

POLLUTE

Version 8

Example 10: Time-varying Transport



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Printed: September 2021 in Canada.

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 is 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:

$$v_b = 2 + 200 * v_a$$

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 (D_m) 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:

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

where n is the porosity, in this example 0.4.

Following are the parameters used in this example:

Property	Symbol	Value	Units
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Darcy Velocity	v_a	variable	m/a
Diffusion Coefficient	D	0.02	m ² /a
Distribution Coefficient	K_d	0	cm ³ /g
Dispersivity ($v_a < 0$)		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_r	4	m
Number of Sub-layers		12	-
Source Concentration	c_0	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	m
Landfill Width	W	1	m
Aquifer Thickness	H_r	1	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 modeling 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 be 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.

Data Entry

Open the Examples project and open Case 10.

General Tab

General Information

Model Title: Case 10: Time-varying advective-dispersive transport

Maximum Depth: 5 m

Darcy Velocity: 1 m/year

Laplace Transform Parameters

TAU: 7 N: 20 SIG: 0 RNU: 2

Run Parameters

Output Units

Time Units: year Depth Units: m Concentration Units: mg/L

All Depths Specified Depths

Concentrations at Specified Times Maximum Concentrations

+ Add X Delete

Depth	Units
0	m
1	m
2	m
3	m
4	m

+ Add X Delete

Time	Units
0	year

In the General tab the Darcy velocity can be specified. If the Time-varying Properties special feature is used, any Darcy velocity entered will be ignored. 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. In this example the concentrations will be calculated at 5 depths: 0, 1, 2, 3, and 4 m

Layers Tab

Layers Tab

+ Add X Delete Copy Paste Move Down Move Up

Name	Sublayers	Thickness	Thickness Units	Dry Density	Density Units	Porosity	Hydrodynamic Dispersion Coefficient	Dispersion Units	Distribution Coefficient	Distribution Units	Fractures	Symbol
Aquitard	12	4	m	1.5	g/cm ³	0.4	0.02	cm ² /a	0	m ³ /kg	None	

The layer data for the layer can be specified on the Layers tab.

Boundaries Tab

Run Auto On Off Save Save As

General Layers Boundaries Special Features Subsurface Model

Top Boundary

Zero Flux
 Constant Concentration
 Finite Mass

Initial Source Concentration: 1000 mg/L
 Rate of Concentration Increase: 0 mg/L/yr
 Volume of Leachate Collected: 0.3 m/a

Specify

Reference Height of Leachate Waste Properties

Reference Height of Leachate: 7.5 m

Bottom Boundary

Zero Flux
 Constant Concentration
 Fixed Outflow Velocity
 Infinite Thickness

Landfill Length: 200 m
 Landfill Width: 1 m
 Base Thickness: 1 m
 Base Porosity: 0.3
 Base Outflow Velocity: 2 m/a

Base Symbol

In this example, the top boundary has a finite mass and the bottom boundary is represented by a fixed outflow aquifer. If the Time-varying Properties special feature is selected, any parameters entered for the Finite Mass will be ignored and the source parameters will be entered in the Time-Varying Properties sub-tab of the Special Features tab.

Special Features

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

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 varying properties. In this example there are 3 time periods viz. 0 to 20 years, 20 to 30 years, and 30 to 130 years.

Run Auto On Off Save Save As

General Layers Boundaries Special Features Subsurface Model

Initial Concentration Profile
 Maximum Sublayer Thickness
 Non-linear Sorption
 Passive Sink
 Print Mass in Base
 Radioactive/Biological Decay
 Time Varying Properties
 Monte Carlo Simulation
 Sensitivity Analysis

Time Varying Properties

Properties Increment within Periods
 Variable Layer Properties
 Variable Decay

Passive Sink

Warning: In the Variable Properties option the accuracy of the calculations will depend on the number of sublayers.

Increment: 1

Property	Value	Units	Increment
Number of Increments:	1		
Start Time:	0	yr	
End Time:	20	yr	
Source Concentration:	1000	mg/L	0
Darcy Velocity:	-0.001	m/a	0
Dispersivity:	0	m	
Base Velocity:	2	m/a	0
Rate for Conc.:	0	mg/L/yr	
Volume Collected:	0.3	m/a	0
Finite Mass Specification:	Ref. Height		
Ref. Height of Leachate:	7.5	m	

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

The screenshot shows the 'Time Varying Properties' dialog box. On the left, there is a list of options with checkboxes. The 'Time Varying Properties' option is checked. The main area contains a table of properties and their values. A warning message is displayed on the right side of the dialog.

Warning: In the Variable Properties option the accuracy of the calculations will depend on the number of sublayers.

