547E+01
	3.300E+00	3.490E+00
40	0.000E+00	2.199E+02
	2.500E-01	2.276E+02
	5.000E-01	2.345E+02
	7.500E-01	2.401E+02
	1.000E+00	2.437E+02
	1.075E+00	2.437E+02
	1.150E+00	2.440E+02
	1.225E+00	2.443E+02
	1.300E+00	2.449E+02
	1.800E+00	1.881E+02
	2.300E+00	1.076E+02
	2.800E+00	4.712E+01
	3.300E+00	1.035E+01
50	0.000E+00	1.488E+02
	2.500E-01	1.546E+02
	5.000E-01	1.602E+02
	7.500E-01	1.656E+02
	1.000E+00	1.704E+02
	1.075E+00	1.705E+02
	1.150E+00	1.706E+02
	1.225E+00	1.709E+02
	1.300E+00	1.713E+02
	1.800E+00	1.603E+02
	2.300E+00	1.120E+02
	2.800E+00	5.985E+01
	3.300E+00	1.789E+01
60	0.000E+00	1.008E+02
	2.500E-01	1.050E+02
	5.000E-01	1.093E+02
	7.500E-01	1.138E+02
	1.000E+00	1.183E+02
	1.075E+00	1.184E+02
	1.150E+00	1.185E+02
	1.225E+00	1.187E+02
	1.300E+00	1.190E+02
	1.800E+00	1.282E+02
	2.300E+00	1.023E+02
	2.800E+00	6.254E+01
	3.300E+00	2.307E+01
70	0.000E+00	6.828E+01
	2.500E-01	7.132E+01
	5.000E-01	7.456E+01
	7.500E-01	7.808E+01
	1.000E+00	8.201E+01
	1.075E+00	8.206E+01
	1.150E+00	8.215E+01
	1.225E+00	8.230E+01
	1.300E+00	8.249E+01
	1.800E+00	9.970E+01
	2.300E+00	8.728E+01
	2.800E+00	5.698E+01
	3.300E+00	1.817E+01

80	0.000E+00	4.629E+01
	2.500E-01	4.847E+01
	5.000E-01	5.087E+01
	7.500E-01	5.358E+01
	1.000E+00	5.679E+01
	1.075E+00	5.682E+01
	1.150E+00	5.689E+01
	1.225E+00	5.699E+01
	1.300E+00	5.713E+01
	1.800E+00	7.584E+01
	2.300E+00	7.026E+01
	2.800E+00	4.642E+01
	3.300E+00	1.154E+01
90	0.000E+00	3.140E+01
	2.500E-01	3.295E+01
	5.000E-01	3.470E+01
	7.500E-01	3.674E+01
	1.000E+00	3.925E+01
	1.075E+00	3.927E+01
	1.150E+00	3.932E+01
	1.225E+00	3.939E+01
	1.300E+00	3.949E+01
	1.800E+00	5.637E+01
	2.300E+00	5.393E+01
	2.800E+00	3.537E+01
	3.300E+00	6.863E+00
100	0.000E+00	2.130E+01
	2.500E-01	2.240E+01
	5.000E-01	2.366E+01
	7.500E-01	2.516E+01
	1.000E+00	2.705E+01
	1.075E+00	2.707E+01
	1.150E+00	2.710E+01
	1.225E+00	2.715E+01
	1.300E+00	2.722E+01
	1.800E+00	4.101E+01
	2.300E+00	4.000E+01
	2.800E+00	2.597E+01
	3.300E+00	4.082E+00
120	0.000E+00	9.819E+00
	2.500E-01	1.037E+01
	5.000E-01	1.101E+01
	7.500E-01	1.182E+01
	1.000E+00	1.287E+01
	1.075E+00	1.288E+01
	1.150E+00	1.290E+01
	1.225E+00	1.293E+01
	1.300E+00	1.296E+01
	1.800E+00	2.176E+01
	2.300E+00	2.284E+01
	2.800E+00	1.723E+01
	3.300E+00	8.038E+00
140	0.000E+00	4.534E+00
	2.500E-01	4.811E+00
	5.000E-01	5.153E+00
	7.500E-01	5.595E+00
	1.000E+00	6.199E+00

	1.000E+00	6.199E+00
	1.075E+00	6.204E+00
	1.150E+00	6.213E+00
	1.225E+00	6.226E+00
	1.300E+00	6.243E+00
	1.800E+00	1.201E+01
	2.300E+00	1.374E+01
	2.800E+00	1.149E+01
	3.300E+00	6.350E+00
160	0.000E+00	2.099E+00
	2.500E-01	2.243E+00
	5.000E-01	2.428E+00
	7.500E-01	2.677E+00
	1.000E+00	3.030E+00
	1.075E+00	3.033E+00
	1.150E+00	3.038E+00
	1.225E+00	3.044E+00
	1.300E+00	3.052E+00
	1.800E+00	6.754E+00
	2.300E+00	8.230E+00
	2.800E+00	7.255E+00
	3.300E+00	4.279E+00
180	0.000E+00	9.745E-01
	2.500E-01	1.050E+00
	5.000E-01	1.151E+00
	7.500E-01	1.292E+00
	1.000E+00	1.498E+00
	1.075E+00	1.500E+00
	1.225E+00	1.505E+00
	1.300E+00	1.510E+00
	1.800E+00	3.809E+00
	2.300E+00	4.858E+00
	2.800E+00	4.426E+00
	3.300E+00	2.701E+00
200	0.000E+00	4.542E-01
	2.500E-01	4.945E-01
	5.000E-01	5.499E-01
	7.500E-01	6.294E-01
	1.000E+00	7.481E-01
	1.075E+00	7.490E-01
	1.150E+00	7.503E-01
	1.225E+00	7.522E-01
	1.300E+00	7.544E-01
	1.800E+00	2.144E+00
	2.300E+00	2.830E+00
	2.800E+00	2.637E+00
	3.300E+00	1.644E+00

Case 16: Monte Carlo Simulation

Description

In this example, Monte Carlo simulation will be used to examine the effect of uncertainty in the service life of a Primary Leachate Collection system. The landfill from example 15 will be used, except the time that the Primary Leachate Collection system begins to fail will vary between 20 and 50 years with a mode of 25 years. Case 15 should be reviewed prior to reading this example, where the implementation of the Variable Properties and Passive Sink special features are described in detail.

The parameters for this example are the same as in Case 15, except for the addition of the Monte Carlo parameters.

Property		Value	Units
Darcy Velocity	v_a	variable	m/a
Sink Outflow Velocity	v_s	variable	m/a
Diffusion Coefficient	D	0.02	m^2/a
Dispersivity		0.4	m
Distribution Coefficient	K	0.0	cm^3/g
Soil Porosity	n	0.4	-
Granular Layer Porosity	n	0.3	-
Dry Density		1.5	g/cm^3
Layer 1 Thickness	H	1.0	m
Layer 2 Thickness	H	0.3	m
Layer 3 Thickness	H	2.0	m
Source Concentration	c_o	1000	mg/L
Ref. Height of Leachate	H_r	7.5	cm
Vol. of Leachate Collected	Q_c	variable	m/a
Landfill Length	L	200.0	m
Landfill Width	W	1.0	m
Aquifer Thickness	h	1.0	m
Aquifer Porosity	n_b	0.3	-
Aquifer Outflow Velocity	v_b	4.0	m/a
Minimum Failure Start Time		20	a
Modal Failure Start Time		25	a
Maximum Failure Start Time		50	a

This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Variable Properties and Passive Sink option. The example is not a prescription for modelling contaminant migration during operation of a landfill. Each landfill has its own unique characteristics and no general prescription can be made. These options should only by used by someone with the hydrogeologic and engineering background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation. This option should not be used for an actual project of importance without the guidance of the program developers.

The use of the Monte Carlo simulation feature for the variation of Variable Properties time periods should be done in consultation with the program developers, since it requires a very thorough knowledge of the program.

Data Entry

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*S*tart the POLLUTEv7 program and open the Examples project. Select Case 16 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

The general data for this example is the same as for Case 15, except that the title is different.

Layer Data

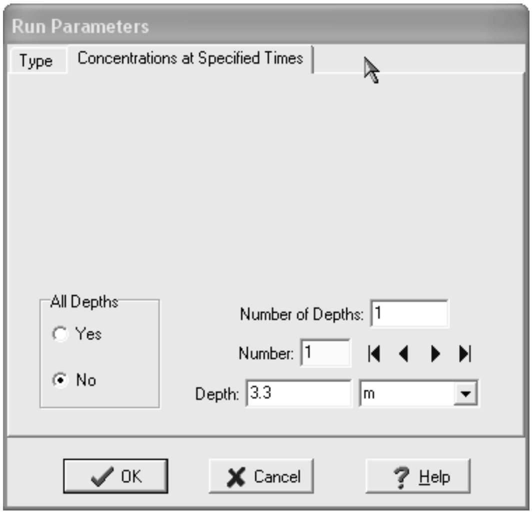
The layer data for this example is the same as for Case 15.

Boundary Conditions

The boundary conditions for this example is the same as for Case 15.

Run Parameters

The run parameters for this example are the same as for Case 15, except that the concentrations will be only be calculated at a depth off 3.3 m. This depth corresponds to the base of the aquitard.



Special Features

The time-varying data, passive sink, and Monte Carlo simulation data for this model can be entered using the Time-varying Data and Passive Sink menu items in the Special Features menu.

Time-Varying Properties

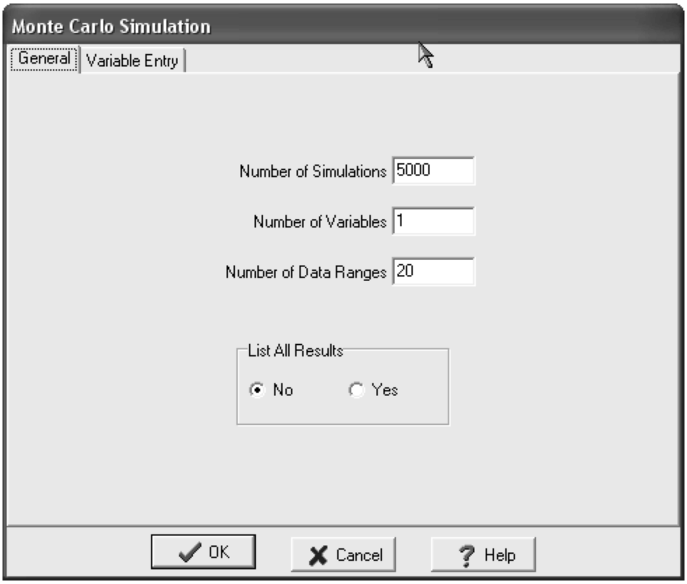
The time-varying properties for this example is the same as for Case 15.

Passive Sink

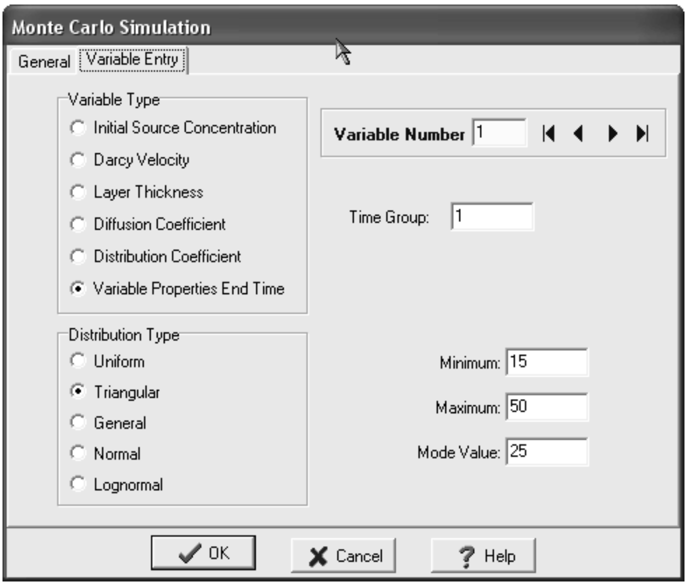
The passive sink data for this example is the same as for Case 15.

Monte Carlo Simulation

The Monte Carlo simulation data can be specified by selecting the Monte Carlo Simulation menu item from the Special Features menu, the form below will be displayed. The number of simulations, variables, and data ranges can be specified on the General tab. The number of simulations is usually between 1000 and 10000. However, the time to compute this many simulations may be quite large. It is suggested as a trial to use less than 50 simulations. In this example we are only going to have one variable.



On the Variable Entry tab below, the type and distribution for the variable can be specified. To vary the failure time of the Primary Leachate Collection system, the Variable Properties end time that corresponds to the time of failure in the input data set is used.



Model Execution

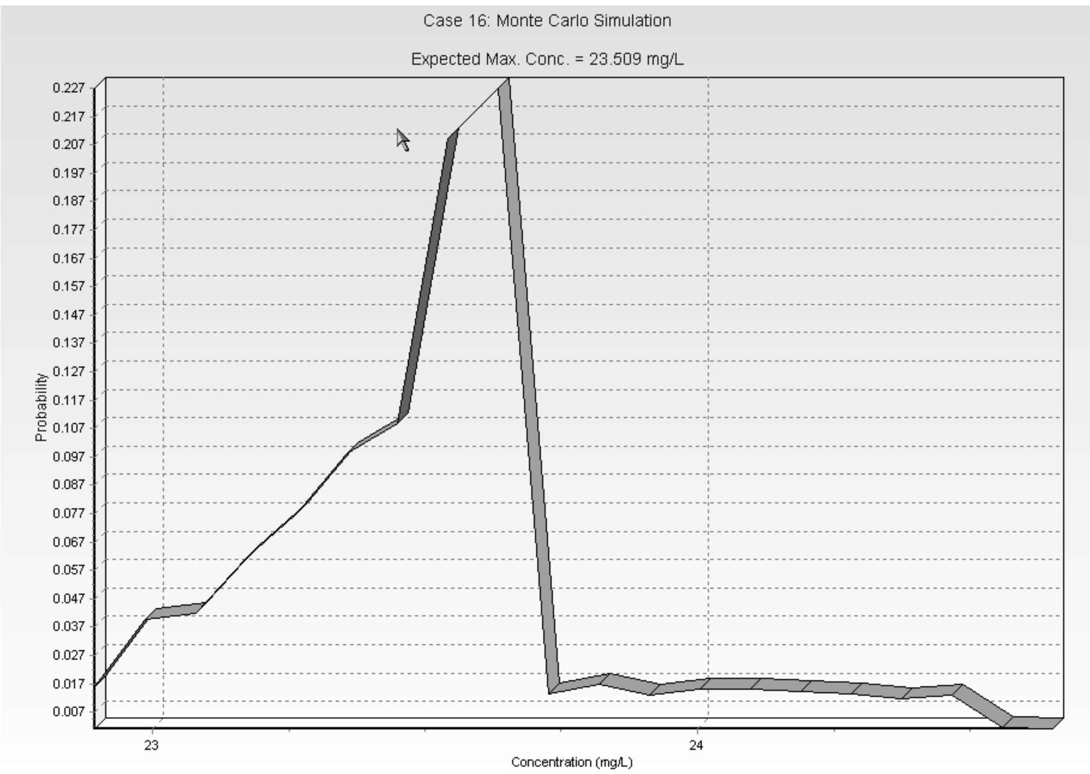
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Distribution of Peak Concentration

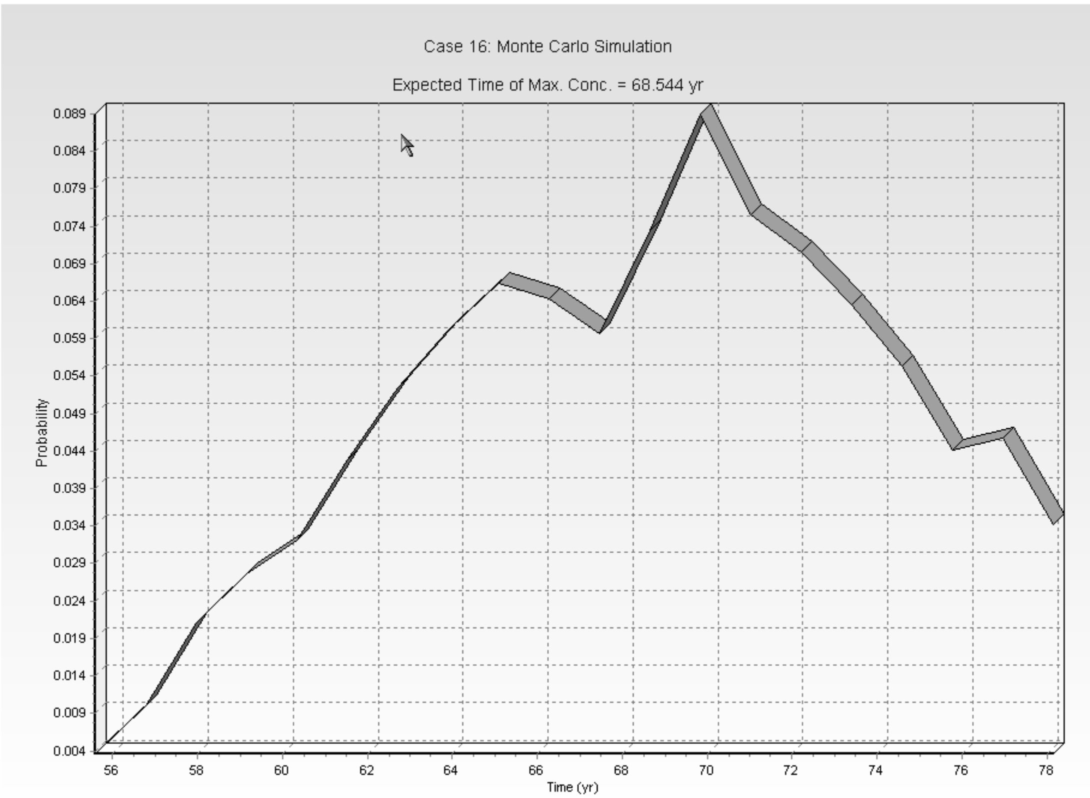
The Distribution of Peak Concentration chart below can be displayed by pressing the Distribution of Peak Concentration button on the Output toolbar or selecting the Distribution of Peak Concentration menu item from the Output menu.



