POLLUTE

Version 8

Example 16: Monte Carlo Simulation

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Version 8

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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.

Following are the parameters used in this example:

Property	Symbol	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	m
Layer 2 Thickness	H	0.3	m
Layer 3 Thickness	H	2	m
Source Concentration	c_0	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	m
Landfill Width	W	1	m
Aquifer Thickness	h	1	m
Aquifer Porosity	n	0.3	-
Aquifer Outflow Velocity	v_b	4	m/a
Minimum Failure Start Time		20	a
Modal Failure Start Time		25	a
Maximum Failure Start Time		50	a

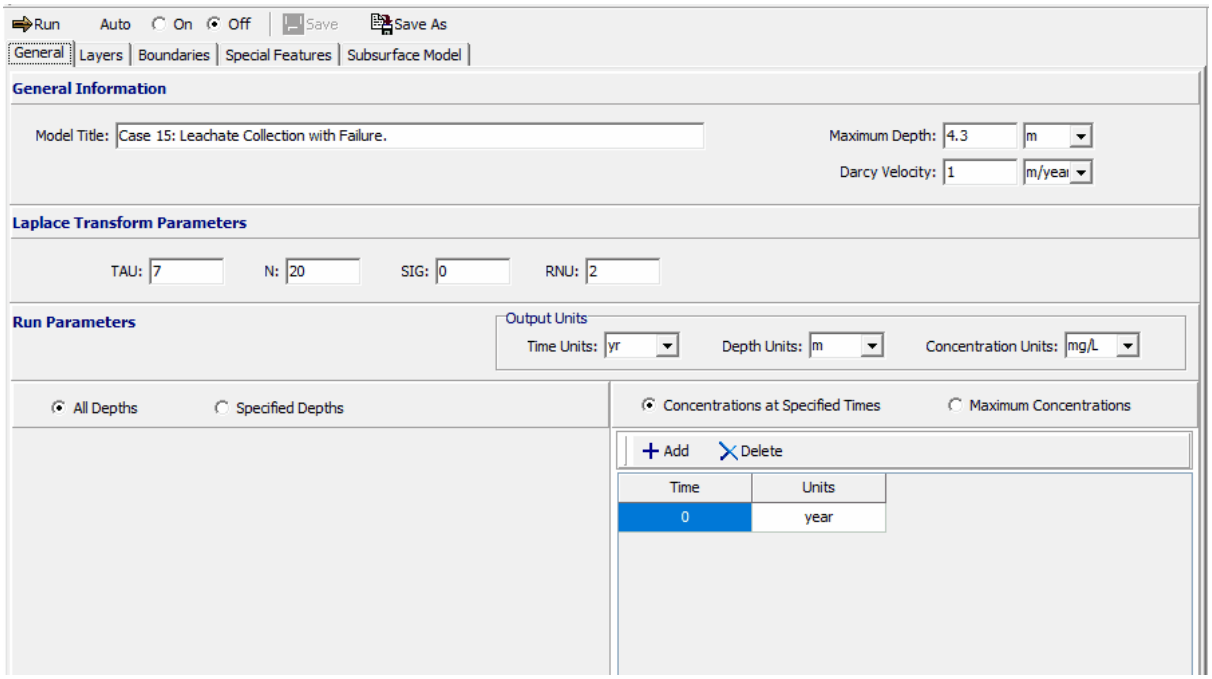
This example is for a hypothetical landfill and is used to illustrate how to prepare an input file and run an analysis using the Variable Properties and Passive Sink option. The example is not a prescription for modeling contaminant migration during operation of a landfill. Each landfill has its own 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 modeling 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

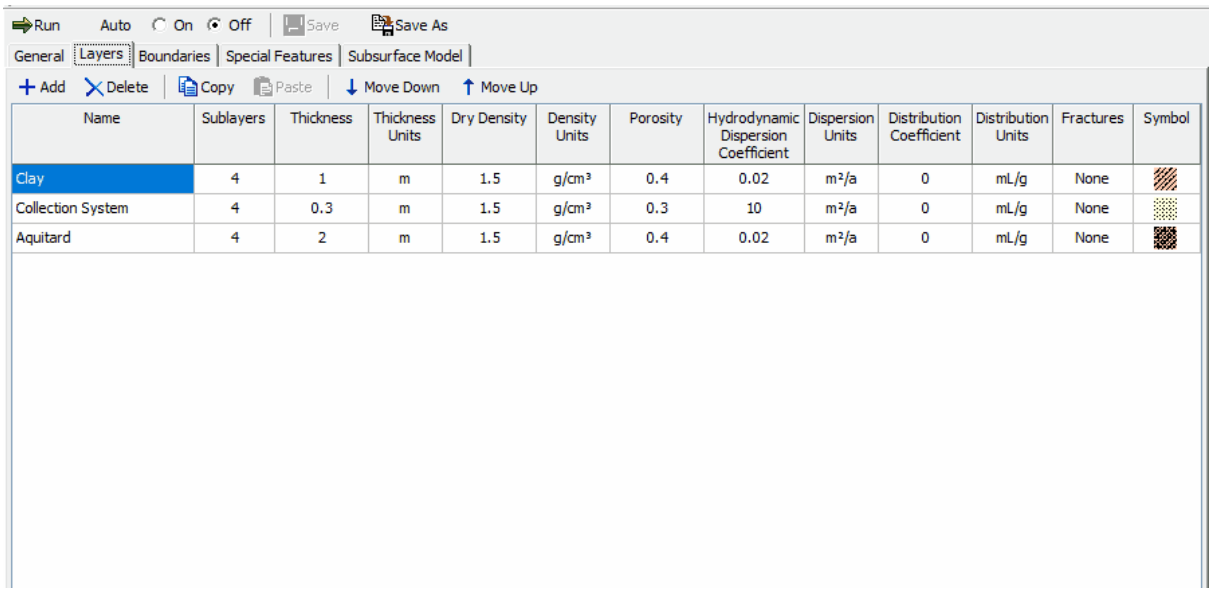
Open the Examples project and open Case 16.

