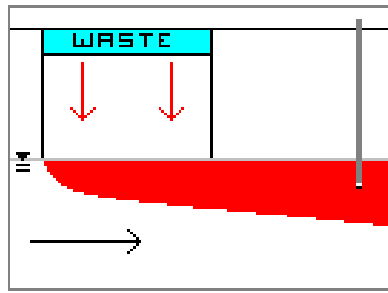


# ***MULTIMED*** for Windows



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Groundwater Fate and Transport Model  
version 1.50

Allison Geoscience Consultants, Inc.

***MULTIMED***  
**for**  
**Windows<sup>®</sup>**

Groundwater Fate and Transport Model

Version 1.50 for  
Windows 95/98/2000/XP  
May 15, 2005

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***MULTIMED***  
**for**  
**Windows<sup>®</sup>**

Disclaimer

Every effort has been made to make the MULTIMED software and its documentation as complete and accurate as possible, but no warranty as to fitness is implied. The calculations provided by MULTIMED and the information provided in its documentation are on an "as is" basis. Allison Geoscience Consultants, Inc. shall have neither liability nor responsibility to any person or entity with respect to any loss or damages arising from use of the software or from information contained in its documentation. Use of the software indicates agreement with these terms.

Please direct all correspondence concerning MULTIMED for Windows to Allison Geoscience Consultants, Inc. at 3926 Perry Lane, Flowery Branch, GA 30542 USA.. You may also email us at [multimed@allisongeoscience.com](mailto:multimed@allisongeoscience.com). This software is protected by copyright laws. "Windows" is a registered trademark of Microsoft Corporation.

## Overview

MULTIMED for Windows from Allison Geoscience Consultants, Inc. is a Windows 95/98/2000/XP version of the MULTIMED (DOS) model distributed by the U.S. Environmental Protection Agency. MULTIMED is an easy to use groundwater flow and transport model that allows you to quickly and easily evaluate the performance of alternative Subtitle D landfill designs. The essential capabilities of MULTIMED for Windows are the same as the DOS version, but its Windows interface makes it much easier to understand and use. MULTIMED is a groundwater exposure assessment model that can predict receptor exposure concentrations for contaminants that move through the groundwater pathway to receptors at the water table or at various locations downgradient of a landfill. MULTIMED can be run in deterministic mode (uses site-specific parameters) or monte carlo mode (uses probability distributions of key parameters).

The name MULTIMED of course implies "multimedia." When the U.S. EPA began development of the original (DOS) version of MULTIMED, they envisioned a multimedia model with modules for the groundwater, surface water, and air pathways. However, during MULTIMED's development, the Agency had a need for a model to assist in evaluation of alternative designs for Subtitle D landfills. The MULTIMED effort was redirected to fill this need. The alternative design rules for the Subtitle D program required evaluation of the landfill's characteristics for contaminant transport in the groundwater only. Because of this new role for MULTIMED, the air and surface water pathways were never enabled. Thus, its name should not be taken to imply a multimedia capability.

MULTIMED is most frequently used with a water balance model such as the HELP model (Hydrologic Evaluation of Landfill Design Package) in posing and testing alternative landfill designs.

Free technical support is available to registered users of MULTIMED for Windows.

## Getting Started

The main screen for MULTIMED initially displays PROJECT VIEW in which settings of all model input parameters are shown arranged in seven groups. Each group of parameters is delineated by a header line with a blue background that displays the group name. For each group, the parameters are listed and the current parameter values and units are displayed. To change the

value of any parameter, click the **Modify** button embedded in the blue-field header line. Doing so displays a more detailed listing for the group's parameters, sometimes with other modify buttons; menus allow you to change the setting of any parameter by entering the new value in the appropriate field.

The seven parameter groups are:

**General Parameters**

**Source Parameters**

**Chemical Parameters**

**Unsaturated Zone Flow Parameters**

**Unsaturated Zone Transport Parameters**

**Saturated Zone Parameters**

**Well Location and Time Parameters**

Once you have set all parameters as desired, you can run MULTIMED by clicking the **Run MULTIMED** button in the upper left portion of the main screen or by clicking the **Run Multimed** menu item from the menu bar.

After MULTIMED has been executed, the main screen will switch automatically to Output View.

You may toggle back and forth between Output View and Project View by clicking the appropriate View buttons in the top center portion of the main screen. You may also plot results from MULTIMED. The plotting tool is accessed by clicking the **Graph** button. Neither the **Output** button nor the **Graph** button is activated until MULTIMED has been executed to produce output.

## General Parameters

The General Parameters are those that control the overall execution of the model. These include:

**Application Type**

**Run Type**

**Source Type**

**Aquifer Source Plane Geometry**

**Active Modules**

**Number of Monte Carlo Iterations**

**Monte Carlo Confidence Interval**

## Application Type

This parameter specifies whether the application of MULTIMED is specifically for a Subtitle D landfill design evaluation or is a general (generic) application for groundwater. When the **Application Type** is set to Subtitle D landfill design evaluation, certain parameter values are preset to appropriate default values and certain parameter ranges are restricted. Such restrictions are not imposed for generic applications.

### Run Type

MULTIMED can be run in deterministic mode in which each parameter is assigned a unique value in accordance with site conditions, or in Monte Carlo mode in which statistical distributions are used for key parameters. Screens on which parameter values are entered will reflect the choice that has been made for this parameter. If the **Run Type** is set to monte carlo mode, you will be required to enter probability density distributions for each key parameter rather than single values.

### Source Type

This parameter specifies whether the source is to be treated as a continual steady-state flux or as a finite-duration transient pulse.