Property	Value	Units	Increment
Number of Increments:	10		
Start Time:	20	yr	
End Time:	30	yr	
Source Concentration:	-1	mg/L	0
Darcy Velocity:	0	m/a	0.0021
Dispersivity:	0.4	m	
Base Velocity:	2	m/a	0.42
Rate for Conc.:	0	mg/L/yr	
Volume Collected:	0.3	m/a	-0.0021
Finite Mass Specification:	Ref. Height		
Ref. Height of Leachate:	7.5	m	

The data for time period two can be specified by pressing the Next button. This time period is from 20 to 30 years. 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).

Property	Value	Units	Increment
Number of Increments:	10		
Start Time:	30	yr	
End Time:	130	yr	
Source Concentration:	-1	mg/L	0
Darcy Velocity:	0.021	m/a	0
Dispersivity:	0.4	m	
Base Velocity:	6.2	m/a	0
Rate for Conc.:	0	mg/L/yr	
Volume Collected:	0.279	m/a	0
Finite Mass Specification:	Ref. Height		
Ref. Height of Leachate:	7.5	m	

The data for time period three can be entered by clicking on the Next button, this time period is from 30 to 130 years. 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., $2 + 200 \cdot 0.021 = 6.2$ m/a).

Model Execution



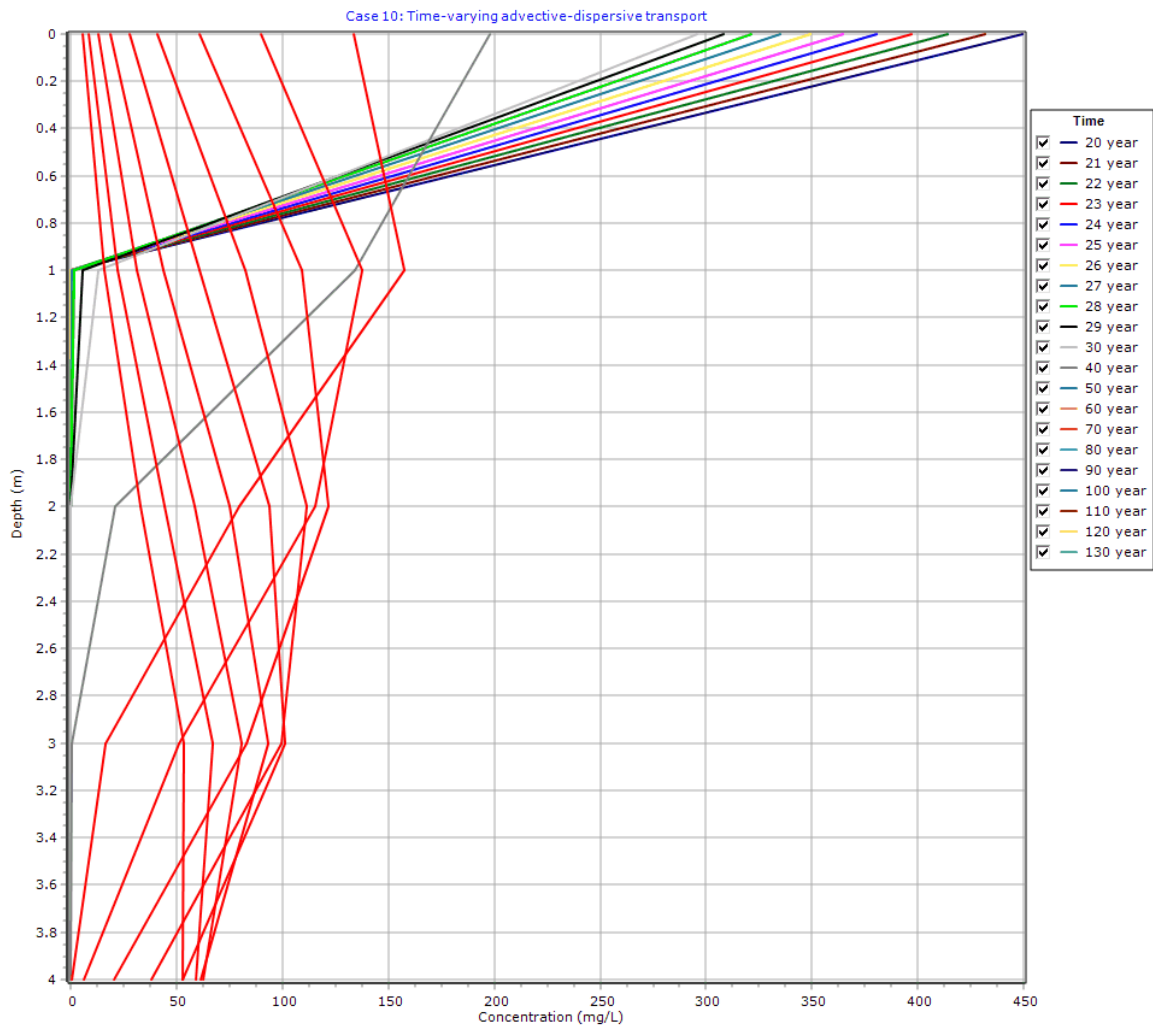
To run the model and calculate the concentrations press the Run button on the toolbar.

Model Output

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

Depth vs Concentration

The Depth vs Concentration chart can be displayed by selecting the Depth vs Concentration item for the Chart Type.



Output Listing

To display the output as a text listing that will show the calculated concentrations as numbers, click on the List tab.

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Case 10: Time-varying advective-dispersive transport

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 cm ² /a	0.4	0 m ³ /kg	1.5 g/cm ³

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

Period	Start Time	End Time	Proportion Mass	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	4.493E+02
	1.000E+00	0.000E+00
	2.000E+00	0.000E+00

	3.000E+00	0.000E+00
	4.000E+00	0.000E+00
21	0.000E+00	4.317E+02
	1.000E+00	1.000E-06
	2.000E+00	1.000E-06
	3.000E+00	1.000E-06
	4.000E+00	9.673E-07
22	0.000E+00	4.140E+02
	1.000E+00	1.000E-06
	2.000E+00	1.000E-06
	3.000E+00	1.000E-06
	4.000E+00	9.373E-07
23	0.000E+00	3.968E+02
	1.000E+00	1.001E-06
	2.000E+00	1.000E-06
	3.000E+00	1.000E-06
	4.000E+00	9.095E-07
24	0.000E+00	3.803E+02
	1.000E+00	2.075E-06
	2.000E+00	1.000E-06
	3.000E+00	1.000E-06
	4.000E+00	8.842E-07
25	0.000E+00	3.645E+02
	1.000E+00	3.657E-04
	2.000E+00	1.000E-06
	3.000E+00	9.998E-07
	4.000E+00	8.613E-07
26	0.000E+00	3.495E+02
	1.000E+00	2.295E-02
	2.000E+00	1.001E-06
	3.000E+00	9.995E-07
	4.000E+00	8.408E-07
27	0.000E+00	3.352E+02
	1.000E+00	3.112E-01
	2.000E+00	1.088E-06
	3.000E+00	9.988E-07
	4.000E+00	8.226E-07
28	0.000E+00	3.215E+02
	1.000E+00	1.726E+00
	2.000E+00	7.774E-06
	3.000E+00	9.978E-07
	4.000E+00	8.068E-07
29	0.000E+00	3.085E+02
	1.000E+00	5.600E+00
	2.000E+00	2.971E-04
	3.000E+00	9.977E-07
	4.000E+00	7.931E-07
30	0.000E+00	2.960E+02
	1.000E+00	1.295E+01
	2.000E+00	5.209E-03
	3.000E+00	1.064E-06

	4.000E+00	7.815E-07
40	0.000E+00	1.981E+02
	1.000E+00	1.340E+02
	2.000E+00	2.090E+01
	3.000E+00	7.031E-01
	4.000E+00	1.518E-03
50	0.000E+00	1.335E+02
	1.000E+00	1.575E+02
	2.000E+00	7.950E+01
	3.000E+00	1.634E+01
	4.000E+00	5.856E-01
60	0.000E+00	9.010E+01
	1.000E+00	1.379E+02
	2.000E+00	1.154E+02
	3.000E+00	5.128E+01
	4.000E+00	6.323E+00
70	0.000E+00	6.092E+01
	1.000E+00	1.093E+02
	2.000E+00	1.218E+02
	3.000E+00	8.301E+01
	4.000E+00	2.051E+01
80	0.000E+00	4.123E+01
	1.000E+00	8.260E+01
	2.000E+00	1.112E+02
	3.000E+00	9.947E+01
	4.000E+00	3.836E+01
90	0.000E+00	2.792E+01
	1.000E+00	6.081E+01
	2.000E+00	9.372E+01
	3.000E+00	1.013E+02
	4.000E+00	5.314E+01
100	0.000E+00	1.892E+01
	1.000E+00	4.404E+01
	2.000E+00	7.521E+01
	3.000E+00	9.350E+01
	4.000E+00	6.134E+01
110	0.000E+00	1.283E+01
	1.000E+00	3.155E+01
	2.000E+00	5.844E+01
	3.000E+00	8.093E+01
	4.000E+00	6.283E+01
120	0.000E+00	8.705E+00
	1.000E+00	2.242E+01
	2.000E+00	4.439E+01
	3.000E+00	6.701E+01
	4.000E+00	5.926E+01
130	0.000E+00	5.907E+00
	1.000E+00	1.585E+01
	2.000E+00	3.316E+01
	3.000E+00	5.371E+01
	4.000E+00	5.264E+01

NOTICE

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