General Tab



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

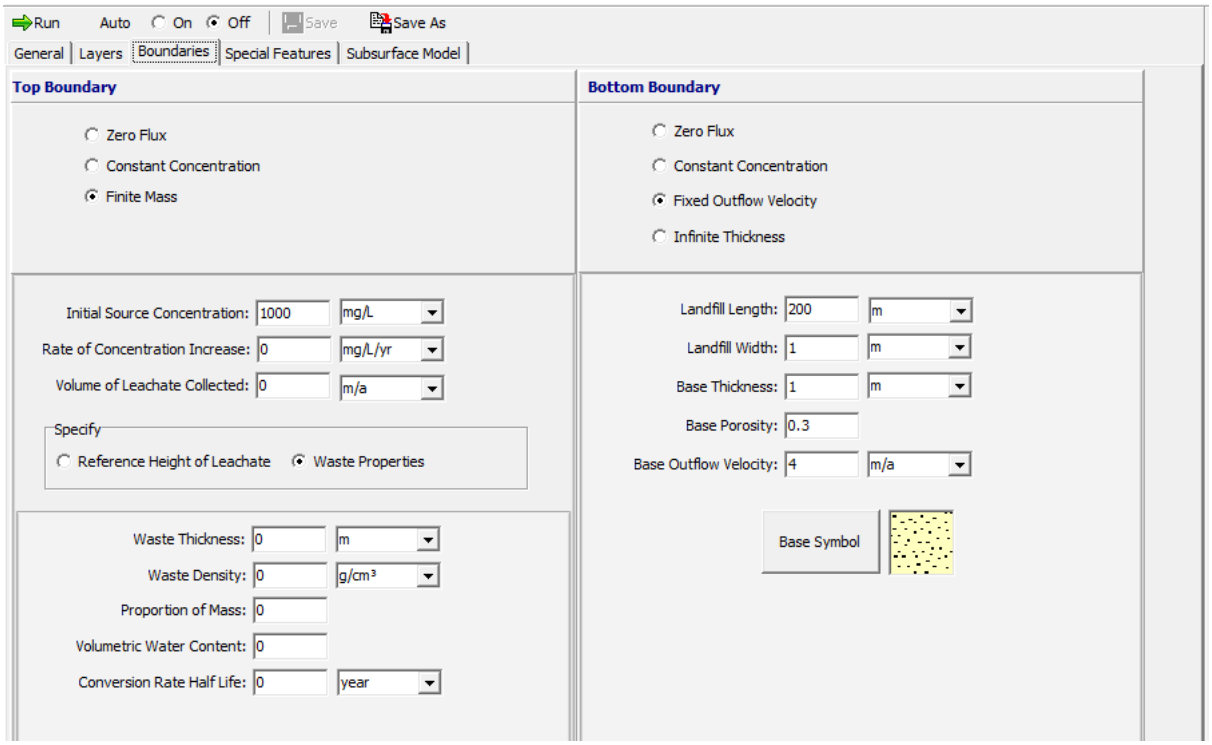
Layers Tab



Name	Sublayers	Thickness	Thickness Units	Dry Density	Density Units	Porosity	Hydrodynamic Dispersion Coefficient	Dispersion Units	Distribution Coefficient	Distribution Units	Fractures	Symbol
Clay	4	1	m	1.5	g/cm³	0.4	0.02	m²/a	0	mL/g	None	
Collection System	4	0.3	m	1.5	g/cm³	0.3	10	m²/a	0	mL/g	None	
Aquitard	4	2	m	1.5	g/cm³	0.4	0.02	m²/a	0	mL/g	None	