### Aquifer Source Plane Geometry

This parameter pertains to the flux of contaminant across the source plane in the saturated zone (aquifer). The actual source plane within the aquifer is treated as a vertical, rectangular plane that forms the downgradient boundary of the mixing zone. The width of this plane is the same as the width of the source. The plane extends from the top of the aquifer downward; its height is computed by the model based on the relative flow velocity in the aquifer and the infiltration rate from the source. The **Aquifer Source Plane Geometry** parameter indicates whether the concentration of contaminant across this rectangular plane is to be treated as uniform (Patch Source) or whether it is to be treated as enriched along the centerline, tapering to each side as in a Gaussian distribution (Gaussian Source).

### Active Modules

This parameter allows the user to indicate which of the MULTIMED modules is to be used. Currently, only the Unsaturated Zone and Saturated Zone modules may be selected. (In effect, this version of MULTIMED is a groundwater model only.) You may elect to run the Saturated Zone module only, but the Unsaturated Zone may be active only when the Saturated Zone is activated.

### Number of MC (Monte Carlo) Iterations

This parameter represents the number of Monte Carlo iterations or realizations that will be performed. Each realization will be performed with a new setting of each monte carlo parameter, each parameter value being selected from its respective probability density function. Typically, hundreds or thousands of realizations should be performed to obtain meaningful results. This parameter is activated only when **Run Type** is set to monte carlo mode.

### MC (Monte Carlo) Confidence Interval

When run in monte carlo mode, MULTIMED calculates confidence bounds for the 80th, 85th, 90th, and 95th percentiles of contaminant concentrations at the receptor well. The output from the monte carlo run will present the calculated contaminant concentration for each of the four percentiles listed above, and for each percentile, will also present upper and lower contaminant concentrations that bracket the calculated concentration within the bounds of the selected confidence interval (up to 90%). Of course, the greater the number of monte carlo iterations, the narrower will be the concentration range for the selected confidence interval. This parameter is activated only when **Run Type** is set to monte carlo mode.

### Source Parameters

These are parameters that have to do with the source of the contaminant (e.g., a waste disposal unit or landfill cell). They include:

**Source Area**

**Source Length**

**Source Width**

**Source Infiltration Rate**

**Outside Recharge Rate**

**Initial Leachate Concentration**

**Source Duration**

**Source Decay Constant**

**Initial Spread of Source**

### Source Area

The area of the waste disposal facility in square meters. This parameter should be a measured value. If **Source Area** is not specified, the **Source Length** and **Source Width** must be specified. Units are square meters.

### Source Length

The length of the waste disposal facility measured along the direction parallel to groundwater flow direction. This may be a measured value. If not entered, MULTIMED will assume a square source and the **Source Length** will be set to the square root of the **Source Area**. Units are meters.

### Source Width

The width of the waste disposal facility measured along the direction perpendicular to groundwater flow direction. This may be a measured value. If not entered, MULTIMED will assume a square source and the **Source Width** will be set to the square root of the **Source Area**. Units are meters.

### Source Infiltration Rate

The percolation rate of leachate from the waste disposal unit into the soil or aquifer. Units are meters per year. The **Source Infiltration Rate** will typically be different from the **Outside Recharge Rate** because of the presence of waste and disturbed material in the waste disposal unit and due to engineering controls in the unit. The **Source Infiltration Rate** may be estimated using a water balance model such as HELP (Hydrologic Evaluation of Landfill Performance).

### Outside Recharge Rate

The ambient percolation rate of water directly into the aquifer system outside the waste disposal unit. Units are meters per year. The **Outside Recharge Rate** will typically be different from the **Source Infiltration Rate** within the confines of the waste disposal unit because of the presence of waste and disturbed material in the waste disposal unit and due to engineering controls in the unit. The **Outside Recharge Rate** may be estimated using a water balance model such as HELP (Hydrologic Evaluation of Landfill Performance).

### Initial Leachate Concentration

This should be the measured concentration of contaminant in the source leachate or the assumed concentration for which the landfill design is being evaluated. Units are actually arbitrary-- the units of the output concentrations will be the same as those used in input. However, most users tend to use mg/L.

Contaminant concentrations in the source leachate can vary considerably over time, so an environmentally conservative approximation may be appropriate. If measured values are not available, the solubility limit of the contaminant may be a good choice for such an approximation.

When using MULTIMED for testing design alternatives for Subtitle D landfills, you can set the Initial Leachate Concentration to 100 times the contaminant Maximum Concentration Level (MCL) in mg/L. Then, if the design results in a contaminant well concentration at or below the MCL, the design may be acceptable. Also, since the model response with respect to this parameter is linear, when calculating a dilution-attenuation factor (DAF), it may be convenient to use a value of 1.0 mg/L.

### Source Duration

This parameter is applicable only when MULTIMED is run with a transient source (see **Source Type** under General Parameters). This parameter is not applicable when MULTIMED is used in Subtitle D landfill design, which must use a steady-state source term.

For the transient source, the **Source Duration** is the total time in years in which leaching from the waste disposal unit occurs. The contaminant concentration in the source when leaching begins is equal to the **Initial Leachate Concentration** and the contaminant concentration in the source leachate decreases over time in accordance with the **Source Decay Constant**.

### Source Decay Constant

The **Source Decay Constant** is used to simulate an exponentially decreasing contaminant concentration in the source leachate. The units for this parameter are per year (1/yr). The contaminant concentration in the source when leaching begins is equal to the **Initial Leachate Concentration** and the contaminant concentration in the source leachate decreases over time in accordance with the **Source Decay Constant**.