Using the chart of the probability of peak chloride concentration predictions can be made about the concentration in the aquifer. For example, in this case, the expected maximum concentration is 23.5 mg/L.

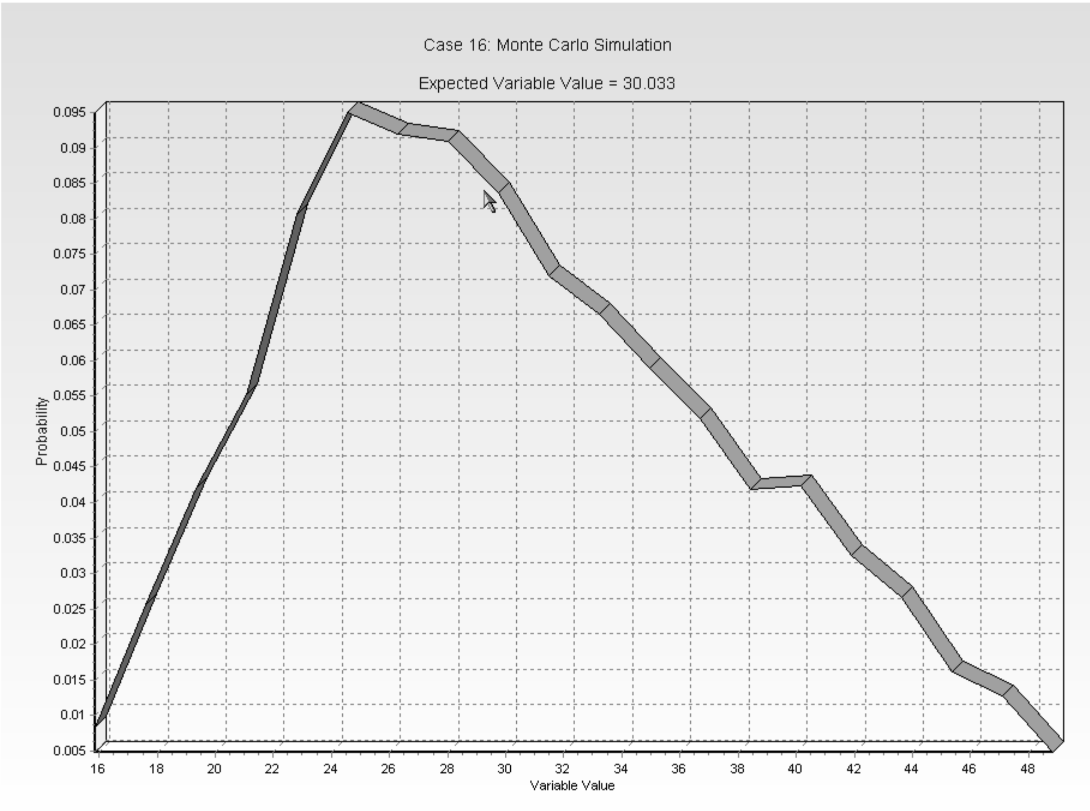
Distribution of the Time of Peak Concentration

The Distribution of the Time Peak Concentration chart below can be displayed by pressing the Distribution of Time of Peak Concentration button on the Output toolbar or selecting the Distribution of Time of Peak Concentration menu item from the Output menu. Using this chart the expected time of the maximum concentration can be predicted. In this example, the expected time is 68.5 years.



Distribution of Variable

The Distribution of Variable chart below can be displayed by pressing the Distribution of Variable button on the Output toolbar or selecting the Distribution of Variable menu item from the Output menu. Using this chart the distribution of the variable can be checked against the distribution that was specified. In this example, the specified distribution was a triangular distribution with a minimum of 15, mode of 25 and maximum of 50.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 16: Monte Carlo Simulation

THE VARIABLE VELOCITY AND/OR CONCENTRATION OPTION HAS BEEN USED
NOTE THAT THE ACCURACY OF THE CALCULATIONS WITH THIS OPTION WILL DEPEND ON THE NUMBER OF SUBLAYERS USED

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	1 m	4	0.02 m2/a	0.4	0 cm3/g	1.5 g/cm3
Collection System	0.3 m	4	10 m2/a	0.3	0 cm3/g	1.5 g/cm3
Aquitard	2 m	4	0.02 m2/a	0.4	0 cm3/g	1.5 g/cm3

Boundary Conditions

Finite Mass Top Boundary

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.3

VARIATION IN PROPERTIES WITH TIME:

Period	Start Time	No. of Steps	Time Step	Source Conc	Rate of Change	Height of Leachate	Volume Collected
1	0 yr	1	20 yr	1000 mg/L	0	7.5 m	0.29 m/a
2	20 yr	5	2 yr	-1 mg/L	0	7.5 m	0.2 m/a
3	30 yr	2	10 yr	-1 mg/L	0	7.5 m	0.2 m/a
4	50 yr	5	10 yr	-1 mg/L	0	7.5 m	0.2 m/a
5	100 yr	5	20 yr	-1 mg/L	0	7.5 m	0.2 m/a

Period	Start Time	End Time	Darcy Velocity	Dispersivity	Base Velocity
1	0 yr	20 yr	1 m/a	0.4 m	4 m/a
2	20 yr	30 yr	1 m/a	0.4 m	4 m/a
3	30 yr	50 yr	1 m/a	0.4 m	4 m/a
4	50 yr	100 yr	1 m/a	0.4 m	4 m/a
5	100 yr	200 yr	1 m/a	0.4 m	4 m/a

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow
1	0 m	1 m	0.01 m/a	0 m/a
	1 m	1.3 m	0.01 m/a	6.67 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
2	0 m	1 m	0.028 m/a	0 m/a
	1 m	1.3 m	0.028 m/a	18.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
3	0 m	1 m	0.046 m/a	0 m/a
	1 m	1.3 m	0.046 m/a	30.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
4	0 m	1 m	0.064 m/a	0 m/a
	1 m	1.3 m	0.064 m/a	42.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
5	0 m	1 m	0.082 m/a	0 m/a
	1 m	1.3 m	0.082 m/a	54.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
6	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
7	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
8	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
9	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
10	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
11	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
12	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
13	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
14	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a
15	0 m	1 m	0.1 m/a	0 m/a
	1 m	1.3 m	0.1 m/a	66.7 m/a
	1.3 m	3.3 m	0 m/a	0 m/a

16	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
17	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
18	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Monte Carlo Simulation Results

Number of Simulations = 5000
Number of Variables = 1
Number of Data Ranges = 20

Variable # 1 Variable Properties End Time
Time Period = 1
Triangular Distribution (Minimum = 15 Maximum = 50 Mode = 25)

Depth = 3.3

DISTRIBUTION OF PEAK CONCENTRATION

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
2.285E+01	2.294E+01	78	0.02	0.02	3.572E-01
2.294E+01	2.303E+01	196	0.04	0.05	9.011E-01
2.303E+01	2.313E+01	208	0.04	0.10	9.601E-01
2.313E+01	2.322E+01	304	0.06	0.16	1.409E+00
2.322E+01	2.331E+01	383	0.08	0.23	1.782E+00
2.331E+01	2.340E+01	489	0.10	0.33	2.284E+00
2.340E+01	2.350E+01	541	0.11	0.44	2.537E+00
2.350E+01	2.359E+01	1044	0.21	0.65	4.916E+00
2.359E+01	2.368E+01	1133	0.23	0.88	5.356E+00
2.368E+01	2.377E+01	66	0.01	0.89	3.132E-01
2.377E+01	2.387E+01	83	0.02	0.91	3.954E-01
2.387E+01	2.396E+01	64	0.01	0.92	3.061E-01
2.396E+01	2.405E+01	73	0.01	0.93	3.505E-01
2.405E+01	2.414E+01	73	0.01	0.95	3.518E-01
2.414E+01	2.424E+01	69	0.01	0.96	3.338E-01
2.424E+01	2.433E+01	65	0.01	0.97	3.157E-01
2.433E+01	2.442E+01	57	0.01	0.99	2.779E-01
2.442E+01	2.451E+01	64	0.01	1.00	3.132E-01
2.451E+01	2.461E+01	6	0.00	1.00	2.947E-02
2.461E+01	2.470E+01	4	0.00	1.00	1.972E-02

Expected Maximum Concentration = 2.351E+01

DISTRIBUTION OF TIME OF PEAK CONCENTRATION

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
5.500E+01	5.619E+01	20	0.00	0.00	2.224E-01
5.619E+01	5.737E+01	52	0.01	0.01	5.905E-01
5.737E+01	5.856E+01	107	0.02	0.04	1.241E+00
5.856E+01	5.975E+01	140	0.03	0.06	1.656E+00
5.975E+01	6.094E+01	163	0.03	0.10	1.967E+00
6.094E+01	6.212E+01	216	0.04	0.14	2.658E+00
6.212E+01	6.331E+01	264	0.05	0.19	3.311E+00
6.331E+01	6.450E+01	303	0.06	0.25	3.873E+00
6.450E+01	6.568E+01	334	0.07	0.32	4.348E+00
6.568E+01	6.687E+01	324	0.06	0.38	4.295E+00
6.687E+01	6.806E+01	300	0.06	0.44	4.048E+00
6.806E+01	6.925E+01	369	0.07	0.52	5.067E+00
6.925E+01	7.043E+01	447	0.09	0.61	6.244E+00
7.043E+01	7.162E+01	380	0.08	0.68	5.398E+00
7.162E+01	7.281E+01	355	0.07	0.75	5.127E+00
7.281E+01	7.400E+01	320	0.06	0.82	4.698E+00
7.400E+01	7.518E+01	279	0.06	0.87	4.162E+00
7.518E+01	7.637E+01	223	0.04	0.92	3.380E+00
7.637E+01	7.756E+01	231	0.05	0.97	3.556E+00
7.756E+01	7.874E+01	173	0.03	1.00	2.704E+00

Expected Time of Maximum Concentration = 68.5444649240847

VARIABLE NUMBER: 1

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
1.500E+01	1.674E+01	42	0.01	0.01	1.333E-01
1.674E+01	1.847E+01	128	0.03	0.03	4.506E-01
1.847E+01	2.021E+01	210	0.04	0.08	8.122E-01
2.021E+01	2.194E+01	276	0.06	0.13	1.163E+00
2.194E+01	2.368E+01	403	0.08	0.21	1.838E+00
2.368E+01	2.541E+01	475	0.10	0.31	2.332E+00
2.541E+01	2.715E+01	460	0.09	0.40	2.418E+00
2.715E+01	2.888E+01	455	0.09	0.49	2.549E+00
2.888E+01	3.062E+01	418	0.08	0.57	2.487E+00
3.062E+01	3.235E+01	360	0.07	0.65	2.267E+00
3.235E+01	3.409E+01	333	0.07	0.71	2.212E+00
3.409E+01	3.582E+01	295	0.06	0.77	2.062E+00
3.582E+01	3.756E+01	259	0.05	0.82	1.901E+00
3.756E+01	3.929E+01	209	0.04	0.86	1.606E+00
3.929E+01	4.103E+01	212	0.04	0.91	1.703E+00
4.103E+01	4.276E+01	163	0.03	0.94	1.366E+00
4.276E+01	4.450E+01	133	0.03	0.97	1.161E+00
4.450E+01	4.623E+01	81	0.02	0.98	7.349E-01
4.623E+01	4.797E+01	64	0.01	1.00	6.029E-01
4.797E+01	4.970E+01	24	0.00	1.00	2.344E-01

Expected Value = 3.003E+01

Case 17: Landfill with Composite Primary Liner

Description

This example demonstrates how to create a landfill with a composite primary liner, primary and secondary leachate collection systems, and a compacted clay secondary liner. The composite primary liner is composed of a 60 mil (1.5 mm) geomembrane in good contact with a 0.9 m thick compacted clay liner. Small holes with an area of 0.1 cm^2 and a frequency of 2.5 per hectare (1 per acre) are assumed for the geomembrane. The method proposed by Giroud et al (1992) is used to calculate the flow (leakage) through the composite liner, these calculations are performed automatically by POLLUTE. Below the composite primary liner is a 0.3 m thick granular secondary leachate collection system, overlying a 0.9 m thick compacted clay secondary liner. There is a 3 m thick aquitard under the secondary liner, which overlies a 3 m thick aquifer.

The landfill has a length (L) of 200 m in the direction parallel to groundwater flow in the underlying aquifer. Consideration is being given to a volatile organic contaminant with an initial source concentration of 1500 µg/L, which is assumed to remain constant with time over the time period being examined in this example. The leachate head on the composite primary liner is assumed to be constant at 0.3 m, the head on the secondary liner is assumed to be 0.3 m, and the groundwater level relative to the top of the aquifer is assumed to be 3 m (i.e., at the top of the aquitard).

The flow in the aquifer must be established based on hydrogeologic data and is represented in terms of the horizontal Darcy velocity (the “Base Outflow Velocity”) in the aquifer at the down-gradient edge of the landfill (see Example 3 for more discussion of Base Outflow Velocity and Aquifer thickness). The parameters used for this example are listed below:

Property		**Value**	**Units**
Geomembrane Contact		Good	-
Geomembrane Holes		Circles	-
Hole Area		0.1	cm^2
Hole Frequency		1	/acre
Geomembrane Thickness		60	mil
Geomembrane Diffusion Coef.		$3.0x10^{-5}$	m^2/a
Source Concentration	c_o	1500	µg/L
Source Type		Constant	-
Landfill Length	L	200	m
Leachate Head on Primary Liner		0.3	m
Leachate Head on Secondary Liner		0.3	m
Groundwater level in Aquifer		3.0	m
Clay Thickness	H	0.9	m
Clay Diffusion Coef.	D	0.02	m^2/a

Property		Value	Units
Clay Distribution Coef.	K_d	0.5	mL/g
Clay Hydraulic Conductivity	k	$1.0x10^{-9}$	m/s
Clay Porosity	n	0.35	-
Clay Dry Density		1.9	g/cm^3
Collection System Thickness	H	0.3	m
Collection System Dispersion Coef.		100	m^2/a
Collection System Density		1.9	g/cm^3
Collection System Distr. Coef.	K_d	0.0	mL/g
Collection System Porosity	n	0.3	-
Aquitard Thickness	H	3.0	m
Aquitard Hydraulic Conductivity	k	$1.0x10^{-5}$	m/s
Aquitard Diffusion Coef.	D	0.02	m^2/a
Aquitard Dry Density		1.9	g/cm^3
Aquitard Distribution Coef.	K_d	0.0	mL/g
Aquitard Porosity	n	0.35	-
Aquifer Thickness	h	3.0	m
Aquifer Porosity	n_b	0.3	-
Base Outflow Velocity	v_b	10	m/a

Data Entry

Start the POLLUTEv7 program and open the Examples project. Select Case 17 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model. The data for this type of model is entered differently than the previous models, since it was created using the Primary and Secondary Liner Landfill quick model. The Data Entry menu has two items, model parameters and run parameters.