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

Boundaries Tab



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

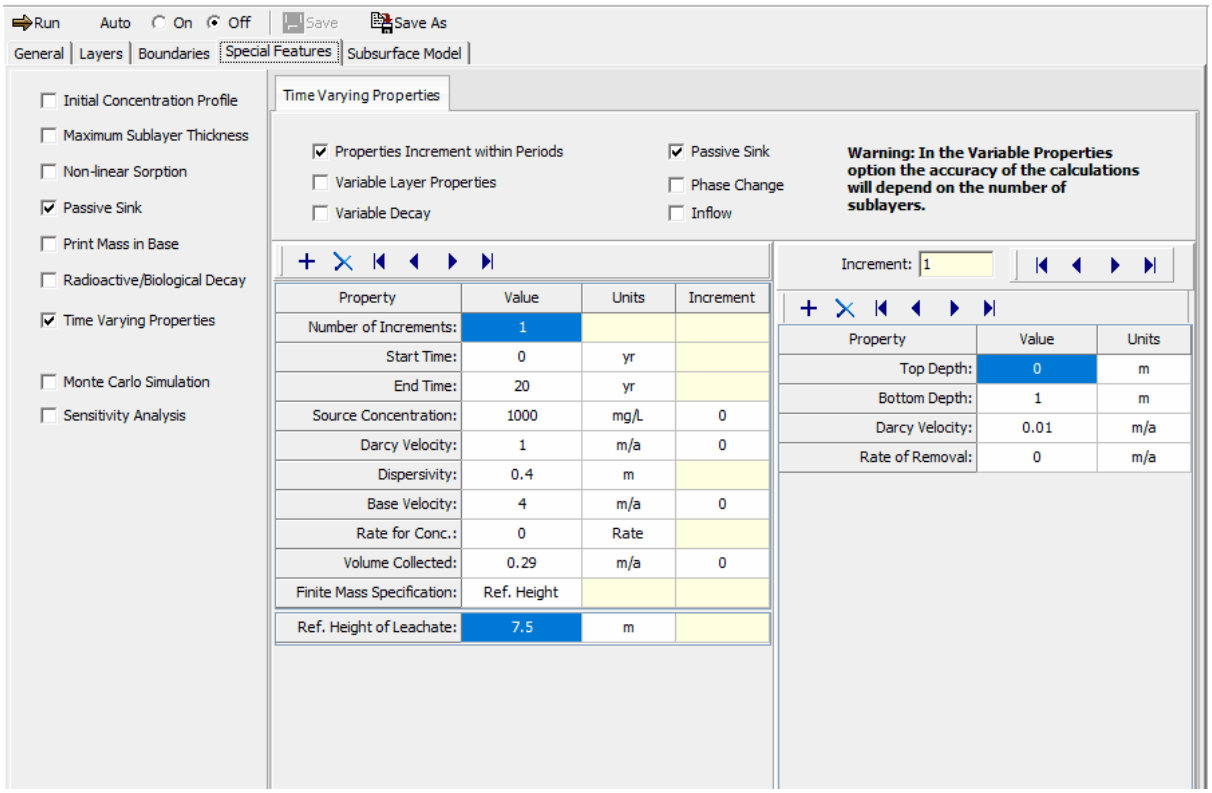
Special Features

The time-varying data, passive sink, and Monte Carlo simulation data for this model can be entered

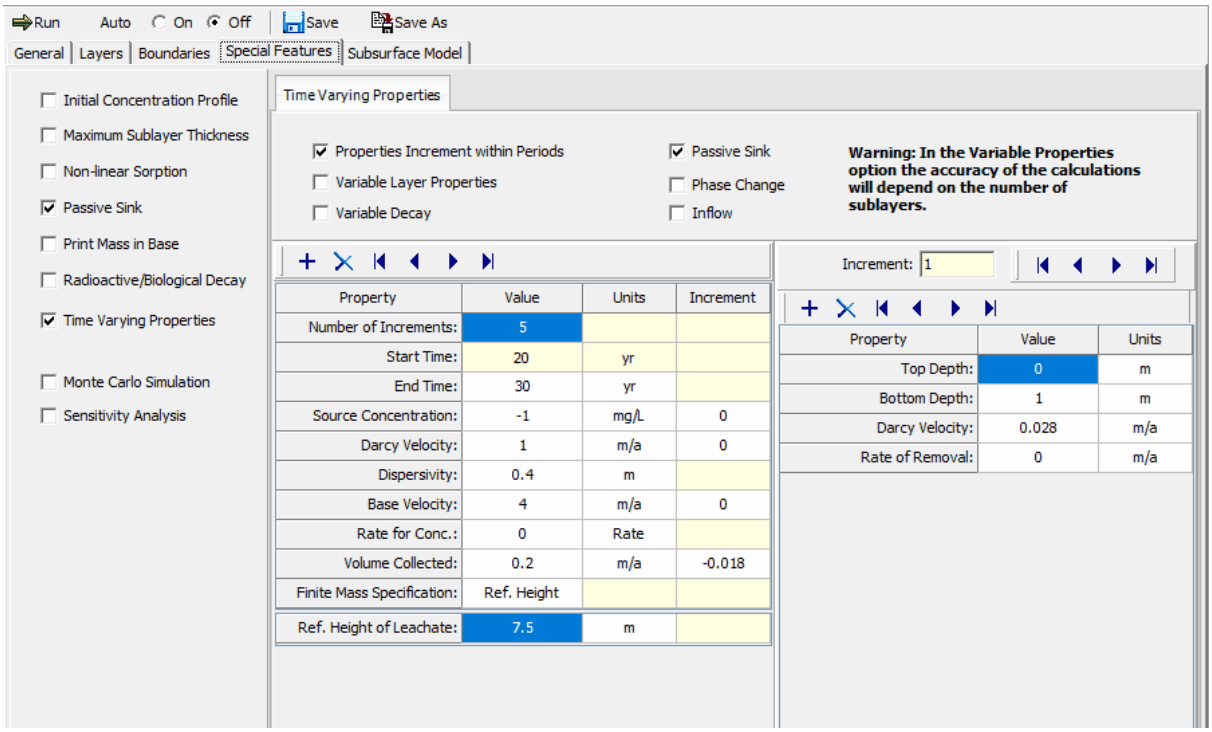
using the Time-varying Properties and Monte Carlo options in the Special Features tab. When these are options are selected the passive sink data is entered as part of the time varying properties.

Time Varying Properties

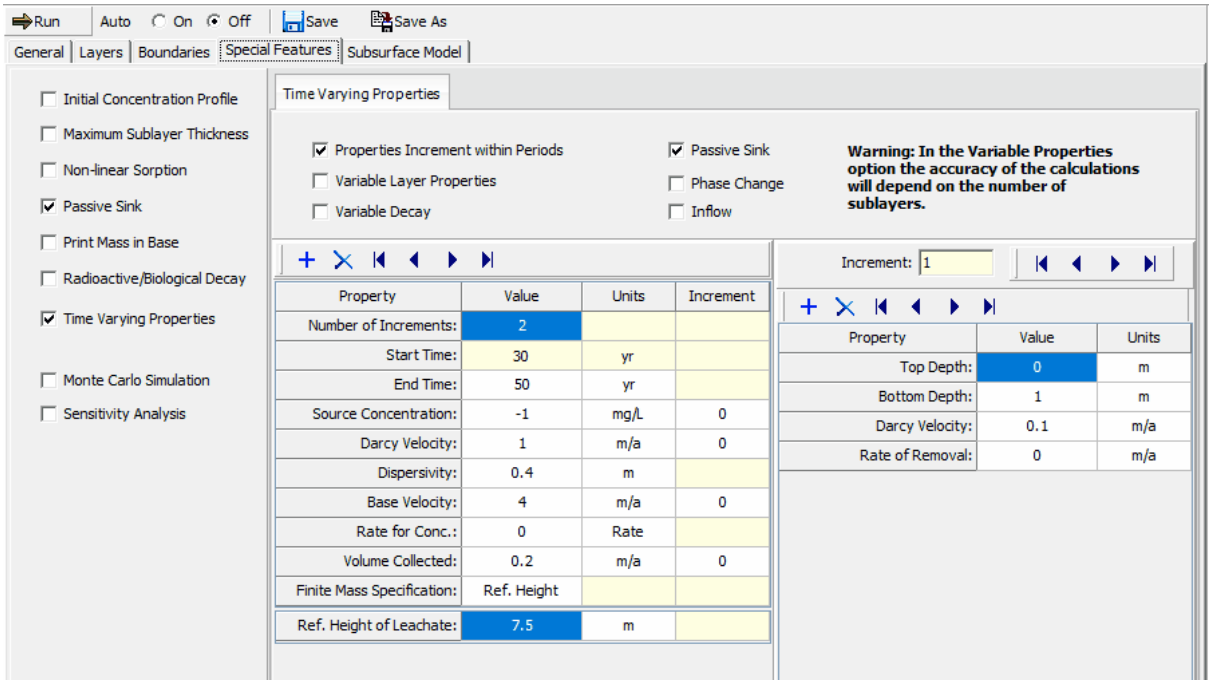
To specify the time-varying properties, check the Time-Varying Properties box on the Special Features tab. The Time-Varying Data sub-tab is used to specify the time period data and whether there are variable layer properties and variable decay. In this example there are 5 time periods.