### Initial Spread of Source

This parameter is the standard deviation of the concentration distribution (y-direction) for the Gaussian source plane. Its units are meters. It is used to estimate the effective width of the contaminant source area at the downgradient edge of the disposal facility. If the **Aquifer Source Plane Geometry** is set to Gaussian source, the **Initial Spread of Source** parameter represents one standard deviation in the Gaussian source concentration distribution (y-direction). MULTIMED uses the entered value to establish the effective downgradient-edge source width at six times this entered standard deviation, thus insuring that 99.86% of the contaminant concentration is accounted for (three standard deviations each side of the mean). If the user

indicates that MULTIMED is to derive this standard deviation, MULTIMED will set it to one-sixth of the **Source Width**. If the **Aquifer Source Plane Geometry** is set to Patch Source, the effective source width at the downgradient edge is simply set equal to the **Source Width**; thus, this parameter is irrelevant.

## Chemical Parameters

Certain parameters are chemical-specific for hydrolysis or sorption. These are:

### Chemical Name

### Dissolved-Phase Decay Coefficient

### Sorbed Phase Decay Coefficient

### Overall Decay Coefficient

### Acid-Catalyzed Hydrolysis Rate Constant

### Neutral Hydrolysis Rate Constant

### Base-Catalyzed Hydrolysis Rate Constant

### Hydrolysis Reference Temperature

### Normalized Distribution Coefficient ( $K_{oc}$ )

### Aquifer Distribution Coefficient ( $K_d$ )

### Chemical Name

This is the name of the chemical that is the contaminant. It is not tied to any internal chemical database, so the name is actually arbitrary. It is helpful to enter a name for later reference when examining stored or printed output files.

### Normalized Distribution Coefficient ( $K_{oc}$ )

The **Normalized Distribution Coefficient** for organic carbon ( $K_{oc}$ ) is used to estimate the contaminant distribution coefficient for the unsaturated zone. It is also used to estimate the **Aquifer Distribution Coefficient** ( $K_d$ ) if the user does not enter a value directly for that parameter. The units of  $K_{oc}$  are mL/g (numerically the same as L/kg).

### Dissolved-Phase Decay Coefficient

The **Dissolved-Phase Decay Coefficient** represents the hydrolysis rate constant for the contaminant chemical in the water in the saturated zone. Its units are per year (1/yr). The **Dissolved-Phase Decay Coefficient** is used with the **Sorbed-Phase Decay Coefficient** to provide the **Overall Decay Coefficient** for hydrolysis in the saturated zone. If the user enters a value for the Overall Decay Coefficient directly, the Dissolved-Phase and Sorbed-Phase Decay Coefficients are not used.

If no values are entered for the Dissolved-Phase or Sorbed-Phase Decay Coefficients, nor is a value entered for the Overall Decay Coefficient, MULTIMED can estimate the Overall Decay Coefficient by using values for the **Acid-Catalyzed Hydrolysis Rate Constant**, the **Base-Catalyzed Hydrolysis Rate Constant**, and the **Neutral Hydrolysis Rate Constant** along with the temperature and pH of the aquifer.

NOTE: The decay constants referenced above represent degradation due to hydrolysis only— other parameters are used to specify biodegradation in the unsaturated and saturated zones (see **Biological Decay Coefficients** associated with the Unsaturated Zone Transport Parameters and the Saturated Zone Parameters).

### Sorbed-Phase Decay Coefficient

The **Sorbed-Phase Decay Coefficient** represents the hydrolysis rate constant for the contaminant chemical in the sorbed-phase in the saturated zone. Its units are per year (1/yr). The **Sorbed-Phase Decay Coefficient** is used with the **Dissolved-Phase Decay Coefficient** to provide the **Overall Decay Coefficient** for hydrolysis in the saturated zone. If the user enters a value for the Overall Decay Coefficient directly, the Dissolved-Phase and Sorbed-Phase Decay Coefficients are not used.

If no values are entered for the Dissolved-Phase or Sorbed-Phase Decay Coefficients, nor is a value entered for the Overall Decay Coefficient, MULTIMED can estimate the Overall Decay Coefficient by using values for the **Acid-Catalyzed Hydrolysis Rate Constant**, the **Base-Catalyzed Hydrolysis Rate Constant**, and the **Neutral Hydrolysis Rate Constant** along with the temperature and pH of the aquifer.

NOTE: The decay constants referenced above represents degradation due to hydrolysis only— other parameters are used to specify biodegradation in the unsaturated and saturated zones (see **Biological Decay Coefficients** associated with the Unsaturated Zone Transport Parameters and the Saturated Zone Parameters).

### Overall Decay Coefficient

The **Overall Decay Coefficient** represents the overall hydrolysis rate constant for the contaminant chemical in the saturated zone. Its units are per year (1/yr). If not entered, the **Overall Decay Coefficient** is computed by MULTIMED by summing the values entered for the **Dissolved-Phase Decay**

**Coefficient** and the **Sorbed-Phase Decay Coefficient**. If the user enters a value for the Overall Decay Coefficient directly, the Dissolved-Phase and Sorbed-Phase Decay Coefficients are not used.

If no value is entered for the Overall Decay Coefficient and likewise none is entered for Dissolved-Phase and Sorbed-Phase Decay Coefficients, MULTIMED can estimate the Overall Decay Coefficient by using values for the **Acid-Catalyzed Hydrolysis Rate Constant**, the **Base-Catalyzed Hydrolysis Rate Constant**, and the **Neutral Hydrolysis Rate Constant** along with the temperature and pH of the aquifer.

NOTE: The decay constants referenced above represents degradation due to hydrolysis only— other parameters are used to specify biodegradation in the unsaturated and saturated zones (see **Biological Decay Coefficients** associated with the Unsaturated Zone Transport Parameters and the Saturated Zone Parameters ).