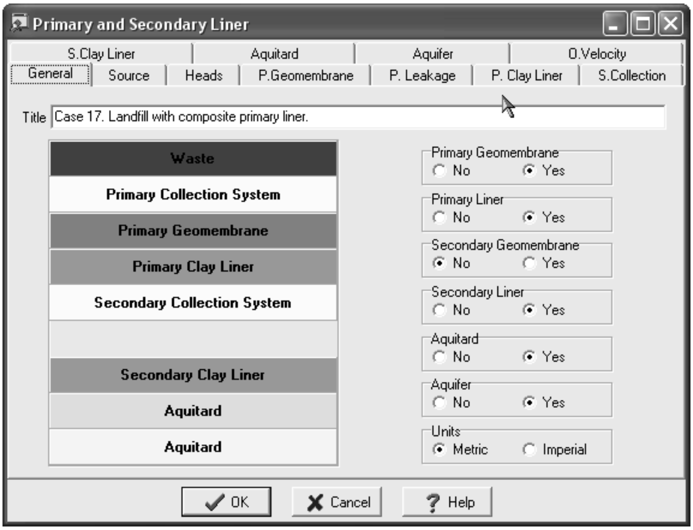
Model Parameters

To specify the model parameters either click on the model or select the Model Parameters menu item from the Data Entry menu. The Primary and Secondary Liner form on the next page will be displayed.

General Tab

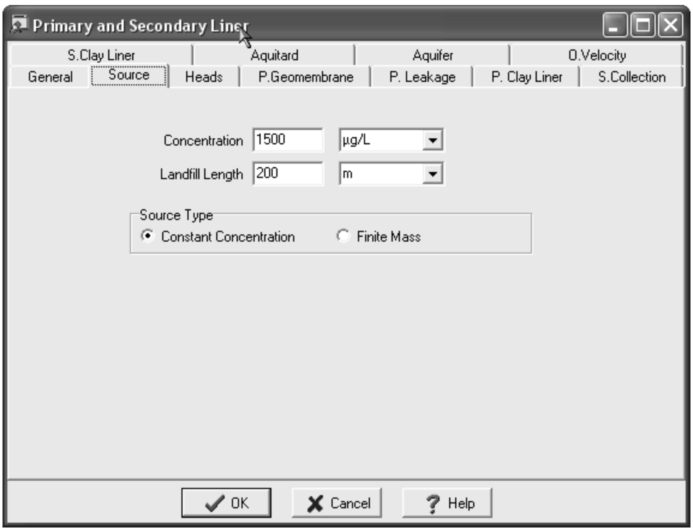
On the General tab shown on the next page, the layers present in the model can be specified. In this example, the model consists of a primary geomembrane, primary liner, secondary liner, aquitard, and aquifer.

Case 17: Landfill with Composite Primary Liner



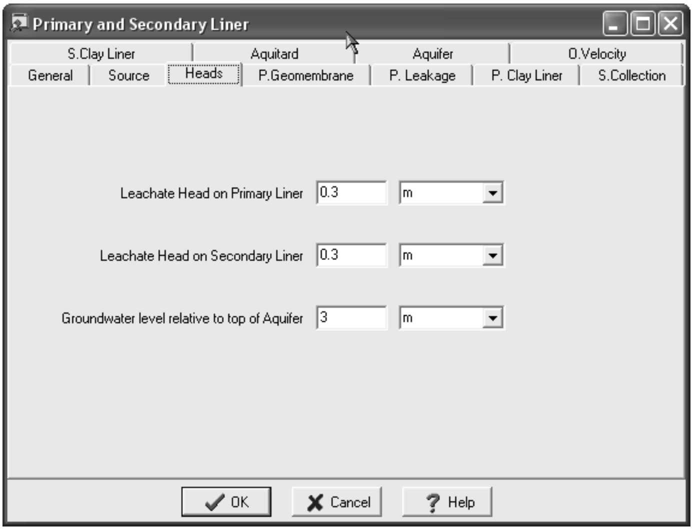
Source Tab

The Source tab shown below is used to specify the source information. In this example the source has a constant concentration 1500 µg/L and a landfill length of 200 m.



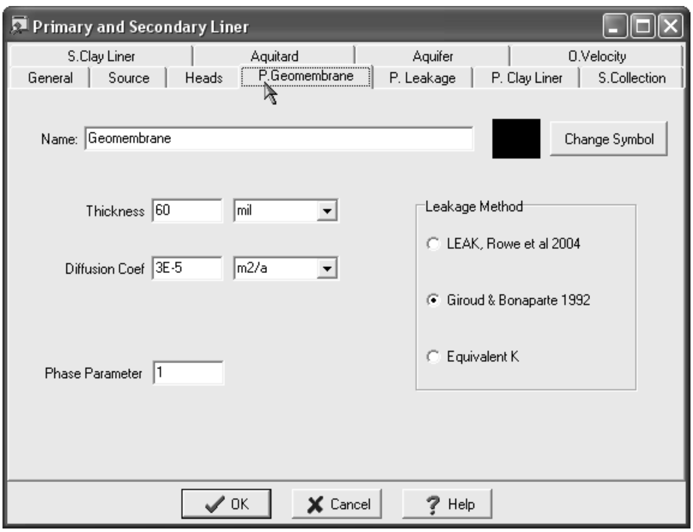
Heads Tab

The Heads tab shown on the next page is used to specify the heads on the liners and the groundwater level relative to the aquifer.



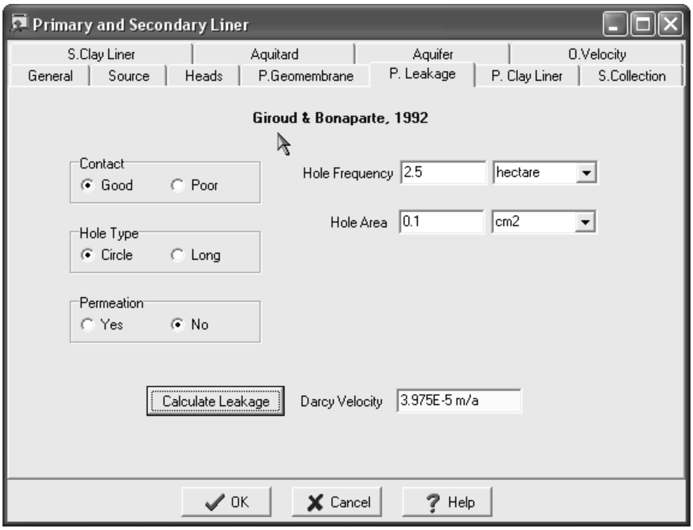
Primary Geomembrane Tab

The Primary Geomembrane tab shown below is used to specify the parameters for the geomembrane and the method to calculate the leakage through the geomembrane. In this example, the leakage through the geomembrane will use the method proposed by Giroud & Bonaparte.



Primary Leakage Tab

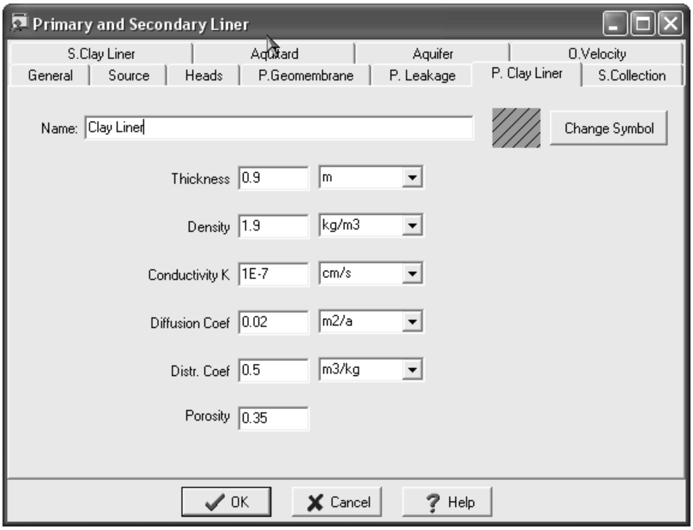
The Primary Leakage tab below is used to specify the parameters for the leakage through the primary geomembrane. After the all of the parameters have been specified the Calculate Leakage button can be pressed to calculate the Darcy velocity through the primary composite liner.



Primary Clay Liner Tab

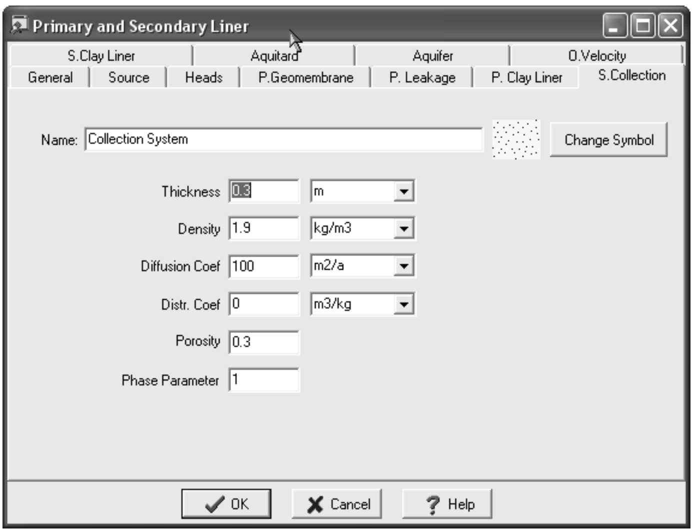
The parameters for the primary clay liner are specified on the Primary Clay Liner tab shown on the next page.

Case 17: Landfill with Composite Primary Liner



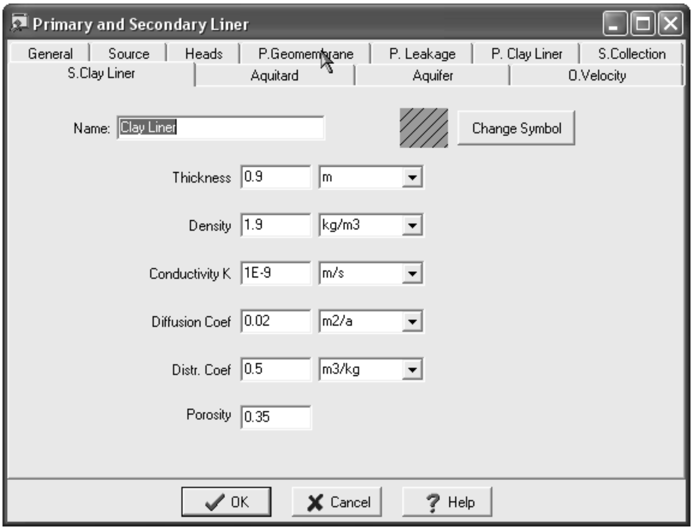
Secondary Collection Tab

The parameters for the secondary leachate collection system are specified on the Secondary Collection tab shown below.



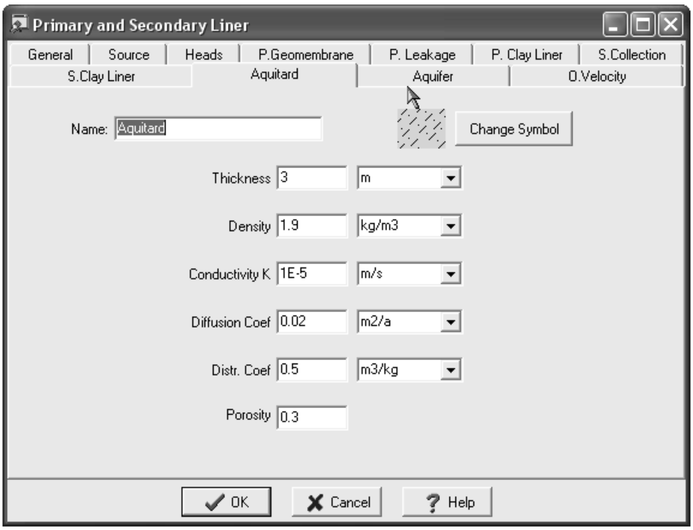
Secondary Liner Tab

The parameters for the secondary clay liner are specified on the Secondary Liner tab shown below.



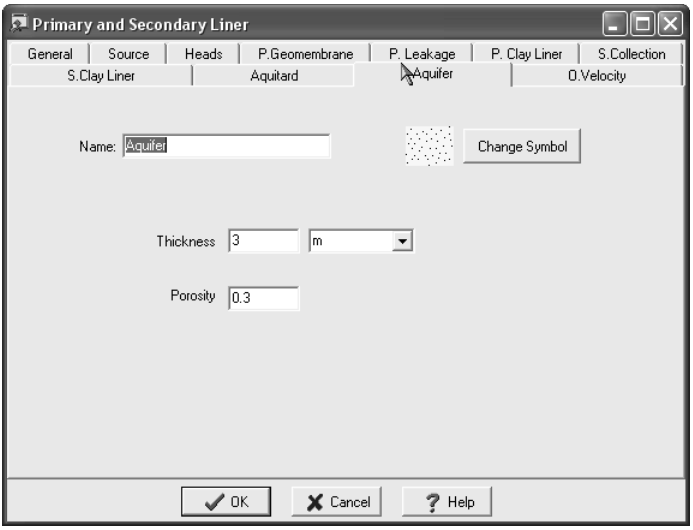
Aquitard Tab

The parameters for the aquitard are specified on the Aquitard tab shown below.



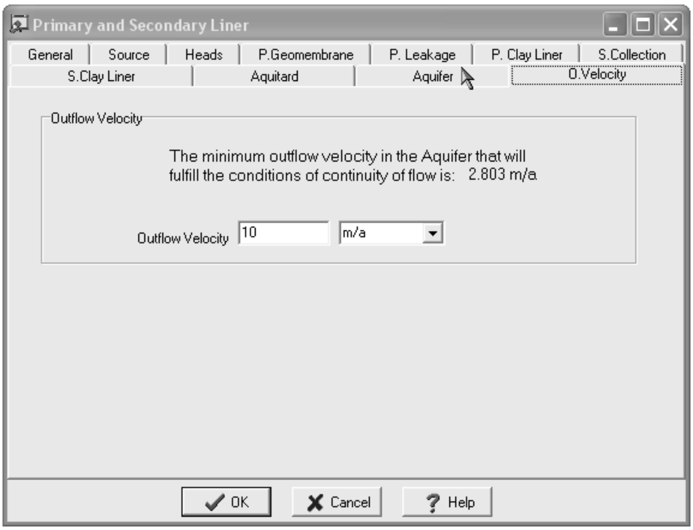
Aquifer Tab

The parameters for the aquifer are specified on the Aquifer tab shown below.



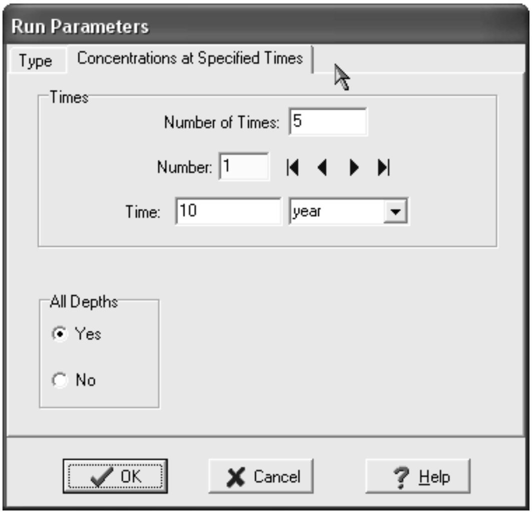
Outflow Velocity Tab

The outflow velocity in the aquifer can be specified on the Outflow Velocity tab shown below. The minimum outflow velocity for the model will be calculated and shown by the program.



Run Parameters

The times and depths to calculate the concentrations can be specified using the Run Parameters menu item on the Data Entry menu. On the Run Parameters form below the times for this model can be specified.