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 property on the left. 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.

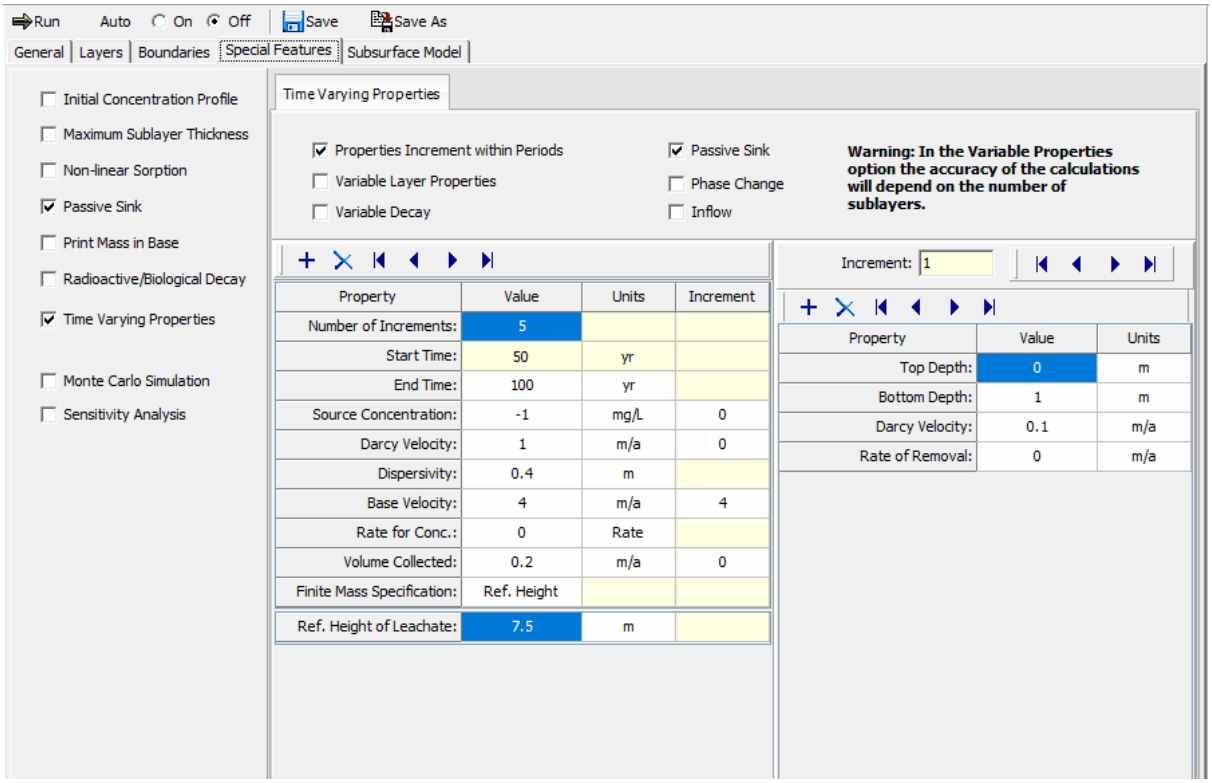


The data for the second time period, from 20 to 30 years, can be specified by pressing the Next arrow. The increment in the Leachate collected results from the increasing Darcy velocity during this period. This increase in Darcy velocity will be taken into account in the Passive Sink property on the left side.

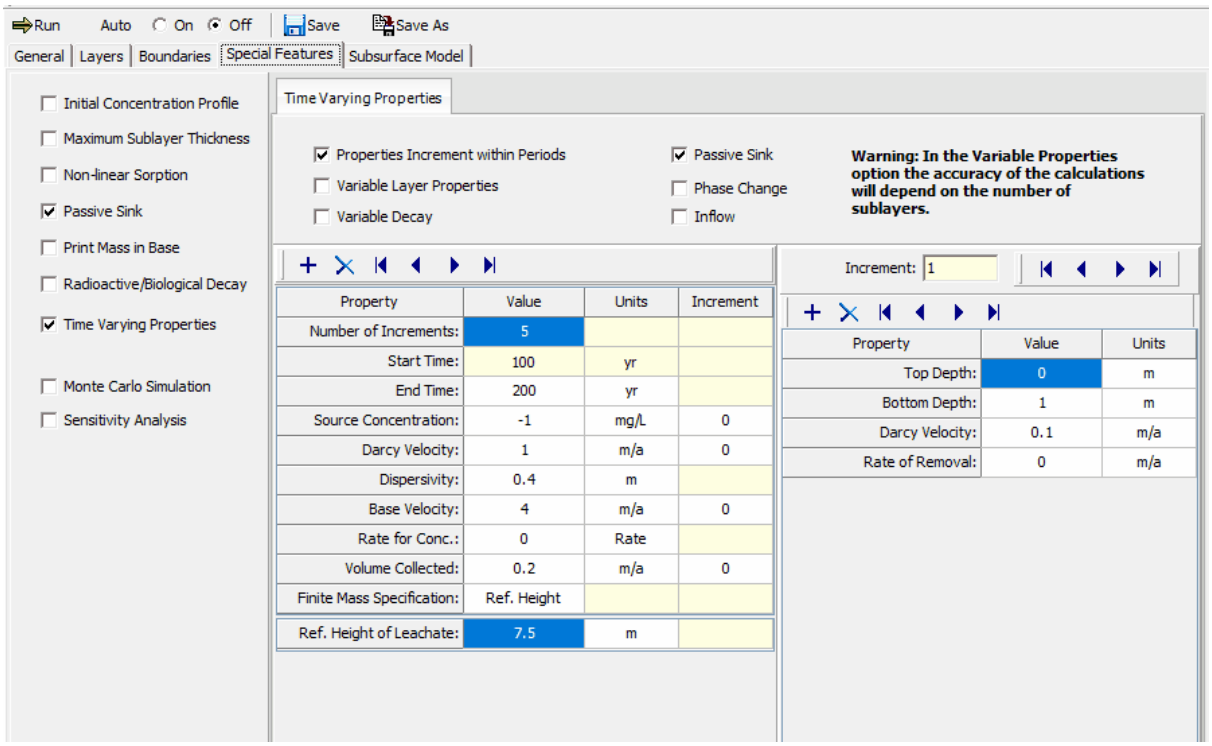


Next the data for time period three from 30 to 50 years can be entered.. Two increments are used to calculate the concentrations at 40 and 50 years. At this point the primary leachate collection system has completely failed and there is no further increase in the Darcy velocity. The Volume of Leachate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

a.



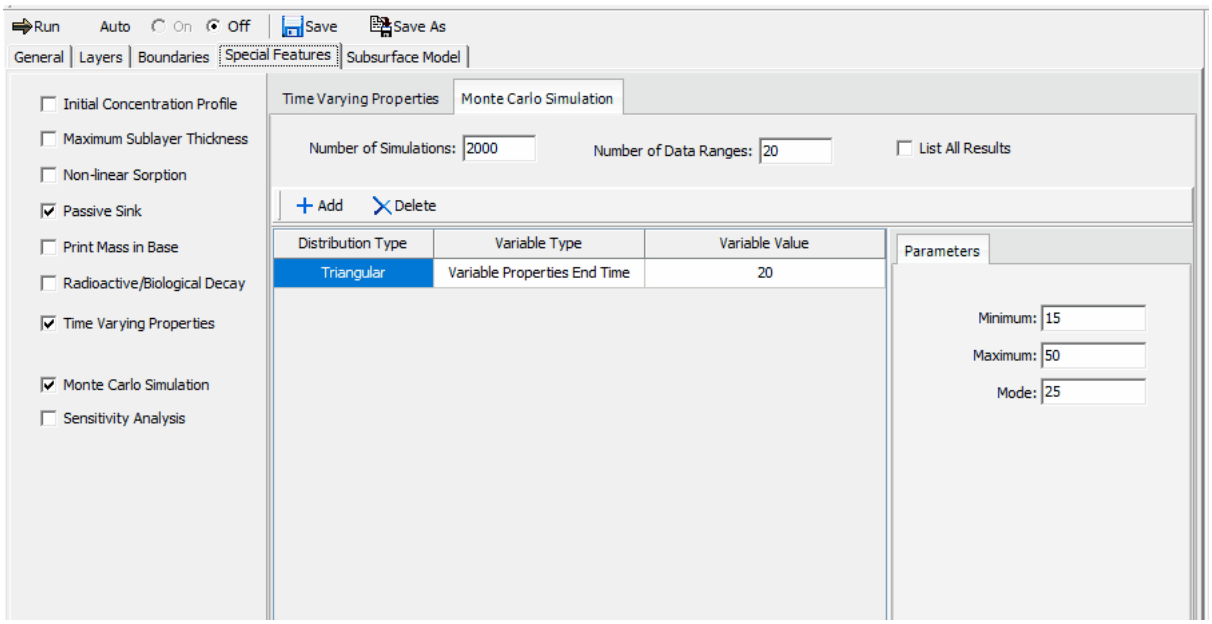
The data for time period four should can be entered by clicking on the next arrow. Five increments are used to calculate the concentrations at 60, 70, 80, 90, and 100 years.



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.

Monte Carlo Simulation

The Monte Carlo simulation data can be specified by selecting the Monte Carlo Simulation sub-tab on the Special Features tab. The number of simulations, variables, and data ranges can be specified. 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.