### Acid-Catalyzed Hydrolysis Rate Constant

The **Acid-Catalyzed Hydrolysis Rate Constant**, the **Base-Catalyzed Hydrolysis Rate Constant**, and the **Neutral Hydrolysis Rate Constant** are used by MULTIMED to calculate overall chemical decay coefficients for the unsaturated zone. If no values are entered for the **Overall Decay Coefficient** for the saturated zone (and likewise none is entered for the **Dissolved-Phase Decay Coefficient** and **Sorbed-Phase Decay Coefficient**), these hydrolysis parameters will also be used to estimate the Overall Decay Coefficient for the saturated zone. The units for the Acid-Catalyzed Hydrolysis Rate Constant are per M per year where M represents the concentration unit mol/L. Thus the units may be expressed 1/(M-yr) or L/(mol-yr).

### Neutral Hydrolysis Rate Constant

The **Neutral Hydrolysis Rate Constant**, the **Acid-Catalyzed Hydrolysis Rate Constant**, and the **Base-Catalyzed Hydrolysis Rate Constant** are used by MULTIMED to calculate overall chemical decay coefficients for the unsaturated zone. If no values are entered for the **Overall Decay Coefficient** for the saturated zone (and likewise none is entered for the **Dissolved-Phase Decay Coefficient** and **Sorbed-Phase Decay Coefficient**), these hydrolysis parameters will also be used to estimate the Overall Decay Coefficient for the saturated zone. The units for the Neutral Hydrolysis Rate Constant are per year (1/yr).

### Base-Catalyzed Hydrolysis Rate Constant

The **Base-Catalyzed Hydrolysis Rate Constant**, the **Acid-Catalyzed Hydrolysis Rate Constant**, and the **Neutral Hydrolysis Rate Constant** are used by MULTIMED to calculate overall chemical decay coefficients for the unsaturated zone. If no values are entered for the **Overall Decay Coefficient** for the saturated zone (and likewise none is entered for the **Dissolved-Phase Decay Coefficient** and **Sorbed-Phase Decay Coefficient**), these hydrolysis parameters will also be used to estimate the Overall Decay Coefficient for the saturated zone. The units for the Base-Catalyzed Hydrolysis Rate Constant are per M per year where M represents the concentration unit moles/L. Thus the units may be expressed 1/(M-yr) or L/(mole-yr).

### Hydrolysis Reference Temperature

The **Hydrolysis Reference Temperature** is the temperature (Celsius) at which the **Acid-Catalyzed Hydrolysis Rate Constant**, the **Base-Catalyzed Hydrolysis Rate Constant**, and the **Neutral Hydrolysis Rate Constant** were calculated. This temperature is normally specified in databases and compilations of these rate constants.

### Aquifer Distribution Coefficient ( $K_d$ )

This is the distribution coefficient for the contaminant chemical in the saturated zone (aquifer). Its units are mL/g (numerically the same as L/kg). The distribution coefficient represents the ratio of the concentration of contaminant sorbed (mg/g) to the concentration dissolved (mg/mL) at equilibrium. This parameter is specific to each chemical and to the mineralogy and other properties of the soil or aquifer material.

If you do not have a value to enter for  $K_d$ , MULTIMED will estimate  $K_d$  based on the fraction organic carbon ( $f_{oc}$ ) and the value of the Normalized Distribution Coefficient for organic carbon ( $K_{oc}$ ). The estimate is made using  $K_d = K_{oc} \times f_{oc}$ .

### Unsaturated Zone Flow Parameters

In the unsaturated zone, flow is characterized by the definition of one or more flow layers, each layer consisting of a material having specific flow characteristics. The flow characteristics are represented by a set of material parameters whose values are set by the user or derived by the model if the user so directs. Each flow layer may consist of only one material, but the materials of adjacent flow layers must necessarily differ in some respect. However, the

materials of two flow layers that are not adjacent may be identical. For example, for the purposes of flow characteristics the user may define the unsaturated zone as consisting of four flow layers. Flow layers 1 and 2 must necessarily have one or more material parameters that are different (else, there would be no point in defining them as separate layers). But flow layers 1 and 3 could be identical with respect to material parameters.

Most of the input required by the user for unsaturated zone flow parameters is simply to specify the parameters associated with each material type. Different material types are distinguished by material numbers (Material 1, Material 2, etc.); the material numbers have no significance as regards sequence, order, or depth. Once the user has defined as many material types as are required by stating their individual parameters, definition of a flow layer consists merely of specifying the layer thickness and the material number which pertains to the layer. The flow layer numbers (Layer 1, Layer 2, etc.) do have sequential significance: Layer 1 is the topmost layer, Layer 2 is immediately beneath Layer 1 and so on.

The user should be aware that the layers defined for flow in the unsaturated zone do not necessarily correspond to the layer definition for transport in the unsaturated zone. The latter are defined separately in Unsaturated Zone Transport Parameters.

Parameters associated with unsaturated zone flow include:

**Layer Numbers**

**Layer Thickness**

**Material Numbers**

**Saturated hydraulic conductivity**

**Effective Porosity**

**Air Entry Pressure Head**

**Residual Water Content**

**van Genuchten Parameters**

**Brooks and Corey Exponent**

### **Flow Layer Number**

In the unsaturated zone, flow is characterized by the definition of one or more flow layers, each layer consisting of a material having specific flow characteristics. Each flow layer is assigned a unique identifying number for easy reference; the layers are numbered sequentially from the top downward: Layer 1 is the topmost layer, Layer 2 is immediately beneath Layer 1 and so on.

### **Flow Layer Thickness**

The thickness in meters of a flow layer.