Model Execution

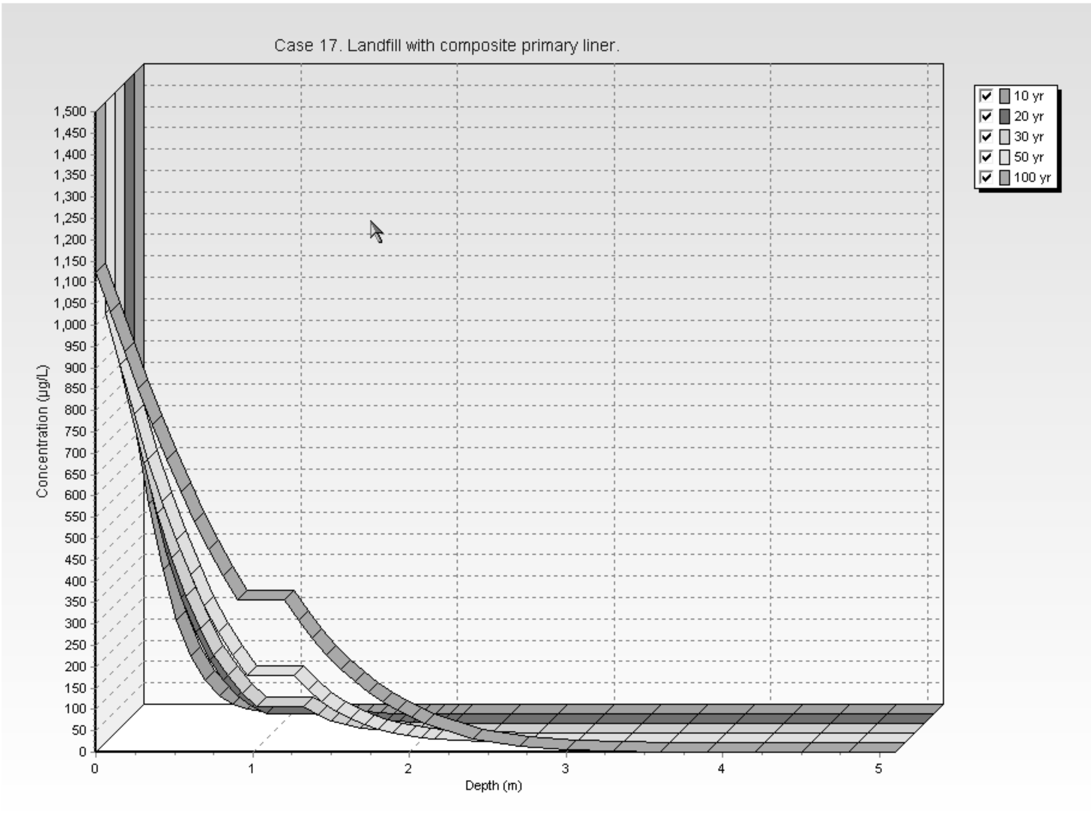
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 17. Landfill with composite primary liner.

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY
CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of μg/L	Coefficient of	Matrix Porosity	Distributon	Dry Density

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 3 m
Base Porosity = 0.3
Base Outflow Velocity = 10 m/a

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow	Phase Parameter
1	0 m	0.001524 m	3.975E-5 m/a	0 m/a	1
	0.001524 m	0.9 m	3.975E-5 m/a	0 m/a	1
	0.9 m	1.2 m	3.975E-5 m/a	0 m/a	1
	1.2 m	2.1 m	3.975E-5 m/a	0 m/a	1
	2.1 m	5.1 m	3.975E-5 m/a	0 m/a	1

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth m	Concentration μg/L
10	0.000E+00	1.500E+03
	1.524E-03	6.823E+02
	9.152E-02	4.917E+02
	1.815E-01	3.370E+02
	2.715E-01	2.190E+02
	3.615E-01	1.345E+02
	4.515E-01	7.798E+01
	5.415E-01	4.256E+01
	6.315E-01	2.181E+01
	7.215E-01	1.044E+01

	6.315E-01	[illegible]
	7.215E-01	1.044E+01
	8.115E-01	4.532E+00
	9.015E-01	1.486E+00
	1.202E+00	1.485E+00
	1.292E+00	5.762E-01
	1.382E+00	2.090E-01
	1.472E+00	7.081E-02
	1.562E+00	2.239E-02
	1.652E+00	6.608E-03
	1.742E+00	1.819E-03
	1.832E+00	4.665E-04
	1.922E+00	1.115E-04
	2.012E+00	2.487E-05
	2.102E+00	5.395E-06
	2.402E+00	1.203E-08
	2.702E+00	6.039E-11
	3.002E+00	6.877E-12
	3.302E+00	7.519E-13
	3.602E+00	6.479E-14
	3.902E+00	4.344E-15
	4.202E+00	2.236E-16
	4.502E+00	8.703E-18
	4.802E+00	2.517E-19
	5.102E+00	8.435E-22
20	0.000E+00	1.500E+03
	1.524E-03	8.260E+02
	9.152E-02	6.636E+02
	1.815E-01	5.199E+02
	2.715E-01	3.968E+02
	3.615E-01	2.946E+02
	4.515E-01	2.126E+02
	5.415E-01	1.488E+02
	6.315E-01	1.007E+02
	7.215E-01	6.553E+01
	8.115E-01	4.031E+01
	9.015E-01	2.239E+01
	1.202E+00	2.238E+01
	1.292E+00	1.332E+01
	1.382E+00	7.670E+00
	1.472E+00	4.275E+00
	1.562E+00	2.305E+00
	1.652E+00	1.202E+00
	1.742E+00	6.060E-01
	1.832E+00	2.954E-01
	1.922E+00	1.393E-01
	2.012E+00	6.381E-02
	2.102E+00	2.913E-02
	2.402E+00	1.208E-03
	2.702E+00	3.221E-05
	3.002E+00	5.508E-07
	3.302E+00	6.278E-09
	3.602E+00	1.246E-10
	3.902E+00	2.172E-11
	4.202E+00	4.988E-12
	4.502E+00	1.028E-12
	4.802E+00	1.848E-13
	5.102E+00	6.496E-15
30	0.000E+00	1.500E+03
	1.524E-03	9.088E+02

	9.152E-02	7.644E+02
	1.815E-01	6.322E+02
	2.715E-01	5.137E+02
	3.615E-01	4.098E+02
	4.515E-01	3.205E+02
	5.415E-01	2.455E+02
	6.315E-01	1.837E+02
	7.215E-01	1.337E+02
	8.115E-01	9.389E+01
	9.015E-01	6.252E+01
	1.202E+00	6.250E+01
	1.292E+00	4.317E+01
	1.382E+00	2.919E+01
	1.472E+00	1.932E+01
	1.562E+00	1.252E+01
	1.652E+00	7.934E+00
	1.742E+00	4.920E+00
	1.832E+00	2.986E+00
	1.922E+00	1.776E+00
	2.012E+00	1.040E+00
	2.102E+00	6.088E-01
	2.402E+00	6.824E-02
	2.702E+00	5.728E-03
	3.002E+00	3.587E-04
	3.302E+00	1.671E-05
	3.602E+00	5.782E-07
	3.902E+00	1.516E-08
	4.202E+00	4.244E-10
	4.502E+00	5.379E-11
	4.802E+00	1.512E-11
	5.102E+00	9.861E-13
50	0.000E+00	1.500E+03
	1.524E-03	1.007E+03
	9.152E-02	8.850E+02
	1.815E-01	7.698E+02
	2.715E-01	6.623E+02
	3.615E-01	5.634E+02
	4.515E-01	4.734E+02
	5.415E-01	3.927E+02
	6.315E-01	3.210E+02
	7.215E-01	2.583E+02
	8.115E-01	2.039E+02
	9.015E-01	1.573E+02
	1.202E+00	1.573E+02
	1.292E+00	1.231E+02
	1.382E+00	9.522E+01
	1.472E+00	7.273E+01
	1.562E+00	5.486E+01
	1.652E+00	4.087E+01
	1.742E+00	3.008E+01
	1.832E+00	2.189E+01
	1.922E+00	1.576E+01
	2.012E+00	1.127E+01
	2.102E+00	8.056E+00
	2.402E+00	2.028E+00
	2.702E+00	4.309E-01
	3.002E+00	7.706E-02
	3.302E+00	1.158E-02
	3.602E+00	1.459E-03
	3.902E+00	1.539E-04
	4.202E+00	1.358E-05

	4.202E+00	1.358E-05
	4.502E+00	1.003E-06
	4.802E+00	6.204E-08
	5.102E+00	6.335E-10
100	0.000E+00	1.500E+03
	1.524E-03	1.124E+03
	9.152E-02	1.030E+03
	1.815E-01	9.383E+02
	2.715E-01	8.503E+02
	3.615E-01	7.662E+02
	4.515E-01	6.862E+02
	5.415E-01	6.106E+02
	6.315E-01	5.398E+02
	7.215E-01	4.738E+02
	8.115E-01	4.127E+02
	9.015E-01	3.567E+02
	1.202E+00	3.566E+02
	1.292E+00	3.092E+02
	1.382E+00	2.666E+02
	1.472E+00	2.285E+02
	1.562E+00	1.948E+02
	1.652E+00	1.652E+02
	1.742E+00	1.393E+02
	1.832E+00	1.170E+02
	1.922E+00	9.780E+01
	2.012E+00	8.154E+01
	2.102E+00	6.789E+01
	2.402E+00	3.197E+01
	2.702E+00	1.387E+01
	3.002E+00	5.537E+00
	3.302E+00	2.031E+00
	3.602E+00	6.839E-01
	3.902E+00	2.112E-01
	4.202E+00	5.978E-02
	4.502E+00	1.548E-02
	4.802E+00	3.554E-03
	5.102E+00	1.703E-04

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this computer program. The user accepts full responsibility for assessing the validity and applicability of the results obtained with this program for any specific case.

Case 18: Phase Change

Description

In this example a phase change in the secondary leachate collection system is modelled using the Phase Change special feature. The landfill has a secondary leachate collection system and liner which overlies a 1 metre thick aquifer. A phase change occurs in the secondary leachate collection system at the interface between the unsaturated and saturated zones, assumed to be .2 and .1 metres thick respectively.

The landfill contains a constant concentration of DCM, which experiences biological decay in the landfill, primary and secondary liners, and the aquifer. A half-life of 10 years in the landfill and 40 years everywhere else is assumed. No biological decay is assumed to occur in the secondary leachate collection system.

The diffusion coefficient of the DCM in the unsaturated zone of the secondary leachate collection system is assumed to be 300 m^2/a, and in the saturated zone to be 100 m^2/a (to represent a high degree of mixing in the saturated zone). The phase change parameter for the DCM in the unsaturated zone is Henry's Constant which is assumed to be 0.1 for DCM in this example.

Two layers are used to model the unsaturated and saturated zones of the .3 metre thick secondary leachate collection system. The first layer represents the unsaturated zone and is .2 metres thick. And the second layer represents the saturated zone and is .1 metre thick.

A Darcy velocity of 0.003 m/a is assumed through the primary liner, and 0 m/a through the secondary liner. Thus, for a 500 metre long landfill the outflow rate in the saturated portion of the secondary leachate collection system would be:

Outflow Rate = (500 * 0.003) / 0.1 = 15 m/a

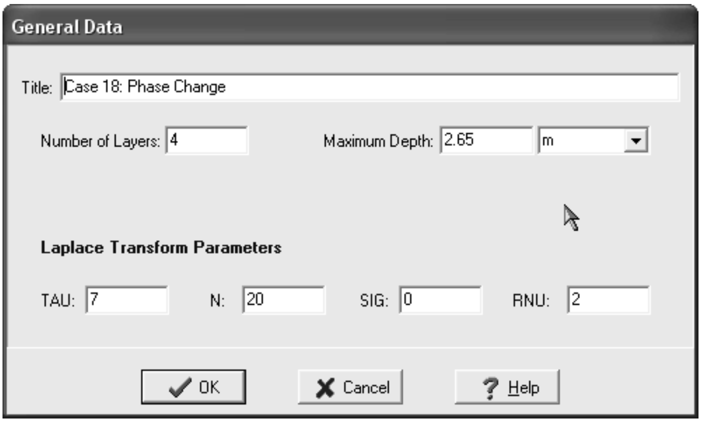
This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Phase Change option. The example is not a prescription for modelling contaminant migration during operation of a landfill. Each landfill has its own unique characteristics and no general prescription can be made. The Phase Change option should only by used by someone with the hydrogeologic background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation.

Data Entry

Start the POLLUTEv7 program and open the Examples project. Select Case 18 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

The general data for this example can be specified by either clicking on the model title or selecting the General Data menu item from the Data Entry menu. On the form below, the Darcy velocity will not show up if the Passive Sink option has already been selected. If the Passive Sink option has not been selected yet, the Darcy velocity will be displayed but will be ignored when the Passive Sink option is selected.

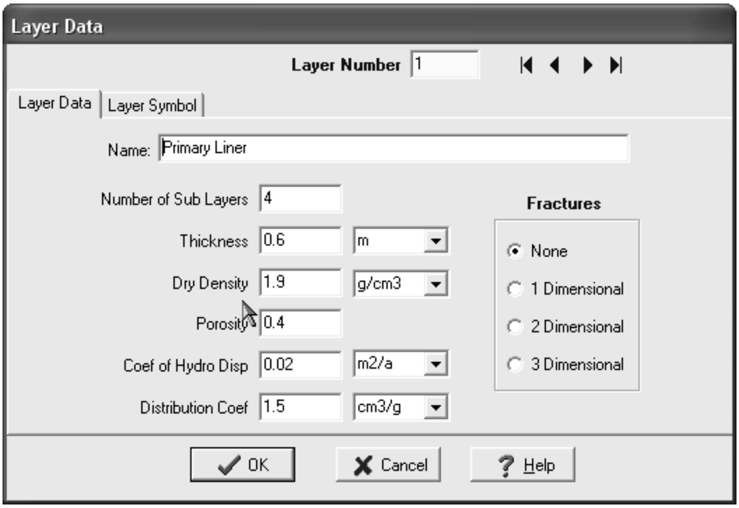


Layer Data

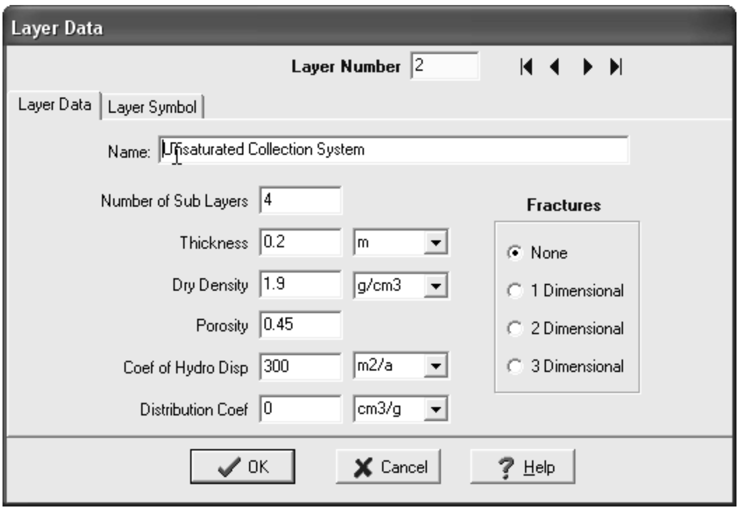
The layer data for this example consists of four layers: a primary liner, a unsaturated collection system, a saturated collection system, and a secondary liner. The data for these layers can be specified on the forms on the next page, by clicking on the model layer or be selecting the Layer Data menu item from the Data Entry menu.

Case 18: Phase Change

Layer 1 Primary Liner

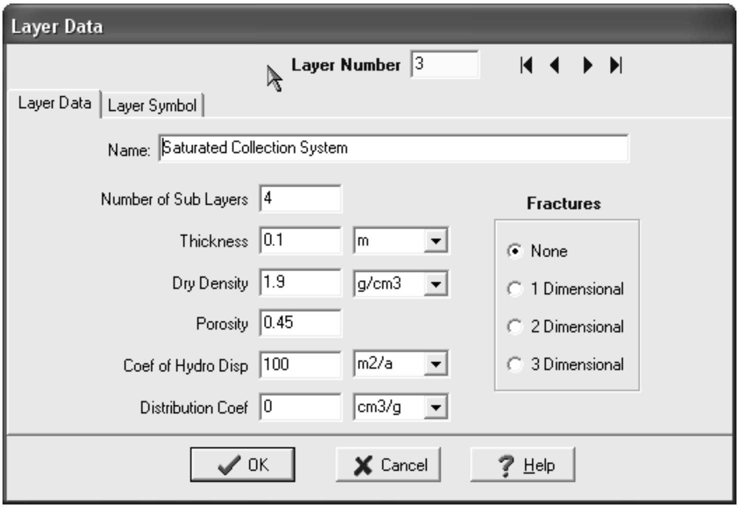


Layer 2 Unsaturated Collection System

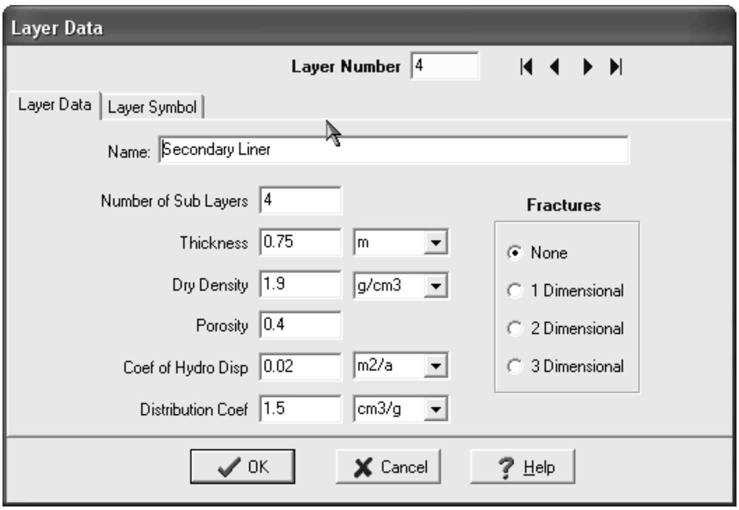


Case 18: Phase Change

Layer 3 Saturated Collection System

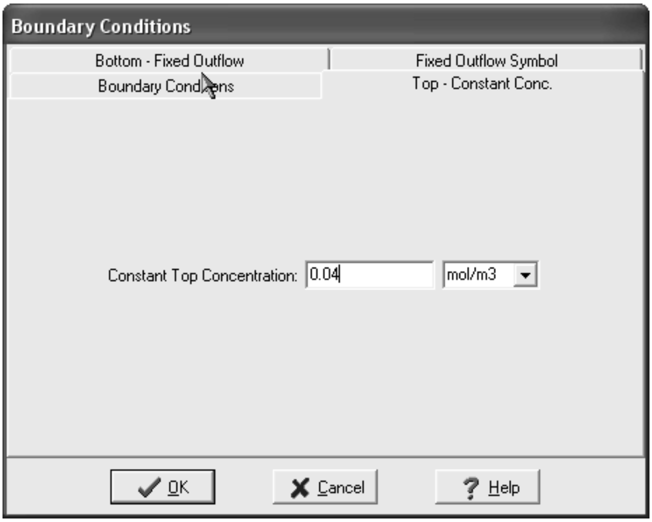


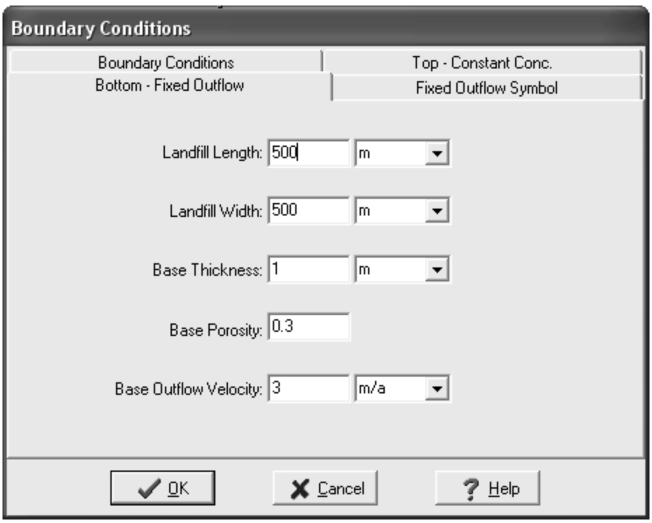
Layer 4 Secondary Liner



Boundary Conditions

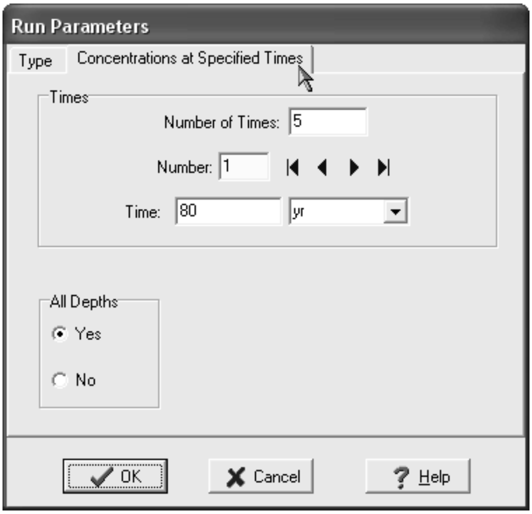
The boundary conditions for this example are a constant concentration top boundary and a fixed outflow bottom boundary. These boundaries can be specified on the forms below,either by clicking on the boundary or by selecting the Boundary Conditions menu item from the Data Entry menu.





Run Parameters

The run parameters for this example can be specified by selecting the Run Parameters menu item from the Data Entry menu. On the form below the times t o calculate the concentration can be specified as 80, 85, 90, 95, and 100 years.

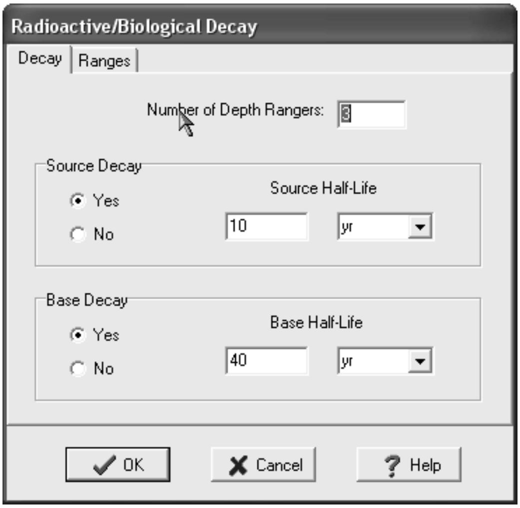


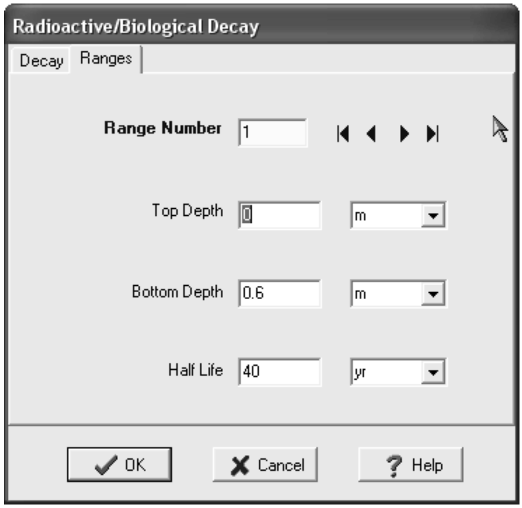
Special Features

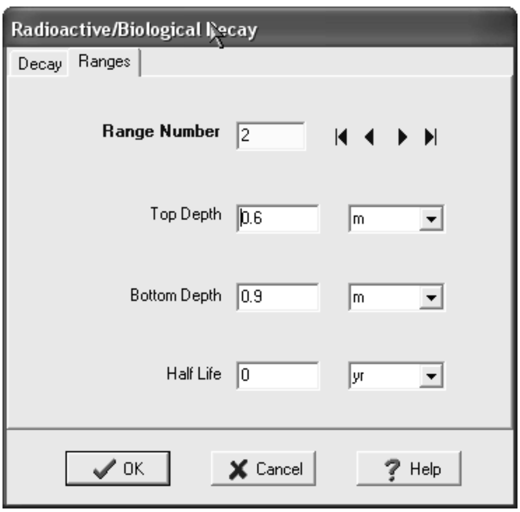
The biological decay and passive sink data for this model can be entered using the Special Features menu.

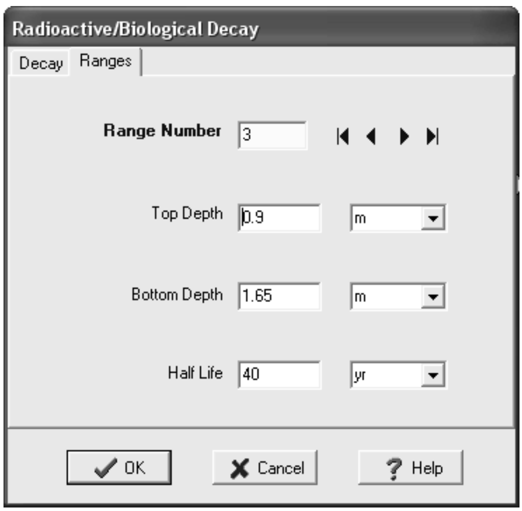
Radioactive/Biological Decay

The data for the biological decay of the DCM can be specified by selecting the Radioactive/Biological Decay menu item from the Special Features menu. In this example there are three decay intervals: one for the primary liner, one for the unsaturated and saturated collection system, and one for the secondary liner. This data is entered on the forms shown below.



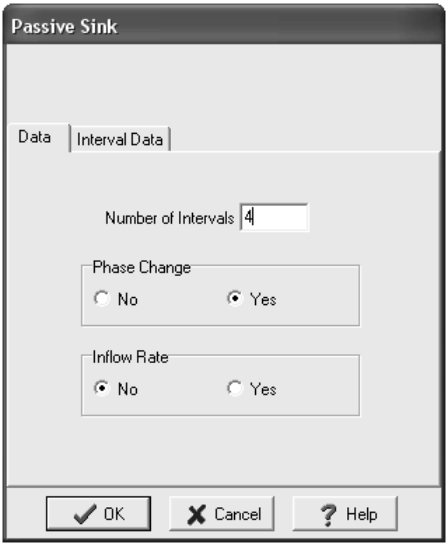


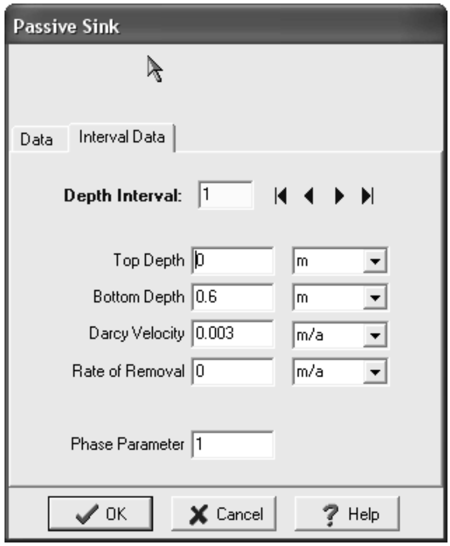


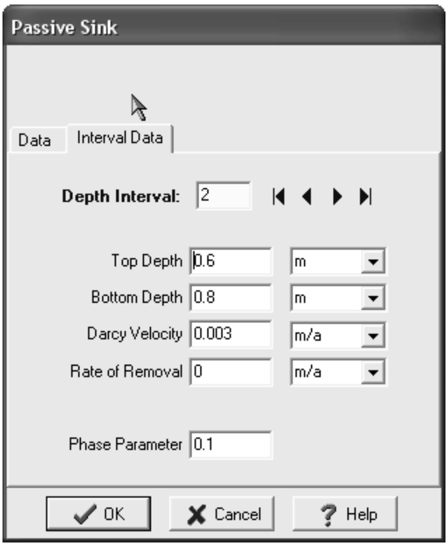


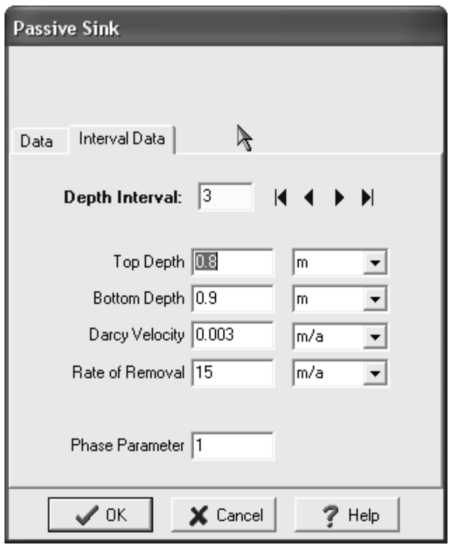
Passive Sink

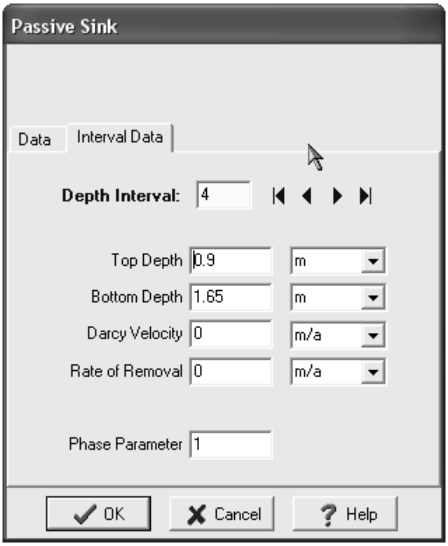
The passive sink data is used to specify the Phase parameter and the horizontal and vertical Darcy velocities. In this example there are four depth intervals for the passive sink as shown in the forms below.











Model Execution

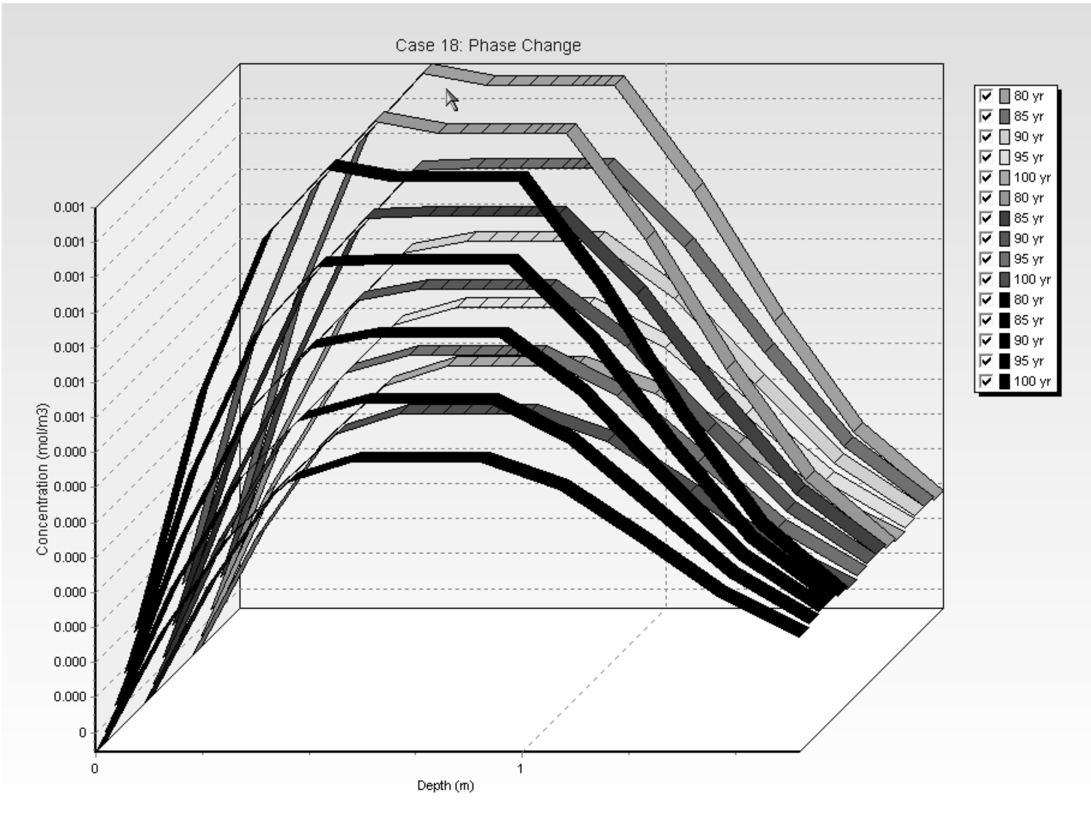
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Depth

The Concentration vs. Depth chart below can be displayed by pressing the Concentration vs Depth button on the Output toolbar or selecting the Concentration vs Depth menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 18: Phase Change

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Primary Liner	0.6 m	4	0.02 m2/a	0.4	1.5 cm3/g	1.9 g/cm3
Unsaturated Collection System	0.2 m	4	300 m2/a	0.45	0 cm3/g	1.9 g/cm3
Saturated Collection System	0.1 m	4	100 m2/a	0.45	0 cm3/g	1.9 g/cm3
Secondary Liner	0.75 m	4	0.02 m2/a	0.4	1.5 cm3/g	1.9 g/cm3

Boundary Conditions

Contant Concentration
Source Concentration = 0.04 mol/m3

Fixed Outflow Bottom Boundary
Landfill Length = 500 m
Landfill Width = 500 m
Base Thickness = 1 m
Base Porosity = 0.3
Base Outflow Velocity = 3 m/a

RADIOACTIVE OR BIOLOGICAL DECAY

First Order Radioactive or Biological Decay Depth Ranges

Minimum Depth	Maximum Depth	Half Life
0 m	0.6 m	40 yr
0.6 m	0.9 m	0 yr
0.9 m	1.65 m	40 yr

Radioactive or Biological Decay Source Half Life = 10 yr

Radioactive or Biological Decay Base Half Life = 40 yr

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow	Phase Parameter
1	0 m	0.6 m	0.003 m/a	0 m/a	1
	0.6 m	0.8 m	0.003 m/a	0 m/a	0.1
	0.8 m	0.9 m	0.003 m/a	15 m/a	1
	0.9 m	1.65 m	0 m/a	0 m/a	1

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

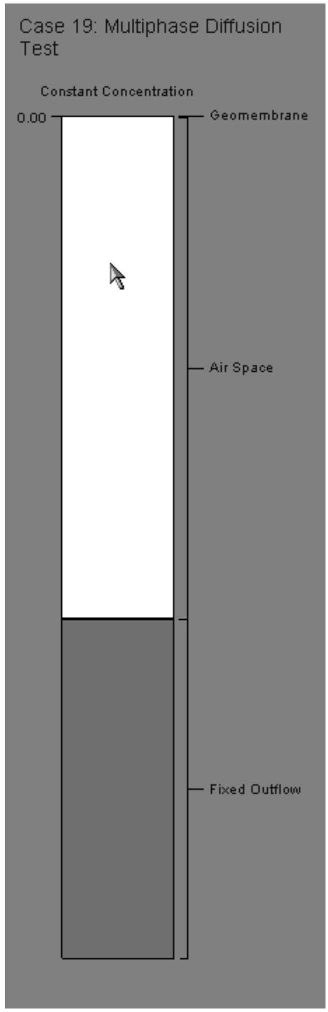
Time yr	Depth m	Concentration mol/m3
80	0.000E+00	1.563E-04
	1.500E-01	4.912E-04
	3.000E-01	7.185E-04
	4.500E-01	8.173E-04
	6.000E-01	8.009E-04
	6.500E-01	8.009E-04
	7.000E-01	8.009E-04
	7.500E-01	8.009E-04
	8.000E-01	8.009E-04
	8.250E-01	8.009E-04
	8.500E-01	8.009E-04
	8.750E-01	8.008E-04
	9.000E-01	8.008E-04
	1.088E+00	6.483E-04
	1.275E+00	4.620E-04
	1.463E+00	3.048E-04
	1.650E+00	2.079E-04
85	0.000E+00	1.105E-04
	1.500E-01	3.922E-04
	3.000E-01	5.930E-04
	4.500E-01	6.923E-04
	6.000E-01	6.960E-04
	6.500E-01	6.960E-04
	7.000E-01	6.960E-04
	7.500E-01	6.960E-04
	8.000E-01	6.960E-04
	8.250E-01	6.960E-04
	8.500E-01	6.960E-04
	8.750E-01	6.960E-04
	9.000E-01	6.959E-04
	1.088E+00	5.830E-04
	1.275E+00	4.321E-04
	1.463E+00	2.982E-04
	1.650E+00	2.118E-04
90	0.000E+00	7.816E-05

	1.500E-01 3.000E-01 4.500E-01 6.000E-01 6.500E-01 7.000E-01 7.500E-01 8.000E-01 8.250E-01 8.500E-01 8.750E-01 9.000E-01 1.088E+00 1.275E+00 1.463E+00 1.650E+00	3.151E-04 4.912E-04 5.870E-04 6.040E-04 6.040E-04 6.040E-04 6.040E-04 6.040E-04 6.040E-04 6.040E-04 6.040E-04 6.040E-04 5.220E-04 4.010E-04 2.881E-04 2.118E-04
95	0.000E+00 1.500E-01 3.000E-01 4.500E-01 6.000E-01 6.500E-01 7.000E-01 7.500E-01 8.000E-01 8.250E-01 8.500E-01 8.750E-01 9.000E-01 1.088E+00 1.275E+00 1.463E+00 1.650E+00	5.527E-05 2.547E-04 4.083E-04 4.985E-04 5.239E-04 5.239E-04 5.239E-04 5.239E-04 5.239E-04 5.239E-04 5.239E-04 5.239E-04 5.239E-04 4.659E-04 3.698E-04 2.754E-04 2.087E-04
100	0.000E+00 1.500E-01 3.000E-01 4.500E-01 6.000E-01 6.500E-01 7.000E-01 7.500E-01 8.000E-01 8.250E-01 8.500E-01 8.750E-01 9.000E-01 1.088E+00 1.275E+00 1.463E+00 1.650E+00	3.908E-05 2.072E-04 3.408E-04 4.242E-04 4.544E-04 4.544E-04 4.544E-04 4.544E-04 4.544E-04 4.544E-04 4.544E-04 4.544E-04 4.544E-04 4.149E-04 3.392E-04 2.609E-04 2.029E-04

Case 19: Multiphase Diffusion Test

Description

In this example a multiphase diffusion test performed by Buss et al. (1995) is modelled. This test involved the migration of toluene from a ‘constant’ source through a 0.1 cm thick HDPE geomembrane, a 18.2 cm thick airspace and into a 12.3 cm water reservoir (assumed to be well mixed). Based on Buss et al. the geomembrane diffusion coefficient was 6 x 10^{-8} cm^2/s and the phase coefficient was 43.8. From Schwarzenbach et al. (1993), the diffusion coefficient and phase coefficient for toluene in air are 0.088 cm^2/s and 0.27 respectively. Based on these parameters the test is modelled for 600 hours and the calculated and observed concentrations in the receptor are provided at the end of this example.

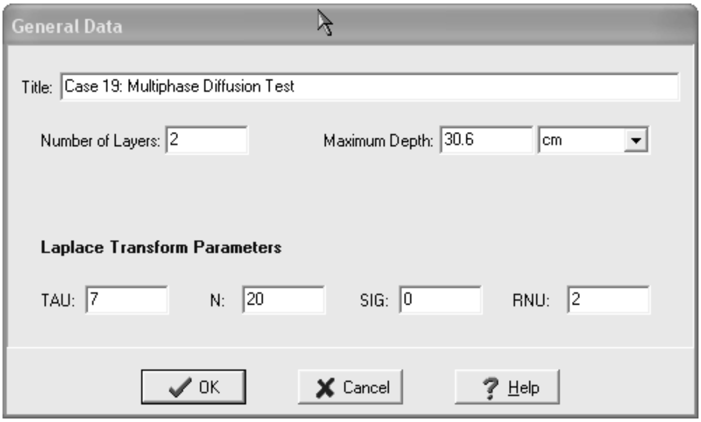


Data Entry

Start the POLLUTEv7 program and open the Examples project. Select Case 19 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

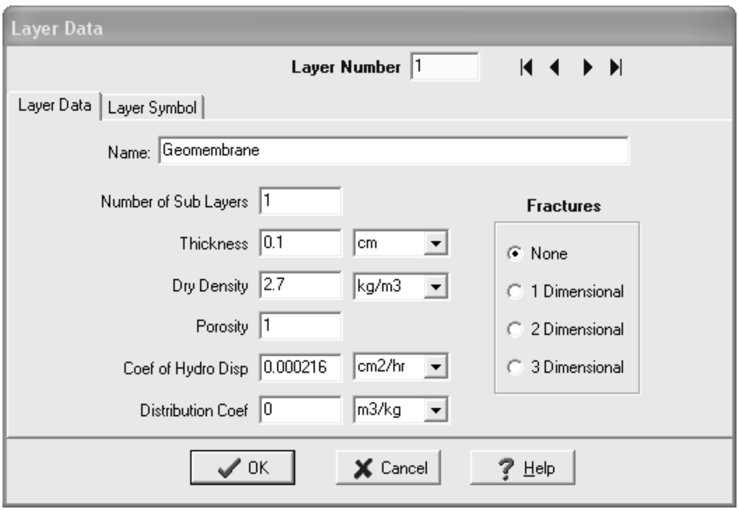
The general data for this example can be specified by either clicking on the model title or selecting the General Data menu item from the Data Entry menu. On the form on the next page, the Darcy velocity will not show up if the Passive Sink option has already been selected. If the Passive Sink option has not been selected yet, the Darcy velocity will be displayed but will be ignored when the Passive Sink option is selected.



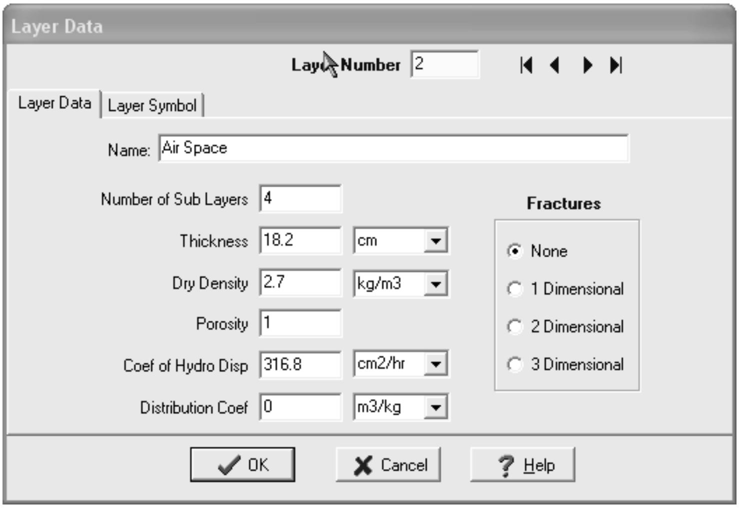
Layer Data

The layer data for this example consists of two layers: a geomembrane and an air space. The data for these layers can be specified on the forms below, by clicking on the model layer or be selecting the Layer Data menu item from the Data Entry menu.

Layer 1 Geomembrane

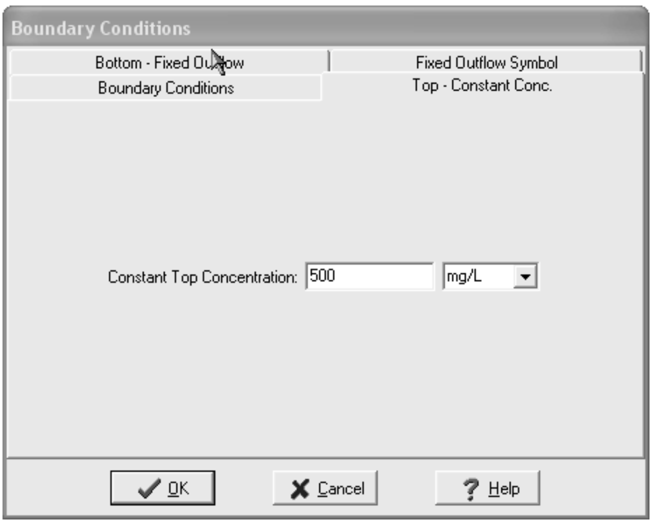


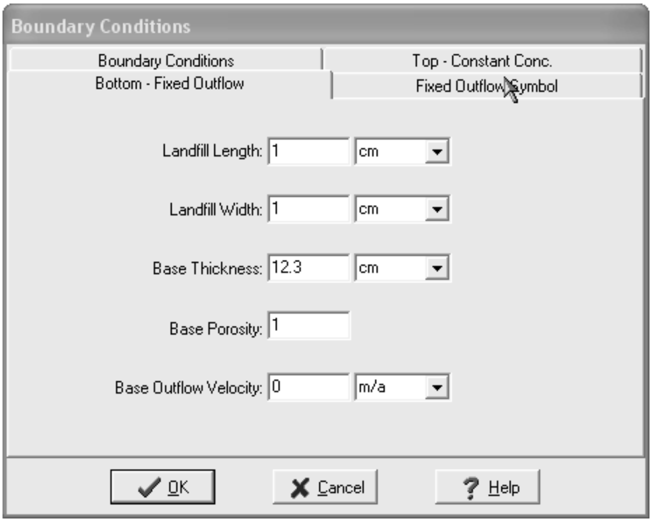
Layer 2 Air Space



Boundary Conditions

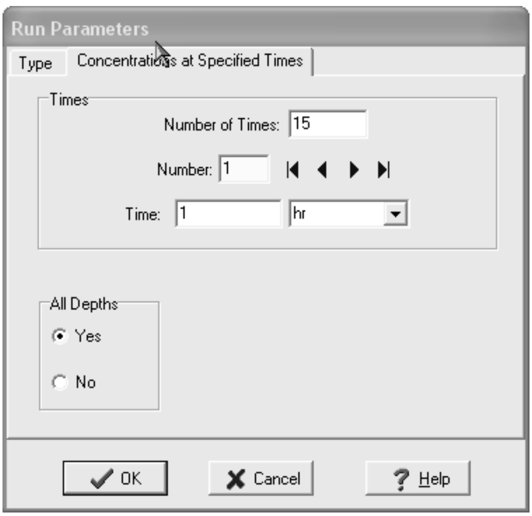
The boundary conditions for this example are a constant concentration top boundary and a fixed outflow bottom boundary. These boundaries can be specified on the forms below,either by clicking on the boundary or by selecting the Boundary Conditions menu item from the Data Entry menu.





Run Parameters

The run parameters for this example can be specified by selecting the Run Parameters menu item from the Data Entry menu. On the form below the times t o calculate the concentration can be specified as 1, 20, 40, 70, 100, 150, 200, 250, 300, 350, 400. 450, 500, 550, and 600 hours.

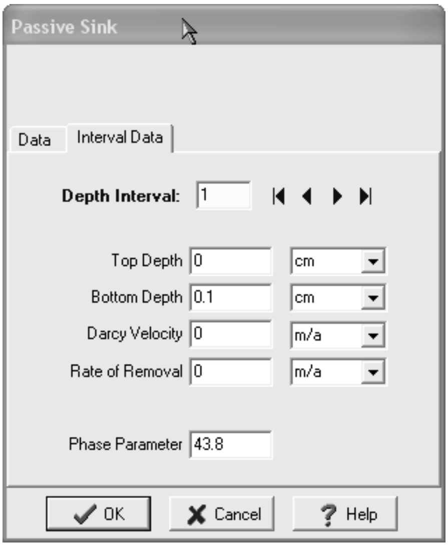


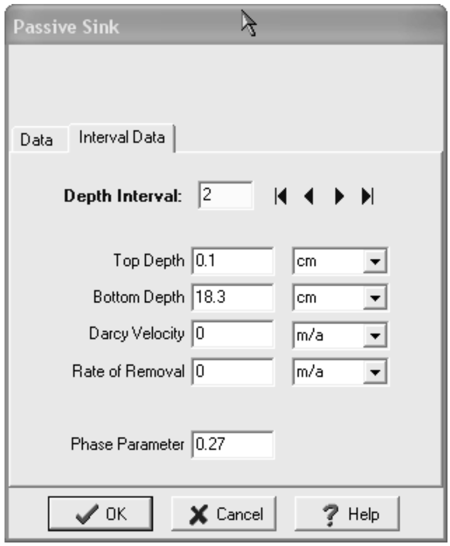
Special Features

The passive sink data for this model can be entered using the Special Features menu.

Passive Sink

The passive sink data is used to specify the Phase parameter and the horizontal and vertical Darcy velocities. In this example there are two depth intervals for the passive sink as shown in the forms below.





Model Execution

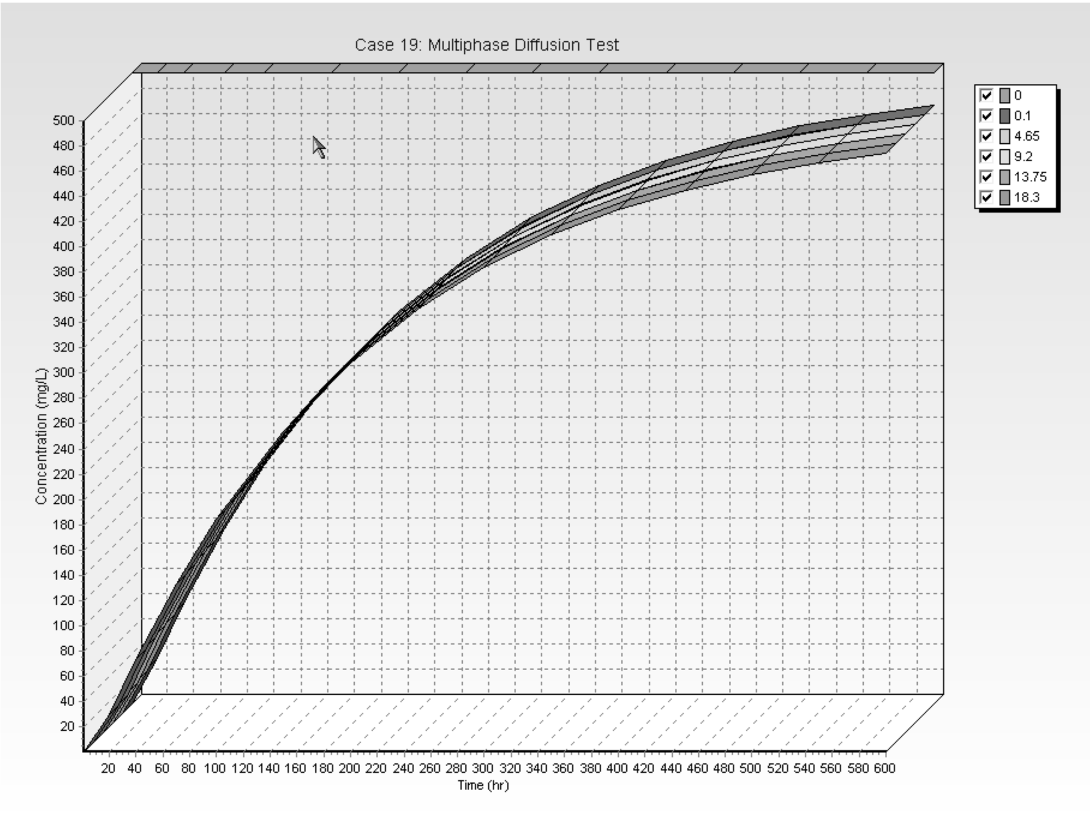
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Concentration vs Time

The Concentration vs. Time chart below can be displayed by pressing the Concentration vs Time button on the Output toolbar or selecting the Concentration vs Time menu item from the Output menu.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 19: Multiphase Diffusion Test

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY
CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	0.1 cm	1	0.000216 cm2/hr	1	0 m3/kg	2.7 kg/m3
Air Space	18.2 cm	4	316.8 cm2/hr	1	0 m3/kg	2.7 kg/m3

Boundary Conditions

Contant Concentration
Source Concentration = 500 mg/L

Fixed Outflow Bottom Boundary
Landfill Length = 1 cm
Landfill Width = 1 cm
Base Thickness = 12.3 cm
Base Porosity = 1
Base Outflow Velocity = 0 m/a

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow	Phase Parameter
1	0 cm	0.1 cm	0 m/a	0 m/a	43.8
	0.1 cm	18.3 cm	0 m/a	0 m/a	0.27

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Calculated Concentrations at Selected Times and Depths

Time hr	Depth cm	Concentration mg/L
1	0.000E+00	5.000E+02
	1.000E-01	1.771E-04
	4.650E+00	7.045E-05
	9.200E+00	2.687E-05
	1.375E+01	9.110E-06
	1.830E+01	6.369E-07
20	0.000E+00	5.000E+02
	1.000E-01	3.622E+01
	4.650E+00	3.420E+01
	9.200E+00	3.234E+01
	1.375E+01	3.062E+01
	1.830E+01	2.906E+01
40	0.000E+00	5.000E+02
	1.000E-01	8.022E+01
	4.650E+00	7.834E+01
	9.200E+00	7.660E+01
	1.375E+01	7.500E+01
	1.830E+01	7.354E+01
70	0.000E+00	5.000E+02
	1.000E-01	1.387E+02
	4.650E+00	1.370E+02
	9.200E+00	1.355E+02
	1.375E+01	1.342E+02
	1.830E+01	1.329E+02
100	0.000E+00	5.000E+02
	1.000E-01	1.890E+02
	4.650E+00	1.876E+02
	9.200E+00	1.863E+02
	1.375E+01	1.851E+02
	1.830E+01	1.840E+02
150	0.000E+00	5.000E+02
	1.000E-01	2.577E+02
	4.650E+00	2.566E+02
	9.200E+00	2.556E+02
	1.375E+01	2.547E+02
	1.830E+01	2.539E+02
200	0.000E+00	5.000E+02
	1.000E-01	3.113E+02
	4.650E+00	3.104E+02
	9.200E+00	3.097E+02
	1.375E+01	3.089E+02
	1.830E+01	3.083E+02
250	0.000E+00	5.000E+02
	1.000E-01	3.530E+02
	4.650E+00	3.523E+02
	9.200E+00	3.517E+02
	1.375E+01	3.512E+02
	1.830E+01	3.507E+02
300	0.000E+00	5.000E+02
	1.000E-01	3.855E+02
	4.650E+00	3.850E+02
	[illegible]	[illegible]

	9.200E+00 1.375E+01 1.830E+01	3.845E+02 3.841E+02 3.837E+02
350	0.000E+00 1.000E-01 4.650E+00 9.200E+00 1.375E+01 1.830E+01	5.000E+02 4.108E+02 4.104E+02 4.100E+02 4.097E+02 4.094E+02
400	0.000E+00 1.000E-01 4.650E+00 9.200E+00 1.375E+01 1.830E+01	5.000E+02 4.305E+02 4.302E+02 4.299E+02 4.297E+02 4.294E+02
450	0.000E+00 1.000E-01 4.650E+00 9.200E+00 1.375E+01 1.830E+01	5.000E+02 4.459E+02 4.456E+02 4.454E+02 4.452E+02 4.450E+02
500	0.000E+00 1.000E-01 4.650E+00 9.200E+00 1.375E+01 1.830E+01	5.000E+02 4.578E+02 4.577E+02 4.575E+02 4.573E+02 4.572E+02
550	0.000E+00 1.000E-01 4.650E+00 9.200E+00 1.375E+01 1.830E+01	5.000E+02 4.672E+02 4.670E+02 4.669E+02 4.668E+02 4.666E+02
600	0.000E+00 1.000E-01 4.650E+00 9.200E+00 1.375E+01 1.830E+01	5.000E+02 4.744E+02 4.743E+02 4.742E+02 4.741E+02 4.740E+02

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this computer program. The user accepts full responsibility for assessing the validity and applicability of the results obtained with this program for any specific case.

Case 20: Sensitivity Analysis

Description

In this example, Sensitivity Analysis will be used to examine the effect of uncertainty in the service life of a Primary Leachate Collection system. The landfill from Cases 15 and 16 will be used, except the time that the Primary Leachate Collection system begins to fail will range from 15 to 50 years. Cases 15 and 16 should be reviewed prior to reading this example, where the implementation of the Variable Properties and Passive Sink special features are described in detail.

The parameters for this example are the same as in Case 15, except for the addition of the Sensitivity Analysis parameters.

Property		Value	Units
Darcy Velocity	v_a	variable	m/a
Sink Outflow Velocity	v_s	variable	m/a
Diffusion Coefficient	D	0.02	m^2/a
Dispersivity		0.4	m
Distribution Coefficient	K	0.0	cm^3/g
Soil Porosity	n	0.4	-
Granular Layer Porosity	n	0.3	-
Dry Density		1.5	g/cm^3
Layer 1 Thickness	H	1.0	m
Layer 2 Thickness	H	0.3	m
Layer 3 Thickness	H	2.0	m
Source Concentration	c_o	1000	mg/L
Ref. Height of Leachate	H_r	7.5	cm
Vol. of Leachate Collected	Q_c	variable	m/a
Landfill Length	L	200.0	m
Landfill Width	W	1.0	m
Aquifer Thickness	h	1.0	m
Aquifer Porosity	n_b	0.3	-
Aquifer Outflow Velocity	v_b	4.0	m/a
Minimum Failure Start Time		15	a
Maximum Failure Start Time		50	a

This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Variable Properties and Passive Sink option. The example is not a prescription for modelling contaminant migration during operation of a landfill. Each landfill has its own unique characteristics and no general prescription can be made. These options should only by used by someone with the hydrogeologic and engineering background necessary to appreciate the subtleties associated with the physical situation and the steps necessary for appropriate modelling of this physical situation. This option should not be used for an actual project of importance without the guidance of the program developers.

Data Entry

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*S*tart the POLLUTEv7 program and open the Examples project. Select Case 20 and open the model by double clicking on it in the model list. After the model is displayed, the data for the model can be displayed and edited using the Data Entry menu or by clicking on that part of the model.

General Data

The general data for this example is the same as for Case 15, except that the title is different.

Layer Data

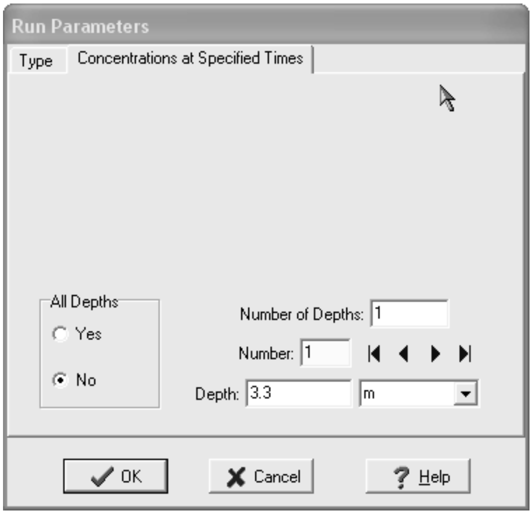
The layer data for this example is the same as for Case 15.

Boundary Conditions

The boundary conditions for this example is the same as for Case 15.

Run Parameters

The run parameters for this example are the same as for Case 15, except that the concentrations will be only be calculated at a depth off 3.3 m as shown on the next page. This depth corresponds to the base of the aquitard.



Special Features

The time-varying data, passive sink, and sensitivity analysis data for this model can be entered using the Time-varying Data and Passive Sink menu items in the Special Features menu.

Time-Varying Properties

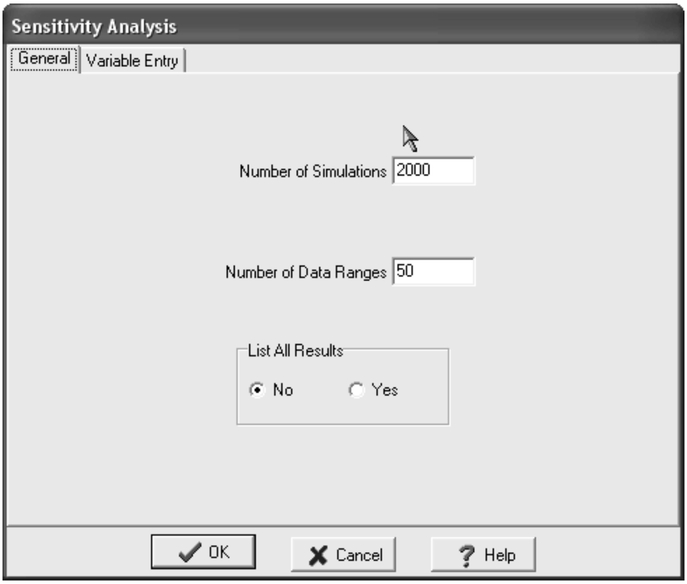
The time-varying properties for this example is the same as for Case 15.

Passive Sink

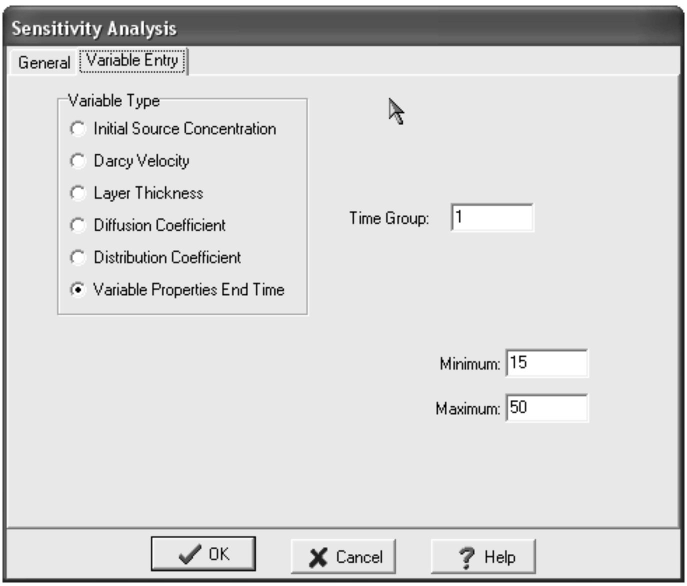
The passive sink data for this example is the same as for Case 15.

Sensitivity Analysis

The sensitivity analysis data can be specified by selecting the Sensitivity Analysis menu item from the Special Features menu, the form on the next page will be displayed. The number of simulations and data ranges can be specified on the General tab. The number of simulations is usually between 1000 and 10000. However, the time to compute this many simulations may be quite large. It is suggested as a trial to use less than 50 simulations.



On the Variable Entry tab below, the type and distribution for the variable can be specified. To vary the failure time of the Primary Leachate Collection system, the Variable Properties end time that corresponds to the time of failure in the input data set is used.



Model Execution

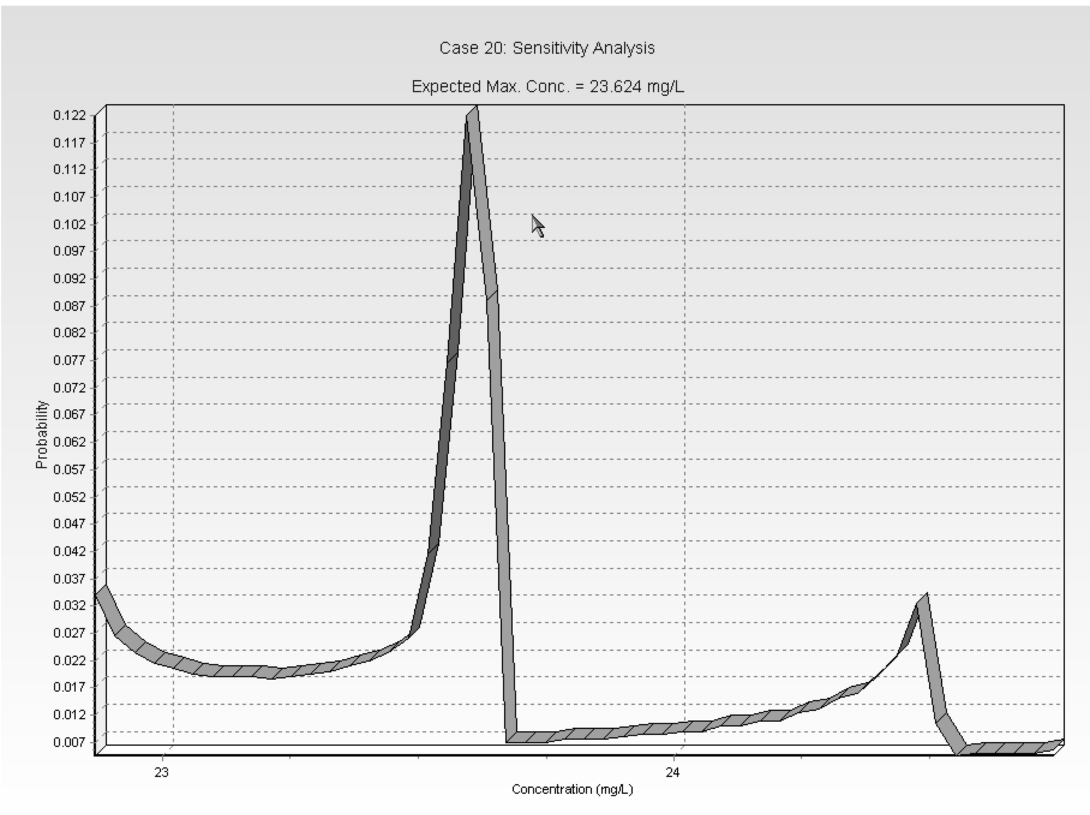
To run the model and calculate the concentrations either select the Run menu item from the Execute menu or press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed. The initial display will depend on your settings in the program's preferences.

Distribution of Peak Concentration

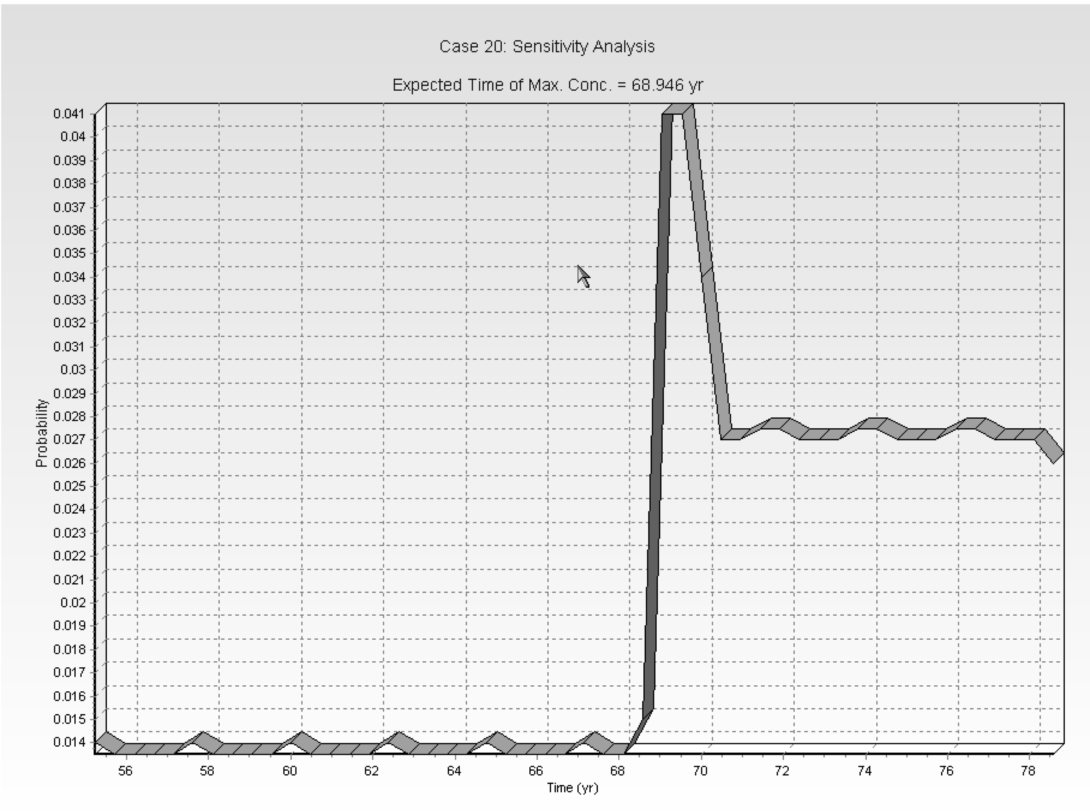
The Distribution of Peak Concentration chart below can be displayed by pressing the Distribution of Peak Concentration button on the Output toolbar or selecting the Distribution of Peak Concentration menu item from the Output menu.



Using the chart of the probability of peak chloride concentration predictions can be made about the concentration in the aquifer. For example, in this case, the expected maximum concentration is 23.6 mg/L.

Distribution of the Time of Peak Concentration

The Distribution of the Time Peak Concentration chart below can be displayed by pressing the Distribution of Time of Peak Concentration button on the Output toolbar or selecting the Distribution of Time of Peak Concentration menu item from the Output menu. Using this chart the expected time of the maximum concentration can be predicted. In this example, the expected time is 68.9 years.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, select the List Output menu item from the Output menu or press the Output Listing button on the Output toolbar.

Case 20: Sensitivity Analysis

THE VARIABLE VELOCITY AND/OR CONCENTRATION OPTION HAS BEEN USED
NOTE THAT THE ACCURACY OF THE CALCULATIONS WITH THIS OPTION WILL DEPEND ON THE NUMBER OF SUBLAYERS USED

THE PASSIVE SINK OPTION HAS BEEN USED
NOTE : THE USER IS RESPONSIBLE FOR ENSURING THAT VELOCITY CHANGES ARE CONSISTENT WITH THE PASSIVE SINK

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Clay	1 m	4	0.02 m2/a	0.4	0 cm3/g	1.5 g/cm3
Collection System	0.3 m	4	10 m2/a	0.3	0 cm3/g	1.5 g/cm3
Aquitard	2 m	4	0.02 m2/a	0.4	0 cm3/g	1.5 g/cm3

Boundary Conditions

Finite Mass Top Boundary

Fixed Outflow Bottom Boundary
Landfill Length = 200 m
Landfill Width = 1 m
Base Thickness = 1 m
Base Porosity = 0.3

VARIATION IN PROPERTIES WITH TIME:

TIME PERIODS WITH THE SAME SOURCE AND VELOCITY

Period	Start Time	No. of Steps	Time Step	Source Conc	Rate of Change	Height of Leachate	Volume Collected
1	0 yr	1	20 yr	1000 mg/L	0	7.5 m	0.29 m/a
2	20 yr	5	2 yr	-1 mg/L	0	7.5 m	0.2 m/a
3	30 yr	2	10 yr	-1 mg/L	0	7.5 m	0.2 m/a
4	50 yr	5	10 yr	-1 mg/L	0	7.5 m	0.2 m/a
5	100 yr	5	20 yr	-1 mg/L	0	7.5 m	0.2 m/a

Period	Start Time	End Time	Darcy Velocity	Dispersivity	Base Velocity
1	0 yr	20 yr	1 m/a	0.4 m	4 m/a
2	20 yr	30 yr	1 m/a	0.4 m	4 m/a
3	30 yr	50 yr	1 m/a	0.4 m	4 m/a

4	50 yr	100 yr	1 m/a	0.4 m	4 m/a
5	100 yr	200 yr	1 m/a	0.4 m	4 m/a

VELOCITY AND SINK PROFILE:

Time Period	Minimum Depth	Maximum Depth	Vertical Velocity	Horizontal Outflow
1	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.01 m/a 0.01 m/a 0 m/a	0 m/a 6.67 m/a 0 m/a
2	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.028 m/a 0.028 m/a 0 m/a	0 m/a 18.7 m/a 0 m/a
3	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.046 m/a 0.046 m/a 0 m/a	0 m/a 30.7 m/a 0 m/a
4	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.064 m/a 0.064 m/a 0 m/a	0 m/a 42.7 m/a 0 m/a
5	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.082 m/a 0.082 m/a 0 m/a	0 m/a 54.7 m/a 0 m/a
6	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
7	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
8	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
9	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
10	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
11	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
12	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
13	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a

14	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
15	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
16	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
17	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a
18	0 m 1 m 1.3 m	1 m 1.3 m 3.3 m	0.1 m/a 0.1 m/a 0 m/a	0 m/a 66.7 m/a 0 m/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Sensitivity Analysis Results

Number of Simulations = 2000
Number of Data Ranges = 50 Variable Properties End Time
Time Period = 1
Uniform Distribution (Minimum = 15 Maximum = 50)

Depth = 3.3

DISTRIBUTION OF PEAK CONCENTRATION

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
2.285E+01	2.289E+01	68	0.03	0.03	7.775E-01
2.289E+01	2.293E+01	53	0.03	0.06	6.070E-01
2.293E+01	2.296E+01	47	0.02	0.08	5.392E-01
2.296E+01	2.300E+01	43	0.02	0.11	4.941E-01
2.300E+01	2.304E+01	41	0.02	0.13	4.719E-01
2.304E+01	2.308E+01	39	0.02	0.15	4.497E-01
2.308E+01	2.312E+01	38	0.02	0.16	4.389E-01
2.312E+01	2.315E+01	38	0.02	0.18	4.396E-01
2.315E+01	2.319E+01	38	0.02	0.20	4.403E-01
2.319E+01	2.323E+01	37	0.02	0.22	4.294E-01
2.323E+01	2.327E+01	38	0.02	0.24	4.418E-01
2.327E+01	2.331E+01	39	0.02	0.26	4.541E-01
2.331E+01	2.335E+01	40	0.02	0.28	4.665E-01
2.335E+01	2.338E+01	42	0.02	0.30	4.907E-01
2.338E+01	2.342E+01	44	0.02	0.32	5.149E-01
2.342E+01	2.346E+01	47	0.02	0.35	5.509E-01
2.346E+01	2.350E+01	52	0.03	0.37	6.105E-01
2.350E+01	2.354E+01	83	0.04	0.41	9.760E-01
2.354E+01	2.358E+01	153	0.08	0.49	1.802E+00

2.358E+01	2.361E+01	244	0.12	0.61	2.879E+00
2.361E+01	2.365E+01	176	0.09	0.70	2.080E+00
2.365E+01	2.369E+01	14	0.01	0.71	1.657E-01
2.369E+01	2.373E+01	14	0.01	0.71	1.660E-01
2.373E+01	2.377E+01	14	0.01	0.72	1.662E-01
2.377E+01	2.381E+01	15	0.01	0.73	1.784E-01
2.381E+01	2.384E+01	15	0.01	0.74	1.787E-01
2.384E+01	2.388E+01	15	0.01	0.74	1.790E-01
2.388E+01	2.392E+01	16	0.01	0.75	1.912E-01
2.392E+01	2.396E+01	17	0.01	0.76	2.035E-01
2.396E+01	2.400E+01	17	0.01	0.77	2.038E-01
2.400E+01	2.403E+01	18	0.01	0.78	2.161E-01
2.403E+01	2.407E+01	18	0.01	0.79	2.165E-01
2.407E+01	2.411E+01	20	0.01	0.80	2.409E-01
2.411E+01	2.415E+01	20	0.01	0.81	2.413E-01
2.415E+01	2.419E+01	22	0.01	0.82	2.659E-01
2.419E+01	2.423E+01	22	0.01	0.83	2.663E-01
2.423E+01	2.426E+01	25	0.01	0.84	3.031E-01
2.426E+01	2.430E+01	26	0.01	0.85	3.157E-01
2.430E+01	2.434E+01	30	0.01	0.87	3.648E-01
2.434E+01	2.438E+01	32	0.02	0.88	3.898E-01
2.438E+01	2.442E+01	38	0.02	0.90	4.636E-01
2.442E+01	2.446E+01	46	0.02	0.93	5.620E-01
2.446E+01	2.449E+01	65	0.03	0.96	7.954E-01
2.449E+01	2.453E+01	21	0.01	0.97	2.574E-01
2.453E+01	2.457E+01	9	0.00	0.97	1.105E-01
2.457E+01	2.461E+01	10	0.01	0.98	1.229E-01
2.461E+01	2.465E+01	10	0.01	0.98	1.231E-01
2.465E+01	2.469E+01	10	0.01	0.99	1.233E-01
2.469E+01	2.472E+01	10	0.01	0.99	1.235E-01
2.472E+01	2.476E+01	11	0.01	1.00	1.361E-01

Expected Maximum Concentration = 2.362E+01

DISTRIBUTION OF TIME OF PEAK CONCENTRATION

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
5.500E+01	5.548E+01	28	0.01	0.01	7.733E-01
5.548E+01	5.595E+01	27	0.01	0.03	7.521E-01
5.595E+01	5.643E+01	27	0.01	0.04	7.586E-01
5.643E+01	5.690E+01	27	0.01	0.05	7.650E-01
5.690E+01	5.738E+01	27	0.01	0.07	7.714E-01
5.738E+01	5.786E+01	28	0.01	0.08	8.067E-01
5.786E+01	5.833E+01	27	0.01	0.10	7.843E-01
5.833E+01	5.881E+01	27	0.01	0.11	7.907E-01
5.881E+01	5.929E+01	27	0.01	0.12	7.971E-01
5.929E+01	5.976E+01	27	0.01	0.14	8.036E-01
5.976E+01	6.024E+01	28	0.01	0.15	8.400E-01
6.024E+01	6.071E+01	27	0.01	0.16	8.164E-01
6.071E+01	6.119E+01	27	0.01	0.18	8.229E-01
6.119E+01	6.167E+01	27	0.01	0.19	8.293E-01
6.167E+01	6.214E+01	27	0.01	0.20	8.357E-01
6.214E+01	6.262E+01	28	0.01	0.22	8.733E-01
6.262E+01	6.310E+01	27	0.01	0.23	8.486E-01
6.310E+01	6.357E+01	27	0.01	0.25	8.550E-01
6.357E+01	6.405E+01	27	0.01	0.26	8.614E-01
6.405E+01	6.452E+01	27	0.01	0.27	8.679E-01
6.452E+01	6.500E+01	28	0.01	0.29	9.067E-01
6.500E+01	6.548E+01	27	0.01	0.30	8.807E-01
6.548E+01	6.595E+01	27	0.01	0.31	8.871E-01

6.595E+01	6.643E+01	27	0.01	0.33	8.936E-01
6.643E+01	6.690E+01	27	0.01	0.34	9.000E-01
6.690E+01	6.738E+01	28	0.01	0.35	9.400E-01
6.738E+01	6.786E+01	27	0.01	0.37	9.129E-01
6.786E+01	6.833E+01	27	0.01	0.38	9.193E-01
6.833E+01	6.881E+01	30	0.01	0.40	1.029E+00
6.881E+01	6.929E+01	82	0.04	0.44	2.831E+00
6.929E+01	6.976E+01	82	0.04	0.48	2.850E+00
6.976E+01	7.024E+01	68	0.03	0.51	2.380E+00
7.024E+01	7.071E+01	54	0.03	0.54	1.903E+00
7.071E+01	7.119E+01	54	0.03	0.57	1.916E+00
7.119E+01	7.167E+01	55	0.03	0.59	1.964E+00
7.167E+01	7.214E+01	55	0.03	0.62	1.977E+00
7.214E+01	7.262E+01	54	0.03	0.65	1.954E+00
7.262E+01	7.310E+01	54	0.03	0.68	1.967E+00
7.310E+01	7.357E+01	54	0.03	0.70	1.980E+00
7.357E+01	7.405E+01	55	0.03	0.73	2.030E+00
7.405E+01	7.452E+01	55	0.03	0.76	2.043E+00
7.452E+01	7.500E+01	54	0.03	0.78	2.019E+00
7.500E+01	7.548E+01	54	0.03	0.81	2.031E+00
7.548E+01	7.595E+01	54	0.03	0.84	2.044E+00
7.595E+01	7.643E+01	55	0.03	0.87	2.095E+00
7.643E+01	7.690E+01	55	0.03	0.89	2.108E+00
7.690E+01	7.738E+01	54	0.03	0.92	2.083E+00
7.738E+01	7.786E+01	54	0.03	0.95	2.096E+00
7.786E+01	7.833E+01	54	0.03	0.97	2.109E+00
7.833E+01	7.881E+01	52	0.03	1.00	2.043E+00

Expected Time of Maximum Concentration = 68.9456445222611

VARIABLE NUMBER: 1

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
1.500E+01	1.570E+01	40	0.02	0.02	3.070E-01
1.570E+01	1.640E+01	40	0.02	0.04	3.210E-01
1.640E+01	1.710E+01	40	0.02	0.06	3.350E-01
1.710E+01	1.780E+01	40	0.02	0.08	3.490E-01
1.780E+01	1.850E+01	40	0.02	0.10	3.630E-01
1.850E+01	1.920E+01	40	0.02	0.12	3.770E-01
1.920E+01	1.990E+01	40	0.02	0.14	3.910E-01
1.990E+01	2.060E+01	40	0.02	0.16	4.050E-01
2.060E+01	2.130E+01	40	0.02	0.18	4.190E-01
2.130E+01	2.200E+01	40	0.02	0.20	4.330E-01
2.200E+01	2.270E+01	40	0.02	0.22	4.470E-01
2.270E+01	2.340E+01	40	0.02	0.24	4.610E-01
2.340E+01	2.410E+01	40	0.02	0.26	4.750E-01
2.410E+01	2.480E+01	40	0.02	0.28	4.890E-01
2.480E+01	2.550E+01	40	0.02	0.30	5.030E-01
2.550E+01	2.620E+01	40	0.02	0.32	5.170E-01
2.620E+01	2.690E+01	40	0.02	0.34	5.310E-01
2.690E+01	2.760E+01	40	0.02	0.36	5.450E-01
2.760E+01	2.830E+01	40	0.02	0.38	5.590E-01
2.830E+01	2.900E+01	40	0.02	0.40	5.730E-01
2.900E+01	2.970E+01	40	0.02	0.42	5.870E-01
2.970E+01	3.040E+01	40	0.02	0.44	6.010E-01
3.040E+01	3.110E+01	40	0.02	0.46	6.150E-01
3.110E+01	3.180E+01	40	0.02	0.48	6.290E-01
3.180E+01	3.250E+01	40	0.02	0.50	6.430E-01

2.900E+01	2.970E+01	40	0.02	0.42	5.870E-01
2.970E+01	3.040E+01	40	0.02	0.44	6.010E-01
3.040E+01	3.110E+01	40	0.02	0.46	6.150E-01
3.110E+01	3.180E+01	40	0.02	0.48	6.290E-01
3.180E+01	3.250E+01	40	0.02	0.50	6.430E-01
3.250E+01	3.320E+01	40	0.02	0.52	6.570E-01
3.320E+01	3.390E+01	40	0.02	0.54	6.710E-01
3.390E+01	3.460E+01	40	0.02	0.56	6.850E-01
3.460E+01	3.530E+01	40	0.02	0.58	6.990E-01
3.530E+01	3.600E+01	40	0.02	0.60	7.130E-01
3.600E+01	3.670E+01	40	0.02	0.62	7.270E-01
3.670E+01	3.740E+01	40	0.02	0.64	7.410E-01
3.740E+01	3.810E+01	40	0.02	0.66	7.550E-01
3.810E+01	3.880E+01	40	0.02	0.68	7.690E-01
3.880E+01	3.950E+01	40	0.02	0.70	7.830E-01
3.950E+01	4.020E+01	40	0.02	0.72	7.970E-01
4.020E+01	4.090E+01	40	0.02	0.74	8.110E-01
4.090E+01	4.160E+01	40	0.02	0.76	8.250E-01
4.160E+01	4.230E+01	40	0.02	0.78	8.390E-01
4.230E+01	4.300E+01	40	0.02	0.80	8.530E-01
4.300E+01	4.370E+01	40	0.02	0.82	8.670E-01
4.370E+01	4.440E+01	40	0.02	0.84	8.810E-01
4.440E+01	4.510E+01	40	0.02	0.86	8.950E-01
4.510E+01	4.580E+01	40	0.02	0.88	9.090E-01
4.580E+01	4.650E+01	40	0.02	0.90	9.230E-01
4.650E+01	4.720E+01	40	0.02	0.92	9.370E-01
4.720E+01	4.790E+01	40	0.02	0.94	9.510E-01
4.790E+01	4.860E+01	40	0.02	0.96	9.650E-01
4.860E+01	4.930E+01	40	0.02	0.98	9.790E-01
4.930E+01	5.000E+01	40	0.02	1.00	9.930E-01

Expected Value = 3.250E+01

NOTICE