Model Execution

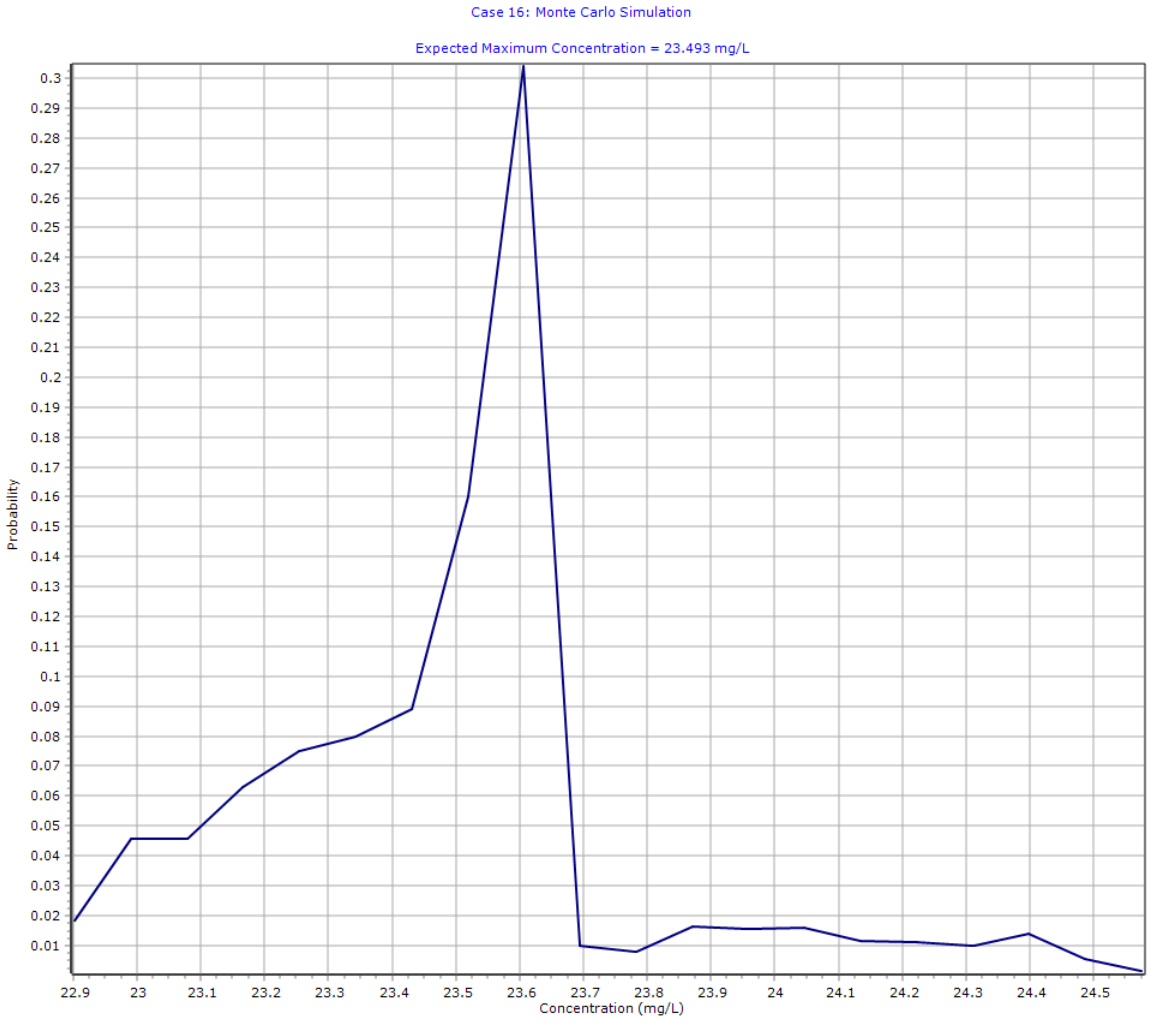
To run the model and calculate the concentrations press the Run button on the toolbar.

Model Output

After the model has been executed, the output for the model will be displayed.

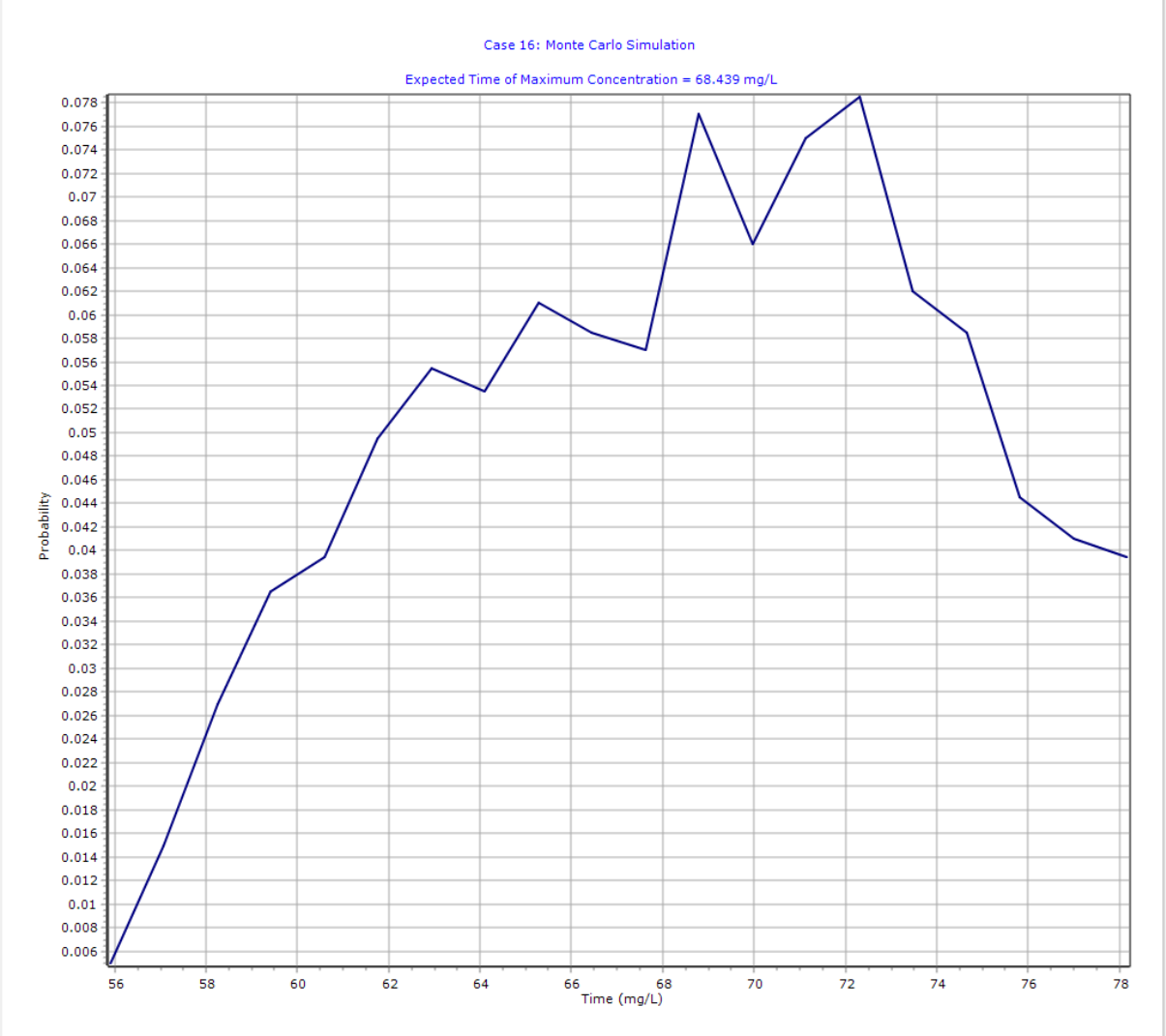
Probability vs Concentration

The Probability vs Concentration chart can be displayed by selecting the Probability vs Concentration item for the Chart Type. 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 23.493 mg/L.



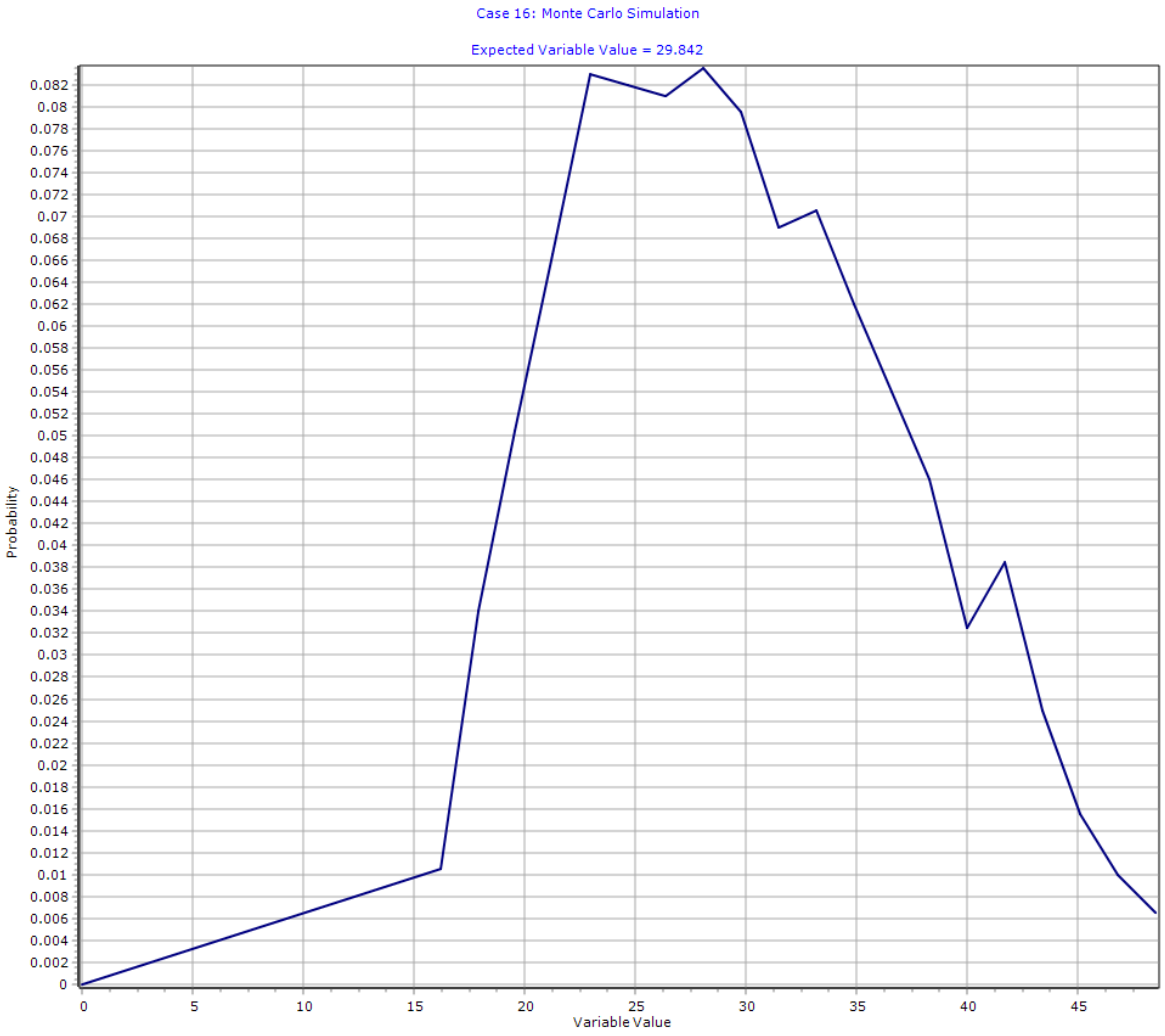
Probability vs Time

The Probability vs Time chart can be displayed by selecting the Probability vs Time item for the Chart Type. Using this chart the expected time of the maximum concentration can be predicted. In this example, the expected time is 68.439 years.



Probability vs Variable Value

The Probability vs Variable Value chart can be displayed by selecting the Probability vs Variable Value item for the Chart Type. 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, click on the List tab.

POLLUTEv8

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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

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

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	Proportion Mass	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 / 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 / 1	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
2 / 2	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
2 / 3	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
2 / 4	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
2 / 5	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
3 / 1	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
3 / 2	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
4 / 1	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
4 / 2	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
4 / 3	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
4 / 4	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
4 / 5	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
5 / 1	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
5 / 2	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

5 / 3	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
5 / 4	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
5 / 5	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 = 2000
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)

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.

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	Proportion Mass	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 / 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 / 1	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
2 / 2	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
2 / 3	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
2 / 4	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
2 / 5	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
3 / 1	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
3 / 2	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
4 / 1	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
4 / 2	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
4 / 3	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
4 / 4	0 m	1 m	0.1 m/a	0 m/a

	1 m 1.3 m	1.3 m 3.3 m	0.1 m/a 0 m/a	66.7 m/a 0 m/a
4 / 5	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
5 / 1	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
5 / 2	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
5 / 3	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
5 / 4	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
5 / 5	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 = 2000
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
2.286E+01	2.295E+01	37	0.02	0.02	4.237E-01
2.295E+01	2.303E+01	91	0.05	0.06	1.046E+00
2.303E+01	2.312E+01	91	0.05	0.11	1.050E+00
2.312E+01	2.321E+01	126	0.06	0.17	1.459E+00
2.321E+01	2.330E+01	150	0.07	0.25	1.744E+00
2.330E+01	2.339E+01	160	0.08	0.33	1.867E+00
2.339E+01	2.347E+01	178	0.09	0.42	2.085E+00
2.347E+01	2.356E+01	320	0.16	0.58	3.763E+00
2.356E+01	2.365E+01	608	0.30	0.88	7.176E+00
2.365E+01	2.374E+01	20	0.01	0.89	2.369E-01
2.374E+01	2.383E+01	16	0.01	0.90	1.903E-01
2.383E+01	2.391E+01	33	0.02	0.92	3.939E-01
2.391E+01	2.400E+01	31	0.02	0.93	3.714E-01

2.400E+01	2.409E+01	32	0.02	0.95	3.847E-01
2.409E+01	2.418E+01	23	0.01	0.96	2.776E-01
2.418E+01	2.427E+01	22	0.01	0.97	2.665E-01
2.427E+01	2.436E+01	20	0.01	0.98	2.431E-01
2.436E+01	2.444E+01	28	0.01	0.99	3.416E-01
2.444E+01	2.453E+01	11	0.01	1.00	1.347E-01
2.453E+01	2.462E+01	3	0.00	1.00	3.686E-02

Expected Maximum Concentration = 2.349E+01

DISTRIBUTION OF TIME OF PEAK CONCENTRATION

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
5.532E+01	5.650E+01	10	0.01	0.01	2.795E-01
5.650E+01	5.767E+01	30	0.01	0.02	8.562E-01
5.767E+01	5.884E+01	54	0.03	0.05	1.573E+00
5.884E+01	6.001E+01	73	0.04	0.08	2.169E+00
6.001E+01	6.118E+01	79	0.04	0.12	2.393E+00
6.118E+01	6.235E+01	99	0.05	0.17	3.057E+00
6.235E+01	6.352E+01	111	0.06	0.23	3.493E+00
6.352E+01	6.469E+01	107	0.05	0.28	3.430E+00
6.469E+01	6.586E+01	122	0.06	0.34	3.982E+00
6.586E+01	6.703E+01	117	0.06	0.40	3.887E+00
6.703E+01	6.820E+01	114	0.06	0.46	3.854E+00
6.820E+01	6.938E+01	154	0.08	0.53	5.297E+00
6.938E+01	7.055E+01	132	0.07	0.60	4.617E+00
7.055E+01	7.172E+01	150	0.07	0.68	5.335E+00
7.172E+01	7.289E+01	157	0.08	0.75	5.676E+00
7.289E+01	7.406E+01	124	0.06	0.82	4.555E+00
7.406E+01	7.523E+01	117	0.06	0.88	4.367E+00
7.523E+01	7.640E+01	89	0.04	0.92	3.374E+00
7.640E+01	7.757E+01	82	0.04	0.96	3.156E+00
7.757E+01	7.874E+01	79	0.04	1.00	3.087E+00

Expected Time of Maximum Concentration = 68.4391550021306

VARIABLE NUMBER: 1

Minimum Value	Maximum Value	Number Occur.	Probability	Cumulative Probability	Expected Value
1.532E+01	1.702E+01	21	0.01	0.01	1.698E-01
1.702E+01	1.873E+01	68	0.03	0.04	6.078E-01
1.873E+01	2.043E+01	101	0.05	0.10	9.886E-01
2.043E+01	2.213E+01	133	0.07	0.16	1.415E+00
2.213E+01	2.383E+01	166	0.08	0.24	1.907E+00
2.383E+01	2.553E+01	164	0.08	0.33	2.024E+00
2.553E+01	2.723E+01	162	0.08	0.41	2.137E+00
2.723E+01	2.893E+01	167	0.08	0.49	2.345E+00
2.893E+01	3.063E+01	159	0.08	0.57	2.368E+00
3.063E+01	3.233E+01	138	0.07	0.64	2.172E+00
3.233E+01	3.403E+01	141	0.07	0.71	2.339E+00
3.403E+01	3.573E+01	124	0.06	0.77	2.163E+00
3.573E+01	3.743E+01	108	0.05	0.83	1.975E+00
3.743E+01	3.913E+01	92	0.05	0.87	1.761E+00
3.913E+01	4.083E+01	65	0.03	0.90	1.299E+00
4.083E+01	4.254E+01	77	0.04	0.94	1.605E+00

4.254E+01	4.424E+01	50	0.03	0.97	1.085E+00
4.424E+01	4.594E+01	31	0.02	0.98	6.988E-01
4.594E+01	4.764E+01	20	0.01	0.99	4.679E-01
4.764E+01	4.934E+01	13	0.01	1.00	3.152E-01
0.000E+00	0.000E+00	0	0.00	0.00	0.000E+00

Expected Value = 2.984E+01