### **Material Number**

Flow is governed by certain physical properties of materials (saturated hydraulic conductivity, effective porosity, etc.). A subsurface unit that has consistent values for these physical properties that control flow is referred to as a "material" and is assigned an identifying number (the **Material Number**). "Materials" thus defined for the purposes of designating flow characteristics may or may not correspond to distinct subsurface lithologic units. The primary purpose in assigning numbers to materials is to make it convenient to associate a particular material with a particular flow layer in the unsaturated zone.

### **Saturated Hydraulic Conductivity**

The **Saturated Hydraulic Conductivity** expresses the ease with which a fluid can move through a porous medium. It is a function of the properties of the medium and the fluid. (Here, the fluid is assumed to be water.) In some materials, stratification and internal structure create preferential flow directions so that the vertical saturated hydraulic conductivity differs from the horizontal saturated hydraulic conductivity. For the unsaturated zone, flow is represented in the vertical direction only, so you should enter the vertical saturated hydraulic conductivity. Units are cm/yr.

### **Effective Porosity**

The **Effective Porosity** is the portion of total porosity that is effective at transmitting water. The effective porosity is typically lower than total porosity due to the presence of pores that are not interconnected with neighbors. You may have to use total porosity if effective porosity is unknown. Typically, it is total porosity of a material that is measured; effective porosity may be difficult to determine. Porosity has no units; it is expressed as a fraction or a percent. The value entered here should be expressed as a fraction, not percent (that is, as a value between 0.0 and 1.0.)

### **Air Entry Pressure Head**

The **Air Entry Pressure Head** is the threshold at which air begins to penetrate saturated soil. Its value can be estimated from soil moisture retention curves. The Air Entry Pressure Head has units of meters.

### **Residual Water Content**

This is the amount of total water content that cannot be removed from the soil,

regardless of suction pressure. Residual water adheres to the soil grains and particles. It is dimensionless and is expressed as a fraction (decimal form), not as percent.

### van Genuchten Parameters

The van Genuchten alpha and beta are empirical parameters used in the van Genuchten relationship to express the functional relationship between relative saturated hydraulic conductivity and water saturation in the unsaturated zone. The units of the alpha parameter are per cm (1/cm). The beta parameter is dimensionless.

The relationship between relative saturated hydraulic conductivity and water saturation may alternatively be represented by means of the Brooks and Corey relationship.

### Brooks and Corey Exponent

This is an empirical, soil-specific parameter used in the Brooks and Corey relationship to express the functional relationship between relative saturated hydraulic conductivity and water saturation in the unsaturated zone. This parameter is dimensionless.

The relationship between relative saturated hydraulic conductivity and water saturation may alternatively be represented by means of the van Genuchten relationship.

## Unsaturated Zone Transport Parameters

In the unsaturated zone, transport is characterized by the definition of one or more transport layers, each layer consisting of a material having specific transport characteristics. The transport characteristics are represented by a set of parameters that control transport (longitudinal dispersivity, percent organic matter, etc.) whose values are set by the user or derived by the model if the user so directs. Adjacent transport layers would ordinarily be expected to possess one or more dissimilar transport parameters. However, the materials of two transport layers that are not adjacent may be identical. For example, for the purposes of transport characteristics the user may define the unsaturated zone as consisting of four transport layers. Transport layers 1 and 2 must necessarily have one or more transport parameters that are different (else, there would be no point in defining them as separate layers). But layers 1 and 3 could be identical with respect to parameters that control transport.

Most of the input required by the user for unsaturated zone transport parameters is simply to specify the parameters associated with each layer. The layers are distinguished by layer numbers. The transport layer numbers (Layer 1, Layer 2, etc.) do have sequential significance: Layer 1 is the topmost layer, Layer 2 is immediately beneath Layer 1 and so on.

Although sorption is relevant in the unsaturated zone, the assumption is made that all contaminant sorption is due to sorption onto soil organic matter. Unlike for the saturated zone, the user does not have direct access to the contaminant distribution coefficient ( $K_d$ ) or the retardation factor. Instead, the retardation factor is computed using a  $K_d$  derived from the contaminant **Normalized Distribution Coefficient** for organic carbon ( $K_{oc}$ ) and **Fraction Organic Carbon** ( $f_{oc}$ ):

$$K_d = K_{oc} \times f_{oc}$$

Then, the retardation factor ( $R$ ) for a layer is computed from:

$$R = 1 + \frac{\rho_b K_d}{\theta S_w}$$

where  $\rho_b$  = bulk density,  $S_w$  = water saturation, and  $\theta$  = porosity.

NOTE: The user should be aware that the layers defined for transport in the unsaturated zone do not necessarily correspond to the layer definition for flow in the unsaturated zone. The latter are defined separately in Unsaturated Zone Flow Parameters.

Parameters associated with transport in the unsaturated zone include:

**Layer Numbers**

**Layer Thickness**

**Longitudinal Dispersivity**

**Bulk Density**

**Percent Organic Matter**

**Biological Decay Coefficient**

**Advanced Control Parameters**

### Transport Layer Number

In the unsaturated zone, transport is characterized by the definition of one or more transport layers, each layer consisting of a material having specific

transport characteristics. Each transport layer is assigned a unique identifying number for easy reference; the layers are numbered sequentially from the top downward: Layer 1 is the topmost layer, Layer 2 is immediately beneath Layer 1 and so on.

### **Transport Layer Thickness**

The thickness in meters of a transport layer.

### **Longitudinal Dispersivity**

This parameter represents the tendency for dispersion of the contaminant in the flow direction (vertical in the unsaturated zone). Its units are meters. This parameter must be entered for each transport layer in the unsaturated zone. By definition, the broad term "dispersion" refers to the spreading and mixing caused by molecular diffusion and mechanical dispersion. Molecular diffusion is considered to be negligible in MULTIMED so that only mechanical dispersion is considered. The value entered here for longitudinal dispersivity is multiplied by the seepage velocity in MULTIMED to obtain longitudinal dispersion of the contaminant.

If no value is entered for longitudinal dispersivity in a transport layer, MULTIMED will use an empirical relationship to estimate it:

$$\text{longitudinal dispersivity (m)} = 0.02 + 0.022L$$

where L is the depth of the unsaturated zone in meters.

### **Bulk Density**

This is the mass of a unit volume of dry soil. The units are g/cm<sup>3</sup>. The bulk density must be entered for each transport layer.

### **Percent Organic Matter**

This parameter specifies the percent of organic matter in an unsaturated zone transport layer. A value must be entered for each transport layer. The percent organic matter is used (along with the contaminant **Normalized Distribution Coefficient** for organic carbon) to estimate the contaminant distribution coefficient for the layer.

### **Biological Decay Rate**

This is the first order rate constant for biological decay (biodegradation) applicable to a transport layer. The units are per year (1/yr). Note: Although

MULTIMED provides for separate values of this parameter for each transport layer in the unsaturated zone (and for the single layer that represents the saturated zone) it is unlikely that you will actually have separate distinct values for each of these layers.

### **Advanced Control Parameters**

Certain parameters having to do numerical techniques used to evaluate the unsaturated zone transport equation may be set by the user. The user is cautioned that these parameters should be changed only with considerable circumspection; their default settings are usually adequate and they rarely require adjustment.

The solution to the transport equation in the layered unsaturated zone is derived using Laplace transform techniques to transform the governing partial differential equation and boundary conditions to an ordinary differential equation. The ordinary differential equation is solved in the Laplace domain, then the solution is inverted using either the convolution theorem or the Stehfest algorithm. The default is the Stehfest algorithm which is computationally faster. However, in some rare cases, it may not converge where the convolution theorem will provide a solution. For this reason, the user is given the opportunity to switch to the convolution theorem scheme. The two schemes have various adjustable parameters that pertain to the number of terms or points used in various integration steps. Generally speaking, the greater the number of points, the greater the accuracy, but the longer the computation time. Using values close to default settings is recommended.

### **Saturated Zone Parameters**

The saturated zone (aquifer) is assumed to consist of one layer having uniform, spatially homogeneous flow and transport properties in the horizontal and vertical directions. There are several parameters that pertain to the aquifer:

**Aquifer Thickness**

**Mixing Zone Thickness**

**Effective Porosity**

**Particle Diameter**

**Bulk Density**

**Saturated Hydraulic Conductivity**

**Hydraulic Gradient**

**Seepage Velocity**

**Longitudinal, Transverse, and Vertical Dispersivities**  
**Fraction Organic Carbon**  
**Temperature**  
**pH**  
**Retardation Factor**  
**Biological Decay Rate**

### **Aquifer Thickness**

This is the overall thickness of the layer in which transport of contaminant occurs in the saturated zone.

### **Aquifer Mixing Zone Thickness**

The **Aquifer Mixing Zone Thickness** is also called "Source Thickness" in some older MULTIMED reports. Its units are meters. A contaminant plume develops beneath a disposal facility due to percolation of water through the facility (and through the unsaturated zone, if present). The Aquifer Mixing Zone Thickness is the vertical thickness of this plume within the aquifer at the point where the plume passes beneath the downgradient boundary of the facility. If no value is entered for Aquifer Mixing Zone Thickness, MULTIMED will estimate it from the relationship:

$$H = \sqrt{2\alpha_v} L + B \left( 1 - \exp\left(-\frac{LQ_f}{V_s \theta B}\right) \right)$$

where:

$H$  = Aquifer Mixing Zone Thickness (m)

$\alpha_v$  = vertical dispersivity (m)

$L$  = length of facility measured parallel to flow direction (m)

$B$  = thickness of the saturated zone (m)

$V_s$  = uniform seepage velocity in the flow (x) direction (m/yr)

$Q_f$  = percolation rate (m/yr)

$\theta$  = effective porosity of saturated zone

### **Effective Porosity**

The value entered for porosity of the aquifer should be an effective porosity. The effective porosity is the portion of total porosity that is effective at transmitting water. The effective porosity is typically lower than total porosity due to the presence of pores that are not interconnected with neighbors. You

may have to use total porosity if effective porosity is unknown. Typically, it is total porosity of a material that is measured; effective porosity may be difficult to determine. Porosity has no units; it is expressed as a fraction or a percent. The value entered here should be expressed as a fraction, not a percent (that is, as a value between 0.0 and 1.0.)

In the absence of a user-specified value or distribution for porosity, MULTIMED can estimate the aquifer Effective Porosity from the mean particle diameter (d) in the aquifer using the relationship:

$$\text{effective porosity } (\theta) = 0.261 - 0.385 \ln(d)$$

where  $\ln(d)$  is the natural logarithm of the mean particle diameter in the aquifer material. Of course, one must enter the mean particle diameter if this empirical relationship is to be used.

### **Aquifer Particle Diameter**

The mean particle diameter for the material comprising the saturated zone. Units are cm. This parameter is used to estimate aquifer **Effective Porosity** if no value is entered for that parameter. No value need be entered for aquifer **Particle Diameter** if you specify the aquifer Effective Porosity.

### **Aquifer Bulk Density**

This is the mass of a unit volume of dry aquifer material in the saturated zone. The units are g/cm<sup>3</sup>.

### **Aquifer Saturated Hydraulic Conductivity**

The saturated hydraulic conductivity expresses the ease with which a fluid can move through a porous medium. It is a function of the properties of the medium and the fluid. (Here, the fluid is assumed to be water.) In some materials, stratification and internal structure create preferential flow directions so the vertical saturated hydraulic conductivity differs from the horizontal saturated hydraulic conductivity. For the saturated zone, flow is represented in the horizontal direction only, so you should enter the horizontal saturated hydraulic conductivity. Units are m/yr.

MULTIMED can derive the saturated hydraulic conductivity from other parameters (porosity, viscosity of water, mean particle diameter, etc.). However, this alternative is discouraged-- deriving this important parameter rather than using a measured value is unlikely to give an accurate result.

$$V_s = \frac{K S}{\theta}$$

### Aquifer Hydraulic Gradient

The hydraulic gradient is a measure of how much the water level elevation changes over a given distance. It is affected by local topography and groundwater recharge and withdrawal volumes and locations. The hydraulic gradient will thus vary temporally with recharge and withdrawal events; the average gradient under natural conditions should be specified here. It is a dimensionless ratio in that it is measured as meters of elevation change per meter of distance.

### Aquifer Seepage Velocity

This is the natural groundwater seepage velocity in the flow direction (horizontally). The units are m/yr. The seepage velocity is difficult to measure directly so MULTIMED will estimate this parameter if the user does not have a measured value. The relationship used to estimate seepage velocity is:

where:

$V_s$  = seepage velocity in the flow direction (m/yr)  
 $K$  = aquifer saturated hydraulic conductivity (m/yr)  
 $S$  = hydraulic gradient (m/m)  
 $\theta$  = effective porosity

### Aquifer Longitudinal, Transverse, and Vertical Dispersivity

These three parameters represent the tendency for dispersion of the contaminant in the longitudinal (horizontal flow), transverse, and vertical directions in the saturated zone. The units of all three are meters. By definition, the broad term "dispersion" refers to the spreading and mixing caused by molecular diffusion and mechanical dispersion. Molecular diffusion is considered to be negligible in MULTIMED so that only mechanical dispersion is considered. Note that the value entered here for longitudinal dispersivity is for the horizontal flow direction; the longitudinal dispersivity in the unsaturated zone applies to the vertical direction.

If no values are entered for these dispersivities, MULTIMED will calculate them as a function of distance to the receptor well:

Longitudinal dispersivity (m) = 0.1 x distance to the receptor well in meters

Transverse dispersivity (m) = longitudinal dispersivity / 3.0

Vertical dispersivity (m) = 0.56 x longitudinal dispersivity

If MULTIMED is run in monte carlo mode and the dispersivities are to be monte carloed, the user may select from several types of distributions including a special distribution by Gelhar which presents the longitudinal dispersivity as a uniform distribution within three intervals. The transverse and vertical dispersivities are calculated from the longitudinal value. See the MULTIMED Subtitle D Landfill Application Manual (Sharp-Hansen et al. 1990 ) for more details.

### Aquifer Fraction Organic Carbon

This parameter specifies the fraction of organic carbon in the aquifer material. The fraction organic carbon is used (along with the contaminant normalized distribution coefficient for organic carbon) to estimate the contaminant distribution coefficient in the aquifer (provided the user has not directly entered a value for the contaminant distribution coefficient in the aquifer). To obtain fraction organic carbon ( $f_{oc}$ ) from percent organic matter (OM%), compute as follows:

$$f_{oc} = \text{OM}\% / (100 \times 1.72)$$

This relationship assumes that organic matter is about 58% organic carbon.

### Aquifer Temperature

This is the groundwater temperature in the aquifer. Units are degrees Celsius.

### Aquifer pH

This is the groundwater pH. It is used with hydrolysis rate constants to compute the overall first-order chemical decay coefficient if that parameter is not entered directly. If the overall chemical decay coefficient is entered directly, the aquifer pH is not used.

### Aquifer Retardation Factor

The retardation factor ( $R$ ) is a dimensionless parameter used to account for retardation of contaminant transport due to sorption. The retardation factor in the saturated zone can be input directly or derived by the model. The factor is computed using:

$$R = 1 + \frac{\rho_b K_d}{\theta}$$

where  $K_d$  = contaminant distribution coefficient,  $\rho_b$  = bulk density, and  $\theta$  = porosity.

### Aquifer Biological Decay Rate

This is the first order rate constant for biological decay (biodegradation) applicable to the saturated zone. The units are per year (1/yr). Note: Although MULTIMED provides for separate values of this parameter for each transport layer in the unsaturated zone and for the single layer that represents the saturated zone, it is unlikely that you will actually have separate distinct values for each of these layers.

## Well Location and Time Options

Well location parameters are used to specify the three-dimensional position of the water sample for which MULTIMED computes the contaminant concentration. The time parameters allow the user to choose times (in elapsed years) at which MULTIMED is to calculate and report the contaminant concentration in the receptor well.

The well location is specified via two parameters: **Radial Distance to Well** and the **Angle Off Plume Axis** (centerline). The vertical location of the water intake in the well is specified as the **Well Screen Depth Fraction**.

### Radial Distance to Well and Angle Off Plume Axis

The well location is specified by entering the radial distance to the well and entering the angle between a line representing the radial distance and the plume centerline. **The Radial Distance to the Well** is measured from the center of the downgradient boundary of the disposal facility to the well. The angle between a line drawn along the radial distance and a line representing the central plume axis is the **Angle Off Plume Axis**. The Radial Distance to Well is specified in meters; the Angle Off Plume Axis is measured counterclockwise.

Note that for Subtitle D applications, the Angle Off Plume Axis should be fixed at zero, as should the Well Screen Depth Fraction.

### Well Screen Depth Fraction

The receptor well is assumed to have a single opening at the **Well Screen Depth Fraction**. This parameter is specified as a fraction (decimal value

between 0 and 1) of the total aquifer thickness and is measured downward from the water table.

For Subtitle D applications, the Well Screen Depth Fraction should be fixed at zero.

### Time Parameters

The time parameters allow the user to specify the times (in elapsed years) that the contaminant concentration in the receptor well is to be calculated and reported. There are three options, accessible by clicking the **Well Calculation Times** button on the **Well Location and Time** screen.

Option 1. Let MULTIMED find and report the time that the peak (maximum) contaminant concentration arrives at the receptor well. To choose this option, select **Search for Maximum Concentration**.

Option 2. Explicitly specify a set of up to 10 elapsed times (in years) for which MULTIMED is to calculate and report the contaminant concentration in the receptor well. To choose this option, select **Specify Elapsed Times for Concentration**, then enter the elapsed times in the table.

Option 3. Specify a starting elapsed time, incremental elapsed time, and number of time increments that MULTIMED is to use in choosing the times at which the contaminant concentration in the receptor well is to be calculated and reported. To choose this option, select **Generate Elapsed Times From Start Time and Increment**, then enter the start time, increment, and number of incremental times to be used in the appropriate boxes.

## Output

After clicking the **Run MULTIMED** button, the result of the calculations will initially be presented in a window with a blue background. The displayed output is a summary of the information presented in the traditional MULTIMED output file. This summary output can be printed by clicking the **Print** button. The full MULTIMED output file can be viewed by clicking the **Full Output** button. Upon clicking the button to view the full output file, the traditional MULTIMED output will be displayed in a scrollable window with a white background. The displayed output will already have been saved in a file whose name corresponds to the input file name specified, except with the extension .OUT. The full output can be printed by clicking the **Print** button. You can also return to the summary output by clicking the Close button when

the full output is displayed.

To stop viewing the output listing and instead view a graph of the contaminant concentration profile at the receptor well, click the **Graph** button in the **View** section on the screen. To return to the **Project** screen where you may view or change input parameters, click the **Project** button in the **View** section of the screen.

## Graphing Results

After clicking the **Run MULTIMED** button, the result of the calculations will initially be presented in a window with a blue background. If the MULTIMED run is deterministic and includes a transient source, you can view a graph of the contaminant concentration at the water table versus time. Also, if you have specified times at which MULTIMED is to calculate the receptor well concentration, you can view a graph showing concentration at the receptor well versus time. If MULTIMED is run in monte carlo mode, you can display a cumulative frequency curve of the simulation results and curves showing how the receptor well concentration changes with infiltration rate and with distance to the receptor well. To select and display a graph, click **Graph** on the **View** section of the main screen. Then, click **New** on the left side of the graph window to select the type of graph to display.

The water table graph will show the concentration at the water table versus time using times internally generated by the model. The receptor well graph will display the receptor well concentration at each of the times explicitly entered by the user (or generated from user-specified start time and increment) as displayed on the **Times for Well Concentration** screen.

The graphs showing the receptor well concentration versus infiltration rate and versus well distance can be used in sensitivity analyses. For example, to evaluate the sensitivity of the receptor concentration to infiltration rate through the source, set up the run as a monte carlo simulation with 500 or more iterations. Set all model parameters except **Source Infiltration Rate** to constant values appropriate for the site. Set the Source Infiltration Rate as a monte carlo variable using a uniform distribution with the minimum value set to the lowest infiltration rate you are interested in and the maximum value set to the highest. After running MULTIMED in this way, a graph showing how the receptor well concentration changes with Source Infiltration Rate can be used to estimate sensitivity of the landfill design to this parameter. The same technique can be used to estimate the sensitivity to Radial Distance to Well.

The Graph option is inactive for deterministic steady-state source runs and for transient source runs in which MULTIMED is to find the arrival time of the maximum well concentration. For transient source runs in which you wish to generate the concentration profile as the peak (maximum) concentration arrives at the well, first let MULTIMED find the arrival time of the maximum concentration in a preliminary run, then repeat the run specifying a series of elapsed times at which MULTIMED is to report the concentration; the elapsed times specified should bracket the arrival time of the peak concentration.

Buttons along the left margin of the graph screen allow you to change the graph title, axis titles, scales, etc. You can also save or print the graph.

To return to the Project screen where you may view or change input parameters or to view the printed output file, click the **Project** or **Output** buttons in the View section of the screen.

## Technical Support

This help document is designed to answer most questions about MULTIMED for Windows and explain how to use it. Technical support is available from Allison Geoscience Consultants, Inc. You may email us at [multimed@allisongeoscience.com](mailto:multimed@allisongeoscience.com). Please include a description of the problem you are having and, if applicable, send as an attachment the input file that generates the problem. You may also call us at 770-535-1191. We are happy to expend reasonable efforts to be of service.

The user manual for the DOS version (Sharp-Hansen et al., 1990 ) distributed by the U.S. EPA Center for Exposure Assessment Modeling also contains information that may be helpful to users of MULTIMED. Accordingly, we have included it on the MULTIMED for Windows CD (in two volumes) as two PDF files. Although we have not edited these document to describe features of MULTIMED for Windows, we have eliminated references to the DOS commands and DOS preprocessor commands that pertain to the DOS version. The remaining information primarily provides technical explanations of MULTIMED parameters and is equally applicable to Windows and DOS versions.

## References

Solhotra, A.M., P. Mineart, S. Sharp-Hansen, and T. L. Allison (1990) Multimedia Exposure Assessment Model (MULTIMED) for Evaluating the Land Disposal of Wastes-- Model Theory. Prepared for Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia.

Sharp-Hansen, S., C. Travers, P. Hummel, and T.L. Allison (1990) A Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model (MULTIMED). Prepared for the Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia.