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EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP)

Parameters/Data Background Document

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ACKNOWLEDGMENTS

A large number of individuals have been involved with the development of EPACMTP since its inception in the early 1990's. Dr. Zubair A. Saleem of the U.S. EPA, Office of Solid Waste (EPA/OSW) has coordinated and guided the development of EPACMTP throughout much of this period. Ms. Ann Johnson, Mr. David Cozzie, and Mr. Timothy Taylor provided review for the development of this background document. This report was prepared by the staffs of HydroGeoLogic, Inc. (HGL), and Resource Management Concepts, Inc. (RMC), under EPA Contract Number 68-W-01-004.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Definition	Section
A_r	anisotropy ratio = K_x/K_z	5.3.6
A_w	area of a WMU (m^2)	2.3.1, 2.4.1, 2.5.1, 2.6.1
B	thickness of the saturated zone (m)	5.3.4.3, 6.6
C_d	metal concentration in the dissolved phase at equilibrium (mg/L)	3.3.3.2
C_s	metal concentration in the sorbed phase at equilibrium (mg/L)	3.3.3.2
C_L	leachate concentration (mg/L)	3.2.3
CV	coefficient of variation (%)	5.2.4
C_w	constituent concentration in the waste (mg/kg)	3.2.2
d_{BG}	depth below grade of WMU (m)	2.3.3, 2.4.6, 2.5.3
D_i	molecular diffusion coefficient in free water for species i (m^2/yr)	3.3.1.1
D_{LF}	landfill depth (m)	2.3.2
D_{lin}	liner thickness (m)	2.4.4
D_s	total sediment thickness (m)	2.4.3
D_u	total depth of the unsaturated zone (m)	5.2.1
D^{s*}	effective molecular diffusion coefficient for species of interest (m^2/y)	6.6
DWS	drinking water standard (mg/L)	3.3.1.2
E_a	Arrhenius activation energy (Kcal/mol)	3.3.2.2.3
F_h	volume fraction of the waste in the landfill at time of closure (m^3/m^3)	2.3.4
FeOx	iron hydroxide content (wt % Fe)	3.3.3.2.3
f_{oc}	fractional organic carbon content (dimensionless)	3.3.3.2.6
f_{oc}^{s}	fractional organic carbon content of the aquifer material (dimensionless)	5.3.11
g	gravitational acceleration (m/s^2)	5.3.4.4
$[H^+]$	hydrogen ion concentration (mol/L)	3.3.2.2.1
H_P	SI ponding depth (m)	2.4.2
I	annual infiltration rate through the source (m/y)	4.3.1, 4.3.2, 4.3.3, 4.3.4
ICLR	climate center index	4.2
ID	metal identification number (unitless)	3.3.3.2.1
IGWR	hydrogeologic environment index (unitless)	3.3.3.2.7,5.3.4.2
IGWT	ground-water type - carbonate/non-carbonate (unitless)	3.3.3.2.7
ISTYPE	soil type	5.2.2

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

Symbol	Definition	Section
IWLOC	R_{rw} (Receptor well) origination method	6.5
I_R	effective recharge rate outside the strip source area (m/y) or recharge rate outside the source area (m/y)	4.4
J	symbol used to denote a for the acid-catalyzed reaction, b for the base-catalyzed reaction and n for the neutral reaction	3.3.2.2.3
K	hydraulic conductivity (m/yr)	5.3.4.4
k_1	nonlinear Freundlich parameter for the unsaturated zone (mg constituent/kg dry soil))	5.2.9
K_a^T	acid-catalyzed hydrolysis rate constant (1/(mol.yr))	3.3.2.2.1
K_a^{Tr}	acid-catalyzed hydrolysis rate constant at reference temperature (1/(mol.yr))	3.3.2.2.3
K_b^T	base-catalyzed hydrolysis rate constant (1/(mol.yr))	3.3.2.2.2
K_b^{Tr}	base-catalyzed hydrolysis rate constant at reference temperature (1/(mol.yr))	3.3.2.2.5
K_d	distribution (solid-aqueous phase) partition coefficient in the unsaturated zone (cm^3/g) (Freundlich Coefficient)	3.3.3, 5.2.8
K_d^s	solid-liquid distribution coefficient of the aquifer (cm^3/g)	5.3.12
K_J^T	hydrolysis rate constant for reaction process J, corrected for the subsurface temperature T (1/(mol.yr) for the acid- and base-catalyzed reactions; 1/yr for the neutral reaction)	3.3.2.2.3
K_J^{Tr}	hydrolysis rate constant for reaction process J, measured at the reference temperature T_r (1/(mol.yr) for the acid- and base-catalyzed reactions; 1/yr for the neutral reaction)	3.3.2.2.3
K_{lin}	saturated hydraulic conductivity of liner (m/y)	2.4.5
K_n^T	neutral hydrolysis rate constant at (1/yr)	3.3.2.2.1
K_n^{Tr}	neutral hydrolysis rate constant at reference temperature (1/yr)	3.3.2.2.3
k_d	soil-water partition coefficient (L/kg)	3.3.2.1
k_{oc}	constituent-specific organic carbon partition coefficient (cm^3/g)	3.3.2.1
k_{ow}	octanol-water partition coefficient (cm^3/g)	3.3.2.1
K_s	saturated hydraulic conductivity (cm/hr)	5.2.3
K_x	hydraulic conductivity in the x direction (m/y)	5.3.5
K_y	hydraulic conductivity in the horizontal transverse (y) direction (m/y)	5.3.6
ℓ	daughter species number	3.3.2.3.1
LOM	leachate organic acid concentration (mol/L)	3.3.3.2.4
LYCHK	constraint on well distance from plume centerline	6.5
LZCHK	constraint on depth of intake point below water table	6.6

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

Symbol	Definition	Section
ℓ	daughter species number	3.3.2.3.1
LN	log normal distribution	5.2.2
M	number of immediate parent species	3.3.2.3.2
m	species number of immediate parent	3.3.2.3.3
MW_ℓ	molecular weight of species ℓ (g/mol.)	3.3.1.3
N	sample size	5.2.4
NO	Normal distribution	5.2.2
$[OH^-]$	hydroxyl ion concentration (mol/L)	3.3.2.2.2
$\%OM$	percent organic matter (dimensionless)	3.3.3.2.5, 5.2.7
PWS	waste volume (m^3)	2.3.5
pH	ground-water pH (standard units)	3.3.3.2.2, 5.2.10, 5.2.13
Q_1^F	background ground-water flux (m^2/y)	6.6
Q_4^F	recharge flux downgradient of the source (m^2/y)	6.6
r	regional hydraulic gradient (m/m)	5.3.4.5
R_g	Universal Gas Constant (1.987E-3 Kcal/deg-mol)	3.3.2.2.3
R_i	retardation factor for species i (dimensionless)	3.3.2.1
R_{rw}	radial distance between waste management unit and well (m)	6.2
R_∞	distance between the center of the source and the nearest downgradient boundary where the boundary location has no perceptible effects on the heads near the source (m)	2.4.8
R^s	retardation coefficient (dimensionless)	5.3.7
SB	log ratio distribution	5.2.2
SD	standard deviation	5.2.4
T_r	hydrolysis reference temperature (°C)	3.3.2.2.6
T	ground-water/subsurface temperature (°C)	3.3.2.2.3, 5.2.12, 5.3.9
t_d	exposure time interval of interest (yr)	6.8
t_p	leaching duration (yr)	2.3.6, 2.4.9, 2.5.2, 2.6.2
V_x	longitudinal ground-water (seepage) velocity (in the x-direction) (m/y)	5.3.5
X	sample mean	5.2.4
x	principal Cartesian coordinate along the regional flow direction (m)	6.4
x_{rw}	distance from the downgradient boundary of the WMU to the receptor well (m)	6.4

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

Symbol	Definition	Section
x_t	average travel distance in the x direction (m)	5.3.8.1
x_w	length of the WMU in the x-direction (parallel to ground-water flow) (m)	6.6
y	principal Cartesian coordinate normal to the flow direction, or distance from the plume centerline (m)	6.5
y_D	source width along the y-axis (m)	6.5
y_{rw}	Cartesian coordinate of the receptor well in the y-direction (m)	6.5
z	principal Cartesian coordinate in the vertical direction (m)	6.6
z^*_{rw}	z-coordinate of the receptor well positive downward from the water table(m)	6.6
	GREEK SYMBOLS	
α	van Genuchten soil-specific shape parameter (1/cm)	5.2.2, 5.2.4.1
α_L	longitudinal dispersivity of the aquifer (m)	5.3.8.1, 6.6
α_{Lu}	longitudinal dispersivity in the unsaturated zone (m)	5.2.6
α_{Ref}	reference longitudinal dispersivity, as determined from the probabilistic distribution (m)	5.3.8.1
α_T	horizontal transverse dispersivity (m)	5.3.8.2, 6.5
α_V	vertical transverse dispersivity (m)	5.3.8.2, 6.6
β	van Genuchten soil-specific shape parameter (dimensionless)	5.2.2, 5.2.4.2
γ	van Genuchten soil-specific shape parameter (dimensionless) = $1 - 1/\beta$	5.2.4
η	species-specific nonlinear Freundlich exponent for the unsaturated zone	5.2.9
η^s	Freundlich exponent for the saturated zone (dimensionless)	5.3.13
θ	soil water content (dimensionless)	3.3.2.1
θ_r	residual soil water content (dimensionless)	5.2.4.3
θ_{rw}	angle measured counter-clockwise from the plume centerline (degrees)	6.3
θ_s	saturated soil water content (dimensionless)	5.2.4.4
λ	overall first-order hydrolysis transformation rate(1/y)	3.3.2.2
λ_1	hydrolysis constant for dissolved phase (1/y)	3.3.2.2.2
λ_2	hydrolysis constant for sorbed phase (1/y)	3.3.2.2.1
λ_b^s	biodegradation rate in the saturated zone (1/yr)	5.3.15
λ_c^s	chemical degradation rate in the saturated zone (1/yr)	5.3.14
λ_{bu}	transformation coefficient due to biological transformation (1/y)	5.2.11

LIST OF SYMBOLS AND ABBREVIATIONS (continued)

Symbol	Definition	Section
λ_{cu}	transformation coefficient due to chemical transformation (1/y)	5.2.10
μ	dynamic viscosity of water (N-s/m^2)	5.3.4.4
$\xi_{\ell m}$	stoichiometric fraction of parent m that degrades into daughter ℓ/speciation factor (dimensionless)	3.3.2.3.4
ρ	density of water (kg/m^3)	5.3.4.4
ρ_b	bulk density of the aquifer (g/cm^3)	3.3.2.1, 5.3.3
ρ_{bu}	soil bulk density of the unsaturated zone (g/cm^3)	5.2.5
ϕ	porosity/water content in the unsaturated zone (dimensionless)	3.3.2.2, 5.3.2
ϕ_e	effective porosity of the saturated zone (dimensionless)	6.6

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1.0 INTRODUCTION

This document provides background information on the parameters and data sources used in **EPA**’s **C**omposite **M**odel for **L**eachate **M**igration with **T**ransformation **P**roducts (EPACMTP). EPACMTP is a subsurface fate and transport model used by EPA’s Office of Solid Waste in the RCRA program to establish regulatory levels for concentrations of constituents in wastes managed in land-based units. This document describes the EPACMTP input parameters, data sources and default parameter values and distributions that EPA has assembled for its use of EPACMTP as a ground-water assessment tool. EPA has also developed a complementary document, the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), which presents the mathematical formulation, assumptions and solution methods underlying the EPACMTP. These two documents together are the primary reference documents for EPACMTP, and are intended to be used together.

The remainder of this section describes how this background document is organized. The parameters and data are documented in six main categories, as follows:

- Section 2 describes the Waste Management Unit (Source) Parameters;
- Section 3 describes the Waste and Constituent Parameters;
- Section 4 describes the Infiltration and Recharge Parameters;
- Section 5 describes the Subsurface Parameters;
- Section 6 describes the Ground-water Well Location Parameters; and
- Section 7 provides a list of References

Several appendices provide complete listings of data distributions for a number of the EPACMTP input parameters.

To facilitate the cross-referencing of information between this document and the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), each section begins with a table that lists the parameters described in that section, and provides, for each parameter, a reference to the equation(s) and/or section number in the *EPACMTP Technical Background Document* (U.S. EPA, 2003a) that describes how each parameter is used in the EPACMTP computer code.

2.0 WASTE MANAGEMENT UNIT (SOURCE) PARAMETERS

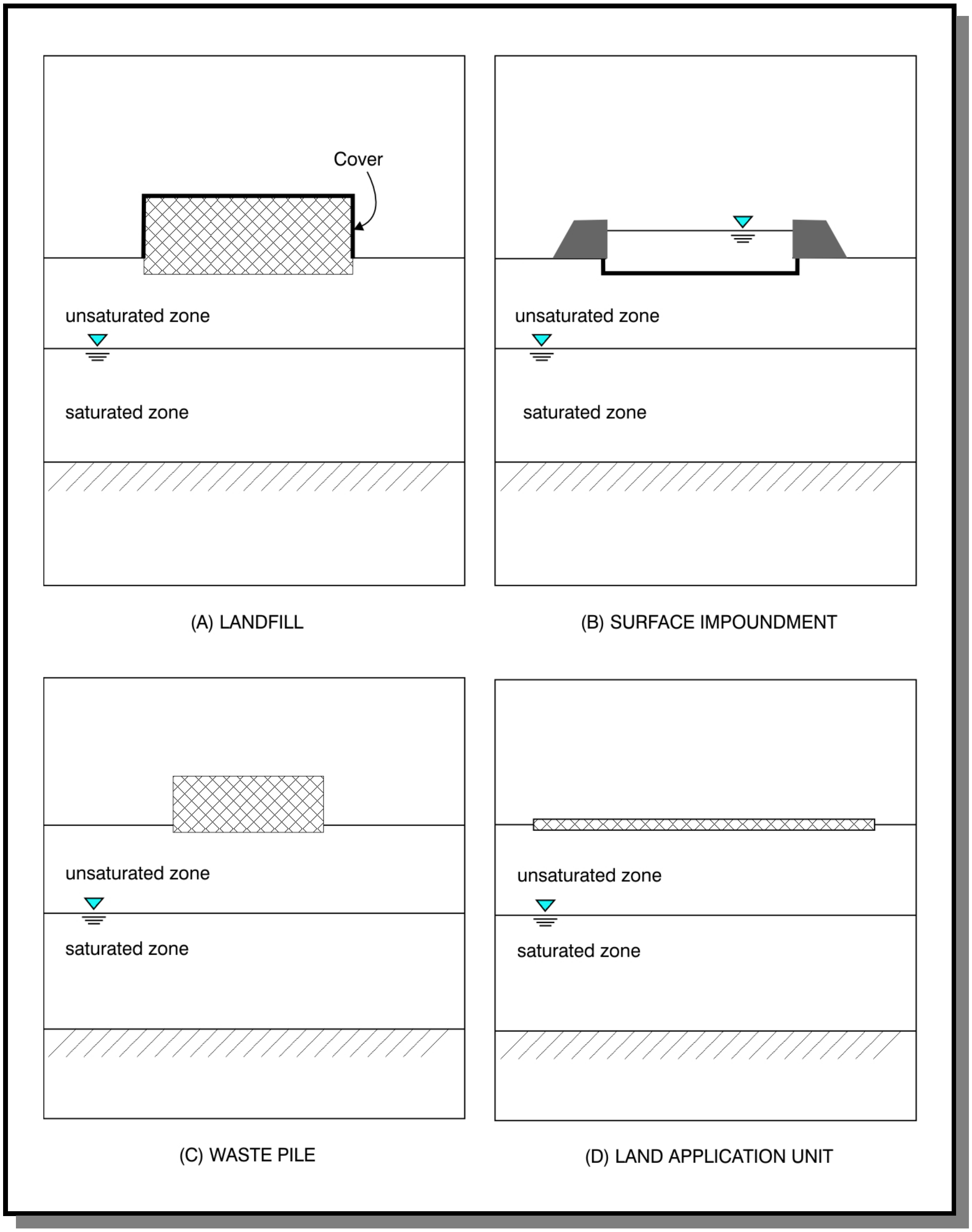
EPACMTP can simulate the subsurface migration of leachate from four different types of waste management units (WMUs). Each of the four unit types reflects waste management practices that are likely to occur at industrial Subtitle D facilities. The WMU can be a landfill, a waste pile, a surface impoundment, or a land application unit. The latter is also sometimes called a land treatment unit. Figure 2.1 presents schematic diagrams of the different types of WMUs modeled in EPACMTP.

Landfill. Landfills (LFs) are facilities for the final disposal of solid waste on land. EPACMTP is typically used to model closed LFs with an earthen cover. LFs may be unlined, or they may have some type of engineered liner, but the model assumes no leachate collection system exists underneath the liner. The LF is filled with waste during the unit’s operational life. Upon closure of the LF, the waste is left in place, and a final soil cover is installed. The starting point for the EPACMTP simulation is the time at which the LF is closed, i.e., the unit is at maximum capacity. The release of waste constituents into the soil and ground water underneath the LF is caused by dissolution and leaching of the constituents due to precipitation which percolates through the LF. The type of liner that is present (if any) controls, to a large extent, the amount of leachate that is released over time from the unit. LFs are modeled in EPACMTP as WMUs with a rectangular footprint and a uniform depth. The EPACMTP model does not explicitly account for any loss processes occurring during the unit’s active life (for example, due to leaching, volatilization, runoff or erosion, or biochemical degradation), however these processes will be taken into account if the input value for leachate concentration is based on a site-specific chemical analysis of the waste (such as results from a Toxicity Characteristic Leaching Procedure (TCLP) or Synthetic Precipitation Leaching Procedure (SPLP) analysis). The leachate concentration used as a model input is the expected initial leachate concentration when the waste is ‘fresh’. Because the LF is closed, the concentration of the waste constituents will diminish with time due to depletion of the landfilled wastes; the model is equipped to simulate this “depleting source” scenario for LFs, but other source options are available, and are explained in Section 2.3.

Surface Impoundment. A surface impoundment (SI) is a WMU which is designed to hold liquid waste or wastes containing free liquid. SIs may be either ground level or below ground level flow-through units. They may be unlined, or they may have some type of engineered liner. Release of leachate is driven by the ponding of water in the impoundment, which creates a hydraulic head gradient across the barrier underneath the unit. The EPACMTP model considers a SI to be a temporary WMU with a finite operational life. At the end of the unit’s operational life, we assume there is no further release of waste constituents to the ground water (that is, there is a clean closure of the SI). SIs are modeled as pulse-type sources; leaching occurs at a constant leachate concentration over a fixed period of time equal to the unit’s operating life. The EPACMTP model assumes a constant ponding depth (depth of waste water in SI) during the operational life (see Section 2.2.4).

Waste Pile. Waste piles (WPs) are typically used as temporary storage or treatment units for solid wastes. Due to their temporary nature, they are typically not covered. Similar to LFs, WPs may be unlined, or they may have some type of engineered liner. EPACMTP assumes that WPs have a fixed operational life, after which the WP is removed. Thus, WPs are modeled as pulse-type sources; leaching occurs at a constant leachate concentration over a fixed period of time which is equal to the unit's operating life (see Section 2.5.2).

Land Application Unit. Land application units (LAUs) (or land treatment units) are areas of land receiving regular applications of waste that is either tilled directly into the soil or sprayed onto the soil and then tilled. EPACMTP models the leaching of wastes after they have been tilled with soil. EPACMTP does not account for the losses due to volatilization during or after waste application. LAUs are only evaluated for the no-liner scenario because liners are not typically used at this type of facility. EPACMTP assumes that an LAU is a temporary WMU with a fixed operational life, after which the waste is no longer land-applied. Thus, LAUs are modeled in EPACMTP as a constant pulse-type leachate source, with a leaching duration equal to the unit's operational life (see Section 2.6.2).



(A) LANDFILL

(B) SURFACE IMPOUNDMENT

(C) WASTE PILE

(D) LAND APPLICATION UNIT

Figure 2.1 WMU Types Modeled in EPACMTP.

2.1 SOURCE PARAMETERS

The input parameters used in EPACMTP to describe the waste management unit are listed below in Table 2.1

Table 2.1 Waste Management Unit (Source) Parameters

WMU Type	Parameter	Symbol	Units	Section	Equation in EPACMTP TBD
LF	Area	A_w	m^2	2.3.1	2.3
	Depth	D_{LF}	m	2.3.2	2.3
	Depth Below Grade	d_{BG}	m	2.3.3	2.2.2.2
	Landfill Waste Fraction (Volume Fraction)	F_h	m^3/m^3	2.3.4	2.5
	Waste Volume	PWS	m^3	2.3.5	
	Leaching Duration	t_p	yr	2.3.6	2.7
SI	Area	A_w	m^2	2.4.1	2.2.2.2
	Ponding Depth	H_P	m	2.4.2	2.17
	Total Sediment Thickness	D_s	m	2.4.3	2.2.2.2
	Liner Thickness	D_{lin}	m	2.4.4	2.24b
	Liner Conductivity	K_{lin}	m/yr	2.4.5	2.24b
	Depth Below Grade	d_{BG}	m	2.4.6	2.24b
	Leak Density	ρ_{leak}	$holes/m^2$	2.4.7	2.24c
	Distance to Nearest Surface Water Body	R_∞	m	2.4.8	2.31
	Operating Life/Leaching Duration	t_p	yr	2.4.9	2.2.2.2
WP	Area	A_w	m^2	2.5.1	2.27
	Operating Life/Leaching Duration	t_p	yr	2.5.2	2.27
	Depth Below Grade	d_{BG}	m	2.5.3	2.2.2.2
LAU	Area	A_w	m^2	2.6.1	2.30
	Operating Life/ Leaching Duration	t_p	yr	2.6.2	2.30

2.2 DATA SOURCES FOR WMU PARAMETERS

Data from two nationwide EPA surveys of non-hazardous (RCRA Subtitle D) industrial facilities were used to develop databases of EPACMTP input values for WMU parameters. Data for LFs, WPs, and LAUs were obtained from an EPA survey of industrial Subtitle D facilities conducted in 1985 (U.S. EPA, 1986, referred to as *"The 1986 Subtitle D Survey"*). The survey provides a statistically representative subset of observations of site specific areas, volumes and locations for industrial Subtitle D facilities in the United States. Data for SIs were obtained from a recent U.S. EPA survey of industrial SIs (U.S. EPA, 2001a, "*Surface Impoundment Study"*). What follows is a general description of the data used from these two studies to compile the databases of WMU input parameters for the EPACMTP model; the actual distributions of values of these WMU input parameters are then summarized in Sections 2.3 - 2.6, and are listed in their entirety in Appendix D.

The WMU locations are shown in Figures 2.2 - 2.5. Information on WMU locations was used to coordinate other WMU-specific data with climate and hydrogeological parameter values. Specifically, we first used the HELP (Schroeder, et. al., 1994) water balance model and climate data from 102 climate stations and three common soil types to develop infiltration and recharge rates for unlined and single-lined WMUs (see Section 4.2 and Appendix A). Then, for each WMU site, we assigned: 1) a climate index corresponding to the nearest, representative climate station (used to select infiltration and recharge rates) (see Section 4.2); 2) a hydrogeologic index according to the regional aquifer type used to generate depth to water and aquifer characteristics (see Sections 5.2 and 5.3); and 3) a soil and aquifer temperature used to calculate hydrolysis transformation rates for organic constituents (see Sections 3.6.2 and 4.3). This allows appropriate site-based climate and hydrogeological parameter values to be generated for each site in the WMU database "on the fly" while the EPACMTP model is running a Monte Carlo analysis.

Landfills

The *1986 Subtitle D Survey* provided LF data consisting of 824 observations of facility locations, area, number of units in the facility, facility design capacity, total remaining facility capacity, and the relative weight of each facility. The relative weight was assigned based on the total number of employees working at the facility and reflects the quantity of the waste managed in that facility. The values of physical characteristics for each WMU were obtained by dividing the facility values by the number of units in the facility.

LF data were screened to eliminate unrealistic observations by placing constraints on the WMU depth and volume . The WMU depth, calculated by dividing the unit capacity by its area, was constrained to be greater than or equal to 2 feet (0.67m), and less than or equal to 33 feet (10m); these limits on unit depth were adopted from a previous analysis used to support the Toxicity Characteristic (TC) Rule (U.S. EPA, 1990). In addition, the LF volume was constrained to be greater than the remaining capacity.

A joint distribution was derived from available unit areas correlated with unit volumes that met the unit depth and remaining capacity constraints. The distribution was assumed to be lognormal. Random samples of this distribution were used in cased where the unit area, the unit volume, or both were missing.

If the WMU depth or remaining capacity constrains were violated, the reported unit volume was replaced with a sample from the joint distribution, based on the reported unit area, based on the assumption that the reported unit area was more likely to be correct.

Figure 2.2 shows the geographic locations of LF WMUs used in developing the EPACMTP database of LF sites. A compete listing of the site-based LF input parameter values is provided in Appendix D.

Figure 2.2 Geographic Locations of Landfill WMUs.

Surface Impoundments

The original EPACMTP database of SI input parameter values (based on the *1986 Subtitle D survey*) was updated with more complete data derived from the results of EPA's recent 5-year study of nonhazardous (Subtitle D) industrial SIs in the United States (U.S. EPA, 2001a). The *Surface Impoundment Study* is the product of a national survey of facilities that operate non-hazardous industrial waste SIs. The updated database is comprised of SI characteristics from 503 SI units located at 143 facilities throughout the United States.

The *Surface Impoundment Study* provided data on impoundment locations, area, operating depths (depth of ponding in the impoundment), depth of the SI base below the ground surface, sludge volume, operational life of the impoundment, closure plans, and proximity of the impoundment to a surface water body.

The current version of the EPACMTP database of SI sites was compiled for analyses included in the U.S. EPA Industrial Waste Management Evaluation Model (U.S. EPA, 2003b). As a result, the database includes assumptions specific to that effort. Specifically, the thickness of sludge at the bottom of SI units was assumed to be 0.2 m for all sites; sites with unknown operating lines and no closure plans were assumed to operate for 50 years; all units were assumed to be built on top of the ground surface; and unknown distances to the nearest surface water body or distances given as >2,000 m were set to 5,000 m.

Figure 2.3 shows the geographic locations of SI WMUs (from the *Surface Impoundment Study*) used in developing the EPACMTP database of SI sites. Due to the scale of this map, the individual units at each facility are not shown. A compete listing of the site-based SI input parameter values is provided in Appendix D.

Figure 2.3 Geographic Locations of Surface Impoundment WMUs.

Waste Piles

The *1986 Subtitle D survey* included 847 WP facilities with data on facility area, number of units, and the total amount of waste placed in the facility (waste volume) in 1985. Unit values were derived by dividing the facility values by the number of units in the facility. No screening constraints were placed on the WP data. The 114 facility areas and the 30 facility waste volumes reporting zero values were set to 0.005 acres (20 m^2) and 0.005 mega-tons (Mton), respectively. These default values were adopted from a previous analysis used to support the Toxicity Characteristic (TC) Rule (U.S. EPA, 1990).

Thirty facilities did not report waste volume. All facilities reported facility area. Missing volume values were replaced by random realizations from the probability distribution of volume conditioned on area. The conditional distribution was assumed to be lognormal and was derived from the non-missing unit area/volume pairs.

Figure 2.4 shows the geographic locations of WP WMUs used in developing the EPACMTP database of WP sites. A compete listing of the site-based WP input parameter values is provided in Appendix D.

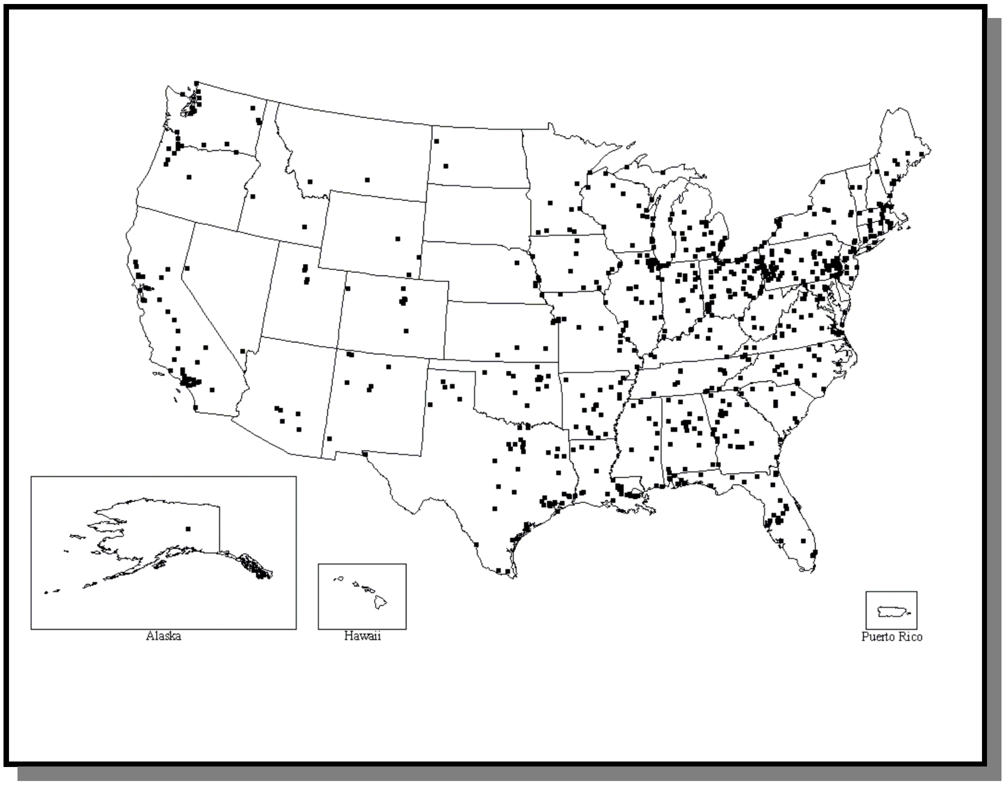


Figure 2.4 Geographic Locations of Waste Pile WMUs.

Land Application Units

The *1986 Subtitle D survey* included 352 LAU facilities, with data on location, area, number of units in each facility, and the total amount of waste managed (waste volume) in 1985. Individual unit values were derived by dividing the facility values by the number of units in the facility. Application rates were derived by dividing the waste managed in 1985 by the site acreage. Unrealistic values were screened from these data by constraining the waste application rates to be less than 10,000 tons/acre/year. This assumes a maximum application rate of 200 dry tons/acre/year with a 2% solids content.

Eight did not report waste volume, and twelve were screened out due to the application rate constraint. Of the 352 facilities, all reported a facility and none were screened. Three reported zero areas and nine reported zero waste volumes were set to 0.005 acres (20 m^2) and 0.005 Mton, respectively.

Missing and screened values were replaced by random realizations from the joint area/volume probability distribution or the corresponding marginal distributions depending on whether both or only one of either the waste volume or area values were missing or screened. The joint distribution was assumed to be lognormal and was derived from the non-missing unit area/volume pairs that met the unit depth constraint.

Figure 2.5 shows the geographic locations of LAU WMUs used in developing the EPACMTP database of LAU sites. A compete listing of the site-based database of LAU input parameter values is provided in Appendix D.

Figure 2.5 Geographic Locations of Land Application Unit WMUs.

2.3 LANDFILLS (LF)

This section discusses the individual WMU-related parameters required to perform a LF analysis using EPACMTP. Most applications of EPACMTP are for national or regional regulatory development purposes, in which case, each of the following LF input parameters is described using a probability distribution. The default distributions are described in the following sections. However, EPACMTP can also be used in a location-waste-specific mode; in this case, each of the following LF input parameters could be assigned a site-specific constant value or a site-specific distribution of values. These site-specific data need to be gathered by the user prior to performing the EPACMTP modeling analysis. However, site-specific implementation of EPACMTP will yield results which may not reflect the site-specific heterogeneities and anisotropic conditions.

The source-specific input parameters for the LF scenario include parameters to determine the amount of waste disposed in the LF and the source leaching duration. Together with the infiltration and recharge rates and the initial waste and leachate concentrations, these parameters are used to determine how much contaminant mass enters the subsurface and over what time period. The source-specific parameters for the LF scenario are individually described in the following sections.

2.3.1 Landfill Area (A_w)

Definition

The LF area is defined as the footprint of the LF. EPACMTP assumes the LF to be rectangular. By default, the length and width of the LF are each calculated as the square root of the area.

Parameter Value or Distribution of Values

The entire distribution is presented in Appendix D. The cumulative frequency distribution of LF area is listed in Table 2.2. For a given percentile (%) frequency and area value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.2 Cumulative Frequency Distribution of Landfill Area.

%	Area (m^2)
0	4.05E+01
10	4.86E+02
25	2.43E+03
50	1.21E+04
75	5.26E+04
80	6.56E+04
85	9.11E+04
90	1.42E+05
95	2.23E+05
100	3.12E+06

Data Sources

The data for LF area listed in Table 2.2 were obtained from EPA's *1986 Subtitle D Survey* (U.S. EPA, 1985).

Use In EPACMTP

The LF area is used to determine the area over which leachate enters the subsurface. It is also one of several parameters used to calculate the total contaminant mass present in the LF at closure. The total contaminant mass is a necessary input when using the LF depleting source option, since the contaminant is leached to the subsurface until the waste in the LF is depleted (see Section 2.2.1.3.3 of the *EPACMTP Technical Background Document*; U.S. EPA, 2003a).

2.3.2 Landfill Depth (D_{LF})

Definition

The LF depth is defined as the average depth of the LF, from top to bottom; the thickness of the cover soil is assumed to be small compared to the depth. Note that the LF depth is measured from the top to the base of the unit, irrespective of where the ground surface is.

Parameter Value or Distribution of Values

The entire distribution is presented in Appendix D. The cumulative frequency distribution of LF depth is listed in Table 2.3. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.3 Cumulative Frequency Distribution of Landfill Depth.

%	Depth (m)
0	5.10E-01
10	8.80E-01
25	1.32E+00
50	2.57E+00
75	4.09E+00
80	4.53E+00
85	5.20E+00
90	6.13E+00
95	7.12E+00
100	1.01E+01

Data Sources

Data for the nationwide distribution of LF depths was obtained from the *1986 Subtitle D survey* (EPA, 1986).

Use In EPACMTP

The LF depth is one of several parameters used to calculate the contaminant mass within the LF; the contaminant mass is an important input for the LF depleting source option (see Section 2.2.1.3.3 of the *EPACMTP Technical Background Document*; U.S. EPA, 2003a).

2.3.3 Landfill Base Depth below Grade (d_{BG})

Definition

The depth below grade is defined as the depth of the bottom of the LF below the surrounding ground surface, as schematically depicted in Figure 2.6.

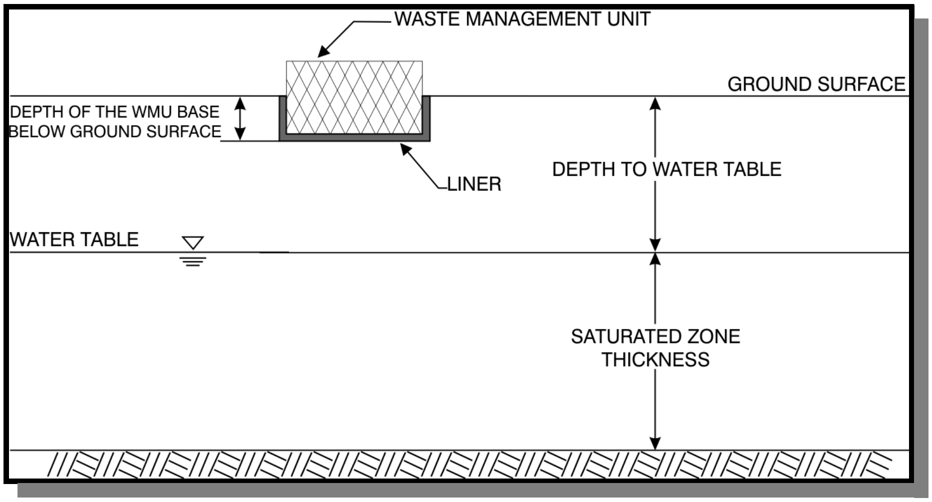


Figure 2.6 WMU with Base Elevation below Ground Surface.

Parameter Value or Distribution of Values

Data for this parameter were not included in the EPA's 1986 *Industrial Subtitle D Survey.* Unless site-specific data are available, users should set this parameter to zero, which is equivalent to assuming the base of the unit lies on the ground surface.

Data Sources

No nationwide distribution of values is currently available. For LF modeling analyses, this parameter value is typically set to zero, unless site-specific data are available.

Use In EPACMTP

If a non-zero value is entered for this input, then the thickness of the vadose zone beneath the LF is adjusted accordingly. In this case, EPACMTP will also verify that the entered value, in combination with the depth to the water table, and magnitude of the unit's infiltration rate, does not lead to a physically infeasible condition (e.g.,the LF base is not in contact with a static water table or an infiltration-induced water table mound) in accordance with the infiltration screening methodology presented in Section 2.2.5 of the *EPACMTP Technical Background Document* (EPA, 2003a).

2.3.4 Waste Fraction (F_h)

Definition

The waste fraction is defined as the fraction of the LF volume occupied by the modeled waste at LF closure.

Parameter Value or Distribution of Values

By default, this parameter is defined as a uniform distribution with lower and upper bounds of 0.036 to 1.0, respectively. However, if warranted by site-specific conditions or other assumptions, this parameter can also be set to 1.0 (the most protective case – equivalent to a monofill scenario), another constant value, or another distribution of values.

Data Sources

The default lower bound of 0.036 (which ensures that the modeled waste unit will always contain a minimum amount of the waste of concern), was obtained from an analysis of waste composition in municipal LFs (Schanz and Salhotra, 1992). The upper bound is the maximum value that is physically possible (the waste in the LF is composed completely of the waste of concern).

Note that an input value for this parameter is required for the LF scenario only.

Use In EPACMTP

EPACMTP uses the waste fraction to calculate the contaminant mass within the LF; the contaminant mass is an important input for the LF depleting source option (see Section 2.2.1.3.3 of the *EPACMTP Technical Background Document*; U.S. EPA, 2003a).

2.3.5 Waste Volume (PWS)

Definition

The waste volume is defined as the volume of the waste of interest (at LF closure) contributed to the Subtitle D LF.

Parameter Value or Distribution of Values

The waste volume is an input parameter that depends on the EPACMTP application. For nationwide risk assessments, EPA has typically assumed a default uniform distribution, where the waste volume is entered as a fraction of the entire landfill volume (see Waste Fraction in Section 2.3.4). If the landfill volume and the waste volume are treated as random parameters, specifying the waste volume in terms of a waste fraction ensures that the modeled waste volume can never exceed the modeled landfill volume.

For site-specific applications of EPACMTP, the waste volume that is entered as an EPACMTP input parameter can be calculated by multiplying the annual waste volume by the number of years of landfill operation. If the annual waste amount is given as a mass value (e.g., tons/year), it should be divided by the waste density in order to yield the value as a volume. The user should ensure that the modeled waste volume does not exceed the landfill volume.

Data Sources

Data sources depend on the EPACMTP application and are typically provided by waste generation data. For nationwide LF modeling analyses, this parameter is typically specified in terms of a waste fraction.

Use In EPACMTP

EPACMTP uses the waste volume to calculate the contaminant mass within the LF; the contaminant mass is an important parameter for the LF depleting source option (see Section 2.2.1.3.3 of the *EPACMTP Technical Background Document*; U.S. EPA, 2003a).

2.3.6 Leaching Duration (t_p)

Definition

The leaching duration is defined as the period of time that leachate is released from the WMU.

Parameter Value or Distribution of Values

By default, this parameter is set as a “derived” parameter to be calculated internally by EPACMTP as a function of the total amount of contaminant that is initially present in the landfill, and the rate of removal through the leaching process. Alternatively, the user may set this parameter to a specific constant value or a distribution of values.

Data Sources

No nationwide distribution of values is currently available. For LF modeling analyses, this parameter is typically set to be internally derived by EPACMTP.

Use In EPACMTP

If the leaching duration is set to a user-provided value or distribution, EPACMTP will model the LF using a pulse source (leaching at a constant concentration over a finite, pre-defined time period).

More commonly, the LF is modeled as a permanent waste management unit; in this case, the EPACMTP model assumes that leaching continues until the waste is depleted. To model this depleting source scenario, this input parameter should be specified as internally derived by EPACMTP. For a detailed discussion of how the LF source depletion rate is calculated, see Section 2.2.1.3.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

2.4 SURFACE IMPOUNDMENT (SI)

This section discusses the individual WMU-related parameters required to perform a SI analysis using EPACMTP. Most applications of EPACMTP are conducted on a national or regional basis for regulatory development purposes, in which case, most of the following SI input parameters would be described using the default probability. Distributions are discussed in the following sections. However, EPACMTP can also be used in a location- or waste-specific mode; in this case, each of the following SI input parameters could be assigned a site-specific constant value or a site-specific distribution of values. These site-specific data need to be gathered by the user prior to performing the EPACMTP modeling analysis.

The source-specific inputs for the SI scenario include parameters to determine the unit dimensions, ponding depth, and leaching duration. Together with the infiltration and recharge rates and the leachate concentration, these parameters are used to determine how much contaminant mass enters the subsurface and over what time period.

The source-specific parameters for the SI scenario are individually described in the following sections, and Figure 2.7 illustrates a compartmentalized SI as implemented in the EPACMTP model. Shown in the figure are, in descending order: the liquid compartment, the sediment compartment (with loose and consolidated sediments), and the vadose zone (with clogged and unaffected native materials).

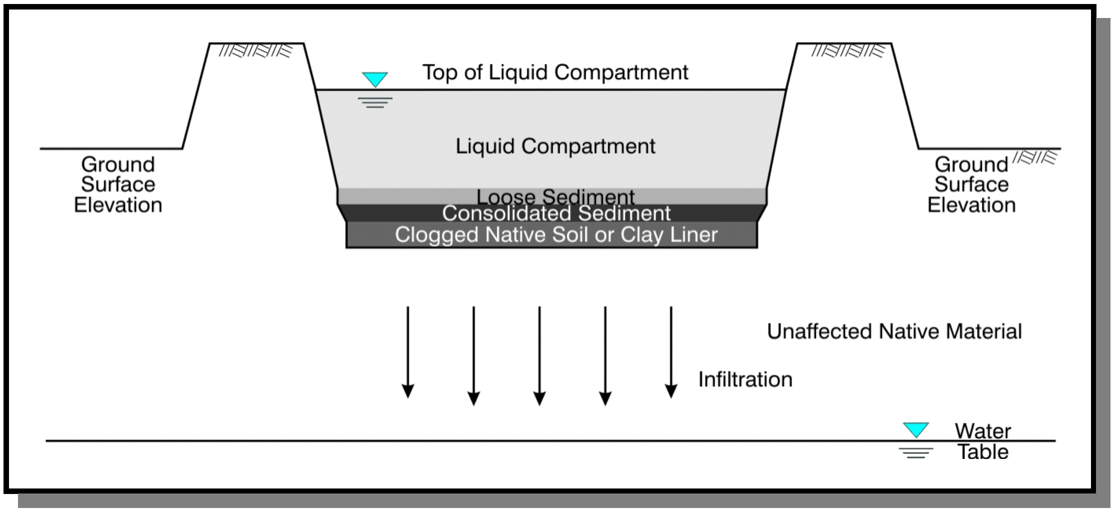


Figure 2.7 Schematic Cross-Section View of SI Unit.

2.4.1 Surface Impoundment Area (A_w)

Definition

The SI area is defined as the footprint of the impoundment. In EPACMTP, the impoundment is assumed to be rectangular. By default the unit is assumed to be square, i.e., to have equal length and width which are each calculated as the square root of the area.

Parameter Value or Distribution of Values

The entire distribution is presented in Appendix D. The cumulative frequency distribution of SI area is listed in Table 2.4. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.4 Cumulative Frequency Distribution of Surface Impoundment Area.

%	Area (m^2)
0	9.30E+00
10	1.74E+02
25	4.01E+02
50	1.77E+03
75	6.97E+03
80	8.90E+03
85	1.67E+04
90	2.83E+04
95	5.16E+04
100	4.86E+06

Data Sources

The data for SI area listed in Table 2.2 were obtained from EPA's *Surface Impoundment Study* (U.S. EPA, 2001a).

Use In EPACMTP

The SI area represents the total surface area over which infiltration and leachate enter the subsurface.

2.4.2 Surface Impoundment Ponding Depth (H_p)

Definition

The ponding depth is the average depth of the wastewater in the liquid compartment as shown in Figure 2.7; that is, this value does not include any sediment accumulated at the base of the unit.

Parameter Value or Distribution of Values

The entire distribution is presented in Appendix D. The cumulative frequency distribution of SI ponding depth is listed in Table 2.5. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.5 Cumulative Frequency Distribution of Surface Impoundment Ponding Depth.

%	SI Ponding Depth (m)
0	1.00E-02
10	4.60E-01
25	9.93E-01
50	1.81E+00
75	2.95E+00
80	3.44E+00
85	3.66E+00
90	4.24E+00
95	5.32E+00
100	1.82E+01

Data Sources

Data for the nationwide distribution of SI ponding depths was obtained from the *2001 Surface Impoundment Study* (EPA, 2001a).

Use In EPACMTP

The SI ponding depth is added to the unconsolidated sediment thickness (one-half of the total sediment thickness; see Section 2.4.4); this sum represents the hydraulic head that drives leakage of water from the SI. EPACMTP uses this parameter in order to calculate SI infiltration rates (see Section 4.3.4).

2.4.3 Surface Impoundment Total Thickness of Sediment (D_s)

Definition

The SI total thickness of sediment is the average thickness of accumulated sediment (sludge) deposits on the bottom of the impoundment. This layer of accumulated sediment is different from an engineered liner underneath the impoundment, but its presence will serve to restrict the leakage of water from an impoundment, especially in unlined units. The EPACMTP model assumes that the accumulated sediment consists of two equally thick layers, an upper unconsolidated layer and a lower consolidated layer (‘filter cake’) that has been compacted due to the weight of the sediment and wastewater above it, and, therefore, has a reduced porosity and permeability.

Parameter Value or Distribution of Values

A default value of 0.2m was adopted for the development of EPA's Industrial Waste Management Evaluation Model (U.S. EPA, 2003b). This agrees with the determination EPA made for values in the SI module of EPACMTP. Alternative data on this parameter are available, and can be extracted from EPA's *Surface Impoundment Survey*. However, these data have not currently been included in EPACMTP database of SI sites. See Section 2.2 for more information on the SI site database.

Data Sources

Data on SI sediment thicknesses were acquired from the nationwide *2001 Surface Impoundment Study* (EPA, 2001a).

Use In EPACMTP

The EPACMTP model uses the SI sediment thickness to calculate the rate of infiltration from unlined and single-lined SIs (see Section 4.2). The calculated infiltration rate is inversely related to the thickness of the sediment layer assuming constant ponding depth. A lower value for sediment thickness will result in a higher infiltration rate, and a greater rate of constituent loss from the impoundment. A detailed description of the EPACMTP SI infiltration module is provided in Section 2.2.2.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

2.4.4 Surface Impoundment Liner Thickness (D_{lin})

Definition

EPACMTP is able to account for infiltration through a single compacted clay liner beneath the SI. In the event that the SI is single-lined, the thickness of the liner must be provided. The liner thickness is defined as the average thickness of the single completed clay liner by which the SI is underlain. Additionally, the base of a lined SI is defined to be the interface between the liner and the native soils below. This definition permits EPACMTP to establish the elevation of the top of the liquid compartment relative to the unit base.

Parameter Value or Distribution of Values

As a default, EPA has assumed the SI clay liner thickness to be a constant 3 ft. or 0.916 m for nationwide or regional analyses. However, liner thickness can be represented by a distribution with the limitation that the minimum value be greater than zero. The clay liner is not allowed to be less than 0.1m to ensure numeric stability of the unsaturated zone flow simulation module.

Data Sources

The default liner thickness of 3 feet is based on typical design criteria for compacted clay liners underneath land disposal units (U.S. EPA, 2003b).

Use In EPACMTP

The EPACMTP model uses the SI liner thickness to calculate the rate of infiltration from the unit (see Section 4.2). The calculated infiltration rate is inversely related to the thickness of the liner assuming constant ponding depth. A detailed description of the EPACMTP SI infiltration module is provided in Section 2.2.2.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

2.4.5 Surface Impoundment Liner Conductivity (K_{lin})

Definition

The liner hydraulic conductivity is defined as the average saturated hydraulic conductivity of the clay liner mentioned in Section 2.4.4.

Parameter Value or Distribution of Values

By default, EPA has assumed the SI liner conductivity for compacted clay liners to be a constant 1.0 x 10^{-7}cm/s or 3.15 x 10^{-2} m/yr for nationwide and regional analyses. However, liner conductivity can be represented by any value or distribution of values with the limitation that the minimum liner conductivity must be greater than zero.

Data Sources

The default value of 1 x 10^{-7} cm/sec is based on typical design criteria for compacted clay liners beneath land disposal units and is the maximum recommended hydraulic conductivity for a compacted clay liner given in the EPA's *Guide for Industrial Waste Management* (U.S. EPA, 2003; EPA530-R-03-001).

Use In EPACMTP

The EPACMTP model uses the SI liner conductivity to calculate the rate of infiltration from the WMU (see Section 4.2). The calculated infiltration rate is directly related to the conductivity of the liner, assuming constant ponding depth. A detailed description of the EPACMTP SI infiltration module is provided in Section 2.2.2.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

2.4.6 Surface Impoundment Base Depth Below Grade (d_{BG})

Definition

This parameter represents the depth of the base of the unit below the surrounding ground surface, as schematically depicted in Figure 2.6.

Parameter Value or Distribution of Values

The default distribution is presented in Appendix D. The cumulative frequency distribution of SI depth below grade is summarized in Table 2.6. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.6 Cumulative Frequency Distribution of Surface Impoundment Depth Below Grade.

%	SI Depth Below Grade (m)
0	0.00E+00
10	0.00E+00
25	0.00E+00
50	1.22E+00
75	3.05E+00
80	3.58E+00
85	3.90E+00
90	4.57E+00
95	5.18E+00
100	3.35E+01

Data Sources

Data for this nationwide distribution for SI base depth below grade from the *2001 Surface Impoundment Study* (EPA, 2001a).

Use In EPACMTP

The depth of the base of the unit below the ground surface reduces the travel distance through the unsaturated zone before leachate constituents reach the water table. If a non-zero value is entered, EPACMTP will verify that the entered value, in combination with the depth to the water table, and magnitude of the unit's infiltration rate, does not lead to a physically infeasible condition (e.g., water table mound height above the ground surface or above the level of the waste liquid in an impoundment) in accordance with the infiltration screening methodology presented in Section 2.2.5 of the *EPACMTP Technical Background Document* (EPA, 2003a).

2.4.7 Surface Impoundment Leak Density (ρ_{leak})

Definition

EPACMTP can also account for infiltration through composite liners. The infiltration is assumed to result from defects (pinholes) in the geomembrane. The pinholes are assumed to have a circular shape and be uniform in size. The leak density is defined as the average number of circular pinholes per hectare.

Parameter Value or Distribution of Values

The cumulative frequency distribution of SI composite liner leak density is listed in Table 2.7.

Table 2.7 Cumulative Frequency Distribution of Leak Density for Composite-Lined SIs.

%	Leak density (No. Leaks/ha)
0	0
10	0
20	0
30	0
40	0.7
50	0.915
60	1.36
70	2.65
80	4.02
90	4.77
100	12.5

Data Sources

A nationwide, default distribution of leak densities (expressed as number of leaks per hectare) have been compiled from 26 leak density values reported in TetraTech (2001). The leak densities are based on liners installed with formal Construction Quality Assurance (CQA) programs.

Use In EPACMTP

The EPACMTP model uses composite liner leak density to calculate the rate of infiltration from composite-lined SIs (see Section 4.2). The calculated infiltration rate is directly related to the leak density of the liner. A lower value of leak density will result in a lower infiltration rate. A detailed description of the EPACMTP SI infiltration module is provided in Section 2.2.2.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

2.4.8 Distance to Nearest Surface Water Body (R_∞)

Definition

The distance to the nearest permanent surface water body (that is, a river, pond or lake); note that this distance can be measured in any direction, not only in the downgradient direction.

Parameter Value or Distribution of Values

The data from the *Surface Impoundment Study* indicated a distribution of values with a range of 30 m to 5,000 m (up to 3.1 miles), and a median value of 360 m. The entire distribution is presented in Appendix D for this parameter. The cumulative frequency distribution is summarized in Table 2.8. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.8 Cumulative Frequency Distribution of Distance to Nearest Surface Water Body.

%	Distance to Nearest Surface Water Body (m)
0	0.00E+00
10	9.00E+01
25	2.40E+02
50	3.60E+02
75	8.00E+02
80	1.17E+03
85	1.60E+03
90	5.00E+03
95	5.00E+03
100	5.00E+03

Data Sources

Data from the EPA's *Surface Impoundment Study* (EPA, 2001a) were used to assign a distance value to each SI unit in the default EPACMTP database of WMU sites.

Use In EPACMTP

In the case of deep unlined impoundments, EPACMTP may calculate very high SI infiltration rates. EPACMTP checks against the occurrence of excessively high rates by calculating the estimated height of groundwater mounding underneath the WMU, and if necessary reduces the infiltration rate to ensure the predicted water table does not rise above the ground surface. The infiltration screening methodology is described in detail in Section 2.2.5 of the *EPACMTP Technical Background Document* (EPA, 2003a). This screening procedure requires as input the distance to the nearest point at which the water table elevation is kept at a fixed value. Operationally, this is taken to be the distance to the nearest surface water body.

2.4.9 Surface Impoundment Leaching Duration (t_p)

Definition

The time period during which leaching from the SI unit occurs. For SIs, the addition and removal of waste during the operational life period are assumed t be more or less balanced, without significant net accumulation of waste. Additionally, industrial SIs are, at the end of their operational life, typically dredged and backfilled. Even if simply abandoned, the waste in the impoundment will drain and/or evaporate relatively quickly. Consequently, in the finite source implementation for SIs, the duration of the leaching period is assumed to be the same as the operational life of the SI.

Parameter Value or Distribution of Values

In a typical SI modeling analysis, the SI is modeled as a temporary waste management unit. In this case, if site-specific data are not available, the user can make use of the distribution of SI operating life values summarized in Table 2.9 and presented in their entirety in Appendix D. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.9 Cumulative Frequency Distribution of Surface Impoundment Operating Life.

%	SI Operating Life (yr)
0	4.00E+00
10	1.50E+01
25	5.00E+01
50	5.00E+01
75	5.00E+01
80	5.00E+01
85	5.00E+01
90	5.00E+01
95	5.00E+01
100	9.50E+01

Data Sources

Data used to define this nationwide distribution of unit-specific operational lives for SIs were obtained from information in the *Surface Impoundment Study* on present age of the unit and the planned closing date (EPA, 2001a). If this information was missing, we assigned an operational life of 50 years.

Use In EPACMTP

EPACMTP assumes that the duration of the leaching period is equal to the unit's operational life; this leaching duration is then used to assign the length of the pulse-source boundary condition in the EPACMTP fate and transport simulation.

2.5 WASTE PILE (WP)

This section discusses the individual WMU-related parameters required to perform a WP analysis using EPACMTP. Most applications of EPACMTP are conducted on a national or regional basis for regulatory development purposes, in which case, most of the WP input parameters could be defined using a default probability distribution, described in the following sections. However, EPACMTP can also be used in a location- or waste-specific mode; in this case, each of the following WP input parameters could be assigned a site-specific constant value or a site-specific distribution of values. These site-specific data need to be gathered by the user prior to performing the EPACMTP modeling analysis.

The WMU-specific input parameters for the WP scenario include the area of the WP, the source leaching duration, and the depth of the base of the unit below grade. Together with the leachate concentration, infiltration rate, and recharge rate, these three parameters are used to determine how much contaminant mass enters the subsurface from the base of the WP over what time period. These WP input parameters are described in the following sections.

2.5.1 Waste Pile Area (A_w)

Definition

The WP area is defined as the footprint of the unit. In EPACMTP, the WP is modeled as being rectangular. By default, the WMU is assumed to be square, i.e., equal length and width. Thus, the length and width of the WP are each calculated as the square root of the area.

Parameter Value or Distribution of Values

The default nationwide distribution is presented in Appendix D. The cumulative frequency distribution of WP area is summarized in Table 2.10. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.10 Cumulative Frequency Distribution of Waste Pile Area.

%	Area (m^2)
0	5.06E+00
10	2.02E+01
25	2.02E+01
50	1.21E+02
75	1.21E+03
80	2.02E+03
85	3.72E+03
90	4.17E+03
95	1.21E+04
100	1.94E+06

Data Sources

The data for WP area listed in Table 2.2 were obtained from EPA's *1986 Subtitle D Survey* (U.S. EPA, 1986).

Use In EPACMTP

The WP area represents the total surface area over which infiltration and leachate enter the subsurface.

2.5.2 Waste Pile Leaching Duration (t_p)

Definition

The time period during which leaching from the WP unit occurs. WPs are a temporary management scenario in which the addition and removal of waste during the operational life period are assumed to be more or less balanced, without significant net accumulation of waste. Typically at the end of the active life of a WP, the waste material is either removed for land filling, or the WP is covered and left in place. If the waste is removed, there is no longer a source of potential contamination. If a WP is covered and left in place, it then becomes equivalent to a LF and should be regulated as a LF. Consequently, in the finite source implementation for WPs, the duration of the leaching period will, for practical purposes, be the same as the operational life of the WP.

Parameter Value or Distribution of Values

Since operational life is not one of the input parameters included in the EPA's *1986 Subtitle D Survey* (U.S. EPA, 1986), EPA has assumed a value of 20 years as a default value for WP operational life. Alternatively, a distribution of values could also be used.

Data Sources

The default value of 20 years is based on professional judgement of typical industrial waste management practices and consistency with EPA regulatory assessments of the active life of a unit.

Use In EPACMTP

EPACMTP assumes that the duration of the leaching period is equal to the unit's operational life; this leaching duration is then used to determine the total contaminant flux from the WP to the subsurface.

2.5.3 Waste Pile Base Depth below Grade (d_{BG})

Definition

This parameter represents the depth of the base of the unit below the ground surface, as schematically depicted in Figure 2.6.

Parameter Value or Distribution of Values

Unless site-specific data are available, users should set this parameter to the default value of zero, which is equivalent to assuming the base of the unit lies on the ground surface.

Data Sources

No survey data on this parameter are currently available. For WP modeling analyses, this parameter value is typically set to a default value of zero.

Use In EPACMTP

Greater depth of the unit below the ground surface reduces the travel distance through the unsaturated zone before leachate constituents reach ground water. If a non-zero value is entered, EPACMTP will verify that the entered value, in combination with the depth to the water table, and magnitude of the unit's infiltration rate, does not lead to a physically infeasible condition (e.g., the WP base is in contact with a static water table or an infiltration-induced watertable mound) in accordance with the infiltration screening methodology presented in Section 2.2.5 of the *EPACMTP Technical Background Document* (EPA, 2003a).

2.6 LAND APPLICATION UNIT (LAU)

This section discusses the individual WMU-related parameters required to perform an LAU analysis using EPACMTP. Many applications of EPACMTP are conducted on a national or regional basis for regulatory development purposes; in which case, most LAU input parameters would be defined using the default probability distributions described in the following sections. However, EPACMTP can also be used in a location-adjusted or waste-specific mode; in this case, each of the following LAU input parameters could be assigned a site-specific constant value or a site-specific distribution of values. These site-specific data need to be gathered by the user prior to performing the EPACMTP modeling analysis.

The WMU-specific input parameters for the LAU scenario include the area of the LAU and the leaching duration. Together with the leachate concentration, infiltration rate, and recharge rate, these two parameters are used to determine how much contaminant mass enters the subsurface from the base of LAU and over what time period. These LAU input parameters are described in the following sections.

2.6.1 Land Application Unit Area (A_w)

Definition

The LAU area is defined as the footprint of the unit. In EPACMTP, the LAU is modeled as being rectangular. By default, the WMU is assumed to be square, i.e., equal length and width. Thus, the length and width of the LAU are each calculated as the square root of the area.

Parameter Value or Distribution of Values

The default nationwide distribution is presented in Appendix D. The cumulative frequency distribution of LAU area is summarized in Table 2.11. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right-hand column.

Table 2.11 Cumulative Frequency Distribution of Land Application Unit Area.

%	Area (m^2)
0	2.02E+01
10	4.05E+01
25	4.05E+03
50	4.05E+04
75	1.82E+05
80	2.43E+05
85	4.05E+05
90	6.48E+05
95	9.11E+05
100	8.09E+07

Data Sources

The data for LAU area summarized in Table 2.11 were obtained from EPA's *1986 Subtitle D Survey* (U.S. EPA, 1986).

Use In EPACMTP

The LAU area represents the total surface area over which infiltration and leachate enter the subsurface.

2.6.2 Land Application Unit Leaching Duration (t_p)

Definition

The time period during which leaching from the LAU occurs. Since LAUs are typically modeled as temporary waste management units using the pulse (or non-depleting) source scenario, this input is equivalent to the operational life. For LAUs, the addition and removal of waste (via leaching, biodegradation, etc.) during the operational life usually are assumed to be more or less balanced, without significant net accumulation of waste. Once waste application ceases at the end of the operational life of the LAU, the leachable waste is expected to be rapidly depleted. Consequently, if the LAU is modeled as a finite source, the duration of the leaching period will, in most cases be the same as the operational life of the LAU.

Parameter Value or Distribution of Values

Since operational life is not one of the input parameters included in the EPA's *1986 Subtitle D Survey* (U.S. EPA, 1986), EPA has assumed a value of 40 years as a default value for LAU operational life. Alternatively, a distribution of values could also be used.

Data Sources

The default value of 40 years is based on professional judgement of typical industrial waste management practices and consistency with existing EPA regulatory assessments on the active life of these units.

Use In EPACMTP

The leaching duration is used to determine the total contaminant flux from the LAU to the subsurface.

3.0 WASTE AND CONSTITUENT PARAMETERS

This section discusses the individual waste and constituent parameters required to perform a modeling analysis using EPACMTP. Each of the input parameters describing the waste and constituent can be specified as a constant value or as a statistical or empirical distribution of values. As a practical matter, however, many of these inputs are commonly set to constant values.

When modeling a WMU using a pulse source term (typically done for the SI, WP, and LAU scenario), the only waste-specific input parameter required by the model is the leachate concentration. When modeling a LF, the waste volume, waste density and the waste concentration are also needed by the model (For a complete listing of the LF source term variables, see Section 2.2.1 of the *EPACMTP Technical Background Document*). These additional waste parameters are used to determine the amount of constituent in the landfill that is available for leaching. The waste volume is entered in EPACMTP in terms of a fraction of the entire LF volume, and is discussed in Section 2 of this document, under the source parameters.

The constituent-specific parameters are used to simulate the chemical fate of constituents as they are transported through the subsurface; these inputs can be divided into three categories:

1) General and Constitutive Input Parameters
    - e.g., molecular weight, molecular diffusion, and regulatory standard in drinking water.
2) Organic Constituent Specific Input Parameters
    - to describe the tendency of the constituent to degrade to form harmless and/or toxic degradation products; and
    - to quantify the capacity of the constituent to adsorb to the organic components of the soil matrix.
3) Non-Linear Metal Constituent Geochemical Input Parameters
    - to determine the mobility of a metal constituent in the subsurface.

The EPACMTP model simulates the ground-water fate and transport of waste constituents by using these constituent-specific parameters in conjunction with the properties of the subsurface.

The waste and constituent parameters are individually described in the following sections.

3.1 WASTE AND CONSTITUENT PARAMETERS

The input parameters used in EPACMTP to describe the modeled waste and constituent are listed in Table 3.1.

Table 3.1 Waste and Constituent Parameters

Parameter Type	Parameter	Symbol	Units	Section	Equation in EPACMTP TBD
Waste	Waste Density	ρ_{hw}	g/cm^3	3.2.1	2.3
	Waste Concentration (conc. of constituent in Waste)	C_W	mg/kg	3.2.2	2.3
	Leachate Concentration (conc. of constituent in leachate)	C_L	mg/L	3.2.3	2.1
All Constituents	Molecular Diffusion Coefficient	D_i	m^2/yr	3.3.1.1	3.15
	Drinking Water Standard	DWS	mg/L	3.3.1.2	
	Molecular Weight	MW	g/mol	3.3.1.3	4.37
Organic Constituents	Organic Carbon Partition Coefficient	k_{oc}	cm^3/g	3.3.2.1	2.29
	Dissolved Phase Hydrolysis Decay Rate	λ_1	1/yr	3.3.2.2.1	3.13
	Sorbed Phase Hydrolysis Decay Rate	λ_2	1/yr	3.3.2.2.2	3.13
	Acid-Catalyzed Hydrolysis Rate Constant	K_a^{Tr}	1/(mol.yr)	3.3.2.2.3	
	Neutral Hydrolysis Rate Constant	K_n^{Tr}	1/yr	3.3.2.2.4	
	Base-Catalyzed Hydrolysis Rate Constant	K_b^{Tr}	1/(mol.yr)	3.3.2.2.5	
	Hydrolysis Reference Temperature	T_r	°C	3.3.2.2.6	
Transformation Products	Degradation Species Number	ℓ	unitless	3.3.2.3.1	4.31
	Number of Immediate Parents	M_ℓ	unitless	3.3.2.3.2	4.31
	Species Number of Immediate Parent	m_ℓ	unitless	3.3.2.3.3	4.31
	Speciation Factor	ξ_{lm}	unitless	3.3.2.3.4	4.31

Table 3.1 Waste and Constituent Parameters (continued)

Parameter Type	Parameter	Symbol	Units	Section	Equation in EPACMTP TBD
Metal Constituents	Metal Identification Number	ID	unitless	3.3.3.2.1	Section G.4.1.2 (Appendix G)
	Soil and Aquifer pH	pH	standard units	3.3.3.2.2	Section G.4.1.2 (Appendix G)
	Iron Hydroxide Content	FeOx	wt % Fe	3.3.3.2.3	Section G.4.1.2 (Appendix G)
	Leachate Organic Acid Concentration	LOM	mol/L	3.3.3.2.4	Section G.4.1.2 (Appendix G)
	Percent Organic Matter	*%OM*	unitless	3.3.3.2.5	Section G.4.1.2 (Appendix G)
	Fraction Organic Carbon	f_{oc}	unitless	3.3.3.2.6	Section G.4.1.2 (Appendix G)
	Ground-water Type (carbonate/ non-carbonate)	IGWT	unitless	3.3.3.2.7	Section G.4.1.2 (Appendix G)

3.2 WASTE CHARACTERISTICS

3.2.1 Waste Density (ρ_{hw})

Definition

The waste density is defined as the average wet bulk density of the waste, i.e., mass of waste per unit volume (kg/L or g/cm^3) containing the constituent(s) of concern and should be measured on the waste as disposed, as opposed to a dry bulk density. This parameter is only used when modeling landfills.

Parameter Value or Distribution of Values

Information on the density of hazardous waste was developed using the densities of 4 major categories of waste (solvents, paints, petroleum products, pesticides) and their contributions to the composition of hazardous wastes in Subtitle D landfills (Schanz and Salhotra, 1992). The results are expressed as an empirical distribution of waste densities, given in Table 3.2. The default distribution shows a relatively narrow range of variation, from 0.7 to 2.1 g/cm^3.

For waste-specific applications of EPACMTP, it is recommended to use appropriate waste-specific data, rather than the default distribution.

Table 3.2 Default Cumulative probability distribution of waste density

Waste Density (g/cm^3)	Cumulative Probability
0.7	0
0.9	0.530
1.12	0.550
1.13	0.551
1.28	0.553
1.30	0.640
1.33	0.728
1.34	0.815
1.36	0.826
1.46	0.904
1.50	0.905
1.62	0.906
1.63	0.994
1.64	0.995
1.65	0.996
2.10	0.998

Data Sources

The default data presented in Table 3.2 were developed by Schanz and Salhotra (1992).

Use In EPACMTP

When modeling a landfill, the EPACMTP model uses the waste density to convert between waste volume and mass; the total mass of the waste in the landfill is then used in conjunction with the waste concentration to derive the contaminant mass available to be leached to the subsurface.

3.2.2 Concentration of Constituent in the Waste (C_w)

Definition

The waste concentration (mg/kg) represents the total fraction of constituent in the waste which may eventually leach out. Strictly speaking, C_w is the total leachable waste concentration. However, from a practical perspective, C_w may be interpreted to represent the total waste concentration and measured accordingly. This approach will be protective because the measured total waste concentration should always be at least as high as the more difficult to quantify "leachable" waste concentration.

The waste concentration used by EPACMTP reflects the average concentration of the constituent(s) of concern in the waste in the WMU at the time of closure. Contaminant losses that may occur during the WMU's active life are not explicitly modeled in EPACMTP. If such losses are significant, it may be appropriate to adjust the waste concentration accordingly (see Section 3.2.4) to represent the remaining constituent concentration available for leaching. However, ignoring these other loss pathways will be protective for the ground-water pathway analysis.

Parameter Value or Distribution of Values

The waste concentration is waste- and constituent-specific. There is no default value or distribution for this parameter.

Data Sources

There is no default value or distribution for this parameter. Waste-specific data should be obtained from appropriate chemical analytical tests on the waste of interest.

Use In EPACMTP

EPACMTP uses the waste concentration to calculate the contaminant mass within the landfill; the contaminant mass is an important input for determining the landfill leaching duration (see Section 2.2.1.3.3 of the *EPACMTP Technical Background Document*; U.S. EPA, 2003a).

3.2.3 Concentration of Constituent in the Leachate (C_L)

Definition

The leachate concentration (mg/L) is the mass of the dissolved constituent per unit volume of water emanating from the base of the WMU. This parameter provides the boundary condition for the EPACMTP simulation of constituent fate and transport through the unsaturated and saturated zone. For a continuous or pulse source, this concentration is constant until leaching stops. For the landfill depleting source option, the initial leaching concentration value must be provided by the user as an EPACMTP input parameter; the model then automatically adjusts the value as the waste is depleted during the simulation.

Parameter Value or Distribution of Values

The leachate concentration is waste- and constituent-specific. There is no default value or distribution for this parameter.

EPACMTP can accommodate a measured value or distribution of values, as determined from an appropriate leaching test procedure such as the Toxicity

Characteristic Leaching Procedure (TCLP) or the Synthetic Precipitation Leaching Procedure.[1]

If EPACMTP is used to back-calculate a loading or leaching risk-based or regulatory limit for organic constituents (that is, the DAF is the only required model output), then the leachate concentration value that is used as an EPACMTP input is not material and an arbitrary value, such as 1 x 10^6 mg/L, can be used. However, if a forward risk analysis is being performed for an organic constituent (when the magnitude of the receptor well concentration is being determined to calculate risk), then actual analytical concentration(s) is/are used as input to the EPACMTP model.

On the other hand, if the constituent of interest is a metal or inorganic with a nonlinear sorption isotherm, then the actual value of the leachate concentration is material to the analysis, no matter if the goal is to calculate risk based on the resulting receptor well concentration (a forward risk calculation) or to determine a threshold waste or leachate concentration based on a defined risk level (a backward risk calculation). The reason for this is that the nonlinear isotherms which can be used to model the adsorption of metals mean that there is a nonlinear relationship between the input leachate concentration and the resulting receptor well concentration. That is, for metals, we can’t calculate a DAF that is constant across all leachate concentrations. So, even when the goal of the analysis is to determine an allowable threshold concentration for a metal constituent (a backward risk calculation), the leachate concentration is an important model input. Such an analysis will typically require repeated simulations, each with a different leachate concentration, until the leachate concentration is identified that results in the receptor well concentration being equal to a given regulatory or risk-based benchmark concentration. Additionally, when we perform an EPACMTP analysis for use in a forward risk calculation for metal constituents, actual analytical concentrations are typically used as input to the EPACMTP model to determine the resulting risk.

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[1] Remember that the DAF is calculated by dividing the input leachate concentration by the resulting receptor well concentration. Since the ground-water transport for organic constituents is linear, if all other model inputs are held constant and the input leachate concentration is doubled, the receptor well concentration will be doubled – but the DAF will remain the same. For this reason, if EPACMTP is being used to back-calculate a threshold waste or leachate concentration, the input leachate concentration for an organic constituent is arbitrary. The value of 1 x 10^6 mg/L is commonly used for this arbitrary concentration simply because its large value makes insignificant any errors due to numerical oscillations in the transport solution.

Data Sources

The waste concentration is waste- and constituent-specific. There is no default value or distribution for this parameter.

Use In EPACMTP

The EPACMTP fate and transport model requires stipulation of the leachate concentration as a function of time, $C_L(t)$. The leachate concentration $C_L(t)$ used in the model directly represents the concentration of the leachate emanating from the base of the waste management unit, as a boundary condition for the numerical fate and transport model. EPACMTP accounts for time variation as either a constant concentration pulse condition, or as an exponentially decreasing leachate concentration (depleting source).

In the finite source option, the simplest and generally most conservative case is to assume that the leachate concentration remains constant until all of the initially present contaminant mass has leached out of the disposal unit. This case is referred to as the pulse (or non-depleting) source scenario. The boundary condition for the fate and transport model then becomes a constant concentration pulse, with defined duration.

A more realistic modeling analysis in the case of a closed landfill with no continued waste addition to the unit, can be conducted by assuming that linear equilibrium partitioning between the solid and liquid phase of the waste leads to an exponential decrease in the leachate concentration over time as a result of depletion of the source. When using this depleting source option, the user specifies the initial leaching concentration, and the model automatically adjusts this rate over time (except for organics with nonlinear isotherms) as explained in Section 2.2.1.3.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

3.3 CONSTITUENT PHYSICAL AND CHEMICAL CHARACTERISTICS

3.3.1 All Constituents

The molecular diffusion coefficient and the molecular weight are constituent-specific inputs required by the model for all types of constituents and modeling analyses. In addition, if a finite source analysis is performed, then a value is required for the applicable drinking water standard for each constituent.

EPACMTP also accounts for constituent-specific transformation and sorption processes. These are discussed in Sections 3.3.2 and 3.3.3 for organic and metal constituents, respectively.

3.3.1.1 Molecular Diffusion Coefficient (D_i)

Definition

Diffusion is defined as the movement of constituent molecules in an environmental medium from areas of high constituent concentrations toward areas with lower constituent concentrations. This process occurs as a result of concentration gradients. Diffusion can occur both in the absence or presence of advective flow. In ground-water flow systems, the process of diffusion is quantified using the diffusion coefficient of the constituent and the concentration gradient of the constituent in ground water.

The coefficient of molecular diffusion is often negligible compared to the dispersivity term in the calculation of the dispersion coefficient and is commonly ignored. However, diffusion can be significant in cases where ground-water velocity is very low.

Parameter Value or Distribution of Values

The molecular diffusion coefficient is a constituent-specific input parameter and should be calculated by the user based on the molecular diffusion coefficient in free water. Molecular diffusion coefficient values for some common organic constituents are included in Appendix C. If data are not available for the modeled constituent, this parameter should be set to zero.

Data Sources

The molecular diffusion coefficient values listed in Appendix C were generated using the Water 9 model (U.S. EPA, 2001b).

Use In EPACMTP

Hydrodynamic dispersion and molecular diffusion are used to calculate the dispersion coefficient, one of the variables in the transport equation (see Section 4.4 of the *EPACMTP Technical Background Document*, U.S. EPA, 2000a).

3.3.1.2 Drinking Water Standard (DWS)

Definition

The drinking water standard (mg/L) is the level assumed to be protective. It may be a Maximum Contaminant Level (MCL) or a health-based number (HBN) (See Section 5.0 of the *IWEM Technical Background Document*, U.S. EPA, 2003c)

. ***Parameter Value or Distribution of Values***

The drinking water standard is a constituent-specific input parameter; the appropriate value must be determined by the user. The default value for this parameter is zero. The drinking water standard must be expressed in the same units used for the leachate concentration, usually mg/L. Although a distribution of values could be used for this input parameter, it is typically specified as a constant value.

Data Sources

Current values for MCLs can be obtained from the EPA's Office of Ground Water and Drinking Water (http://www.epa.gov). See Section 5 of the *IWEM Technical Background Document,* U.S. EPA, 2003c for a discussion of sources for HBN values.

Use In EPACMTP

The drinking water standard is used in finite source scenarios when the depleting landfill source option is invoked to determine the duration of the exponentially decaying concentration boundary condition (t_p). Leaching is assumed to continue until the constituent concentration in the leachate has dropped below the drinking water standard. The leaching duration, t_p, is determined by setting Equation 2.12 in the EPACMTP Technical Background Document (U.S. EPA, 2003a) equal to the DWS and solving for t (time).

3.3.1.3 Molecular Weight (MW)

Definition

The molecular weight (g/mol) is defined as the amount of mass in one mole of molecules of a constituent as determined by summing the atomic weights of the elements in that constituent, multiplied by their stochiometric factors.

Parameter Value or Distribution of Values

The molecular weight is a constituent-specific input parameter; the appropriate value must be provided by the user. There is no default value.

Data Sources

Compilations of chemical data such as molecular weight are available on many web sites and in most chemistry reference books.

Use In EPACMTP

The use of this parameter is reserved for future versions of EPACMTP to automatically calculate the parent to degradation product yield or decay coefficients for chain decay simulations.

3.3.2 Organic Constituents

This section describes the parameters used in EPACMTP for organic constituents. The parameters to be discussed are the organic carbon partition coefficient, sorbed and dissolved phase hydrolysis decay rate, acid, neutral, and base-catalyzed hydrolysis rate constants, and the reference temperature.

For organic constituents, EPACMTP takes into account adsorption behavior of organic constituents by calculating a retardation factor based on the organic carbon distribution coefficient (k_{oc}) of each constituent and fractional organic carbon in the soil (f_{oc}) (See Section 3.2.1).

In order to model the subsurface fate and transport of organic constituents, EPACMTP generates a single first-order degradation rate, which includes both biodegradation and chemical hydrolysis (in both sorbed and dissolved phases). The biodegradation rate is typically set to zero (due to the difficulty in accurately estimating it), but a non-zero value can be specified by the user. The user can directly specify the hydrolysis rates, or they can be internally calculated by the model (see Section 3.3.2.2). If calculated, EPACMTP requires that the hydrolysis rate constants and the reference temperature at which they were measured be specified . EPACMTP then uses these rate constants along with the ground-water temperature and pH to derive the sorbed-phase and dissolved-phase hydrolysis rates. These two hydrolysis rates and the biodegradation rate (if non-zero) are then combined into the overall first-order degradation rate. If the products of this degradation are themselves toxic, they can be included in the modeling analysis by specifying them to be part of a decay chain, with the current organic constituent as the parent chemical.

If desired, the user can override the default of no biodegradation, by providing appropriate values of the biodegradation rate coefficient for the unsaturated and saturated zone (see Section 5 of this document).

3.3.2.1 Organic Carbon Partition Coefficient (k_{oc})

Definition

The organic carbon partition coefficient (cm^3/g) is the ratio of a constituent's concentration in a theoretical soil containing only organic carbon to its concentration in the ground water. Thus, k_{oc} describes the affinity of a constituent to attach itself to organic carbon. This parameter is applicable to organic constituents which tend to sorb onto the organic matter in soil or in an aquifer. Constituents with high k_{oc} values tend to move more slowly through the soil and ground water. Volatile organics tend to have low k_{oc} values, whereas semi-volatile organics often have high k_{oc} values.

Parameter Value or Distribution of Values

The organic carbon partition coefficient is a constituent-specific input parameter; values for some common organic constituents are included in Appendix C. Although commonly specified as a constant value, this parameter can also be specified as a distribution of values. If constituent-specific data for the organic to be modeled are not available, this input value can be set to zero – a value that means the constituent's ground-water concentration will not be decreased due to adsorption.

Data Sources

Organic carbon partition coefficient (k_{oc}) values can be obtained from many constituent property handbooks, as well as online databases, (e.g., Kollig, Ellington, Karickhoff, Kitchens, Long, Weber and Wolfe, 1993 or *Handbook of Environmental Data on Organic Constituents,* Verschueren, 1983). Sometimes, these references provide an *octanol-water partition coefficient* (k_{ow}), rather than a k_{oc} value. These two coefficients are roughly equivalent parameters. A number of conversion formulas exist to convert k_{ow} values into k_{oc}; these can be found in handbooks on environmental fate data (*e.g.*, Verschueren, 1983; Kollig et. al., 1993). This conversion factor accounts for the mass difference, expressed as a percentage, between pure organic carbon and natural organic matter which also includes elements in addition to carbon (Enfield, Carsel, Cohen, Phan and Walters, 1982). Different conversion formulas exist for different constituents and environmental media, and there is no single formula that is valid for all organic constituents; therefore, the conversion formula should be chosen and used with some caution.

Use In EPACMTP

For organic constituents, the effect of equilibrium sorption is expressed in EPACMTP through the retardation coefficient, R, which is a function of the chemical-specific organic carbon partition coefficient, k_{oc}:

$$R = 1 + \frac{\rho_b k_d}{\theta} \tag{3.1}$$

where

$$k_d = f_{oc} \cdot k_{oc} \tag{3.2}$$

where

R = retardation coefficient for species i (dimensionless)
ρ_b = soil bulk density for the unsaturated zone (g/cm^3)
θ = soil water content (dimensionless)
k_d = soil-water partition coefficient (L/kg)
f_{oc} = fractional organic carbon content in the soil or aquifer (unitless)
k_{oc} = organic carbon partition coefficient (cm^3/g)

The fractional organic carbon can be estimated from the percentage organic matter (%OM) in the soil or aquifer, as

$$f_{oc} = \frac{\%OM}{174} \tag{3.3}$$

where

$\%OM$ = percent organic matter in the soil (unitless)
174 = conversion factor

3.3.2.2 Parameters Related to Chemical Hydrolysis

The transport of organic constituents can be influenced in part by chemical hydrolysis, a process that is represented in the EPACMTP model by means of an overall first-order chemical decay coefficient. This overall decay coefficient includes both dissolved phase and sorbed phase decay. Dissolved phase and sorbed phase decay rates can be specified directly, or they can be derived based on chemical-specific hydrolysis rate constants and the ground-water temperature and pH. In the latter case, the hydrolysis rate constants for each constituent can be obtained from reference documents compiled by EPA's Environmental Research Laboratory in Athens, GA (U.S. EPA, 1993 and Kollig et al., 1993).

The hydrolysis process as modeled in EPACMTP is affected by aquifer pH, aquifer temperature, and constituent sorption:

The overall first-order transformation rate for hydrolysis is calculated as:

$$\lambda = \frac{\lambda_1 \phi + \lambda_2 \rho_b k_d}{\phi + \rho_b k_d} \tag{3.4}$$

where:

λ = Overall first-order hydrolysis transformation rate (1/yr)
λ_1 = Dissolved phase hydrolysis transformation rate (1/yr); see Section 3.3.2.2.1
λ_2 = Sorbed phase hydrolysis transformation rate (1/yr); see Section 3.3.2.2.2
ϕ = Porosity (water content in the unsaturated zone) (dimensionless)
ρ_b = Bulk density (kg/L)
k_d = Partition coefficient (L/kg)

The calculation of the sorbed phase and dissolved phase hydrolysis rates from the hydrolysis rate constants is described in the following sections.

3.3.2.2.1 Dissolved Phase Hydrolysis Decay Rate (λ_1)

Definition

Hydrolysis is defined as the decomposition of organic constituents by interaction with water. The dissolved phase hydrolysis decay rate (1/yr) is the rate at which the dissolved portion of the contaminant mass is hydrolyzed.

Parameter Value or Distribution of Values

The dissolved phase hydrolysis decay rate can be directly input by the user (as either a constant value or distribution of values) or it can be set to be internally derived by the model. In the latter case, it is calculated as follows:

$$\lambda_1 = K_a^T [H^+] + K_n^T + K_b^T [OH^-] \tag{3.5}$$

where

λ_1 = First-order decay rate for dissolved phase (1/yr)
K_a^T, K_n^T, K_b^T = Hydrolysis rate constants; calculated as described in Sections 3.3.2.2.3, 3.3.2.2.4, and 3.3.2.2.5
$[H^+]$ = Hydrogen ion concentration (mole/L)
$[OH^-]$ = Hydroxyl ion concentration (mole/L)

$[H^+]$ and $[OH^-]$ are computed from the pH of the soil or aquifer using

$$[H^+]=10^{-pH}$$

$$[OH^-]=10^{-(14-pH)}$$

Data Sources

In the absence of site-specific data, this parameter typically is set to be derived by the model based on the constituent-specific hydrolysis rate constants (see Sections 3.3.2.2.3 through 3.3.2.2.6).

Use In EPACMTP

The dissolved phase hydrolysis rate is used to calculate the overall first-order transformation rate for hydrolysis as presented in Equation 3.4.

3.3.2.2.2 Sorbed Phase Hydrolysis Decay Rate (λ_2)

Definition

Hydrolysis is defined as the decomposition of organic constituents by interaction with water. The sorbed phase hydrolysis decay rate (1/yr) is the rate at which the sorbed portion of the contaminant mass is hydrolyzed.

Parameter Value or Distribution of Values

The sorbed phase hydrolysis decay rate can be directly input by the user (as either a constant value or distribution of values) or it can be set to be internally derived by the model. If it is specified in the input file as derived by EPACMTP, the effective sorbed phase decay rate is calculated as:

$$\lambda_2 = 10K_a^T[H^+] + K_n^T \tag{3.6}$$

where:

λ_2 = First-order hydrolysis rate for sorbed phase (1/yr)
K_a^T = Acid-catalyzed hydrolysis rate constant (1/mole/yr); see Section 3.3.2.2.3
K_n^T = Neutral hydrolysis rate constant (1/yr); see Section 3.3.2.2.4
10 = Acid-catalyzed hydrolysis enhancement factor
$[H^+]$ = Hydrogen ion concentration (computed from the pH of the soil or aquifer using $[H^+] = 10^{-pH}$)

Data Sources

In the absence of site-specific data, this parameter typically is set to be derived by the model based on the constituent-specific hydrolysis rate constants (see Sections 3.3.2.2.3 through 3.3.2.2.6).

Use In EPACMTP

The sorbed phase hydrolysis rate is used to calculate the overall first-order transformation rate for hydrolysis as presented in Equation 3.4.

3.3.2.2.3 Acid-Catalyzed Hydrolysis Rate Constant (K_a^{Tr})

Definition

The tendency of a constituent to hydrolyze is expressed through several constituent-specific rate constants. The acid-catalyzed rate constant (1/mol-yr) is one of the values that is used to quantify how the rate of the hydrolysis reaction is affected by the pH (specifically at the acidic end of pH) of the subsurface. The superscript T_r indicates that the value is measured at a specified reference temperature.

Parameter Value or Distribution of Values

The acid-catalyzed rate constant is a constituent-specific input parameter; values for some common organic constituents are included in Appendix C. Although commonly specified as a constant value, this parameter can also be specified as a distribution of values. If constituent-specific data for the organic to be modeled are not available, this input value can be set to zero – a conservative value that means the constituent's ground-water concentration will not be decreased due to chemical hydrolysis at the acidic end of the scale. However, if the modeled constituent hydrolyzes to form one or more toxic degradation products, then setting this input to zero and not modeling the formation of the toxic degradation product could result in an underestimation of the risk of exposure via the ground-water pathway.

Data Sources

(K_a^{Tr}) values can be obtained from some constituent property handbooks (e.g., Kollig et al, 1993 or *Handbook of Environmental Data on Organic Constituents,* Verschueren, 1983).

Use In EPACMTP

The acid-catalyzed hydrolysis rate constant is influenced by ground-water temperature, while acid- and base catalyzed rate constants are also influenced by pH. As shown below, the Arrhenius equation is used to convert the input hydrolysis rate constants, measured at a specified reference temperature (T_r), to the actual temperature of the subsurface:

$$K_J^T = K_J^{T_r} \exp \left[E_a/R_g\left(\frac{1}{T_r + 273} - \frac{1}{T + 273}\right)\right] \tag{3.7}$$

K_J^T = Hydrolysis rate constant for reaction process J, corrected for the subsurface temperature T_r (1/mol-yr for the acid- and base-catalyzed reactions; 1/yr for the neutral reaction)
K_J^{Tr} = Hydrolysis rate constant for reaction process J, measured at reference temperature T (1/mol-yr for the acid- and base-catalyzed reactions; 1/yr for the neutral reaction)
J = *a* for the acid-catalyzed reaction, *b* for base-catalyzed reaction, and *n* for the neutral reaction
T = Temperature of the subsurface (°C)
T_r = Reference temperature (°C)
R_g = Universal gas constant (1.987E-3 Kcal/deg-mole)
E_a = Arrhenius activation energy (Kcal/mole)

Note that, using the generic activation energy of 20 Kcal/mole recommended by Wolfe (1985), the factor E_a/R_g has a numerical value of 10,000.

The temperature-corrected rate constants are then used in Equations 3.5 and 3.6 to calculate the sorbed phase and dissolved phase hydrolysis rate constants from which the overall hydrolysis transformation rate is calculated. The overall first-order transformation rate is one of the parameters required to solve the advection-dispersion equation (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)).

3.3.2.2.4 Neutral Hydrolysis Rate Constant (K_n^{Tr})

Definition

The tendency of a constituent to hydrolyze is expressed through several constituent-specific rate constants. The neutral rate constant (1/yr) is used to quantify how the rate of the hydrolysis reaction is unaffected by the pH of the subsurface. The superscript T_r indicates that the value is measured at a specified reference temperature.

Parameter Value or Distribution of Values

The neutral rate constant is a constituent-specific input parameter; values for some common organic constituents are included in Appendix C. Although commonly specified as a constant value, this parameter can also be specified as a distribution of values. If constituent-specific data for the organic to be modeled are not available, this input value can be set to zero – a conservative value that means the constituent's ground-water concentration (under pH neutral conditions) will not be decreased due to chemical hydrolysis. However, if the modeled constituent hydrolyzes to form one or more toxic degradation products, then setting this input to zero and not modeling the formation of the toxic degradation product could result in an underestimation of the risk of exposure via the ground-water pathway.

Data Sources

K_n^{Tr} values can be obtained from some constituent property handbooks (e.g., Kollig et al, 1993 or *Handbook of Environmental Data on Organic Constituents,* Verschueren, 1983).

Use In EPACMTP

As shown in Equation 3.7, the Arrhenius equation is to used convert the input hydrolysis rate constants, measured at a specified reference temperature (T_r), to the actual temperature of the subsurface. The temperature-corrected rate constants are then used in Equations 3.5 and 3.6 to calculate the sorbed phase and dissolved phase hydrolysis rate constants from which the overall hydrolysis transformation rate is calculated. The overall first-order transformation rate is one of the parameters required to solve the advection- dispersion equation (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)).

3.3.2.2.5 *Base-Catalyzed Hydrolysis Rate Constant* (K_b^{Tr})

Definition

The tendency of each constituent to hydrolyze is expressed through several constituent-specific rate constants. The base-catalyzed rate constant (1/mol-yr) is one of the values that is used to quantify how the rate of the hydrolysis reaction is affected by the pH of the subsurface, in this case under more alkaline conditions. The superscript T_r indicates that the value is measured at a specified reference temperature.

Parameter Value or Distribution of Values

The base-catalyzed rate constant is a constituent-specific input parameter; values for some common organic constituents are included in Appendix C. Although commonly specified as a constant value, this parameter can also be specified as a distribution of values. If constituent-specific data for the organic to be modeled are not available, this input value can be set to zero – a conservative value that means the constituent's ground-water concentration will not be decreased due to chemical hydrolysis at the alkaline end of the scale. However, if the modeled constituent hydrolyzes to form one or more toxic degradation products, then setting this input to zero and not modeling the formation of the toxic degradation product could result in an underestimation of the risk of exposure via the ground-water pathway.

Data Sources

The K_b^{Tr} values can be obtained from some constituent property handbooks (e.g., Kollig et al, 1993 or *Handbook of Environmental Data on Organic Constituents,* Verschueren, 1983).

Use In EPACMTP

As shown in Equation 3.7, the Arrhenius equation is used to convert the input hydrolysis rate constants, measured at a specified reference temperature (T_r), to the actual temperature of the subsurface. The temperature-corrected rate constants are then used in Equations 3.5 and 3.6 to calculate the sorbed phase and dissolved phase hydrolysis rate constants from which the overall hydrolysis transformation rate is calculated. The overall first-order transformation rate is one of the parameters required to solve the advection-dispersion equation (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)).

3.3.2.2.6 *Reference Temperature (T_r)*

Definition

The reference temperature (°C) is the temperature at which the input hydrolysis rate constants were measured.

Parameter Value or Distribution of Values

The chemical-specific hydrolysis rate constants are measured at a constant reference temperature; the default value is 25 degrees Celsius.

Data Sources

Hydrolysis rate constants can be obtained from some constituent property handbooks (e.g., Kollig et al, 1993 or *Handbook of Environmental Data on Organic Constituents,* Verschueren, 1983). The data source used for the hydrolysis rate constants should also state the temperature at which the values were measured.

Use In EPACMTP

As shown in Equation 3.7, the reference temperature is used in the Arrhenius equation to convert the input hydrolysis rate constants to the actual temperature of the subsurface. The temperature-corrected rate constants are then used in Equations 3.5 and 3.6 to calculate the sorbed phase and dissolved phase hydrolysis rate constants from which the overall hydrolysis transformation rate is calculated. The overall first-order transformation rate is one of the parameters required to solve the advection-dispersion equation (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)).

3.3.2.3 Parameters Related to Hydrolysis Transformation Products

In the event that the products of this chemical degradation process are toxic and their constituent-specific parameters are known, they can be included in the simulation by specifying them to be part of a transformation (or decay) chain. Note that when a multi-species simulation such as this is performed, the necessary chemical-specific parameters must be repeated for each species in the decay chain. In addition, the following parameters are required for each degradation species in a decay chain analysis: degradation product species number, number of immediate parents for each degradation product species, species number(s) of immediate parent(s), and fraction of the parent species that decays into the given degradation product species.

3.3.2.3.1 Degradation Product Species Number (ℓ)

Definition

The degradation product species number is an index number that uniquely identifies a constituent and its properties in EPACMTP.

Parameter Value or Distribution of Values

Degradation product species numbers begin with the number 2 (the parent species number is 1). Up to 6 degradation products per parent are permitted in EPACMTP (numbered 2-7).

Data Sources

The degradation product species number is a construction of convenience for EPACMTP, and as such, there are no data sources. The value of the parameter is governed by the number of degradation products in a particular transformation chain.

Use In EPACMTP

The degradation product species number allows EPACMTP to track and associate degradation products with its properties and relationships to its immediate parent and daughters.

3.3.2.3.2 Number of Immediate Parents (M_ℓ)

Definition

The number of immediate parents (M_ℓ) is defined as the total number of individual species which degrade directly into degradation product species ℓ. This parameter is used in EPACMTP together with the species number of the immediate parent (see next section) to represent the structure of the chain decay reaction. The value of this parameter is zero for the parent species and one for each degradation product species. The maximum value of M_ℓ is one because the EPACMTP model can handle simulation of only one constituent that has a non-zero initial leachate concentration (that is, one original parent species per decay chain). For example, if constituent A degrades into constituent B, and B degrades to C, then degradation product B has one immediate parent (A) and degradation product C also has one immediate parent (B).

Parameter Value or Distribution of Values

The number of immediate parent species is governed by the specific transformation chain to be simulated using EPACMTP.

Data Sources

The number of immediate parent species is governed by the decay chain reaction being simulated. Reaction chemistry or constituent property handbooks (e.g., Kollig et al, 1993, or Handbook of Environmental Data on Organic Constituents, Verschueren, 1983) may contain chain decay structures for organic constituents.

Use In EPACMTP

The number of immediate parent species of a degradation product species allows EPACMTP to track its relationships to its immediate parent.

3.3.2.3.3 Species Number(s) of Immediate Parent(s) ($m_\ell(i), i = 1, M_\ell$)

Definition

The species number $m_\ell(i)$ of the immediate parent is the ordinal number (see Section 3.3.2.3.1) of the toxic degradation product that directly degrades into the degradation product of concern. For example, consider again the straight decay chain where constituent A degrades into constituent B which degrades into constituent C shown in the example below:

Parameter	Definition	Value for Constituent A	Value for Constituent B	Value for Constituent C
ℓ	species number	1	2	3
M_ℓ	number (quantity) of immediate parents	0	1	1
$m_\ell(i)$	species number of immediate parent	0	1	2

Parameter Value or Distribution of Values

The species number of immediate parent species is governed by the specific decay chain to be simulated using EPACMTP and by the numbering system chosen by the user.

Data Sources

The numbering of immediate parent species is governed by the decay chain reaction being simulated and the user's discretion. Reaction chemistry or constituent property handbooks (e.g., Kollig et al, 1993, or *Handbook of Environmental Data on Organic Constituents*, Verschueren, 1983) may contain chain decay structures for organic constituents.

Use In EPACMTP

The association of an immediate parent to a degradation product species number allows EPACMTP to track and associate a degradation product with its properties and relationships to its immediate parent and degradation products.

3.3.2.3.4 Fraction of the Parent Species ($\xi_{\ell m}$)

Definition

The coefficient $\xi_{\ell m}$ is called the fraction of the parent species which expresses how many units of species ℓ are produced in the decay of each unit of parent m. The value of the speciation factor is thus determined by the reaction stoichiometry, as well as the units used to express concentration. For instance, consider the following hydrolysis reaction in which 2 units of degradation product B and 1 unit of degradation product C are formed from the hydrolysis of 3 units of parent A:

$$3A + 2H_2O \rightarrow 2B\,(OH)^- + 2H^+ + C$$

where

A = parent compound A
H_2O = water molecule
B = degradation product compound B
C = degradation product compound C
(OH)- = hydroxide ion
H+ = hydrogen ion

In this example, ξ_{BA} is equal to $\frac{2}{3}\frac{MW_B}{MW_A}$ and ξ_{CA} is equal to $\frac{1}{3}\frac{MW_C}{MW_A}$

where

MW_ℓ = the molecular weight of species ℓ (g/mol)
ξ_{BA} = speciation factor between parent A and degradation product B
ξ_{CA} = speciation factor between parent A and degradation product C

Parameter Value or Distribution of Values

The value of this parameter is determined by the species and reaction stoichiometry and is constant for the entire simulation.

Data Sources

The fraction of parent species is governed by the stoichiometry of the decay chain reaction being simulated and individual constituent properties. Reaction chemistry or constituent property handbooks (e.g., Kollig et al, 1993, or *Handbook of Environmental Data on Organic Constituents*, Verschueren, 1983) may contain chain decay structures for organic constituents.

Use In EPACMTP

EPACMTP uses the fraction of parent species to determine how much of a parent species decays to form an immediate daughter. Similarly, the same factor is used to determine how much degradation product species is produced from its immediate parent. These relationships are applied in both the unsaturated and saturated fate and transports simulations (see Equations 3.14 and 4.31, respectively in the *EPACMTP Technical Background Document*, (U.S. EPA, 2003a)).

3.3.3 Metals

In the subsurface, metal constituents may undergo reactions with ligands in the pore water and with surface sites on the solid aquifer or soil matrix material. Reactions in which the metal is bound to the solid matrix are referred to as sorption reactions and metal that is bound to the solid is said to be sorbed. The ratio of the concentration of metal sorbed to the concentration in the mobile aqueous phase at equilibrium is referred to as the partition coefficient (K_d). During contaminant transport, sorption to the solid matrix results in retardation of the contaminant front. Thus, transport models such as EPACMTP incorporate the contaminant partition coefficient into the overall retardation factor (the ratio of the average linear particle velocity to the velocity of that portion of the plume where the contaminant is at 50 percent dilution). The use of K_d in EPACMTP transport modeling implies the assumption that local equilibrium between the solutes and the sorbents is attained, meaning that the rate of sorption reactions is fast relative to advective-dispersive transport of the contaminant.

Users can specify a constant value or distribution of values for the K_d (a linear isotherm); alternatively, tables of non-linear sorption isotherms (for a suite of 21 metals, some with varying oxidation states) or equations comprising pH-based (linear) isotherms are available within EPACMTP. Both the non-linear isotherms and the pH-based isotherms were developed especially for use with the EPACMTP model.

The pH-dependent isotherms were developed for 12 metals using the empirical relationships as described in Loux, Chafin and Hassan (1990). These isotherms were originally developed as an alternative to the MINTEQA2-derived isotherms (U.S. EPA, 1996 and 1999) because, at that time, there were limitations in the database of adsorption reactions that made the MINTEQA2 modeling less accurate for metals that form anions or neutral species in aqueous solution. However, ensuing improvements in the MINTEQA2 database of adsorption reactions and modeling methodology have resulted in a new set of non-linear isotherms which supercede the pH-based isotherms. However, the option to use these pH-based isotherms is still available in the EPACMTP model, and so they are described in this document.

The non-linear isotherms were estimated using the geochemical speciation model, MINTEQA2, and are tabulated into auxiliary input files for use by the EPACMTP model. These isotherms reflect the tendency of K_d to decrease as the total metal concentration in the system increases. The non-linear isotherms available for use in EPACMTP are specified in terms of the dissolved metal concentration and the corresponding sorbed concentration at a series of total metal concentrations.

For a particular metal, K_d values in a soil or aquifer are dependent upon the metal concentration and various geochemical characteristics of the soil or aquifer and the associated pore water. Geochemical parameters that have the greatest influence on the magnitude of K_d include the pH of the system and the nature and concentration of sorbents associated with the soil or aquifer matrix. In the subsurface beneath a disposal facility, the concentration of leachate constituents may also influence K_d. Although the dependence of metal partitioning on the total metal concentration and on pH and other geochemical characteristics is apparent from partitioning studies reported in the scientific literature, K_d values for many metals are not available for the range of metal concentrations or geochemical conditions needed in risk assessment modeling. For this reason, MINTEQA2 was used to estimate partition coefficients. The use of a speciation model allows K_d values to be estimated for a range of total metal concentrations in various model systems designed to depict natural variability in those geochemical characteristics that most influence metal partitioning.

The development of these non-linear (concentration-dependent) metal partition coefficients is described in Appendix B.1. The following sections describe the available options and the input parameters required to perform ground-water fate and transport modeling of metal constituents using the EPACMTP model.

3.3.3.1 Empirical K_d Data

There are two sources of empirical K_d data that can be used to model metals transport using linear isotherms: K_d data compiled from a recent comprehensive literature survey and pH-based isotherms that are based on the empirical laboratory-based data of Loux et al (1990). These two types of empirical K_d data are described in the following sections.

3.3.3.1.1 K_d Data Compiled from a Literature Survey

In the absence of site-specific data, the distribution coefficient for metals can be specified as a statistical or empirical distribution of values. A comprehensive literature review of K_d values was conducted for the EPA's *RCRA Hazardous Waste Listing Determination for Inorganic Chemical Manufacturing Wastes* (U.S. EPA, 2000). For this project, K_d was defined as an empirical distribution of values when sufficient data were available (six or more literature K_d values) or as a log uniform distribution of values when fewer data were found in the scientific literature (five or fewer literature K_d values). This literature review focused on identifying and compiling experimentally derived K_d values for soil and aquifer materials from published literature. Collected values were compiled along with geochemical and measurement parameters most likely to influence K_d. Details of the literature search and data collection strategy are given in Appendix I of the *Risk Assessment for the Listing Determination for Inorganic Chemical Manufacturing Wastes: Background Document* (U.S. EPA, 2000) along with the resulting distributions of K_d values.

If site-specific K_d data are unavailable, the EPACMTP user can specify that one of these default distributions be used for the coefficient of the Freundlich isotherm for the unsaturated and saturated zones. That is, the appropriate distribution, gleaned from (U.S. EPA, 2000), should be entered twice in the EPACMTP input file, once in the unsaturated zone parameter group and again for the aquifer parameter group.

3.3.3.1.2 pH-based Isotherms

pH-dependent isotherms for 15 metal species were determined from empirical relationships as described in Loux et al., 1990. Many of these metals form anions or neutral species in aqueous solution (e.g., $HAsO_3^{2-}$, $H_2AsO_3^-$, and $H_3AsO_3^0$).

The pH-dependent empirical relationships were determined from linear least squares analysis of laboratory measurements from aquifer materials and their corresponding ground water and leachate samples collected from six municipal landfills, as well as other published data. In these experiments, the concentrations of trace metal contaminants in the ground-water/aquifer material samples were augmented with additions (spikes), and the spiked samples were allowed to equilibrate for 48 hours. After equilibration, the trace metal remaining in solution was measured. The difference between the total trace metal in the system (the metal originally in the sample plus the amount added) and the amount remaining in solution at equilibrium was regarded as adsorbed. The distribution coefficient was determined as the ratio of amount of trace metal adsorbed to the amount remaining in solution. The resulting relationships give K_d as a function of pH only; the inherent nonlinear character of metal adsorption as a function of total metal concentration is not represented.

In EPACMTP Monte Carlo analyses for nationwide assessments, a different pH value is generated for each Monte Carlo iteration. Upon the selection of a pH, the corresponding K_d is automatically calculated from the appropriate empirical relationship.

No empirical relation was available for Sb^{III}; so the Sb^{V} relationship can be used for both the +3 and +5 oxidation states. Also, the As^{III} species is adsorbed somewhat less strongly than As^{V}, and Se^{VI} is adsorbed less strongly than Se^{IV}. However, the contrast in adsorption affinity between different oxidation states for these metals is not nearly so marked as the contrast in Cr^{III} and Cr^{VI}. Therefore, the As^{III} and Se^{VI} relationships can be used to represent both oxidation states for these metals. The resulting empirical relationships are presented in Table 3.3.

Table 3.3 Empirical pH-dependent Adsorption Relations (Loux et al., 1990)

Metal Species	K_d (liters kg^{-1})
As^{III}	$10^{(0.0322\ pH\ +\ 1.24)}$
Ba^{II}	$10^{(0.190\ pH\ +\ 0.638)}$
Cd^{II}	$10^{(0.397\ pH\ -\ 0.943)}$
Cr^{VI}	$10^{(-0.117\ pH\ +\ 2.07)}$
Hg^{II}	$10^{(0.122\ pH\ +\ 1.42)}$
Ni^{II}	$10^{(0.332\ pH\ -\ 0.471)}$
Pb^{II}	$10^{(0.0768\ pH\ +\ 1.55)}$
Sb^{V}	$10^{(-0.207\ pH\ +\ 2.996)}$
Se^{VI}	$10^{(-0.296\ pH\ +\ 2.71)}$
Tl	$10^{(0.110\ pH\ +\ 1.102)}$

3.3.3.2 MINTEQA2-Derived Sorption Isotherm Data

In the absence of site-specific data, the distribution coefficient for metals can be automatically drawn from tabulated data comprising a set of non-linear sorption isotherms created especially for use with the EPACMTP model. This option for modeling the fate and transport of selected metals incorporates metal-specific geochemical interactions that control the mobility of metals in the subsurface. This modeling procedure was originally developed at the EPA's National Exposure Research Laboratory, Ecosystems Research Division for the Hazardous Waste Identification Rule (HWIR) and utilizes nationwide distributions of key geochemical parameters that impact metal mobility in the subsurface.

In this methodology, the MINTEQA2 metal speciation code was used to generate nonlinear adsorption isotherms for each metal. That is, a set of isotherms was produced for each metal reflecting the range in geochemical environments expected at waste sites across the nation.

To compute the adsorption distribution coefficient (K_d) values for a particular metal, a value was selected for each of the five master variables and the MINTEQA2 model was executed over a range of total metal concentrations. The result is a nonlinear adsorption isotherm that can be represented by the variation in K_d with total metal concentration (or, with equilibrium dissolved concentration). This procedure was repeated (separately for each metal) for numerous combinations of master variable settings. The final result from MINTEQA2 was nonlinear K_d versus metal concentration curves for combinations of master variable settings spanning the range of reasonable values.

For each metal, the resulting set of isotherms was tabulated into a supplementary input data file for use by the EPACMTP model. In the fate and transport modeling for a particular metal, EPACMTP is executed and the probability distributions for these five variables form the basis for the Monte-Carlo selection of the appropriate adsorption isotherm. A detailed discussion of the MINTEQA2 simulation procedure for generating the metals sorption isotherms is provided in Appendix B.1.

MINTEQA2-derived sorption isotherms have been developed for the following metals: antimony (V), arsenic (III), barium, beryllium, cadmium, chromium (III), chromium (VI), copper (II), mercury (II), nickel, lead, selenium (VI), thallium (I), vanadium, and zinc.

As implemented in EPACMTP, it is assumed that the non-linearity of the isotherms is most important in the unsaturated zone where metals concentrations are relatively high. Although MINTEQA2 isotherms were also generated for the saturated zone, upon reaching the water table and mixing of the leachate with ambient ground water, the metals concentration is considered to be low enough that a linear isotherm (single K_d value not dependent on metal concentration) can always be used. The appropriate saturated zone retardation factor is determined based on the maximum ground-water concentration underneath the source.

Geochemical factors that are known to have direct impact on adsorption in ground-water systems are: (1) ground-water composition, (2) subsurface pH, (3) hydrous ferric oxide adsorbent content of the soil/aquifer in the subsurface, (4) concentration of organic acids in the leachate, and (5) natural soil organic matter content of the soil/aquifer in the subsurface (particulate and dissolved). For a given metal at a given total concentration, the propensity for adsorption changes greatly as these parameters vary. For the MINTEQA2 modeling, two ground-water types were used (carbonate and non-carbonate) and for each ground-water type, the natural variability of the remaining three parameters (since only low concentrations of leachate organic acids are expected in the leachate emanating from industrial waste management units, only the low range was modeled for leachate organic acid content) was divided into three ranges: high, medium, and low. The approximate mid-point of each range was identified, and in the MINTEQA2 modeling, these mid-point values were used to simulate each range of values for pH, hydrous ferric oxide content, and natural organic matter. For the non-carbonate ground-water type, one isotherm (as a function of metal concentration) was developed for each combination of the three possible values for the four master variables. This process was then repeated for the carbonate ground-water type. For each ground-water type, separate isotherms were developed for the unsaturated and saturated zone. For each metal, a set of 648 isotherms was developed.

The following EPACMTP input parameters are required to model metals transport using the MINTEQA2 non-linear isotherms: metal identification number, soil and aquifer pH, hydrous ferric oxide adsorbent content, leachate organic matter concentration, percent organic matter of the soil, fraction organic carbon of the aquifer, and ground-water composition. Each of these inputs, including the data sources and the default EPACMTP input distributions (which correspond to the values used in the MINTEQA2 modeling) for each of the five master variables, are described in the following sections.

3.3.3.2.1 Metal Identification Number (ID)

Definition

The metal identification number is simply an arbitrary number assigned to each metal in order to provide a simple means of specifying which metal is being modeled.

Parameter Value or Distribution of Values

The metal contaminants whose partition coefficients have been estimated using MINTEQA2 include arsenic (As), antimony (Sb), barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), fluoride (F), mercury (Hg), manganese (Mn), molybdenum (Mo), lead (Pb), nickel (Ni), selenium (Se), silver (Ag), thallium (Tl), vanadium (V), and zinc (Zn).

Several of these metals occur naturally in more than one oxidation state. The modeling described here is restricted to the oxidation states that are most likely to occur in waste systems or most likely to be mobile in ground-water waste systems. For arsenic, chromium, and selenium, partition coefficients were estimated for two oxidation states. These were: As(III) and As(V), Cr(III) and Cr(VI), and Se(IV) and Se(VI). For antimony, molybdenum, thallium, and vanadium, only one oxidation state was modeled although multiple oxidation states occur. For all four of these metals, the choice of which state to model was dictated by practical aspects such as availability of sorption reactions and by subjective assessment of the appropriate oxidation state. The oxidation states modeled were Sb(V) (there were no sorption reactions available for Sb(III)), Mo(VI) (molybdate seems the most relevant form from literature reports), thallium (I) (this form is more frequently cited in the literature as having environmental implications), and V(V) (vanadate; sorption reactions were not available for other forms).

The metal identification number for each metal with a set of MINTEQA2-derived non-linear isotherms is presented in Table 3.4. The appropriate identification number should be specified in the EPACMTP input file as a constant value.

Table 3.4 Metals that have MINTEQA2-derived Non-linear Isotherms

Metal Species	Metal ID
Ba	1
Cd	2
Cr (III)	3
Hg	4
Ni	5
Pb	6
Ag	7
Zn	8
Cu	9
V	10
Be	11
Mo	12
As (III)	13
Cr (VI)	14
Se (VI)	15
Tl	16
Sb (V)	17
Co	18
Mn	19
F	20
As (V)	21
Se (IV)	22

Data Sources

These metal identification numbers were arbitrarily created for convenience during modeling; the list of available metals was determined by the availability of toxicity and sorption data and their likely occurrence in industrial waste management scenarios under consideration for Agency rule-making.

Use In EPACMTP

The metal identification number is used by the EPACMTP model to identify which supplemental input file contains the appropriate non-linear isotherm data.

3.3.3.2.2 Soil and Aquifer pH (pH)

Definition

A measure of the acidity or alkalinity of the moisture present in the vadose zone or the ground water. pH is measured on a scale of 0 to 14, with 7 representing a neutral state. Values less than 7 are acidic, and values greater than 7 are basic. pH is calculated as the negative logarithm of the concentration of hydrogen ions in a solution.

For modeling purposes, pH is assumed to be the same in the unsaturated zone and in the saturated zone.

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values, a default distribution of pH values may be used. The data are represented by an empirical distribution with low and high values of 3.2 and 9.7, respectively and a median value of 6.8. The distribution is shown in Figure 3.5.

Table 3.5 Probability distribution of soil and aquifer pH

Cumulative Probability (%)	pH Value
0.0	3.21E+00
1.0	5.40E+00
5.0	6.31E+00
10.0	7.11E+00
25.0	7.59E+00
50.0	7.69E+00
75.0	7.80E+00
90.0	7.90E+00
95.0	8.09E+00
100.0	9.69E+00

Data Sources

The distribution of pH values shown in Table 3.5 was obtained through analysis of nearly 25,000 field measured pH values of uncontaminated ground water obtained from EPA's STORET database (U.S. EPA, 1996). Note that the upper and lower bounds of this distribution were established by reference to reported values in the open literature.

Use In EPACMTP

The ground-water pH is one of the most important subsurface parameters controlling the mobility of metals. Most metals are more mobile under acidic (low pH) conditions, as compared to neutral or alkaline (pH of 7 or higher) conditions. The pH may also affect the hydrolysis rate of organic constituents; some constituents degrade more rapidly or more slowly as pH varies. The pH of most aquifer systems is slightly acidic, the primary exception being aquifers in solution limestone settings. These may also be referred to as ‘karst’, ‘carbonate’ or ‘dolomite’ aquifers. The ground water in these systems is usually alkaline.

The EPACMTP model assumes that the ground-water/aquifer system is well buffered with respect to pH. That is, in the modeling analysis, there is no effect on the ambient pH from the leachate emanating from the base of the WMU.

3.3.3.2.3 Iron Hydroxide Content (FeOx)

Definition

The nature and amount of solid matter in the subsurface to which metals are attracted (the adsorbent) are important in determining the extent to which a constituent’s transport through the ground-water pathway is retarded due to adsorption. Iron hydroxides (FeOx) represent one of the dominant adsorbents for metal sorption in environmental systems, and were one of the geochemical master variables used in the calculation of the non-linear sorption isotherms using the MINTEQA2 model. Although other sorbents such as clay minerals, carbonate minerals, hydrous aluminum and manganese oxides, and silica may sorb metals in the subsurface, accounting for ferric hydroxide and particulate organic matter (see Section 3.3.3.2.5 for a discussion on particulate organic matter) is sufficient to produce a realistic, yet protective, modeling analysis for most natural ground-water systems.

Parameter Value or Distribution of Values

In the MINTEQA2 modeling that was used to calculate the isotherms for a number of metals, the type of ferric oxide that was assumed to be present was in the form of the mineral goethite (FeOOH), a common form of ferric oxide in soils. A database of sorption reactions for goethite reported by Mathur (1995) was used with the diffuse-layer sorption model in MINTEQA2 to represent the interactions of protons and metals with the goethite surface. Further details of the MINTEQA2 modeling procedure are given in Appendix B.1.

Lacking a site-specific value or distribution of values for this input parameter, a default distribution may be used. The limited data on iron hydroxide content that are available (Loux et al., 1990) were used to define a uniform distribution, with a minimum of 0.0126 and a maximum of 1.115 percent iron hydroxide by weight. A summary of this default distribution is presented in Table 3.6.

Table 3.6 Probability distribution of fraction iron hydroxide

Cumulative Probability (%)	Iron Hydroxide Content (wt %)
0.0	1.82E-02
1.0	2.89E-02
5.0	4.37E-02
10.0	6.85E-02
25.0	9.36E-02
50.0	9.84E-02
75.0	1.04E-01
90.0	1.09E-01
95.0	1.14E-01
100.0	1.19E-01

Data Sources

The default distribution is based on analyses by Loux et al., (1990) on aquifer samples collected by the U.S. EPA Office of Solid Waste (OSW) in Florida, New Jersey, Oregon, Texas, Utah, and Wisconsin.

Use In EPACMTP

The iron hydroxide content of the subsurface is one of the most important subsurface parameters controlling the mobility of metals. In EPACMTP, accounting for ferric hydroxide determines the extent to which a constituent's transport through the ground-water pathway is retarded due to adsorption.

3.3.3.2.4 Leachate Organic Matter (LOM)

Definition

In addition to the metal contaminants, the leachate exiting a WMU may contain elevated concentrations of leachate organic matter. This organic matter may consist of various compounds including organic acids that represent primary disposed waste or that result from the breakdown of more complex organic substances. Many organic acids found in leachate have significant metal-complexing capacity that may influence metal mobility. This input represents the concentration of these anthropogenic organic acids in the leachate emanating from the base of the WMU.

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values for the concentration of organic acids in the leachate (which can then be used to help generate site-specific k_d values), the influence of leachate organic matter on metal sorption may be represented by using a default distribution of values for this input parameter. The default distribution is uniform, with a minimum of 0.001173 mg/L and a maximum of 0.00878 mg/L. A summary of this default distribution is presented in Table 3.7.

Table 3.7 Probability distribution of leachate organic matter

Cumulative Probability (%)	Concentration of Leachate Organic Matter (mg/L)
0.0	1.05E+02
1.0	1.40E+02
5.0	1.94E+02
10.0	2.84E+02
25.0	3.76E+02
50.0	3.94E+02
75.0	4.12E+02
90.0	4.30E+02
95.0	4.47E+02
100.0	4.67E+02

Data Sources

In an effort to incorporate in the ground-water modeling the solubilizing effect of organic acids, a default distribution of leachate organic matter concentrations was developed based on data presented by Gintautas, Huyck, Daniel, and Macalady (1993). This study examined leachates from six landfills from across the U. S. and found that over 30 different acids were present. The range of leachate organic matter concentration levels given in the default distribution is based on the measured total organic carbon among the six landfill leachates in this study.

Use In EPACMTP

The concentration of anthropogenic organic acids in leachate is one of the most important subsurface parameters controlling the mobility of metals. In EPACMTP, this parameter is used to quantify metal-complexing capacity that may influence metal mobility.

3.3.3.2.5 Percent Organic Matter (%OM)

Definition

The nature and amount of solid matter in the subsurface to which metals are attracted (the adsorbent) are important in determining the extent to which a constituent's transport through the ground-water pathway is retarded due to adsorption. Particulate organic matter present in the unsaturated zone (input to EPACMTP as percent organic matter) represents one of the dominant adsorbents for metal sorption in environmental systems and was one of the geochemical master variables used in the calculation of the non-linear sorption isotherms using the MINTEQA2 model. Although other sorbents such as clay minerals, carbonate minerals, hydrous aluminum and manganese oxides, and silica may sorb metals in the subsurface, accounting for ferric hydroxides (See Section 3.3.3.2.3 for a discussion of FeOx) and particulate organic matter (in the soil and aquifer) is sufficient to produce a realistic, yet protective, modeling analysis for most natural ground-water systems. In EPACMTP modeling, the amount of particulate organic matter in the soil (as opposed to the aquifer, represented by the term f_{oc}) is represented by the percent organic matter (%OM).

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values for this input parameter (which can then be used to help generate site-specific k_d values), a default distribution may be used. In the EPACMTP model, there are three default soil types (sandy loam, silty loam, and silty clay loam); each soil type has a unique distribution of values for each of the soil parameters, including the percent organic matter. When modeling a metal using the MINTEQA2-derived isotherms, the default distribution for percent organic matter in the unsaturated zone is based on the default distribution for percent organic matter for the silty loam soil type. The silty loam soil type is intermediate in weight percent organic matter in comparison with the other two and is the most frequently occurring soil type. The default distribution type is Johnson SB; the minimum value is 0.0 and the maximum value is 8.51. A summary of this default distribution is presented in Table 3.8.

Table 3.8 Probability distribution of percent organic matter in the unsaturated zone

Cumulative Probability (%)	Percent Organic Matter in the Unsaturated Zone (unitless)
0.0	4.08E-03
1.0	3.76E-02
5.0	6.07E-02
10.0	1.04E-01
25.0	1.78E-01
50.0	2.04E-01
75.0	2.38E-01
90.0	2.87E-01
95.0	3.82E-01
100.0	1.80E+00

Data Sources

The default distribution described above for the percent organic matter in the unsaturated zone is based on data presented in Carsel and Parrish, 1988.

Use In EPACMTP

The percent organic matter in the unsaturated zone is used in EPACMTP because the nature and amount of solid matter in the subsurface to which metals are attracted (the adsorbent) are important in determining the extent to which a constituent's transport through the ground-water pathway is retarded due to adsorption. As the adsorption of a contaminant in the unsaturated zone increases, more of the contaminant is removed from the system, and is unavailable for transport.

3.3.3.2.6 Fraction Organic Carbon (f_{oc})

Definition

The nature and amount of solid matter in the subsurface to which metals are attracted (the adsorbent) are important in determining the extent to which a constituent's transport through the ground-water pathway is retarded due to adsorption. Particulate organic matter present in the saturated zone represents one of the dominant adsorbents for metal sorption in environmental systems and was one of the geochemical master variables used in the calculation of the non-linear sorption isotherms using the MINTEQA2 model. Although other sorbents such as clay minerals, carbonate minerals, hydrous aluminum and manganese oxides, and silica may sorb metals in the subsurface, accounting for ferric hydroxide (see Section 3.3.3.2.3 for a discussion of FeOx) and particulate organic matter (in the soil and aquifer) is sufficient to produce a realistic, yet protective, modeling analysis for most natural ground-water systems. In EPACMTP modeling, the amount of particulate organic matter in the aquifer is represented by the fraction organic carbon, or f_{oc} (as opposed to the soil, represented by the term %OM).

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values for this input parameter (which can then be used to help generate site-specific k_d values), a default distribution may be used. In the EPACMTP model, there are three default soil types (sandy loam, silty loam, and silty clay loam); each soil type has unique distribution of values for each of the soil parameters, including the percent organic matter. When modeling a metal using the MINTEQA2-derived isotherms, the default distribution for fraction organic carbon in the saturated zone is based on the default distribution for percent organic matter for the sandy loam soil type, however, this value is converted from percent organic matter to fraction organic carbon using Equation 5.1. The sandy loam soil type is higher in weight percent organic matter in comparison with the other soil types. The default distribution type is Johnson SB; the minimum value is 0.0 and the maximum value is 11.0. A summary of this default distribution is presented in Table 3.9.

Table 3.9 Probability distribution of fraction organic carbon in the saturated zone

Cumulative Probability (%)	Fraction Organic Carbon in the Saturated Zone (unitless)
0.0	1.61E-05
1.0	1.31E-04
5.0	2.30E-04
10.0	4.31E-04
25.0	8.00E-04
50.0	9.27E-04
75.0	1.10E-03
90.0	1.35E-03
95.0	1.88E-03
100.0	1.24E-02

Data Sources

The default distribution described above for the fraction organic carbon in the saturated zone is based on data presented in Carsel, Parrish, Jones, Hansen, and Lamb, 1988.

Use In EPACMTP

The fraction organic carbon in the saturated zone is one of the most important subsurface parameters controlling the mobility of metals, since it is used in determining the extent to which a constituent's transport through the ground-water pathway is retarded due to adsorption. .

3.3.3.2.7 Ground-water Type (IGWT)

Definition

Ground-water chemistry exerts an important influence on metal partition coefficients. The major ions present in ground water may compete with trace metals for sorption sites. Also, inorganic ligands may complex with some metals, thereby reducing their tendency to sorb. For the purposes of this modeling, partition coefficients were estimated separately for two ground-water compositional types, one with composition representative of a carbonate-terrain system and one representative of a non-carbonate system. The two ground-water compositional types are correlated with the hydrogeologic environment index in EPACMTP (see Section 5.3.4.2). In EPACMTP, this parameter may take on one of thirteen values, but issues of practicality limit the number of ground-water types for which separate partition coefficients can be estimated to just two. The broadest division of ground waters that may be made for the thirteen hydrogeologic environments in EPACMTP is carbonate and non-carbonate types of ground waters. Thus, these are the two broad types for which coefficients were estimated.

Parameter Value or Distribution of Values

By default, the ground-water type is directly correlated to the hydrogeologic environment setting in EPACMTP. In the default databases of WMU sites that have been compiled into auxiliary input files (called the site data files), each WMU site has been classified by the predominant hydrogeologic environment at the site. In EPACMTP, there are thirteen possible hydrogeologic environments. For the "solution limestone" hydrogeologic environment setting (IGWR = 12), the ground-water type is set to carbonate. The ground-water type for the other twelve possible hydrogeologic settings in EPACMTP are represented by the non-carbonate ground-water type.

Data Sources

The ground-water type is simply an arbitrary number assigned to provide a simple means of specifying which set of isotherms should be used (there is one set for carbonate ground water and another set for non-carbonate ground water). For both ground-water types, a representative, charge-balanced ground-water chemistry specified in terms of major ion concentrations and natural pH was selected from the literature. The carbonate system was represented by a well sample reported for a limestone aquifer (Freeze and Cherry, 1979). This ground water had a natural pH of 7.5 and was saturated with respect to calcite. The non-carbonate system was represented by a sample reported from an unconsolidated sand and gravel aquifer with a natural pH of 7.4 (White, Hem, and Waring, 1963). An unconsolidated sand and gravel aquifer was selected to represent the non-carbonate compositional type because it is the most frequently occurring of the twelve (non-carbonate) hydrogeologic environments in EPACMTP. More details about the MINTEQA2 modeling methodology and the compositions of both the carbonate and non-carbonate representative ground-water samples are presented in Appendix B.1.

Use In EPACMTP

The ground-water type is one of the most important subsurface parameters controlling the mobility of metals, since the major ions present in ground water may compete with trace metals for sorption sites. This may result in less availability of sorption sites for contaminants as they enter the ground water.

4.0 INFILTRATION AND RECHARGE PARAMETERS

This section discusses the individual parameters related to infiltration and recharge that are required to perform a modeling analysis using EPACMTP. Although most applications of EPACMTP are conducted on a national or regional basis for regulatory development purposes, EPACMTP can also be used in a location or a waste-specific mode. In either case, each of the input parameters related to the climatic characteristics of the site(s) being modeled can be specified as a constant value or as a statistical or empirical distribution of values. As a practical matter, however, many of these inputs are commonly specified as distributions of values as part of the regional site-based modeling methodology.

In EPACMTP, the infiltration and recharge-related input parameters include the climate center location, infiltration and recharge rates, and the soil and aquifer temperature. The climate center location is specified as an index that represents the climate center nearest to the waste site being modeled. The climate center index allows the model to access a default set of infiltration and recharge rates that are specific to a WMU type, soil type, and geographic location.

The infiltration rate is defined as the rate at which leachate flows from the bottom of the WMU (including any liner) into the unsaturated zone beneath the WMU. Recharge is the regional rate of aquifer recharge outside of the WMU. Infiltration rate is among the most sensitive site-specific parameters in an EPACMTP evaluation, whereas the model is usually much less sensitive to recharge. For landfills (LFs), waste piles (WPs), and land application units (LAUs), the infiltration rate is determined primarily by the local climatic conditions, especially annual precipitation and WMU liner characteristics. For SIs, the infiltration rate is a function of the surface impoundment ponding depth, liner characteristics, and the presence of a ‘sludge’ layer at the bottom of the impoundment. The regional recharge rate is a function of the annual precipitation rate, and varies with geographical location and soil type.

These infiltration and recharge-related parameters are individually described in the following sections.

4.1 INFILTRATION AND RECHARGE PARAMETERS

The input parameters that are used in EPACMTP to describe the climatic characteristics of the WMU site to be modeled are listed in Table 4.1 on the following page.

Table 4.1 Climate Parameters

Parameter	Symbol	Units	Section	Equation in EPACMTP TBD
Climate Center Index	*ICLR*	–	4.2	--
Landfill Infiltration Rate	I	m/yr	4.3.1	3.4
Waste Pile Infiltration Rate	I	m/yr	4.3.2	3.4
Land Application Unit Infiltration Rate	I	m/yr	4.3.3	3.4
Surface Impoundment Infiltration Rate	I	m/yr	4.3.4	2.24
Recharge Rate	I_R	m/yr	4.4	4.10

4.2 CLIMATE CENTER INDEX (ICLR)

Definition

The climate center index is simply a sequential number assigned to each of 102 climate centers in the default database included with EPACMTP in order to provide a simple means of specifying which infiltration and recharge rates should be used to model the given WMU site.

Parameter Value or Distribution of Values

The climate centers for which default infiltration rates (for LFs, WPs, and LAUs) and recharge rates (for LFs, WPs, SIs, and LAUs) are available are listed in Table 4.2. The geographic locations are depicted in Figure 4.1. For each of the locations listed in Table 4.2, the U.S. EPA used the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder, Dozier, Zappi, McEnroe, Sjostrom, and Peton, 1994) to compute recharge rates for all units, as well as infiltration rates for LAUs and for LFs and WPs with no-liner and single-liner designs. Appendix A provides additional information about how EPA used the HELP model, in conjunction with data from climate stations across the United States, to develop these nationwide recharge and infiltration rate distributions, as well as a detailed discussion of how infiltration rates were developed for different liner designs for each type of WMU.

In developing this default distribution of infiltratoin rates, we started with an existing database of no-liner infiltration rates for LFs, WPs and LAUs. Also existing were recharge rates for 97 climate stations in the lower 48 contiguous United States (ABB, 1995), that are representative of 25 specific climatic regions (developed with HELP version 3.03). We then added five climate stations (located in Alaska, Hawaii, and Puerto Rico) to ensure coverage throughout all of the United States. Rather than calculating infiltration rates for each of the 102 individual climate stations, infiltration rates were calculated for the 25 climate regions, and then assigned the same value to each climate station in one group. In order to reduce the number of required HELP simulations, one station from each climate region was simulated, and the resulting value assigned to each climate station within the region. To be protective, EPA chose the climate center with the highest average precipitation in each climate region (which would tend to maximize constituent transport) to represent the region. Individual infiltration rates were calculated for each of the five climate centers not assigned to a climate region (centers from Alaska, Hawaii, and Puerto Rico).

Table 4.2 Climate Centers Used in the HELP Modeling to Develop Infiltration and Recharge Rates

Index	City	State	Index	City	State	Index	City	State
1	Fresno	CA	29	Dodge City	KS	57	Tampa	FL
2	Boise	ID	30	Midland	TX	58	San Antonio	TX
3	Denver	CO	31	St. Cloud	MN	59	Hartford	CT
4	Grand Junction	CO	32	E. Lansing	MI	60	Syracuse	NY
5	Pocatello	ID	33	North Omaha	NE	61	Worchester	MA
6	Glasgow	MT	34	Tulsa	OK	62	Augusta	ME
7	Bismarck	ND	35	Brownsville	TX	63	Providence	RI
8	Pullman	WA	36	Dallas	TX	64	Portland	ME
9	Yakima	WA	37	Oklahoma City	OK	65	Nashua	NH
10	Cheyenne	WY	38	Concord	NH	66	Ithaca	NY
11	Lander	WY	39	Pittsburgh	PA	67	Boston	MA
12	Los Angeles	CA	40	Portland	OR	68	Schenectady	NY
13	Sacramento	CA	41	Caribou	ME	69	Lynchburg	VA
14	San Diego	CA	42	Chicago	IL	70	New York City	NY
15	Santa Maria	CA	43	Burlington	VT	71	Philadelphia	PA
16	Ely	NV	44	Bangor	ME	72	Seabrook	NJ
17	Rapid City	SD	45	Rutland	VT	73	Indianapolis	IN
18	Cedar City	UT	46	Seattle	WA	74	Cincinnati	OH
19	Albuquerque	NM	47	Montpelier	VT	75	Bridgeport	CT
20	Las Vegas	NV	48	Sault St. Marie	MI	76	Orlando	FL
21	Phoenix	AZ	49	Put-in-Bay	OH	77	Greensboro	NC
22	Tucson	AZ	50	Madison	WI	78	Jacksonville	FL
23	El Paso	TX	51	Columbus	OH	79	Watkinsville	GA
24	Medford	OR	52	Cleveland	OH	80	Norfolk	VA
25	Great Falls	MT	53	Des Moines	IA	81	Shreveport	LA
26	Salt Lake City	UT	54	E. St. Louis	IL	82	Astoria	OR
27	Grand Island	NE	55	Columbia	MO	83	New Haven	CT
28	Flagstaff	AZ	56	Topeka	KS	84	Plainfield	MA
85	Knoxville	TN	91	Tallahassee	FL	97	Miami	FL
86	Central Park	NY	92	New Orleans	LA	98	Annette	AK
87	Lexington	KY	93	Charleston	SC	99	Bethel	AK

Index	City	State	Index	City	State	Index	City	State
88	Edison	NJ	94	W. Palm Beach	FL	100	Fairbanks	AK
89	Nashville	TN	95	Atlanta	GA	101	Honolulu	HI
90	Little Rock	AK	96	Lake Charles	LA	102	San Juan	PR

Data Sources

The list of available climate centers was determined by the availability of meteorological data required for the HELP model and geographic coverage of the United States.

Use In EPACMTP

EPACMTP includes a database of infiltration rates and regional recharge rates for 102 climate centers located throughout the United States. The climate center index is a sequential number assigned to each climate center in the default database included with EPACMTP in order to provide a simple means of specifying which infiltration and recharge rates should be used to model the given WMU site (See Appendix A for a discussion on the determination of infiltration and recharge rates).

This parameter is used as a part of the regional site-based modeling methodology, in which a number of parameters related to the characteristics of the waste site are drawn from a correlated set of data. These default databases of site-related parameters (one for each WMU type) are commonly referred to as the site data files. To perform a Monte Carlo analysis using the regional site-based modeling methodology, the climate center index is provided in the site data files as the default setting, which will ensure that the appropriate climatic data is used for each WMU site in the database. However, if a location-adjusted or quasi-site-specific analysis is being performed, this input can either be omitted from the input file (if site-specific infiltration and recharge rates are available) or assigned a climate center index that is most appropriate to make use of the default location- and soil-specific infiltration and recharge rates which are included in the site data file. Usually this is the nearest climate center. However, this is not always the case. Especially in coastal and mountain regions, the nearest climate center does not always represent conditions that most closely approximate conditions at a specific site.

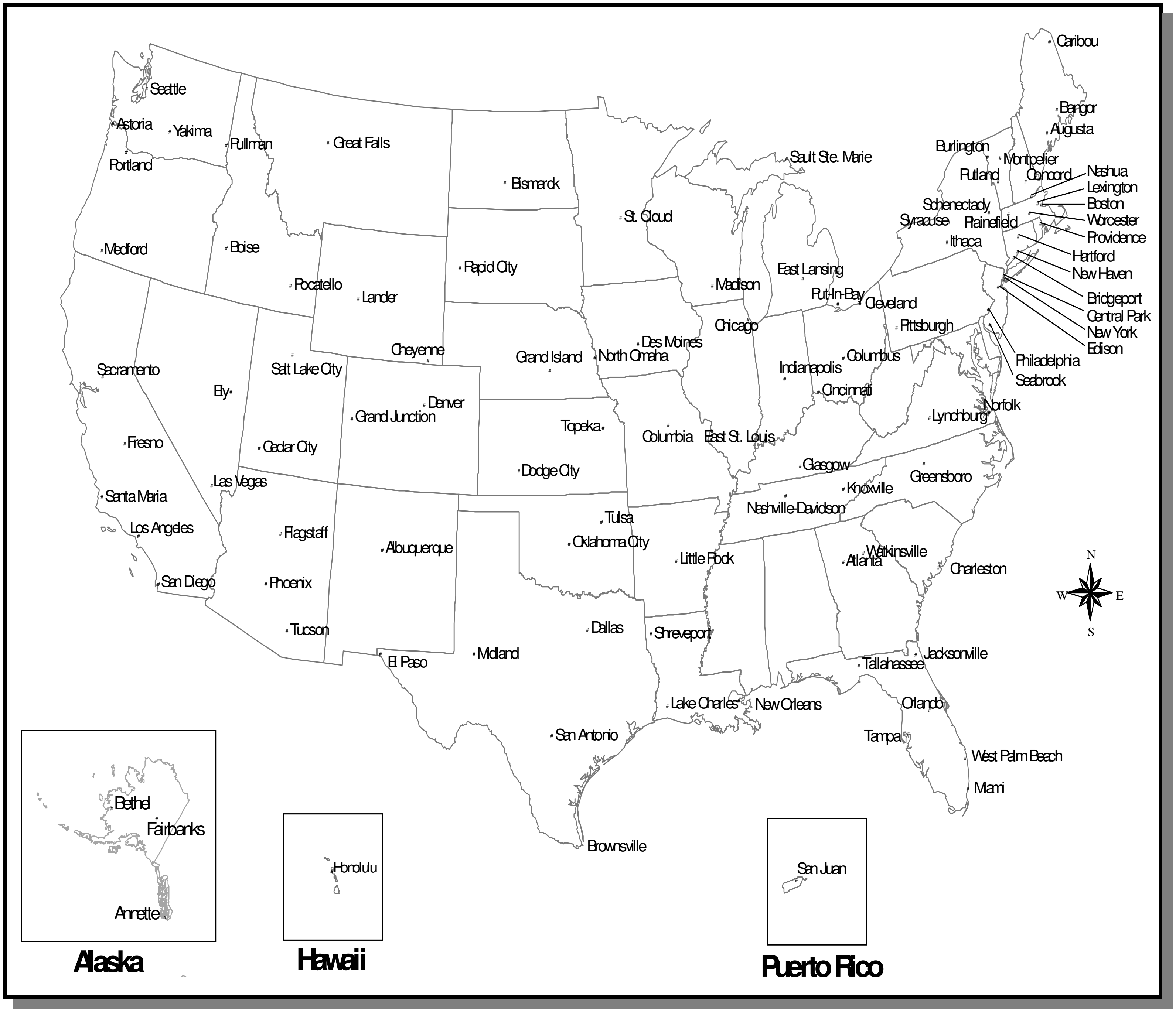

Figure 4.1 Locations of EPACMTP Climate Stations

4.3 INFILTRATION RATES

The EPACMTP model requires input of the net rate of vertical downward percolation of water and leachate through the unsaturated zone to the water table. Infiltration refers to the water that percolates through a WMU to the underlying soil, whereas recharge is water percolating through the soil to the aquifer outside the footprint of the WMU. The model allows the infiltration rate to be different from the ambient regional recharge rate. These rates can differ for a variety of reasons, including the engineering design of the WMU, topography, land use, and vegetation. Note that both infiltration and recharge are specified as areal rates, with the units of cubic meters of fluid (water or leachate) per square meter per year ($m^3/m^2/yr$). Thus, the units for infiltration and recharge simplify to meters per year (m/yr).

Infiltration and recharge rates for use in EPACMTP modeling applications have been estimated for selected soil types at cities around the country through the use of the HELP water-balance model (Version 3.03) (Schroeder et al., 1994), as summarized below. Further details about the HELP modeling inputs, assumptions for each type of WMU, and the resulting databases of infiltration and recharge rates are given in Appendix A.

Using the Soil Conservation Service’s (SCS) county-by-county soil mapping database, the soil classifications in the U.S. were grouped according to the U.S. Department of Agriculture's definitions of coarse, medium, and fine textures. These three categories are represented in EPACMTP by soils equivalent in properties to sandy loam (SNL), silt loam (SLT), and silty clay loam (SCL). An analysis of the SCS database indicates that coarse grained soils, medium grained soils, and fine grained soils represent 15.4 percent, 56.6 percent, and 28.0 percent, respectively, of the soils that have been mapped by the SCS.

The National Oceanic and Atmospheric Administration (NOAA) has data on precipitation and evaporation rates in the United States. This nationwide database was used to categorize the meteorological conditions in the U. S. into 18 climatic regions; 102 cities covering all 18 of the climatic regions were selected as climatic centers for the HELP model (Figure 4.1). For each selected city, climatic data for five years were accessed and used to develop leaching rates for different types of waste management scenarios as a function of site location and soil type. The resulting HELP-model-generated infiltration and recharge rates are incorporated into EPACMTP.

EPACMTP provides default values for infiltration rate as a function of WMU type, liner design, and site location. These values were calculated for unlined and single-lined landfills, waste piles, and land application units for each of the 102 climatic centers with the HELP model, using the procedure described in Appendix A. For composite-lined landfills and waste piles, these values are chosen from an empirical distribution of values based on the results of a literature review (TetraTech, 2001). In the case of surface impoundments, EPACMTP directly calculates the infiltration rate as a function of WMU characteristics, including liner type.

Because the infiltration rate from a WMU is difficult to measure directly, a model such as HELP is used to estimate the WMU infiltration rates for use in EPACMTP.

The data sources for infiltration rates for each type of WMU and the resulting infiltration rates are summarized in the following sections.

4.3.1 Landfill Infiltration Rate (I)

Definition

The landfill infiltration rate (m/yr) is defined as the rate at which water/leachate percolates through the landfill to the underlying soil. The landfill infiltration rate may be different from the ambient regional recharge rate due to the engineering design of the landfill (e.g., landfill cover soil that has a lower conductivity than the regional soils), topography, land use, and vegetation.

For the no-liner case, a two-foot (0.61m) soil cover was assumed to represent Subtitle D landfills that do not contain a liner and leak detection system, and therefore would not be required by the regulations to have a cap of less permeability than the liner system. Two feet was selected as the thickness of the cover as the minimum requirement of Subtitle D. Three default soil types were selected: sandy loam, silt loam, and silty clay loam, corresponding to the coarse, medium, and fine grained soil types as described in Section 4.3. These three soil types are assumed to support vegetation in the United States and are the three soil types used in the leachate flux analysis performed in support of the TC Rule modeling analysis (U.S. EPA, 1990).

For the single-clay liner case, a 3-ft. (0.914m) clay cover with a hydraulic conductivity of 1×10^{-7} cm/sec, a 1-ft. (0.305m) layer of loam overlying the cover (to support vegetation and drainage), a 10-ft. (3.05m) waste layer, a 1-ft. (0.305m) percolation layer, and a 3-ft. (0.914m) clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec were specified in the HELP model input file. Additionally, the modeling assumed that there is no leachate collection system and that the infiltration rate is constant (that is, no increase in hydraulic conductivity of liner) over the modeling period.

A composite liner was defined as a 60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-ft. (0.914m) compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. As in the single-clay liner case, this scenario assumes a constant infiltration rate (i.e., no increase in hydraulic conductivity of liner) over the modeling period.

Parameter Value or Distribution of Values

When the EPACMTP model is run for an unlined or single-lined landfill using the regional, site-based methodology, the model selects a site at random from those in the site data file for each Monte Carlo realization. Since the landfill cover and soil type for the landfills in the *1986 Subtitle D Survey* were unknown, a random combination of landfill cover soil type and regional soil type are then generated from a national joint probability distribution (assuming that the relative frequency of different soil and cover types is nationally uniform) (U.S.EPA, 1990). The climate center index associated with the chosen site and the randomly generated soil types are then used by the model to determine the recharge and infiltration values of the site from the HELP database also included in the site data file. In the case of unlined landfills, if the cover type and soil type underneath the unit are the same, the infiltration rate will be identical to the regional recharge rate for that soil type.

The cumulative frequency distributions of LF infiltration for the three default liner scenarios are presented in Table 4.3, and are based on the estimates described in the following sections; the LF infiltration rates for each climate center are presented in Appendix A.

Table 4.3 Cumulative Frequency Distribution of Landfill Infiltration

%	No Liner Infiltration Rate (m/yr)	Clay Liner Infiltration Rate (m/yr)	Composite Liner Infiltration Rate (m/yr)
0	1.00E-05	1.00E-05	0.00E+00
10	1.35E-02	9.44E-03	0.00E+00
25	6.58E-02	2.53E-02	0.00E+00
50	1.09E-01	4.32E-02	0.00E+00
75	2.74E-01	4.45E-02	7.30E-05
80	3.12E-01	4.77E-02	7.30E-05
85	3.53E-01	4.77E-02	1.12E-04
90	4.11E-01	4.86E-02	1.69E-04
95	4.56E-01	4.86E-02	2.83E-04
100	1.08E+00	5.26E-02	4.01E-04

Data Sources

The HELP model (Schroeder, et al., 1994) was used to estimate the rate at which leachate emanates from the base of the landfill for the no-liner and single-clay liner scenarios, using the procedure described in Appendix A.

For the composite liner case, the EPACMTP model randomly selects an infiltration rate from a default database of values which were compiled from a literature review of leak detection system flow rates (TetraTech, 2001).

When the EPACMTP model is run for a composite-lined landfill using the regional, site-based methodology, the model selects an infiltration rate at random from those in the default distribution for each Monte Carlo realization.

In a location-specific modeling analysis, the site-specific infiltration rate can be directly specified in the input file – either as a constant value or as a statistical or empirical distribution of values.

Use In EPACMTP

The landfill infiltration rate is used by the model to determine the leaching duration and leachate concentration when the landfill depleting source option is used. Infiltration rate is also used by the model to determine the leachate flux to the subsurface and as an input to the subsurface flow and transport modules.

4.3.2 Waste Pile Infiltration Rate (I)

Definition

The waste pile infiltration rate is defined as the rate at which water/leachate percolates through the waste pile to the underlying soil. The waste pile infiltration rate may be different from the ambient regional recharge rate due to the engineering design of the waste pile (e.g., uncovered waste has a different conductivity than the regional soils), topography, land use, and vegetation.

For the purposes of estimating leaching rates using the HELP model, waste piles were considered to be similar to non-covered landfills. Thus, the infiltration rates for unlined and single-lined waste piles were generated using the same general procedures as for landfills, but with the following modifications. Because of the limited requirements for leachate collection systems in most states, after closure, waste piles will approximate the landfill configuration selected for modeling, i.e., waste covered by two feet of soil. Modeling of closed waste piles was, therefore, not necessary as their leaching characteristics are similar to closed landfills. Active waste piles, however, differ from landfills in that the waste generally remains uncovered. So the HELP model was used to model the leachate flux for waste piles through active, uncovered piles without leachate collection systems.

For the unlined scenario, the waste piles were modeled as a one-layer landfill, with the uncovered waste material comprising the layer. The waste material was assumed to be a moderate permeability waste – coal bottom ash with a permeability of 4.1×10^{-4} cm/sec.

For the single-lined scenario, an additional parameter – waste type permeability – is used. Since waste piles are not typically covered, the permeability of the waste itself can be a factor in determining the rate of leachate released due to water percolating through the WMU. For waste piles, the HELP modeling was conducted using three categories of waste permeability: high permeability (0.041 cm/sec); moderate permeability (0.0041 cm/sec); and low permeability (0.00005 cm/sec). The waste permeability is generally correlated with the grain size of the waste material, ranging from coarse- to fine-grained materials. Additionally, the modeling assumed that there is no leachate collection system and that the infiltration rate is constant (that is, no increase in hydraulic conductivity of liner) over the modeling period.

For the composite-lined scenario, the EPACMTP model randomly selects an infiltration rate from a default database of values which were compiled from a literature review of leak detection system flow rates (TetraTech, 2001). For the purposes of this literature review, a composite liner was defined as a 60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-ft.(0.914m) compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. As in the single-clay liner case, this scenario assumes a constant infiltration rate (i.e., no increase in hydraulic conductivity of liner) over the modeling period.

Parameter Value or Distribution of Values

The cumulative frequency distributions of WP infiltration for the three default liner scenarios are presented in Table 4.4, based on the estimates described in the following section; the WP infiltration rates for each climate center are presented in Appendix A.

Table 4.4 Cumulative Frequency Distribution of Waste Pile Infiltration

%	No Liner Infiltration Rate (m/yr)	Clay Liner Infiltration Rate (m/yr)	Composite Liner Infiltration Rate (m/yr)
0	3.00E-04	1.00E-05	0.00E+00
10	6.02E-02	2.64E-02	0.00E+00
25	1.28E-01	9.50E-02	0.00E+00
50	2.55E-01	1.27E-01	0.00E+00
75	3.91E-01	1.33E-01	7.30E-05
80	4.49E-01	1.33E-01	7.30E-05
85	4.76E-01	1.34E-01	1.16E-04
90	5.38E-01	1.35E-01	1.67E-04
95	6.14E-01	1.35E-01	2.80E-04
100	1.82E+00	1.36E-01	4.01E-04

Data Sources

The HELP model (Schroeder et. al., 1994) was used to estimate the rate at which leachate emanates from the base of the waste pile for the no-liner and single-clay liner scenarios. This modeling methodology is summarized here and is more fully described in Appendix A.

Use In EPACMTP

When the EPACMTP model is run for an unlined or single-lined waste pile using the regional, site-based methodology,the model selects a site at random from those in the site data file for each Monte Carlo realization The climate center index associated with the chosen site and the randomly generated soil types are then used by the model to determine the recharge and infiltration values of the site from the HELP databases also included in the site data file.

When the EPACMTP model is run for a composite-lined waste pile using the regional, site-based methodology, the model selects an infiltration rate at random from those in the default distribution for each Monte Carlo realization.

In a location-specific modeling analysis, the site-specific infiltration rate can be directly specified in the input file – either as a constant value or as a statistical or empirical distribution of values.

Once the waste pile infiltration rate is generated, it is used by the model to determine the leachate flux to the subsurface and as an input to the subsurface flow and transport modules.

4.3.3 Land Application Unit Infiltration Rate (I)

Definition

The land application unit infiltration rate is defined as the rate at which water/leachate percolates through the land application unit to the underlying soil. Although the actual infiltration rate at a land application site may be slightly different from the ambient regional recharge rate due to the additional water in the land applied sludge, topography, land use, and vegetation, the default Monte Carlo analysis in EPACMTP assumes that these rates are identical.

Based upon sensitivity analyses using a range of waste application rates, EPA established that the addition of amounts of water through application of sludge-type wastes does not significantly impact the soil water balance, and therefore has little to no effect on the calculated net infiltration. Only for sites located in arid regions of the United States with very little natural precipitation did high application rates have an appreciable effect. For more representative waste application rates, the effect disappeared because introducing additional moisture in the simulated water balance resulted in a commensurate increase in runoff and removal by evapotranspiration.

Based on these results, the land application unit infiltration rates at the 102 climate centers were taken to be the same as the ambient regional recharge rate for that climatic center and soil type. In addition, the recharge rate for a given climate center and soil type is taken to be the same as the corresponding landfill infiltration rate.

Parameter Value or Distribution of Values

When the EPACMTP model is run for a land application unit using the regional, site-based methodology, he model selects a site at random from those in the site data file for each Monte Carlo realization The climate center index associated with the chosen site and the randomly generated soil types are then used by the model to determine the recharge and infiltration values of the site from the HELP databases also included in the site data file.

The cumulative frequency distribution of LAU infiltration for the no-liner scenario is presented in Table 4.5, based on the estimates described in the following sections; the LAU infiltration rates for each climate center are presented in Appendix A.

Table 4.5   Cumulative Frequency Distribution of Land Application Unit Infiltration

%	No Liner Infiltration Rate (m/yr)
0	1.00E-05
10	1.30E-02
25	7.04E-02
50	1.10E-01
75	2.01E-01
80	2.57E-01
85	2.89E-01
90	3.26E-01
95	3.65E-01
100	7.45E-01

Data Sources

In a location-specific modeling analysis, the site-specific infiltration rate can be directly specified in the input file – either as a constant value or as a statistical or empirical distribution of values.

The HELP model was used to estimate the rate at which leachate emanates from the base of the land application unit for the no-liner scenario. This modeling methodology is summarized here and is more fully described in Appendix A.

Use In EPACMTP

Once the land application unit infiltration rate is generated, it is used by the model to determine the leachate flux to the subsurface and as an input to the subsurface flow and transport modules.

4.3.4 Surface Impoundment Infiltration Rate (I)

Definition

The surface impoundment infiltration rate is defined as the rate at which water/leachate percolates through the surface impoundment to the underlying soil. The surface impoundment infiltration rate is generally larger than the ambient regional recharge rate due to the hydraulic head created by the wastewater in the impoundment.

For the surface impoundment scenario, the leachate flux rate is computed as a derived parameter, as part of the unsaturated zone flow module in EPACMTP. The algorithm is described in the *EPACMTP Technical Background Document* (US EPA, 2003a). In a typical Monte Carlo modeling analysis of a surface impoundment, the infiltration rate is derived by the EPACMTP model. Technically, the SI infiltration rate is not really an input parameter; rather, the model calculates infiltration rates “on the fly” during the simulation. In the event that the SI is reported to have its base below the water table, EPACMTP calculates the infiltration using Darcy’s law based on the hydraulic gradient across and the hydraulic conductivity of the consolidated sediment and any liner material at the bottom of the impoundment unit. Based on unit-specific data from EPA’s Surface Impoundment Study (US EPA 2001a), EPA assumed a fixed sediment layer thickness of 20 cm at the base of the impoundment. In addition, the EPACMTP model assumes that the depth of clogging underneath the impoundment was 0.5 m in all cases, and that saturated hydraulic conductivity of the clogged layer is 10% of that of the native soil underlying the impoundment.

For unlined SIs, the primary parameters that control the infiltration rate are the ponding depth in the impoundment, the thickness and permeability of any accumulated sediment layer at the base of the impoundment, and the presence of a ‘clogged’ (i.e., reduced permeability) layer of native soil under the impoundment caused by the migration of solids from the impoundment.

For single-lined SIs, infiltration rates are typically calculated inside of EPACMTP in the same manner as described for unlined units, with the exception that a compacted clay liner (with a given thickness and hydraulic conductivity) is added at the bottom of the WMU and the effect of clogged native material is not included due to the filtering effects of the liner. For more information on the EPACMTP inputs used to describe the SI liner thickness and conductivity, see Sections 2.4.4.and 2.4.5.

For the composite-lined SI, the EPACMTP model determines its infiltration rate using a default distribution of leak densities expressed as number of leaks per hectare (see Section 2.4.7).

Parameter Value or Distribution of Values

When the EPACMTP model is run for any of the three default liners for the surface impoundment scenario using the regional, site-based methodology, the model selects a site at random from those in the site data file for each Monte Carlo realization. Using the characteristics of the chosen site and the methods described above, the model automatically calculates the infiltration rate. The climate center index associated with the chosen site and the randomly generated soil types are then used to determine the recharge rate for the site from the HELP database also included in the site data file.

The cumulative frequency distributions of SI infiltration for the three default liner scenarios (produced by running a standard regional site-based modeling analysis) are presented in Table 4.6; the SI infiltration rates for each climate center are presented in Appendix A.

Table 4.6 Cumulative Frequency Distribution of Surface Impoundment Infiltration

%	No Liner Infiltration Rate (m/yr)	Clay Liner Infiltration Rate (m/yr)	Composite Liner Infiltration Rate (m/yr)
0	3.78E-15	3.78E-15	0.00E+00
10	2.71E-01	4.22E-02	0.00E+00
25	5.21E-01	6.29E-02	0.00E+00
50	1.14E+00	1.08E-01	4.88E-05
75	2.27E+00	1.63E-01	2.02E-04
80	2.58E+00	1.76E-01	2.67E-04
85	2.94E+00	1.94E-01	3.55E-04
90	3.51E+00	2.17E-01	4.98E-04
95	4.51E+00	2.69E-01	7.51E-04
100	2.23E+01	7.98E-01	3.69E-03

Data Sources

In a location-specific modeling analysis, the site-specific infiltration rate can be directly specified in the input file – either as a constant value or as a statistical or empirical distribution of values.

To create the surface impoundment site data file for use with EPACMTP, EPA used unit-specific data for SIs from EPA's *Surface Impoundment Study* (U.S. EPA, 2001a). The resulting sediment layer permeability has a relatively narrow range of variation between 1.26×10^{-7} and 1.77×10^{-7} cm/s. This database of surface impoundment sites is tabulated in Appendix D.

Default data on leak density were compiled from 26 leak density values reported in TetraTech (2001). Further details of the methodology and data used to derive SI infiltration for the composite liner scenario are presented in Section 4.2.2.4 of the *IWEM Technical Background Document* (U.S. EPA, 2003c).

Use In EPACMTP

The surface impoundment infiltration rate is used by the model to determine the leachate flux to the subsurface and as an input to the subsurface flow and transport modules.

4.4 RECHARGE RATE (I_R)

Definition

The recharge rate is the rate at which water percolates through the soil to the water table outside the footprint of the WMU. The recharge rate is determined by regional climatic conditions, such as precipitation, evapotranspiration, surface run-off, and regional soil type. The ambient regional rate may be different from the infiltration rate through the WMU due to the engineering design of the unit (e.g., landfill cover soil of a different type, hydraulic head of the impoundment, or low waste conductivity), topography, land use, and/or vegetation. The recharge rate is determined by the regional climatic and soil conditions, such as precipitation, evapotranspiration, surface run-off, and regional soil type. Note that both infiltration and recharge are specified as areal rates, with the units of cubic meters of fluid (water or leachate) per square meter per year ($m^3/m^2/yr$). Thus, the units for infiltration and recharge simplify to meters per year (m/yr).

Parameter Value or Distribution of Values

EPA created the database of recharge rates for the three primary soil types across the United States (SNL, SLT, and SCL) and ambient climate conditions at 102 climate stations through the use of the HELP water-balance model as presented in Appendix A. The ambient regional recharge rate for a given climate center and soil type (for all four WMU types) was assumed to be the same as the corresponding unlined LF infiltration rate. The cumulative frequency distribution of recharge (produced by running a standard regional site-based modeling analysis for a landfill) are presented in Table 4.7; the recharge rate for each climate center is presented in Appendix A.

Table 4.7 Cumulative Frequency Distribution of Regional Recharge Rate

%	Recharge Rate (m/yr)
0	1.00E-05
10	1.35E-02
25	6.86E-02
50	1.22E-01
75	3.08E-01
80	3.42E-01
85	3.90E-01
90	4.38E-01
95	4.67E-01
100	1.15E+00

Data Sources

The HELP model was used to estimate the ambient regional recharge rate, using the procedure described in Appendix A. Note that the recharge rate for a given climate center and soil type (for all 4 types of WMUs) is assumed to be the same as the corresponding unlined landfill infiltration rate (see Section 4.3.1.1).

Use In EPACMTP

When the EPACMTP model is run using the regional, site-based methodology, the model selects a site at random from those in the site data file for each Monte Carlo realization. The climate center index associated with the chosen site and the randomly generated soil type are then used by the model to determine the recharge value of the site from the HELP database also included in the site data file.

In a location-specific modeling analysis, the site-specific regional recharge rate can be directly specified in the input file – either as a constant value or as a statistical or empirical distribution of values.

Once the recharge rate is generated, it is used by the model as an input to the subsurface flow and transport modules.

5.0 HYDROGEOLOGICAL PARAMETERS

EPACMTP treats the subsurface aquifer system as a composite domain, consisting of an unsaturated (vadose) zone and an underlying saturated zone (an unconfined aquifer). The boundary between the two zones is the water table. The unsaturated zone and saturated zone modules are computationally linked through continuity of flow and constituent concentration across the water table directly underneath the waste management unit (WMU). The model accounts for the following processes affecting constituent fate and transport as the constituent migrates from the bottom of a WMU through the unsaturated and saturated zones: advection, hydrodynamic dispersion and molecular diffusion, linear or nonlinear equilibrium sorption, first-order decay and zero-order production reactions (to account for transformation breakdown products), and dilution due to recharge in the saturated zone.

This section discusses the individual hydrogeological parameters characterizing the soil and aquifer that are required to perform a modeling analysis using EPACMTP. Although most applications of EPACMTP are conducted on a national or regional basis for regulatory development purposes, EPACMTP can also be used in a location-specific mode. In either case, each of the input parameters describing the soil and aquifer beneath the waste site being modeled can be specified as a constant value or as a statistical or empirical distribution of values. As a practical matter, however, many of these inputs are commonly specified using a distribution of values.

There are a number of data sources available to obtain parameter values for the unsaturated and saturated zone modeling in EPACMTP. For unsaturated zone modeling, we used a database of soil hydraulic properties for various soil types, assembled by Carsel and Parrish (1988), in combination with information from the Soil Conservation Service (SCS) on the nationwide prevalence of different soil types across the United States. Another primary data source was the Hydrogeologic Database for Ground-Water Modeling (HGDB), assembled by Rice University on behalf of the American Petroleum Institute (API) (Newell, Hopkins, and Bedient, 1990). This database provides probability distributions of a number of key ground-water modeling parameters for various types of subsurface environments.

The HGDB was developed from a survey of the hydrogeologic characteristics at actual hazardous waste sites in the United States and provides site specific data on ground water parameters (aquifer thickness, unsaturated zone thickness, hydraulic gradient and hydraulic conductivity) collected by independent investigators for approximately 400 hazardous waste sites throughout the U.S. These site-specific data were then regrouped into 13 hydrogeologic environments, based on the USGS classification of aquifer regions (Heath, 1984) (12 specific environments and one category called “other”). The result is a database of aquifer types, with each aquifer type consisting of an empirical distribution of values for each of the four aquifer parameters.

These hydrogeological parameters are individually described in the following sections.

5.1 HYDROGEOLOGICAL PARAMETERS

The hydrogeological input parameters include parameters to characterize both the flow regime and constituent transport in both the unsaturated zone and aquifer in the vicinity of the modeled WMU. These parameters are listed in Table 5.1.

5.2 UNSATURATED ZONE PARAMETERS

In the unsaturated zone, EPACMTP simulates one-dimensional, vertically downward flow and transport of constituents between the base of the WMU and the water table. The unsaturated zone-specific model inputs used by the model to simulate the fate of constituents as they are transported through the subsurface include the unsaturated zone thickness, hydraulic conductivity and other hydraulic properties of the soil, the bulk density of the soil, the dispersivity in the unsaturated zone, percent organic matter, and parameters describing the sorption and/or degradation of the modeled constituent. The primary output from the unsaturated zone module is the predicted contaminant concentration entering the saturated zone at the water table, either as a function of time (the breakthrough curve) or at steady-state.

These unsaturated zone parameters are individually described in the following sections.

5.2.1 Unsaturated Zone Thickness (D_u)

Definition

The unsaturated zone thickness is the vertical distance from the ground surface to the water table. The water table in this case is meant to represent the ‘natural’ water elevation, as it is or would be without the influence from the WMU. The presence of a WMU, particularly a surface impoundment, may cause a local rise in the water table called mounding. The EPACMTP model assumes that the unsaturated zone thickness value you have entered does not include mounding. The model will calculate the predicted impact of the WMU and liner design (if any) on the ground water as part of the modeling evaluation.

Note that in cases where the WMU is excavated, such that the base of the unit is below ground surface, the unsaturated zone thickness should be the long-term average regional depth to ground water, measured outside the footprint of the WMU. The input variable *Depth Below Grade* (see Sections 2.3.3, 2.4.6, and 2.5.3) is used to correct the unsaturated zone thickness beneath an excavated WMU.

Table 5.1 Hydrogeological Parameters

Module	Parameter	Symbol	Units	Section	Equation in EPACMTP Tech. Bkgd. Doc
Unsaturated Zone	Unsaturated Zone Thickness	D_u	m	5.2.1	3.9
	Soil Type Index	ISTYPE	unitless	5.2.2	
	Soil Hydraulic Conductivity	K_s	cm/hr	5.2.3.1	3.4
	Alpha	α	1/cm	5.2.3.2	3.1
	Beta	β	unitless	5.2.3.3	3.1
	Residual Water Content	θ_r	unitless	5.2.3.4	3.1
	Saturated Water Content	θ_s	unitless	5.2.3.5	3.1
	Soil Bulk Density	ρ_{bu}	g/cm3	5.2.3.6	3.16
	Percent Organic Matter	*%OM*	unitless	5.2.3.7	3.10
	Dispersivity	α_{Lu}	m	5.2.4	3.9
	Leading Coefficient of Freundlich Isotherm	K_d	cm^3/g	5.2.5.1	3.11
	Exponent of Freundlich Isotherm	η	unitless	5.2.5.2	3.18
	Chemical Degradation Rate	λ_{cu}	1/yr	5.2.6	3.13
	Biodegradation Rate	λ_{bu}	1/yr	5.2.7	3.12
	Soil Temperature	T	°C	5.2.8	4.4.3.3
	Soil pH	pH	standard units	5.2.9	4.4.3.4
Saturated Zone	Particle Diameter	d	cm	5.3.1	4.1
	Porosity	ϕ	unitless	5.3.2	4.2
	Bulk Density	ρ_b	g/cm3	5.3.3	4.3
	Hydrogeologic Environment Index	IGWR	unitless	5.3.4.2	
	Saturated Zone Thickness	B	m	5.3.4.3	2.31
	Hydraulic Conductivity	K	m/yr	5.3.4.4	4.4
	Regional Hydraulic Gradient	r	unitless	5.3.4.5	4.6
	Seepage Velocity	V_x	m/yr	5.3.5	4.6
	Anisotropy Ratio	A_r	unitless	5.3.6	4.5
	Retardation Coefficient	R^s	unitless	5.3.7	4.18
	Longitudinal Dispersivity	α_L	m	5.3.8.1	4.19

Module	Parameter	Symbol	Units	Section	Equation in EPACMTP Tech. Bkgd. Doc
Saturated zone	Horizontal Transverse Dispersivity	α_T	m	5.3.8.2	4.28
	Vertical Dispersivity	α_V	m	5.3.8.3	4.29
	Aquifer Temperature	T	°C	5.3.9	4.4.3.3
	Ground-water pH	*pH*	standard units	5.3.10	Section 4.4.3.4
	Fractional Organic Carbon Content	f_{oc}^{s}	unitless	5.3.11	4.30
	Leading Coefficient of Freundlich Isotherm	K_d^s	cm^3/g	5.3.12	4.18
	Exponent of Freundlich Isotherm	η^s	unitless	5.3.13	4.34
	Chemical Degradation Rate	λ_c^s	1/yr	5.3.14	Section 4.4.3.9
	Biodegradation Rate	λ_b^s	1/yr	5.3.15	Section 4.4.3.9

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values to input, a default distribution of unsaturated zone thickness values may be used as part of the regional site-based modeling methodology. As described in Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), the regional site-based modeling methodology is an attempt to ensure that the combination of parameter values randomly generated by the Monte Carlo module of EPACMTP represents a realistic set of site conditions. The cumulative frequency distribution of unsaturated zone thickness listed in Table 5.2 was generated by performing a default landfill modeling analysis using the regional site-based modeling methodology; the entire Hydrogeologic Database for Modeling (HGDB) from which these values were derived is presented in Appendix D.

Table 5.2 Cumulative Frequency Distribution of Unsaturated Zone Thickness

%	Unsaturated Zone Thickness (m)
0	3.05E-01
10	1.68E+00
25	3.96E+00
50	6.10E+00
75	1.52E+01
80	1.83E+01
85	2.93E+01
90	4.27E+01
95	5.08E+01
100	6.10E+02

Data Sources

EPA obtained data on the unsaturated zone thickness from the Hydrogeologic Database for Modeling (HGDB; Newell et al., 1990; U.S. EPA, 1997d). A database of soil hydraulic properties for various soil types, assembled by Carsel and Parrish (1988) was also used, in combination with information from the Soil Conservation Service (SCS) on the nationwide prevalence of different soil types across the United States. The Hydrogeologic Database for Modeling (HGDB) from which the values shown in Table 5.2 were derived is presented in its entirety in Appendix D.

In the regional site-based Monte Carlo analysis that is typically used for nationwide modeling applications, the resulting distribution of values for the thickness of the unsaturated zone is produced through Monte Carlo sampling of the HGDB, based on the hydrogeologic environment assigned to the waste site selected for each model realization. In a location-adjusted or quasi-site-specific modeling analysis, the site-specific unsaturated zone thickness can be directly specified as a constant value or an empirical or statistical distribution of values.

Use In EPACMTP

The EPACMTP model uses the unsaturated zone thickness to determine the travel distance of leachate constituents in the unsaturated zone.

5.2.2 Soil Type (ISTYPE)

Definition

Soil type is a way to group or classify soils with similar properties. EPACMTP incorporates three soil types, sandy loam, silt loam, and silty clay loam, that represent the most prevalent soil types across the U.S.

The soil type is indicated by a numerical index which is simply a sequential number assigned to each soil type in the default database included with EPACMTP in order to provide a simple means of specifying which distributions should be used to generate the input values for the soil characteristics required to run the model.

Parameter Value or Distribution of Values

The soil types for which default data are available are listed in Table 5.3; the corresponding soil parameter distributions are summarized in Section 5.2.3. When performing a regional site-based modeling analysis of a landfill, waste pile, or land application unit, the soil type is randomly chosen based on the nationwide frequency of occurrence, based on Soil Conservation Service (SCS) soil mapping data. These percentages are shown below in Table 5.3. When performing a regional site-based modeling analysis of a WMU, the soil type for each unit is specified in the default site data file.

Table 5.3 Default EPACMTP Soil Types

Soil Type Index	Texture	Soil Name	Abbreviation	Frequency of Occurrence
1	medium	silt loam	SLT	56.6%
2	coarse	sandy loam	SNL	15.4%
3	fine	silty clay loam	SCL	28%

Data Sources

Parameter distributions for soil parameters were compiled by Carsel and Parrish (1988). Information on the relative frequency of each soil type was obtained from the U.S. Soil Conservation Service as part of the risk analysis in support of EPA's development of the Toxicity Characteristic Final Rule (U.S. EPA, 1990).

Use In EPACMTP

To perform a typical Monte Carlo analysis using the regional site-based modeling methodology, the soil type index should be left in its default setting, ensuring that the appropriate climatic data is used for each WMU site in the database. However, if a location-specific analysis is being performed, then this input can either be omitted from the input file (if site-specific values for the soil characteristics are available) or set to the appropriate constant value to make use of the default soil data which are included in the model.

5.2.3 Soil Hydraulic Characteristics

EPACMTP uses the so-called van Genuchten model to describe the soil hydraulic characteristics. The parameters used to describe the soil hydraulic characteristics include residual water content, saturated water content, and two van Genuchten empirical water soil moisture parameters (alpha and beta).

Solution of the unsaturated zone flow requires knowledge of the soil characteristic curves, i.e., the relationship between water saturation and pressure head and between hydraulic conductivity and water saturation. The van Genuchten (1980) model is widely used for predicting soil-water content as a function of pressure head. Descriptive statistical values for the parameters used in this model have been determined by Carsel and Parrish (1988) for 12 soil classifications. The statistical distributions for the parameters presented in Carsel and Parrish (1988) (as well as the bulk density and percent organic matter from Carsel et al., 1988) for the three default soil types used in EPACMTP are presented in Table 5.4. The variables analyzed by Carsel and Parrish include saturated hydraulic conductivity (K_s), residual water content (θ_r), saturated water content (θ_s), and three empirical constants (α, β, and γ). Probability distributions for α, β, and γ for all 12 soil types from Carsel and Parrish (1988) are presented in Table 5.6.

5.2.3.1 Soil Hydraulic Conductivity (K_s)

Definition

The hydraulic conductivity of the soil is a measure of the soil's ability to transmit water under fully saturated conditions.

Parameter Value or Distribution of Values

If site-specific data are available, then the soil hydraulic conductivity can be specified as a constant value or an empirical or statistical distribution of values.

Table 5.4 Statistical parameters for soil properties for three soil types used in the EPACMTP model (Carsel and Parrish, 1988 and Carsel et al., 1988). All values are in arithmetic space

Variable	Distribution Type	Limits of Variation Minimum	Maximum	Mean	Standard Deviation
Soil Type - Silty Clay Loam					
K_S cm/hr	SB	0.	3.5	0.017	2.921
θ_r	NO	0.00	0.115	0.089	0.0094
α cm^{-1}	SB	0.00	0.15	.009	.097
β	NO	1.0	1.5	1.236	0.061
% OM	SB	0.0	8.35	0.11	5.91
ρ_b	Constant	-	-	1.67	-
θ_s	Constant	-	-	0.43	-
Soil Type - Silt Loam					
K_S cm/hr	LN	0.	15.0	.343	.989
θ_r	SB	0.00	0.11	.068	0.071
α cm^{-1}	LN	0.00	0.15	.019	0.012
β	SB	1.0	2.0	1.409	1.629
% OM	SB	0.0	8.51	0.105	5.88
ρ_b	Constant	-	-	1.65	-
θ_s	Constant	-	-	0.45	-
Soil Type - Sandy Loam					
K_S cm/hr	SB	0.	30.0	2.296	24.65
θ_r	SB	0.	0.11	0.065	0.074
α cm-1	SB	0.	0.25	0.070	0.171
β	LN	1.35	3.00	1.891	0.155
% OM	SB	0.0	11.0	0.074	7.86
ρ_b	Constant	-	-	1.60	-
θ_s	Constant	-	-	0.41	-

% OM = Percent Organic Matter
NO = Normal distribution
SB = Log ratio distribution, $Y = \ln[(x-A)/(B-x)]$, $A < x < B$
LN = Log normal distribution, $Y = \ln[x]$
where Y = normal distributed parameter
x = actual data
K_s = Saturated Hydraulic Conductivity
θ_r = Residual water content
α,β = van Genuchten parameters
ρ_b = Bulk density
θ_s = Saturated Water Content

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; hydraulic conductivity is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including hydraulic conductivity, is shown in Table 5.4, above. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.5 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.5, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.5 Cumulative Frequency Distribution of Soil Hydraulic Conductivity

%	Soil Hydraulic Conductivity (cm/hr)
0	4.30E-05
10	6.79E-03
25	2.33E-02
50	8.90E-02
75	3.99E-01
80	6.09E-01
85	9.97E-01
90	1.93E+00
95	4.41E+00
100	2.79E+01

Data Sources

The databases of soil characteristics for the three default soil types (which include soil hydraulic conductivity) were derived from soil hydraulic property data reported by Carsel and Parrish (1988).

Use In EPACMTP

The hydraulic conductivity of the soil is used as an input to the unsaturated zone flow module and is used to calculate the moisture content in the soil under a given rate of leachate infiltration from the WMU.

Table 5.6 Descriptive statistics for van Genuchten water retention model parameters, α, β, and γ (Carsel and Parrish, 1988)

	Parameter α, cm^{-1}					Parameter β					Parameter γ			
Soil Type	**X**	**SD**	**CV**	**N**		**X**	**SD**	**CV**	**N**		**X**	**SD**	**CV**	**N**
Clay[a]	0.008	0.012	160.3	400		1.09	0.09	7.9	400		0.08	0.07	82.7	400
Clay Loam	0.019	0.015	77.9	363		1.31	0.09	7.2	364		0.24	0.06	23.5	364
Loam	0.036	0.021	57.1	735		1.56	0.11	7.3	735		0.36	0.05	13.5	735
Loamy Sand	0.124	0.043	35.2	315		2.28	0.27	12.0	315		0.56	0.04	7.7	315
Silty Clay	0.005	0.005	113.6	126		1.09	0.06	5.0	374		0.08	0.05	51.7	374
Silty Clay Loam	0.010	0.006	61.5	641		1.23	0.06	5.0	641		0.19	0.04	21.5	641
Silt	0.016	0,007	45.0	82		1.37	0.05	3.3	82		0.27	0.02	8.6	82
Silt Loam	0.020	0.012	64.7	1093		1.41	0.12	8.5	1093		0.29	0.06	19.9	1093
Sandy Clay	0.027	0.017	61.7	46		1.23	0.10	7.9	46		0.19	0.06	34.7	46
Sandy Clay Loam	0.059	0.038	64.6	214		1.48	0.13	8.7	214		0.32	0.06	53.0	214
Sandy Loam	0.075	0.037	49.4	1183		1.89	0.17	9.2	1183		0.47	0.05	10.1	1183
Sand	0.145	0.029	20.3	246		2.68	0.29	20.3	246		0.63	0.04	6.3	246

N = Sample size, X = Mean
SD = Standard Deviation
CV = Coefficient of Variation (percent)
[a] = Agricultural Soil, Clay 60 percent
γ = 1-1/β

5.2.3.2 Alpha (α)

Definition

Alpha is a soil-specific shape parameter that is obtained from an empirical relationship between pressure head and volumetric water content; it is one of the parameters in the van Genuchten (1980) model used for modeling soil-water content as a function of pressure head, and is used to calculate the moisture content in the soil under a given rate of leachate infiltration from the WMU.

Parameter Value or Distribution of Values

If site-specific data are available, then the van Genuchten parameter alpha can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; van Genuchten parameter alpha is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including the van Genuchten parameter alpha, is shown in Table 5.4. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.7 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.7, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.7 Cumulative Frequency Distribution of Alpha

%	Alpha (1/cm)
0	1.29E-03
10	5.96E-03
25	9.35E-03
50	1.52E-02
75	2.71E-02
80	3.26E-02
85	4.22E-02
90	5.90E-02
95	8.92E-02
100	2.18E-01

Data Sources

The databases of soil characteristics for the three default soil types (which include the van Genuchten parameter (α)) were derived from soil hydraulic property data reported by Carsel and Parrish (1988).

Use In EPACMTP

The van Genuchten parameter alpha is an input to the unsaturated zone flow module and is used to calculate the moisture content in the soil under a given rate of leachate infiltration from the WMU.

5.2.3.3 Beta (β)

Definition

Beta is a soil-specific shape parameter that is obtained from an empirical relationship between pressure head and volumetric water content; it is one of the parameters in the van Genuchten (1980) model used for modeling soil-water content as a function of pressure head.

Parameter Value or Distribution of Values

If site-specific data are available, then the van Genuchten parameter beta can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; van Genuchten parameter beta is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including the van Genuchten parameter beta, is shown in Table 5.4. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.8 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.8, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.8 Cumulative Frequency Distribution of Beta

%	Beta (unitless)
0	1.03E+00
10	1.20E+00
25	1.27E+00
50	1.37E+00
75	1.53E+00
80	1.58E+00
85	1.68E+00
90	1.82E+00
95	1.96E+00
100	2.50E+00

Data Sources

The databases of soil characteristics for the three default soil types (which include the van Genuchten parameter (β)) were derived from soil hydraulic property data reported by Carsel and Parrish (1988).

Use In EPACMTP

The van Genuchten parameter beta is an input to the unsaturated zone flow module and is used to calculate the moisture content in the soil under a given rate of leachate infiltration from the WMU.

5.2.3.4 Residual Water Content (θ_r)

Definition

At atmospheric pressure, the saturated water content represents the maximum fraction of the total volume of soil that is occupied by the water contained in the soil. The soil will remain saturated as the pressure head is gradually decreased. Eventually, as the pressure head decreases to a threshold known as the bubbling pressure, the water will begin to drain from the soil. The moisture content will continue to decline as the pressure head is lowered until it reaches some irreducible residual water content. Should the pressure head be further reduced, the soil would not lose any additional moisture.

Parameter Value or Distribution of Values

If site-specific data are available, then the residual water content of the soil can be specified as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see

Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; residual water content is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including the residual water content of the soil, is shown in Table 5.4. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.9 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.9, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.9 Cumulative Frequency Distribution of Residual Water Content

%	Residual Water Content (unitless)
0	1.06E-02
10	4.89E-02
25	6.09E-02
50	7.46E-02
75	8.57E-02
80	8.80E-02
85	9.07E-02
90	9.37E-02
95	9.81E-02
100	1.15E-01

Data Sources

The databases of soil characteristics for the three default soil types (which include the residual water content) were derived from soil hydraulic property data reported by Carsel and Parrish (1988).

Use In EPACMTP

The residual water content is an input to the unsaturated zone flow module and is used to calculate the moisture content in the soil under a given rate of leachate infiltration from the WMU.

5.2.3.5 Saturated Water Content (θ_s)

Definition

At atmospheric pressure, the saturated water content represents the maximum fraction of the total volume of soil that is occupied by the water contained in the soil.

Parameter Value or Distribution of Values

If site-specific data are available, then the saturated water content of the soil can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; saturated water content is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including the saturated water content of the soil, is shown in Table 5.4. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.10 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling. For a given percentile (%) frequency and value pair in Table 5.10, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.10 Cumulative Frequency Distribution of Saturated Water Content

%	Saturated Water Content (unitless)
0	4.10E-01
10	4.10E-01
25	4.30E-01
50	4.50E-01
75	4.50E-01
80	4.50E-01
85	4.50E-01
90	4.50E-01
95	4.50E-01
100	4.50E-01

Data Sources

The databases of soil characteristics for the three default soil types (which include the saturated water content) were derived from soil hydraulic property data reported by Carsel and Parrish (1988).

Use In EPACMTP

The saturated water content is an input to the unsaturated zone flow module and is used to calculate the moisture content in the soil under a given rate of leachate infiltration from the WMU.

5.2.3.6 Soil Bulk Density (ρ_b)

Definition

The dry bulk density of the soil is the ratio of the mass of the solid soil to its total volume.

Parameter Value or Distribution of Values

If site-specific data are available, then the soil bulk density can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; soil bulk density is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including the soil bulk density, is shown in Table 5.4. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.11 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.11, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.11 Cumulative Frequency Distribution of Soil Bulk Density

%	Soil Bulk Density (g/cm3)
0	1.60E+00
10	1.60E+00
25	1.65E+00
50	1.65E+00
75	1.67E+00
80	1.67E+00
85	1.67E+00
90	1.67E+00
95	1.67E+00
100	1.67E+00

Data Sources

The databases of soil characteristics for the three default soil types (which include the bulk density) were derived from soil property data reported by Carsel et al (1988).

Use In EPACMTP

The dry soil bulk density (mass of soil per unit volume) is used to calculate the retardation coefficient of organic constituents and to convert soil mass to volume.

5.2.3.7 Percent Organic Matter (%OM)

Definition

The percent organic matter is a measure of the organic material that is present within the soil of the unsaturated zone, measured as a weight percent.

Parameter Value or Distribution of Values

If site-specific data are available, then the percent organic matter in the soil can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of soil hydraulic conductivity values may be used as part of the regional site-based modeling methodology (see Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). The EPACMTP model includes a database of soil characteristics for each of three default soil types; hydraulic conductivity is one of the soil characteristics included in these default databases. A statistical summary of the values used for each of the three default soil types, including the percent organic matter in the soil, is shown in Table 5.4. The cumulative frequency distribution of soil hydraulic conductivity values listed in Table

5.12 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.12, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.12 Cumulative Frequency Distribution of Percent Organic Matter

%	Percent Organic Matter (unitless)
0	3.58E-03
10	1.05E-01
25	7.87E-02
50	4.05E-02
75	1.18E-01
80	1.42E-01
85	1.72E-01
90	2.15E-01
95	2.96E-01
100	1.69E+00

Data Sources

The databases of soil characteristics for the three default soil types (which include the percent organic matter) were derived from soil property data reported by Carsel et al (1988).

Use In EPACMTP

For organic constituents, the percent organic matter in the soil which is specified in the input file is internally converted by the EPACMTP model to fractional organic carbon content through the following equation (Enfield et al., 1982):

$$f_{oc} = \% \, OM \, / \, 174 \tag{5.1}$$

where:

f_{oc} = fractional organic carbon content,
$\%OM$ = percent organic matter, and
174 = conversion factor.

Once the fractional organic carbon content is obtained, it is used to calculate the unsaturated zone linear distribution coefficient for organic constituents (k_d, see Section 5.2.8) assuming that hydrophobic binding dominates the sorption process

(Karickhoff, 1985). The distribution coefficient is then used to calculate the amount by which contaminant transport is retarded relative to the ambient ground-water flow velocity within the vadose zone.

This input is not used for modeling the transport of metals.

5.2.4 Unsaturated Zone Longitudinal Dispersivity (α_{Lu})

Definition

Dispersion is the phenomenon by which a dissolved constituent in soil or ground water is mixed with uncontaminated water and becomes reduced in concentration at the perimeter of the plume. Not all of a constituent is traveling at the same velocity, due to differences in pore size and flow path length and friction along pore walls, resulting in mixing along the flow path which decreases solute concentrations. Note that the unsaturated zone longitudinal dispersivity is measured along the path of flow, that is, in the downward direction.

Parameter Value or Distribution of Values

The longitudinal dispersivity of the soil can be input as a constant value or a distribution of values, if site-specific data are available. If not, the dispersivity can be derived as a linear function of the total depth of the unsaturated zone according the following equation which is based on a regression analysis of data presented by EPRI (1985):

$$\alpha_{Lu} = 0.02 + 0.022\, D_u \tag{5.2}$$

where

α_{Lu} = longitudinal dispersivity (m)
D_u = total depth of the unsaturated zone (m)

The cumulative frequency distribution of soil hydraulic conductivity values listed in Table 5.13 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. The unsaturated zone dispersivity was specified as a derived variable in the input file, and this distribution of values was created through the Monte Carlo sampling of unsaturated zone thickness from the linked WMU site and HGDB databases (see Section 5.3.4). For a given percentile (%) frequency and value pair in Table 5.13, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.13 Cumulative Frequency Distribution of Dispersivity

%	Dispersivity (m)
0	2.67E-02
10	5.70E-02
25	1.07E-01
50	1.54E-01
75	3.54E-01
80	4.23E-01
85	6.65E-01
90	9.59E-01
95	1.00E+00
100	1.00E+00

Data Sources

Lacking site-specific data to input, Equation 5.1 is used to calculate the unsaturated zone dispersivity. This equation is based on a regression analysis of data presented by EPRI (1985) (shown in Table 5.14) and has a correlation coefficient of 0.66.

Use In EPACMTP

The longitudinal dispersivity of the unsaturated zone is an input to the unsaturated zone transport module and is used to calculate the concentration history (breakthrough curve) of the constituent plume arriving at the water table.

Table 5.14 Compilation of field dispersivity values (EPRI, 1985)

Author	Type of Experiment	Vertical Scale of Experiment (m)	Longitudinal Dispersivity α_L(m)
Yule and Gardner (1978)	Laboratory	0.23	0.0022
Hildebrand and Himmelblau (1977)	Laboratory	0.79	0.0018
Kirda et al. (1973)	Laboratory	0.60	0.004
Gaudet et al. (1977)	Laboratory	0.94	0.01
Brissaud et al. (1983)	Field	1.00	0.0011, 0.002
Warrick et al. (1971)	Field	1.20	0.027
Van de Pol et al. (1977)	Field	1.50	0.0941
Biggar and Nielsen (1976)	Field	1.83	0.05
Kies (1981)	Field	2.00	0.168
Jury et al. (1982)	Field	2.00	0.0945
Andersen et al. (1968)	Field	20.00	0.70
Oakes (1977)	Field	20.00	0.20

5.2.5 Freundlich Adsorption Isotherm Parameters

An adsorption isotherm is an expression of the equilibrium relationship between the aqueous concentration and the sorbed concentration of a chemical constituent (organic or metal) at a constant temperature. One of the general models of the sorption process is the Freundlich isotherm, defined as follows:

$$S = KC^{\eta} \tag{5.3a}$$

where:

S = mass of constituent that is sorbed per dry unit weight of solid (mg/kg)
K = Leading coefficient of the Freundlich isotherm (mg/kg)/(mg/L)$^{\eta}$
C = aqueous concentration of the constituent at equilibrium with the sorbed mass (mg/L)
η = Freundlich isotherm exponent (dimensionless)

If the sorptive behavior of a constituent can be described by the Freundlich isotherm, then when log C is plotted against log S, the resulting relationship will be linear with a slope of η and an intercept of log K. A special case is when η is equal to 1.0. In this case, the sorption isotherm is linear and the leading Freundlich coefficient is known as the linear solid-liquid phase distribution coefficient (K_d). A linear isotherm is commonly used to describe the subsurface fate and transport of organic constituents, assuming that hydrophobic binding dominates the sorption process (Karickhoff, 1985). In this case, the K_d can be calculated as follows:

$$\boldsymbol{K_d = k_{oc}\, f_{oc}} \qquad (5.3b)$$

where

K_d = leading Freundlich coefficient (distribution coefficient) (cm^3/g)
k_{oc} = normalized organic carbon distribution coefficient (cm^3/g)
f_{oc} = fractional organic carbon content (dimensionless)

Equation (5.3a) may be recast as:

$$\boldsymbol{S = (KC^{\eta-1})C = K_d(C)C} \qquad (5.3c)$$

where:

S = mass of constituent that is sorbed per dry unit weight of solid (mg/kg)
K = Leading coefficient of the Freundlich isotherm $(mg/kg)/(mg/L)^{\eta}$
C = aqueous concentration of the constituent at equilibrium with the sorbed mass (mg/L)
η = Freundlich isotherm exponent (dimensionless)
K_d = distribution coefficient (cm^3/g)

The distribution coefficient, K_d, in Equation 5.3c is non-linear and is a function of aqueous concentration. In EPACMTP, the non-linear K_d function in Equation (5.3c) may be more general than the Freundlich type (see Section 5.2.5.1) below.

To model the fate and transport of constituents with EPACMTP, the user must specify two adsorption isotherm parameters: the Freundlich sorption coefficient (K or K_d) and the Freundlich exponent (η). These two parameters are described in Sections 5.2.5.1 and 5.2.5.2, below.

5.2.5.1 Leading Coefficient of Freundlich Isotherm for Unsaturated Zone (K or K_d)

Definition

The leading coefficient of the Freundlich isotherm is a constant used to describe the sorptive behavior of a constituent. When the sorption data are plotted as log C versus log S, the intercept of the resulting line is equal to log K. In the special case of a linear isotherm, the leading Freundlich coefficient is known as the linear solid-liquid phase distribution coefficient (K_d) (commonly called the distribution coefficient).

Parameter Value or Distribution of Values

When modeling organic constituents with EPACMTP, the leading Freundlich coefficient is generally specified as a derived parameter in the input file. If derived, the leading Freundlich coefficient (K_d) is automatically assumed linear and calculated by the model according to Equation 5.3b. In this case, f_{oc} is internally calculated from the percent organic matter specified in the unsaturated zone-specific input group according to Equation 5.2, and k_{oc} is a constituent-specific input value (see Section 3 of this document). However, if site-specific data are available, a constant value or distribution of values could be used for the leading Freundlich coefficient.

When modeling metals transport in the unsaturated zone with EPACMTP, the leading Freundlich coefficient can be specified as a constant value or as a distribution of values, based either on site-specific data or adsorption data reported in the scientific literature. Alternatively, tables of non-linear sorption isotherms developed using the MINTEQA2 geochemical model, or equations comprising *pH*-based (linear) isotherms can be used. For the latter two cases (non-linear isotherms or pH-based linear isotherms) this input parameter is not used; the record in the input file is ignored by the model. Instead, the non-linear K_d (Equation 5.3c) is either provided in tabular form as a function of the concentration value or calculated as a function of *pH* (see Sections 3.3.3.2 and 3.3.3.1.2, respectively).

Data Sources

Generally, the K_d for organic constituents is specified as a derived parameter; however, if this option is not appropriate and site-specific data are not available, there are studies in the scientific literature that provide compilations of K_d's that have been measured in the field (for instance, see *Risk Assessment for the Listing Determinations for Inorganic Chemical Manufacturing Wastes*; U.S. EPA, 2000). In this case, the leading Freundlich coefficient would be specified as either a constant value or a distribution of values (and the Freundlich exponent would be set to its default value of 1.0).

The leading Freundlich coefficient for metals is specified using either the non-linear MINTEQA2 isotherms or pH-based linear isotherms that were developed specifically for use with the EPACMTP model (see Section 3.3.3). However, if neither of these two options is appropriate and site-specific data are not available, there are studies in the scientific literature that provide compilations of K_d's that have been measured in the field (for instance, see Appendix I of U.S. EPA, 2000). In this case, the leading Freundlich coefficient would be specified as either a constant value or a distribution of values.

Use In EPACMTP

The leading Freundlich coefficient (also called the distribution coefficient) is one of the parameters used to calculate the amount by which contaminant transport is retarded relative to the ambient ground-water flow velocity within the unsaturated zone. It is an input to the unsaturated zone transport module. For organic constituents that are subject to hydrolysis, this input is also used as a parameter to calculate the overall hydrolysis rate.

5.2.5.2 Exponent of Freundlich Isotherm for Unsaturated Zone (η)

Definition

The exponent of the Freundlich isotherm is a constant used to describe the sorptive behavior of a constituent. When the sorption data are plotted as log C versus log S, the slope of the resulting line is equal to η. In the special case of a linear isotherm, the exponent of the Freundlich isotherm is equal to 1.0.

Parameter Value or Distribution of Values

For modeling organic constituents, the default value of the Freundlich exponent is 1.0, meaning a linear adsorption isotherm is used.

Generally, the distribution coefficient for metals is specified using either tabulated non-linear MINTEQA2 isotherms or pH-based linear isotherms that were developed specifically for use with the EPACMTP model (see Section 3.3.3). In these two cases, the K_d data is read in from an auxiliary input file or internally calculated, and the Freundlich isotherm coefficient and exponent are not used. If the leading Freundlich coefficient is specified using an empirical distribution of values (e.g., based on reported K_d values in the scientific literature), then the Freundlich isotherm exponent should be set equal to 1.0.

If this parameter is omitted from the data file, it is assigned a default value of 1.0, which is equivalent to specifying a linear sorption isotherm.

In EPACMTP Version 2.0, only the case of $\eta = 1$ is permitted. Non-linear isotherms (see Equation 5.3c) are handled using the tabular type of input described in Section 3.3.3.2.

Data Sources

For modeling organic constituents, the Freundlich isotherm exponent is generally set to its default value of 1.0, and so no specific data source is used to determine the appropriate value for the Freundlich exponent.

For modeling metal constituents, the Freundlich isotherm exponent is not used as an input parameter, and so no specific data source is used (see Section 3.3.3.2). If literature or site-specific data are used to specify a non-linear adsorption isotherm, modeling of the adsorption process is implemented via tabular input describing the relationship in Equation 5.3c.

Use In EPACMTP

The Freundlich exponent is one of the parameters used to calculate the amount by which contaminant transport is retarded relative to the ambient ground-water flow velocity within the unsaturated zone; it is an input to the unsaturated zone transport module.

5.2.6 Chemical Degradation Rate Coefficient for Unsaturated Zone (λ_{cu})

Definition

EPACMTP accounts for all transformation processes (both biological and chemical) using a lumped first-order decay coefficient. This overall decay coefficient is the sum of the chemical and biological transformation coefficients. The chemical degradation coefficient for the unsaturated zone is simply the rate of decay that is caused by chemical (usually hydrolysis) reactions in the unsaturated zone.

Parameter Value or Distribution of Values

By default, the chemical degradation coefficient in the unsaturated zone is set to be internally derived using the hydrolysis rate constants and the unsaturated zone properties according to Equation 3.4. However, if site-specific data are available, this parameter can be specified as a constant value or a distribution of values. In this case, the hydrolysis rate constants can be omitted from the input file.

Data Sources

If this parameter is not derived by the model, then a site-specific data source must be used to determine the appropriate input value.

Use In EPACMTP

The chemical degradation coefficient is used by the model to calculate the amount by which contaminant concentrations within the vadose zone are attenuated due to chemical hydrolysis; it is an input to the unsaturated zone transport module and is one of the parameters required to solve the transport equation for dissolved leachate constituents (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

5.2.7 Biodegradation Rate Coefficient for Unsaturated Zone (λ_{bu})

Definition

EPACMTP accounts for all transformation processes (both biological and chemical) using a lumped first-order decay coefficient. This overall decay coefficient is the sum of the chemical and biological transformation coefficients. The biological degradation coefficient for the unsaturated zone is simply the rate of decay that is caused by biological processes in the unsaturated zone.

Parameter Value or Distribution of Values

By default, the biological degradation coefficient in the unsaturated zone is set equal to zero. However, if site-specific data are available, this parameter can be specified as a constant value or a distribution of values.

Data Sources

If the input value of this parameter is non-zero, then a site-specific data source must be used to determine the appropriate input value.

Use In EPACMTP

The biological degradation coefficient is used by the model to calculate the amount by which contaminant concentrations within the vadose zone are attenuated due to biological processes; it is an input to the unsaturated zone transport module and is one of the parameters required to solve the transport equation for dissolved leachate constituents (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

5.2.8 Soil Temperature (T)

Definition

The soil temperature is the long-term average temperature within the vadose zone. Note that although the temperature within the vadose zone is not an explicit model input, this temperature is assumed by EPACMTP to be the same as that of the aquifer.

Parameter Value or Distribution of Values

As modeled in EPACMTP, soil temperature affects the transformation rate of constituents that are subject to hydrolysis, through the effect of temperature on reaction rates (see Section 3.3.2.2). In the development of the site data files for each WMU type, information on average annual temperatures in shallow ground-water systems (Todd, 1980) were used to assign a temperature value to each WMU in the modeling database, based on the unit's geographical location. For each WMU site, the assigned temperature was an average of the upper and lower values for that temperature region, as shown in Figure 5.1. In other words, all WMU's located in the band between 10° and 15° were assigned a temperature value of 12.5 °C.

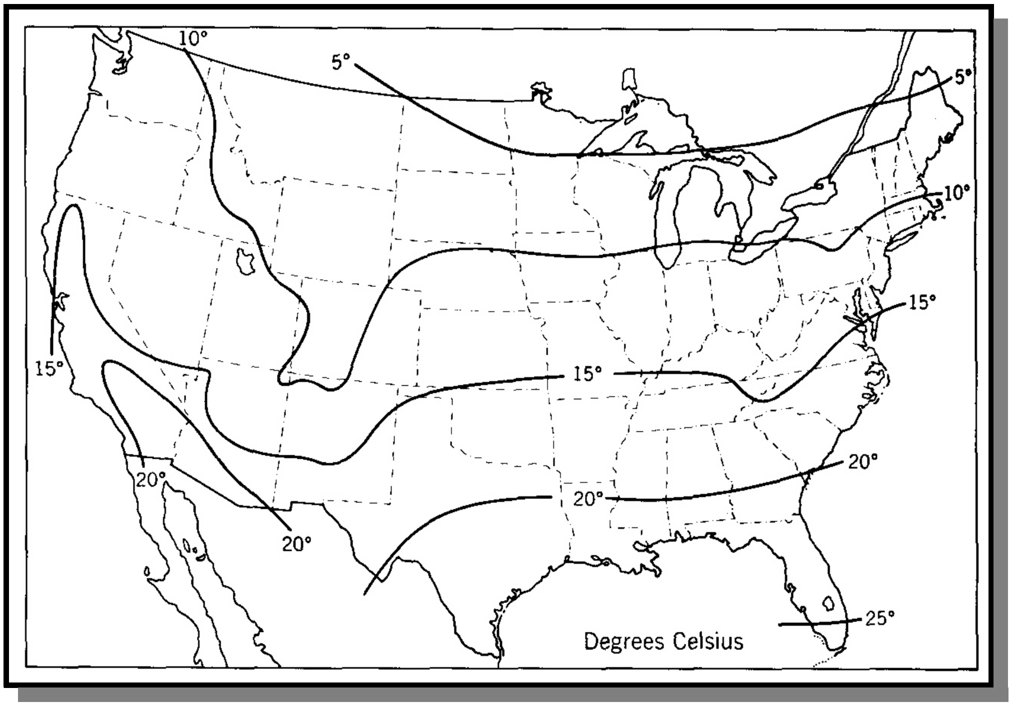

Figure 5.1 Ground-water Temperature Distribution for Shallow Aquifers in the United States (from Todd, 1980)

Data Sources

Information on average annual temperatures in shallow ground-water systems from Todd (1980) were used to assign a temperature value to each WMU site in the site data files, based on the unit's geographical location.

Use In EPACMTP

When the EPACMTP model is run using the regional, site-based methodology, for each Monte Carlo realization, the model selects a site, at random, from those in the site data file. Since the original data sets did not include all the site-related input files required by the EPACMTP model, other data sources, such as this map of ground-water temperatures, are utilized to create a complete data set. For each WMU site, the ground-water temperature was assigned using the data from Todd (1980) and the unit's geographical location.

In a location-adjusted modeling analysis, a site-specific ground-water temperature can be directly specified in the input file – either as a constant value or as a statistical or empirical distribution of values.

The aquifer temperature associated with the modeled site and the specified hydrolysis rate constants are then used by the model to derive the appropriate temperature-dependent first-order hydrolysis rate for organic constituents. Note that although the temperature of the ground-water within the vadose zone is not an explicit model input, the EPACMTP model assumes that the soil temperature is the same as that of the aquifer.

5.2.9 Soil pH (pH)

pH is defined as the negative of the base-10 logarithm of the hydrogen ion [H^+] concentration in solution. pH is a measure of acidity. pH values below 7 indicate acidic conditions; values above 7 indicate alkaline conditions.

Parameter Value or Distribution of Values

A nationwide ground-water pH distribution was derived from EPA's STORET database (U.S. EPA, 1996). EPACMTP assumes that the ground water is sufficiently buffered such that pH is not influenced by the input of contaminants or changes in temperature. The default distribution is an empirical distribution with a median value of 6.8 or lower and upper bounds of 3.2 and 9.7, respectively. Note that the value generated for the ground-water pH is assumed to apply to the unsaturated zone as well.

Data Sources

The pH data distribution was developed from nearly 25,000 field-measured pH values in EPA's STORET water quality database (U.S. EPA, 1996). EPA used these data to develop a pH distribution for ground water that is used in EPACMTP for the unsaturated zone as well.

Use In EPACMTP

pH is used in the calculation of hydrolysis rates for organic constituents, in accordance with Equation 3.6.

pH is also one of the key parameters that controls sorption and mobility of metal constituents. When the default, MINTEQA2 sorption isotherms are used in EPACMTP, pH is one of the key master variables that controls the selection of a particular isotherm for each model realization in the Monte Carlo simulation process.

5.3 SATURATED ZONE PARAMETERS

In the saturated zone, EPACMTP simulates ground-water flow and three-dimensional constituent transport from the water table to a downgradient well. The saturated zone-specific inputs used by the model to simulate the fate of constituents as they are transported through the subsurface include particle diameter, porosity, bulk density, aquifer thickness, hydraulic conductivity, hydraulic gradient, anisotropy ratio, dispersivity, ground-water temperature and pH, and parameters describing the sorption and/or degradation of the modeled constituent. The primary model output is a prediction of the constituent concentration arriving at a downgradient well.

The primary source of data for the default distributions used in the saturated zone module is the Hydrogeologic Database for Ground-Water Modeling (HGDB), assembled by Rice University on behalf of the American Petroleum Institute (API) (Newell et al., 1990). This database provides probability distributions for the following three aquifer-specific inputs for various types of subsurface environments: aquifer thickness, hydraulic conductivity, and hydraulic gradient (data on the unsaturated zone thickness is also included in this database, but this parameter is discussed with the other unsaturated zone parameters in Section 5.2).

All of the saturated zone parameters are individually described in the following sections.

5.3.1 Particle Diameter (d)

Definition

The particle diameter is defined as the mean diameter of the particles constituting the aquifer materials.

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values, this input value can be specified using a default distribution of values (the default option) or it can be derived based on the aquifer's porosity. The default distribution of values was created from data compiled by Shea (1974) and is presented below in Table 5.15. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.16 lists the cumulative frequency distribution of particle diameter that is generated in a default landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.16, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.15 Empirical distribution of mean particle diameter (based on Shea, 1974)

Cumulative Probability	Particle Diameter (cm)
$3.9\text{x}10^{-4}$	0.000
$7.8\text{x}10^{-4}$	0.038
$1.6\text{x}10^{-3}$	0.104
$3.1\text{x}10^{-3}$	0.171
$6.3\text{x}10^{-3}$	0.262
$1.25\text{x}10^{-2}$	0.371
$2.5\text{x}10^{-2}$	0.560
$5.0\text{x}10^{-2}$	0.792
$1.0\text{x}10^{-1}$	0.904
$2.0\text{x}10^{-1}$	0.944
$4.0\text{x}10^{-1}$	0.976
$8.0\text{x}10^{-1}$	1.000

Table 5.16 Cumulative Frequency Distribution of Particle Diameter

%	Particle Diameter (cm)
0	4.00E-04
10	1.50E-03
25	5.57E-03
50	1.91E-02
75	4.09E-02
80	4.60E-02
85	5.56E-02
90	7.62E-02
95	9.73E-02
100	2.11E-01

Alternatively, if the particle diameter is treated as a derived parameter, then its value is calculated using the value of porosity (which may be constant or randomly generated from a probability distribution) using the following empirical relationship based on data reported by Davis (1969):

$$d = \exp\left[\, 0.261 - \phi\gamma\, 0.0385 \right] \tag{5.4}$$

where:

d = mean particle diameter (cm)
ϕ = total porosity (dimensionless)
γ = van Genuchten soil-specific shape parameter (dimensionless)

Data Sources

For Monte Carlo analyses, an empirical distribution of values is typically used for the mean particle diameter. This distribution of values is based on data compiled by Shea (1974) in which a frequency distribution of particle sizes is presented that is based on analysis of 11,000 samples.

Alternatively, if the particle diameter is treated as a derived parameter, then its value is calculated from the porosity using Equation 5.4 based on data reported by Davis (1969).

Use In EPACMTP

For Monte Carlo analyses, the mean particle diameter is typically used to calculate porosity and bulk density of the aquifer materials. Bulk density is an input to the saturated zone flow and transport modules. In the transport module, it is one of several parameters used to calculate the degree to which contaminant velocities are retarded relative to the ambient ground-water flow velocity within the aquifer.

5.3.2 Porosity (ϕ)

Definition

Porosity is the ratio of the volume of void spaces in rock or sediment to the total volume of rock or sediment. For contaminant transport modeling, it is more appropriate to use effective porosity, ϕ_e, than total porosity. The effective porosity can be significantly smaller than the total porosity. However, the EPACMTP input parameter porosity can represent either total or effective porosity, depending upon how it is specified, as described below.

Parameter Value or Distribution of Values

Lacking a site-specific value or distribution of values, this input value can be calculated based on the aquifer's particle diameter by rewriting Equation 5.4 to solve for porosity, as shown below:

$$\phi = 0.261 - 0.0385 \ln(d) \tag{5.5}$$

where:

d = mean particle diameter (cm)
ϕ = total porosity (dimensionless)

Equation 5.5 yields the total porosity of the aquifer, but for contaminant transport modeling, it is more appropriate to use effective porosity, ϕ_e, than total porosity. The effective porosity can be significantly smaller than the total porosity, although a constant relationship between these two parameters cannot be established. McWorter and Sunada (1977) present data on total and effective porosity for a range of aquifer materials. Their data was used to create a default methodology whereby the EPACMTP model calculates the effective porosity based on the total porosity and the grain size (see Table 5.17).

For Monte Carlo assessments, the effective porosity of the aquifer is, by default, specified as a derived parameter in the EPACMTP input file. In this case, the model assumes that the actual ratio between effective and total porosity varies uniformly between the upper and lower value for ϕ_e/ϕ in each particle-size class for a given value of the mean aquifer grain size class. For a given value of the mean aquifer grain size, the total porosity can thus be converted into effective porosity.

Please note that EPACMTP makes the conversion from total of effective porosity only if porosity is specified as a derived parameter (porosity is calculated from grain size), the default setting in the input file. In all other cases, no conversion is performed and the user must specify the actual porosity data to be used by the model, providing a constant value or distribution of values for either total porosity or effective porosity directly.

Table 5.17 Ratio between effective and total porosity as a function of particle diameter (after McWorter and Sunada, 1977)

Mean Particle Diameter (cm)	ϕ_e/ϕ Range
$\leq$ 6.25 10^{-3}	0.03 - 0.77
6.25 10^{-3} - 2.5 10^{-2}	0.04 - 0.87
2.5 10^{-2} - 5.0 10^{-2}	0.31 - 0.91
5.0 10^{-2} - 1.0 10^{-1}	0.58 - 0.94
> 1.0 10^{-1}	0.52 - 0.95

Data Sources

If the porosity is treated as a derived parameter (the default setting), then the total porosity is calculated from the mean particle diameter using Equation 5.5 which is based on data reported by Davis (1969). The total porosity is then converted to effective porosity by randomly choosing a ratio between effective and total porosity; this conversion is accomplished through the use of ranges of values for the ratio between effective and total porosity as a function of mean particle diameter that are derived from data presented in McWorter and Sunada (1977).

Use In EPACMTP

For Monte Carlo analyses, the porosity, whether directly input or derived, is used to calculate the bulk density of the aquifer materials. Bulk density is an input to the saturated zone flow and transport modules. In the saturated zone flow module, bulk density is used in the calculation of the ground-water seepage velocity. In the transport module, bulk density is one of several parameters used to calculate the degree to which contaminant velocities are retarded relative to the ambient ground-water flow velocity within the aquifer.

5.3.3 Bulk Density (ρ_b)

Definition

Bulk density is defined as the mass of aquifer solid material per unit volume of the aquifer, in g/cm^3 or mg/L. Bulk density takes into account the fraction of the volume that is taken up by pore space.

Parameter Value or Distribution of Values

Lacking site-specific data for bulk density, this input can be derived from the porosity of the aquifer. Assuming the particle density to be 2.65 g/cm^3, the bulk density can be calculated using the following equation from Freeze and Cherry (1979):

$$\rho = 2.85 (1- \phi) \qquad (5.6)$$

where

ρ_b = bulk density of the soil (g/cm^3).
ϕ = total porosity of the aquifer material (dimensionless)

Table 5.18 lists the cumulative frequency distribution of bulk density that is generated in a default landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in Table 5.18, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.18 Cumulative Frequency Distribution of Bulk Density

%	Soil Bulk Density (g/cm3)
0	1.16E+00
10	1.30E+00
25	1.43E+00
50	1.56E+00
75	1.63E+00
80	1.64E+00
85	1.66E+00
90	1.70E+00
95	1.72E+00
100	1.80E+00

Data Sources

In the absence of a site specific value or distribution of values for bulk density, this input can be specified as a derived parameter in the EPACMTP input file. In this case, the input value is calculated from the aquifer porosity by assuming the particle density to be 2.65 g/cm^3 and using the relationship from Freeze and Cherry (1979) that is presented as Equation 5.6.

Use In EPACMTP

Bulk density is an input to the saturated zone flow and transport modules. In the saturated zone flow submodule, bulk density is used in the calculation of the ground-water seepage velocity. In the transport flow submodule, bulk density is one of several parameters used to calculate the degree to which contaminant velocities are retarded relative to the ambient ground-water flow velocity within the aquifer.

5.3.4 Aquifer Characteristics

In the absence of site-specific data to input, default distributions of correlated values can be used in EPACMTP for the following aquifer characteristics:

1. Depth to ground water;
2. Saturated zone thickness;
3. Saturated zone hydraulic conductivity; and
4. Saturated zone hydraulic gradient.

These default distributions are derived from the Hydrogeologic Database for Ground-Water Modeling (HGDB), assembled by Rice University on behalf of the American Petroleum Institute (API) (Newell et al., 1990). The data in this hydrogeological database were collected by independent investigators for approximately 400 hazardous waste sites throughout the United States; the geographical locations of these sites are shown in Figure 5.2 (p. 5-37). In the HGDB, the data are grouped into twelve subsurface environments, which are based on EPA's DRASTIC classification of hydrogeologic settings (U.S. EPA, 1985). Table 5.19 lists these hydrogeologic environments, and a brief description of each environment is presented in Section 5.3.4.2. Table 5.19 includes a total of 13 categories; 12 are distinct subsurface environments, while the 13th category, which is labeled "other" or "unknown", was used for waste sites that could not be classified into one of the first 12 environments. The subsurface parameter values in this 13th category are simply averages of the parameter values in the 12 actual subsurface environments. The resulting database of aquifer types, with each aquifer type consisting of an empirical distribution of values for each of the four aquifer parameters, is presented in its entirety in Appendix D.

Table 5.19 HGDB Hydrogeologic Environments (from Newell et al., 1990)

Region	Description
1	Metamorphic and Igneous
2	Bedded Sedimentary Rock
3	Till Over Sedimentary Rock
4	Sand and Gravel
5	Alluvial Basins Valleys and Fans
6	River Valleys and Flood Plains with Overbank Deposits
7	River Valleys and Flood Plains without Overbank
8	Deposits
9	Outwash
10	Till and Till Over Outwash
11	Unconsolidated and Semi-consolidated Shallow
12	Aquifers
13	Coastal Beaches
	Solution Limestone
	Other (Not classifiable)

The key feature of this database is that it provides a set of correlated values of the four parameters for each of the 400 sites in the database. That is, the value of each parameter is associated with the three other subsurface parameters reported for the same site. The regional site-based modeling methodology in EPACMTP preserves these correlations because having information on some parameters allows us to develop more accurate estimates for missing parameter values. As described in Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), the regional site-based modeling methodology is an attempt to ensure that the combination of parameter values that are randomly generated by the Monte Carlo module of EPACMTP represents a realistic set of site conditions. This methodology is called ‘regional site-based’ because waste site databases are linked by each site’s geographic location and underlying aquifer type to regional databases of climatic and subsurface parameters, respectively. In this way, the regional site-based approach attempts to approximate the ideal situation where we have a complete set of the site-specific input data required to run the EPACMTP model for each waste site in a statistically valid subset of the universe of waste management units in the United States.

In developing the regional site-based modeling methodology in EPACMTP, the U.S. EPA used the HGDB in conjunction with a geographical classification of aquifers developed by the United States Geological Survey (Heath, 1984) to assign each waste site in our nationwide database of Subtitle D WMU’s (see Section 2.2) to one of the 13 subsurface environments included in the HGDB. For each type of WMU, we used information on its location (see Figures 2.2 - 2.5), in combination with USGS state-by-state aquifer maps to determine the type of subsurface environment at that site. Sites that could not be classified into one of the 12 categories were assigned as “other” (that is, they were assigned to environment number 13). The regional site-based modeling methodology in EPACMTP is then used to assign a probability distribution of hydrogeologic parameter values to each WMU location. This methodology is consistent with the methodology used to assign HELP-derived infiltration and recharge rates to each waste site in our nationwide database of Subtitle D WMU’s (see Section 4.2 and Appendix A).

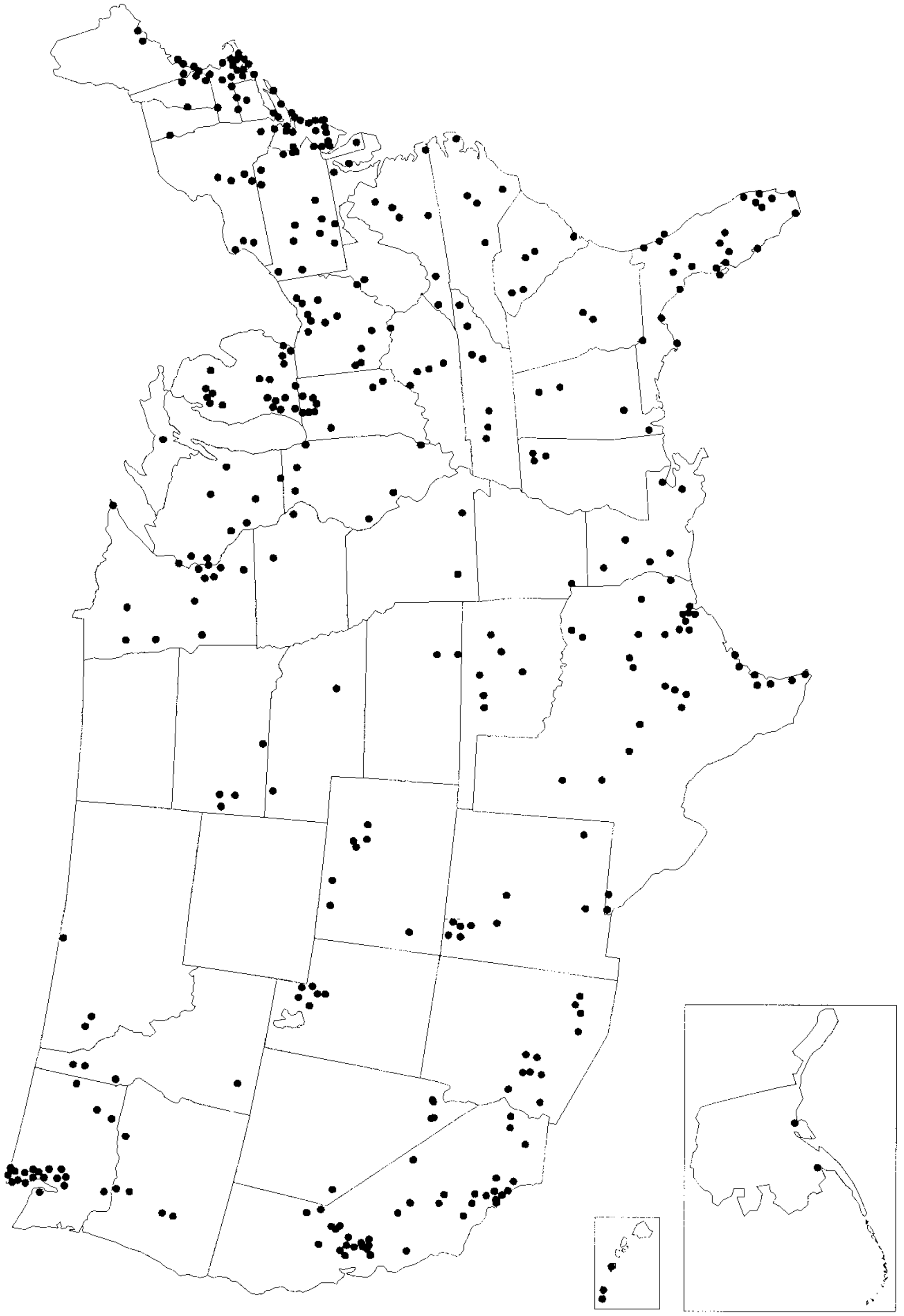

Figure 5.2 Geographical distribution of sites in the API-HGDB data base (Reproduced from API, 1989)

5.3.4.1 Methodology

Fundamentally, the approach used for a site-based Monte Carlo analysis consists of conducting the modeling analysis for the existing sites in our nationwide database of Subtitle D WMU's (see Section 2.2) on the assumption that these sites are an adequate representation of the universe of possible waste sites in the U.S. Since the original data sets (derived from the *1986 Subtitle D Survey* (U.S. EPA, 1986) and the *Surface Impoundment Study* (U.S. EPA, 2001a) only include the area, volume, location and relative weight of the facility, other data sources were utilized to determine the additional input parameters required by the EPACMTP model.

As summarized above, the ground-water parameter values are generated using the existing WMU parameter databases (which assign each waste site to a climate region and a hydrogeologic environment) together with the HGDB database of hydrogeologic parameters and the databases of HELP-derived infiltration and recharge rates. These databases are all included in an auxiliary input file called the site data file. The following is a description of how the regional, site-based modeling methodology is used to generate these hydrogeologic parameter values during the course of a typical Monte Carlo analysis for nationwide assessment purposes:

- For each Monte Carlo realization, EPACMTP selects a WMU site, at random, from the database of WMU sites. The original databases of WMU sites from which the data in the site data file were compiled included the facility location, area and volume. The EPACMTP model samples the sites in the site data files with replacement, i.e., the same site may be selected more than once. The probability of selecting a specific site depends on the relative weight assigned to that site in the original survey. Note that even if the same site is sampled more than once during the course of a Monte Carlo analysis in EPACMTP, the specific values of infiltration rate, hydrogeologic parameters, and receptor well location will still vary; likewise, the resulting receptor well concentration value will change, as well.

- Given the waste site's geographic location, the climatic region in which the site is located was identified and added to the WMU site database in the EPACMTP site data file. For landfills, waste piles, and land application units, the climatic region, the generated soil type, and the liner design (if any) are then used by the model to determine the infiltration rate of the site. In the no-liner and single-clay liner scenarios, these infiltration rates are determined using the database of rates generated with the HELP water balance model. For the composite liner scenario, these infiltration rates are internally calculated by the model using the relationships described in Sections 4.3.1 and 4.3.2. For surface impoundments (all liner scenarios), the infiltration rates are internally calculated by the model using the relationships described in Sections 4.3.4. For all WMU types, the climatic region and the generated soil type are used by the model to determine the ambient regional recharge rate of the site.

- Given the waste site's geographic location, the aquifer underlying the site was classified (using USGS state ground-water resources inventory maps) and added to the WMU site database in the EPACMTP site data file. The hydrogeologic parameters for the site are determined by selecting at random a set of aquifer characteristics (depth to ground water, aquifer thickness, hydraulic gradient, and hydraulic conductivity) from those available in the HGDB database for that hydrogeologic environment. In the case where the selected set of aquifer characteristics has missing values, a joint probability distribution (derived for each ground-water region) is used to generate the missing value as a function of the known values.

- The remaining parameters for the waste site (e.g., x, y and z coordinates of the receptor well) are generated according to their specifications in the input file. The ground-water flow and transport modules are then used to compute the resulting receptor well concentration for the site.

- These steps are then repeated for the desired number of iterations to yield a distribution of receptor well concentrations which represent the nationwide distribution of drinking water exposure concentrations. These modeling results can then be directly used in a forward risk calculation, or they can be post-processed to yield the ground-water dilution-attenuation factor (DAF) that can be used in a backward risk calculation to calculate an allowable threshold for the waste or leachate concentration.

5.3.4.2 Hydrogeologic Environment (IGWR)

Definition

The different hydrogeologic environments are represented in EPACMTP by means of a numerical index. The hydrogeologic environment index is simply a sequential number assigned to each hydrogeologic environment in the default database included with EPACMTP in order to provide a simple means of specifying which correlated set of aquifer characteristics should be used to model the given WMU site.

Parameter Value or Distribution of Values

To perform a standard Monte Carlo analysis using the regional site-based modeling methodology, the hydrogeologic environment index should be left in its default setting which will ensure that the appropriate climatic data is used for each WMU site in the database. However, if a location-adjusted or a quasi-site-specific analysis is being performed, then this input can either be omitted from the input file (if site-specific infiltration and recharge rates are available) or set to the appropriate constant value to make use of the default set of aquifer characteristics which are included in the site data file.

The text boxes on the following pages provide a summary of the characteristics of each hydrogeologic environment.

Hydrogeologic Environment Descriptions

1) Igneous and Metamorphic Rocks
This hydrogeologic environment is underlain by consolidated bedrock of volcanic origin. This hydrogeologic environment setting is typically associated with steep slopes on the sides of mountains, and a thin soil cover. Igneous and metamorphic rocks generally have very low porosities and permeabilities This hydrogeologic environment can occur throughout the United States, but is most prevalent in the western US.

2) Bedded Sedimentary Rock
Sedimentary rock is formed through erosion of bedrock. Deposited layers of eroded material may later be buried and compacted to form sedimentary rock. Generally, the deposition is not continuous but recurrent, and sheets of sediment representing separate events come to form distinct layers of sedimentary rock. Typically, these deposits are very permeable and yield large quantities of ground water. Examples of this hydrogeologic environment setting are found throughout the United States.

3) Till Over Sedimentary Rock
This hydrogeologic environment is found in glaciated regions in the northern United States which are frequently underlain by relatively flat-lying consolidated sedimentary bedrock consisting primarily of sandstone, shale, limestone, and dolomite. The bedrock is overlain by glacial deposits which consist chiefly of till, a dense unsorted mixture of soil and rock particles deposited directly by ice sheets. Ground water occurs both in the glacial deposits and in the sedimentary bedrock. Till deposits often have low permeability.

4) Sand and Gravel
Sediments are classified into three categories based upon their relative sizes; gravel, consisting of particles that individually may be boulders, cobbles or pebbles; sand, which may be very coarse, coarse, medium, fine or very fine; and mud, which may consist of clay and various size classes of silt. Sand and gravel hydrogeologic environments are very common throughout the United States and frequently overlie consolidated and semi-consolidated sedimentary rocks. Sand and gravel aquifers have very high permeabilities and yield large quantities of ground water.

5) Alluvial Basins, Valleys and Fans
Thick alluvial deposits in basins and valleys bordered by mountains typify this hydrogeologic environment. Alluvium is a general term for clay, silt, sand and gravel that was deposited during comparatively recent geologic time by a stream or other body of running water. The sediments are deposited in the bed of the stream or on its flood plain or delta, or in fan shaped deposits at the base of a mountain slope. Alluvial basins, valleys and fans frequently occupy a region extending from the Puget Sound-Williamette Valley area of Washington and Oregon to west Texas. This region consists of alternating basins or valleys and mountain ranges. The surrounding mountains, and the bedrock beneath the basins, consist of granite and metamorphic rocks. Ground water is obtained mostly from sand and gravel deposits within the alluvium. These deposits are interbedded with finer grained layers of silt and clay.

6) River Alluvium with Overbank Deposits
This hydrogeologic environment is characterized by low to moderate topography and thin to moderately thick sediments of flood-deposited alluvium along portions of a river valley. The alluvium is underlain by either unconsolidated sediments or fractured bedrock of sedimentary or igneous/metamorphic origin. Water is obtained from sand and gravel layers which are interbedded with finer grained alluvial deposits. The alluvium typically serves as a significant source of water. The flood plain is covered by varying thicknesses of fine-grained silt and clay, called overbank deposits. The overbank thickness is usually greater along major streams and thinner along minor streams but typically averages 5 to 10 feet.

Hydrogeologic Environment Descriptions (continued)

7) River Alluvium without Overbank Deposits
This hydrogeologic environment is identical to the River Alluvium with Overbank Deposits environment except that no significant fine-grained flood plain deposits occupy the stream valley. The lack of fine grained deposits may result in significantly higher recharge in areas with ample precipitation.

8) Outwash
Sand and gravel removed or "washed out" from a glacier by streams is termed outwash. This hydrogeologic environment is characterized by moderate to low topography and varying thicknesses of outwash that overlie sequences of fractured bedrock of sedimentary, metamorphic or igneous origin. These sand and gravel outwash deposits typically serve as the principal aquifers within the area. The outwash also serves as a source of regional recharge to the underlying bedrock.

9) Till and Till Over Outwash
This hydrogeologic environment is characterized by low topography and outwash materials that are covered by varying thicknesses of glacial till. The till is principally unsorted sediment which may be interbedded with localized deposits of sand and gravel. Although ground water occurs in both the glacial till and in the underlying outwash, the outwash typically serves as the principal aquifer because the fine grained deposits have been removed by streams. The outwash is in direct hydraulic connection with the glacial till and the glacial till serves as a source of recharge for the underlying outwash.

10) Unconsolidated and Semi-consolidated Shallow Surficial Aquifers
This hydrogeologic environment is characterized by moderately low topographic relief and gently dipping, interbedded unconsolidated and semi-consolidated deposits which consist primarily of sand, silt and clay. Large quantities of water are obtained from the surficial sand and gravel deposits which may be separated from the underlying regional aquifer by a low permeability or confining layer. This confining layer typically "leaks", providing recharge to the deeper zones.

11) Coastal Beaches
This hydrogeologic environment is characterized by low topographic relief, near sea-level elevation and unconsolidated deposits of water-washed sands. The term beach is appropriately applied only to a body of essentially loose sediment. This usually means sand-size particles, but could include gravel. Quartz particles usually predominate. These materials are well sorted, very permeable and have very high potential infiltration rates. These areas are commonly ground-water discharge areas although they can be very susceptible to the intrusion of saltwater.

12) Solution Limestone
Large portions of the central and southeastern United States are underlain by limestones and dolomites in which the fractures have been enlarged by solution. Although ground water occurs in both the surficial deposits and in the underlying bedrock, the limestones and dolomites, which typically contain solution cavities, generally serve as the principal aquifers. This type of hydrogeologic environment is often described as "karst."

13) Unknown Environment
If the subsurface hydrogeological environment is unknown, or it is different from any of the twelve main types used in EPACMTP, select the subsurface environment as Type 13. In this case, EPACMTP will assign values of the hydrogeological parameters (depth to ground water, saturated zone thickness, saturated zone hydraulic conductivity, and saturated zone hydraulic gradient) that are simply national average values.

Data Sources

In the absence of site-specific data, default distributions of values can be used for the following aquifer characteristics: depth to ground water and aquifer thickness, hydraulic conductivity, and hydraulic gradient. These default distributions are derived from the Hydrogeologic Database for Ground-Water Modeling (HGDB), assembled by Rice University on behalf of the American Petroleum Institute (API) (Newell et al., 1990) and are linked to the WMU sites in the site data file using the hydrogeologic environment index.

Use In EPACMTP

EPACMTP includes a database of aquifer characteristics for 13 hydrogeologic environments. The hydrogeologic environment index is a sequential number assigned to each hydrogeologic environment in the default database included with EPACMTP in order to provide a simple means of specifying which correlated set of aquifer characteristics should be used to model the given WMU site using the regional site-based modeling methodology.

5.3.4.3 Saturated Zone Thickness (B)

Definition

The saturated zone thickness is the vertical thickness of the zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. In an unconfined aquifer such as that simulated by the EPACMTP model, the water table is at the top of the saturated zone. Usually the base of the saturated zone is an impermeable layer, e.g., bedrock.

Parameter Value or Distribution of Values

If site-specific data are available, then the saturated zone thickness can be specified in the input file as a constant value or an empirical or statistical distribution of values. In this case, if your site has a highly stratified hydrogeology, it may be difficult to precisely define the “base of the aquifer,” but the stratification may effectively limit the vertical plume travel distance, so it may be appropriate to enter the maximum vertical extent of the plume as an “effective” saturated zone thickness.

Lacking site-specific data, a default distribution of saturated zone thickness values may be used as part of the regional site-based modeling methodology. As described in Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), the regional site-based modeling methodology is an attempt to ensure that the combination of parameter values that is randomly generated by the Monte Carlo module of EPACMTP represents a realistic set of site conditions. The cumulative frequency distribution of saturated zone thickness listed in Table 5.20 was generated by performing a default landfill modeling analysis using the regional site-based modeling methodology; the entire Hydrogeologic Database for Modeling (HGDB) from which these values were derived is presented in Appendix D. For a given percentile (%) frequency and value pair in Table 5.20, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.20 Cumulative Frequency Distribution of Saturated Zone Thickness

%	Saturated Zone Thickness (m)
0	3.05E-01
10	4.27E+00
25	7.62E+00
50	1.43E+01
75	3.24E+01
80	4.83E+01
85	6.66E+01
90	9.14E+01
95	1.52E+02
100	9.14E+02

Data Sources

In the regional site-based Monte Carlo analysis used for nationwide modeling applications, the distribution of values for the thickness of the saturated zone is produced through Monte Carlo sampling of the HGDB, based on the hydrogeologic environment assigned to the waste site selected (from the default database) for each model realization. The HGDB (Newell et al., 1990; U.S. EPA, 1997d) is an empirical database of aquifer characteristics developed from a survey of hazardous waste sites in the United States that provides data on hydrogeologic parameters (aquifer thickness, unsaturated zone thickness, hydraulic gradient and hydraulic conductivity) that are required by the EPACMTP model. The HGDB from which the values shown in Table 5.20 were derived is presented in its entirety in Appendix D.

In a location-specific modeling analysis, saturated zone thickness must be derived from a site-specific data source and specified in the input file as a constant value or an empirical or statistical distribution of values.

Use In EPACMTP

The thickness of the saturated zone is an input to the saturated zone flow module. It is used in EPACMTP to describe the thickness of the ground-water zone over which the leachate plume can mix with ground water and impacts the dilution rates in the saturated zone.

5.3.4.4 Hydraulic Conductivity (K)

Definition

Hydraulic conductivity is a measure of the ability to transmit water under a unit hydraulic gradient.

Parameter Value or Distribution of Values

If site-specific data are available, then the hydraulic conductivity can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of hydraulic conductivity values may be used as part of the regional site-based modeling methodology. As described in Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), the regional site-based modeling methodology is an attempt to ensure that the combination of parameter values that is randomly generated by the Monte Carlo module of EPACMTP represents a realistic set of site conditions. The cumulative frequency distribution of hydraulic conductivity listed in Table 5.21 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology; the entire Hydrogeologic Database for Modeling (HGDB) from which these values were derived is presented in Appendix D. For a given percentile (%) frequency and value pair in Table 5.21, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.21 Cumulative Frequency Distribution of Hydraulic Conductivity

%	Hydraulic Conductivity (m/yr)
0	3.15E+00
10	1.73E+02
25	8.04E+02
50	1.89E+03
75	1.10E+04
80	1.39E+04
85	2.21E+04
90	3.15E+04
95	7.48E+04
100	4.29E+06

Alternatively, the hydraulic conductivity can be specified as a derived parameter. In this case it is calculated within EPACMTP from the particle diameter using the Kozeny-Carman equation (Bear, 1979) shown below:

$$K = \frac{\rho g}{\mu} \frac{\phi^2}{(1-\phi^2)} \frac{d^2}{1.8} \tag{5.7}$$

where:

K = hydraulic conductivity (cm/s)
ρ = density of water (kg/m^3)
g = acceleration due to gravity (m/s^2)
μ = dynamic viscosity of water (N-s/m^2)
d = mean particle diameter (m)
ϕ = total porosity of the aquifer material (dimensionless)

In Equation 5.7 shown above, the constant 1.8 includes a unit conversion factor to yield K in units of cm/s. Both the density and the dynamic viscosity of water are functions of temperature and are computed using the regression equations presented in CRC (1981).

Data Sources

In the regional site-based Monte Carlo analysis used for nationwide modeling applications, the distribution of values for the hydraulic conductivity is produced through Monte Carlo sampling of the HGDB, based on the hydrogeologic environment assigned to the waste site selected (from the default database) for each model realization. The HGDB (Newell et al., 1990; U.S. EPA, 1997d) is an empirical database of aquifer characteristics developed from a survey of hazardous waste sites in the United States that provides data on hydrogeologic parameters (aquifer thickness, unsaturated zone thickness, hydraulic gradient and hydraulic conductivity) that are required by the EPACMTP model. The HGDB from which the values shown in Table 5.21 were derived is presented in its entirety in Appendix D.

If specified as a derived parameter, the aquifer hydraulic conductivity is calculated from the mean particle diameter using the Kozeny-Carman equation (Bear, 1979).

In a location-specific modeling analysis, hydraulic conductivity must be derived from a site-specific data source and specified in the input file as a constant value or an empirical or statistical distribution of values.

Use In EPACMTP

The aquifer hydraulic conductivity is an input to the saturated zone flow module. The hydraulic conductivity, together with the hydraulic gradient, controls the ground-water flow rate. Assigning a low hydraulic conductivity value will not necessarily result in lower predicted ground-water exposures. In a broader sense, it means that siting a WMU in a low permeability aquifer setting is not always more protective than a high permeability setting. Low ground-water velocity means that it will take longer for the exposure to occur, and as a result, there is more opportunity for natural attenuation to degrade contaminants. However, for long-lived waste constituents, it also means that little dilution of the plume may occur.

5.3.4.5 Regional Hydraulic Gradient (r)

Definition

Hydraulic gradient measures the head difference between two points as a function of their distance. For an unconfined aquifer such as that modeled with EPACMTP, the hydraulic gradient is simply the slope of the water table in a particular direction. It is calculated as the difference in the elevation of the water table measured at two locations divided by the distance between the two locations. In EPACMTP, this parameter represents the average horizontal ground-water gradient in the vicinity of the WMU location. The gradient is meant to represent the ‘natural’ ground-water gradient as it is, or would be, without influence from the WMU. The presence of a WMU, particularly a surface impoundment, may cause local mounding of the water table and associated higher local ground-water gradients. The EPACMTP model assumes that the gradient value specified in the input file does not include mounding; rather, the model will calculate the predicted impact on the ground water of the WMU and liner design (if any) as part of the modeling evaluation.

Parameter Value or Distribution of Values

If site-specific data are available, then the regional hydraulic gradient can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of regional hydraulic gradient values may be used as part of the regional site-based modeling methodology. As described in Section 5.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a), the regional site-based modeling methodology is an attempt to ensure that the combination of parameter values that is randomly generated by the Monte Carlo module of EPACMTP represents a realistic set of site conditions. The cumulative frequency distribution of regional hydraulic gradient listed in Table 5.22 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology; the entire Hydrogeologic Database for Modeling (HGDB) from which these values were derived is presented in Appendix D. For a given percentile (%) frequency and value pair in Table 5.22, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.22 Cumulative Frequency Distribution of Regional hydraulic gradient

%	Regional Hydraulic Gradient (unitless)
0	2.00E-06
10	9.00E-04
25	2.00E-03
50	5.70E-03
75	1.51E-02
80	2.00E-02
85	2.46E-02
90	3.10E-02
95	4.90E-02
100	4.91E-01

Data Sources

In the regional site-based Monte Carlo analysis used for nationwide modeling applications, the distribution of values for the regional hydraulic gradient is produced through Monte Carlo sampling of the HGDB, based on the hydrogeologic environment assigned to the waste site selected (from the default database) for each model realization. The HGDB (Newell et al., 1990; U.S. EPA, 1997d) is an empirical database of aquifer characteristics developed from a survey of hazardous waste sites in the United States that provides data on hydrogeologic parameters (aquifer thickness, unsaturated zone thickness, hydraulic gradient and hydraulic conductivity) that are required by the EPACMTP model. The HGDB from which the values shown in Table 5.22 were derived is presented in its entirety in Appendix D.

In a location-specific modeling analysis, regional hydraulic gradient must be derived from a site-specific data source and specified in the input file as a constant value or an empirical or statistical distribution of values.

Use In EPACMTP

The hydraulic gradient and the hydraulic conductivity (see Section 5.3.4.4) are inputs to the saturated zone flow module, and together they control the ground-water flow rate, in accordance with Darcy's Law. The effect of varying ground-water flow rate on contaminant fate and transport is complex. Intuitively, it would seem that factors that increase the ground-water flow rate would cause a higher ground-water exposure level at the receptor well, but this is not always the case. A higher ground-water velocity will cause leachate constituents to arrive at the well location more quickly. For constituents that are subject to degradation in ground water, the shorter travel time will cause the constituents to arrive at the well at higher concentrations as compared to a case of low ground-water velocity and long travel times. On the other hand, a high ground-water flow rate will tend to increase the degree of dilution of the leachate plume, due to mixing and dispersion. This will in turn tend to lower the magnitude of the concentrations reaching the well. The modeling scenario evaluated in EPACMTP is based on the maximum constituent concentrations at the well (either a peak concentration or the maximum time-averaged concentration), rather than how long it might take for that exposure to occur. Therefore, a higher ground-water flow rate may result in lower predicted exposure levels at the well.

5.3.5 Seepage Velocity (V_x)

Definition

Seepage velocity is the average linear velocity of a water particle in a ground water system. It is equal to the Darcy velocity divided by effective porosity.

Parameter Value or Distribution of Values

The ground-water seepage velocity is related to the aquifer properties through Darcy's law. The regional seepage velocity may be input directly, as a constant value or a distribution of values. If site specific data are not available, it may be specified in the input file as a derived parameter. In this case, it is computed as:

$$V_x = \frac{K_x}{\phi_e} r \tag{5.8}$$

where

V_x = longitudinal ground water seepage velocity (in the x-direction) (m/yr)
K_x = longitudinal hydraulic conductivity (in the x-direction) (m/yr)
r = regional hydraulic gradient (dimensionless)
ϕ_e = effective porosity (dimensionless)

Default lower and upper bounds for the seepage velocity are 0.1 and $1.1\text{x}10^4$ m/yr, respectively. This range of values is based on survey data reported by Newell et al (1990).

The cumulative frequency distribution for the seepage velocity listed in Table 5.23 was generated by performing a default nationwide landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.23 Cumulative Frequency Distribution of Ground-water Seepage Velocity

%	Seepage Velocity (m/yr)
0	2.17E+00
10	5.99E+00
25	5.11E+00
50	4.08E+01
75	6.73E+02
80	4.02E+02
85	2.53E+00
90	6.57E+00
95	2.27E+00
100	4.13E+01

Data Sources

In the regional site-based Monte Carlo analysis that is typically used for nationwide modeling applications, the seepage velocity is, by default, internally derived using the correlated values for hydraulic conductivity and gradient that are produced through Monte Carlo sampling of the HGDB, based on the hydrogeologic environment assigned to the waste site selected for each model realization. The default lower and upper bounds for this input are based on survey data reported by Newell et al (1990).

If specified as a derived parameter, the regional ground-water seepage velocity is calculated from the hydraulic conductivity and gradient, and the aquifer porosity using Equation 5.8 with upper and lower bounds based on survey data reported by Newell et al (1990).

In a location-adjusted or quasi-site-specific modeling analysis, the site-specific hydraulic gradient must be derived from a site-specific data source and specified in the input file as a constant value or an empirical or statistical distribution of values.

Use In EPACMTP

The seepage velocity that is provided as an EPACMTP input parameter represents ambient ground water flow conditions, that is, without the WMU present. The EPACMTP saturated zone flow module calculates the final distribution of seepage velocities in the model domain, taking into account infiltration from the WMU. These calculated seepage velocities are then used in the saturated zone transport module to simulate the fate and transport of leachate constituents.

5.3.6 Anisotropy Ratio (A_r)

Definition

The anisotropy ratio is a factor used to specify the relationship between the horizontal and vertical aquifer hydraulic conductivities. It is defined as the ratio of the horizontal hydraulic conductivity to the vertical hydraulic conductivity.

Parameter Value or Distribution of Values

Although the aquifer properties are assumed to be uniform, the EPACMTP model can accommodate the situation where the horizontal and vertical aquifer hydraulic conductivities are different. The anisotropy ratio is a factor used to specify the relationship between these two hydraulic conductivity values and is defined according to the following equation:

$$A_r = K_x / K_z \tag{5.9}$$

where:

A_r = anisotropy ratio = K_x/K_z.
K_x = hydraulic conductivity in the x direction (m/yr)
K_z = hydraulic conductivity in the z direction (m/yr)

The default value of A_r is 1, which indicates an isotropic system. Note that in the EPACMTP model, the horizontal transverse hydraulic conductivity is assumed to be equal to the horizontal longitudinal conductivity, i.e., $K_y = K_x$.

Data Sources

Because anisotropy ratios observed in the field may commonly be on the order of 100:1 or even larger (Freeze and Cherry, 1979), a uniform distribution of A_r with limits of 1 and 100 may be reasonable for some applications of the model. However, for nationwide assessment purposes, the default value of A_r is 1, which indicates an isotropic system.

Use In EPACMTP

The anisotropy ratio is used to estimate the vertical conductivity from the horizontal conductivity. However, by default, the vertical conductivity is set equal to the horizontal conductivity. The horizontal and vertical conductivities are inputs to the saturated zone flow module.

5.3.7 Retardation Coefficient for the Saturated Zone (R^s)

Definition

The retardation coefficient is a measure of the degree to which contaminant velocities are retarded relative to that of the bulk mass of ground water within the aquifer. A value of 1.0 indicates that the constituent is conservative; in other words, it is not subject to adsorption and travels at the same speed as the bulk mass of ground-water. Values greater than 1.0 indicate that the constituent transport is retarded due to adsorption.

Parameter Value or Distribution of Values

In most modeling applications using EPACMTP, the retardation coefficient is specified as a derived variable; however, if site-specific data are available, this input parameter can be set to a constant value or a distribution of values.

For constituents modeled with a linear adsorption isotherm (typically, organics and metals modeled with a pH-dependent isotherm or a constant k_d value), when the retardation coefficient is specified as a derived variable in the EPACMTP input file, it is calculated according to the following equation:

$$R^s = 1 + \frac{\rho_b K_d}{\phi} \qquad (5.10)$$

where

R^s = retardation coefficient for the saturated zone (dimensionless)
ρ_b = bulk density of the porous media [g/cm^3]
k_d = distribution coefficient [cm^3/g]
ϕ = porosity

For constituents modeled with a nonlinear adsorption isotherm (that is, R^s is no longer constant but is a function of metal concentration), R^s must be specified in the input file as a derived variable and the K_d-concentration relation must be specified by the user in one of two ways: 1) in terms of the two Freundlich parameters (k_1 and η; see Sections 5.3.12 and 5.3.13); or 2) in terms of the tabulated MINTEQA2-derived isotherms (see Section 3.3.3.2).

For the modeling of metals, the EPACMTP user has three options for specifying the relationship between dissolved and adsorbed concentrations: 1) MINTEQA2-derived non-linear isotherms, 2) pH-dependent empirical isotherms, or 3) an empirical distribution of values. In the case of the first option, the non-linear isotherm is only used in the unsaturated zone; a linear sorption isotherm (e.g., an effective K_d value) is used for the saturated zone. This effective K_d value is determined from the maximum contaminant concentration at the water table and values of the five environmental master variables (pH, iron-oxide, leachate organic matter, natural organic matter in the aquifer, and ground water environment type (carbonate or non-carbonate)), following the procedure described in Appendix B.

Data Sources

Lacking site-specific data, Equation 5.10 is used to calculate the retardation coefficient for constituents that are modeled using a linear adsorption isotherm. For constituents modeled with a non-linear adsorption isotherm, the effective retardation coefficient is calculated inside EPACMTP, based upon the nonlinear concentration-K_d relationship as given by MINTEQA2-derived isotherms.

Use In EPACMTP

The retardation coefficient is an input to the saturated zone transport module.

5.3.8 Dispersivity

The transport of the contaminant plume in the saturated zone is controlled by two mechanisms: advection and dispersion. The EPACMTP saturated zone flow module simulates both of these mechanisms. Dispersion is the phenomenon by which a constituent plume in flowing ground water is mixed with uncontaminated water and becomes reduced in concentration at the perimeter of the plume. Not all of a contaminant plume is traveling at the same velocity due to differences in pore size and flow path length and friction along pore walls, resulting in mixing along the flow path which decreases solute concentrations. Note that the saturated zone dispersivity is measured in three directions: longitudinal (along the flow path, or in the x-direction), horizontal transverse (perpendicular to the flow path, or in the y-direction), and vertical (in the z-direction).

The model computes the longitudinal, horizontal transverse, and vertical dispersion coefficients as the product of the seepage velocity and longitudinal (α_L), transverse (α_T) and vertical (α_V) dispersivities. A literature review indicated the absence of a generally accepted theory to describe dispersivities, although a strong dependence on scale has been noted (EPRI, 1985; Gelhar, Welty, and Rehfeldt, 1992). In the absence of user-specified values or distributions, the longitudinal dispersivity is represented through a probabilistic formulation and the horizontal transverse and vertical dispersivities are, by default, calculated from the longitudinal dispersivity, as described below.

For non-degrading contaminants, the dilution caused by dispersive mixing is a controlling factor in determining the concentration observed at a receptor well. However, in Monte Carlo analyses involving varying well location, the predicted maximum well concentration is relatively insensitive to dispersion. The reason for this is as follows: low dispersivities will lead to a compact, concentrated plume. If the plume is relatively small, the likelihood that the receptor well will intercept the plume is reduced, but the concentration in the well, if it does, will be high. High dispersivities will lead to a more dilute plume which occupies a greater volume, thereby increasing the likelihood that a receptor well will intercept the plume. Concentrations in the plume, however, are likely to be lower than in the first case. In the course of a full Monte Carlo analysis, these effects will tend to compensate for each other.

5.3.8.1 Longitudinal Dispersivity (α_L)

Definition

Dispersion is the phenomenon by which a contaminant plume in flowing ground water is mixed with uncontaminated water and becomes reduced in concentration at the perimeter of the plume. The longitudinal dispersivity is the characteristic length that defines spatial extent of dispersion of contaminants, measured in the longitudinal direction, that is, along the flow path or in the x-direction.

Parameter Value or Distribution of Values

If site-specific data are available, then the longitudinal dispersivity can be specified in the input file as a constant value or an empirical or statistical distribution of values.

In the absence of site-specific data, the longitudinal dispersivity is, by default, represented through a probabilistic formulation as shown in Table 5.24, and the horizontal transverse and vertical dispersivities are then calculated from the longitudinal dispersivity. The distribution shown in Table 5.24 is based on data presented in EPRI (1985). For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column. Within each of the three classes shown in Table 5.24, the longitudinal dispersivity is assumed to be uniform. Note that the values of longitudinal dispersivity in this table are based on a receptor well distance of 152.4 m. For distances other than 152.4 m, the following equations are used:

$$\alpha_L(x_t) = \alpha_{Ref}(x_t = 152.4)\,(x_t / 152.4)^{0.5} \tag{5.11}$$

where:

$$x_t = 0.5\, x_w + x_r \tag{5.12}$$

α_L = longitudinal dispersivity (m)
x_t = average travel distance in the x direction (m)
x_w = length of the WMU in the x-direction (parallel to ground water flow) (m)
x_{rw} = distance from the downgradient boundary of the WMU to the receptor well (m)
α_{Ref} = reference longitudinal dispersivity, as determined from the probabilistic distribution (m)

Table 5.24 Probabilistic representation of longitudinal dispersivity

%	α_L (m)*
0	0.1
10	1.0
70	10.0
100	100.0

*Assumes x_t = 152.4 m (see Equation 5.11)

In other words, the travel distance x_t is equal to the distance between the receptor well and the downgradient facility boundary (x_{rw}), plus one-half of the facility dimension. The average distance for all of the contaminants to migrate to the edge of the waste management unit is equal to one half the length of the unit or ½ x_w. The default minimum value of α_L is 0.1 m.

Table 5.25 lists the cumulative frequency distribution of longitudinal dispersivity that is generated in a default landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.25 Cumulative Frequency Distribution of Longitudinal Dispersivity

%	Longitudinal Dispersivity (m)
0	1.00E-01
10	1.22E+00
25	3.62E+00
50	8.96E+00
75	2.54E+01
80	4.32E+01
85	6.53E+01
90	9.21E+01
95	1.35E+02
100	3.18E+02

Data Sources

The relationship in Equation 5.11 was derived based on a professional review of data presented in EPRI (1985). More recently, Gelhar et al. (1992) have compiled and documented results from a large number of studies in which dispersivity values have been reported. These studies represent a wide range of spatial scales, from a few meters to more than 10,000 meters. The data as presented by Gelhar et al. (1992) show a clear correlation between scale and apparent dispersivity. Equation 5.11 used in EPACMTP describes the observed data reasonably well. The field data suggest a somewhat steeper slope of the distance-dispersivity relation on a log-log scale than is used in the modeling analyses. However, a sensitivity analysis performed using EPACMTP (HydroGeoLogic, 1992) has shown that the model results are virtually identical when the slope is varied from 0.5 to 1.5. For this reason the original relationship as shown in Equation 5.11 has been retained.

The data presented by Gelhar et al. (1992) also show that the ratios between longitudinal, and horizontal and vertical transverse dispersivities used in the nationwide modeling, are consistent with published data.

Use In EPACMTP

The longitudinal dispersivity is an input to the saturated zone transport module.

5.3.8.2 Horizontal Transverse Dispersivity (α_T)

Definition

Dispersion is the phenomenon by which a contaminant plume in flowing ground water is mixed with uncontaminated water and becomes reduced in concentration at the perimeter of the plume. The horizontal transverse dispersivity is the characteristic length that defines spatial extent of dispersion of contaminants, measured in the horizontal transverse direction, that is, perpendicular to the flow path, or in the y-direction.

Parameter Value or Distribution of Values

If site-specific data are available, then the horizontal transverse dispersivity can be specified in the input file as a constant value or an empirical or statistical distribution of values.

In the absence of site-specific data, the horizontal transverse dispersivity is, by default, calculated from the longitudinal dispersivity using the following equation:

$$\alpha_T = \alpha_L / 8 \tag{5.13}$$

where:

α_L = longitudinal dispersivity (m)
α_T = horizontal transverse dispersivity (m)

Note that in EPACMTP, the input value for α_T is actually the ratio of α_L to α_T. Although the user can define a different value for the ratio of the longitudinal to the transverse dispersivity, the ratio of $\alpha_L/\alpha_T = 8$ is used by default.

Table 5.26 lists the cumulative frequency distribution of horizontal transverse dispersivity that is generated in a default landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.26 Cumulative Frequency Distribution of Horizontal Transverse Dispersivity

%	Horizontal Transverse Dispersivity (m)
0	1.25E-02
10	1.53E-01
25	4.52E-01
50	1.12E+00
75	3.17E+00
80	5.40E+00
85	8.16E+00
90	1.15E+01
95	1.69E+01
100	3.97E+01

Data Sources

By default, the transverse (α_T) dispersivity is calculated by the EPACMTP model as a fraction of the longitudinal dispersivity. The dispersivity relationship described above has been derived based on a professional review of data presented in EPRI (1985). More recently, Gelhar et al. (1992) have compiled and documented results from a large number of studies in which dispersivity values have been reported. The data presented by Gelhar et al. (1992) show that this default ratio between longitudinal and horizontal transverse dispersivities is consistent with published data.

Use In EPACMTP

The horizontal transverse dispersivity is an input to the saturated zone transport module.

5.3.8.3 Vertical Dispersivity (α_v)

Definition

Dispersion is the phenomenon by which a contaminant plume in flowing ground water is mixed with uncontaminated water and becomes reduced in concentration at the perimeter of the plume. The vertical dispersivity is the characteristic length that defines spatial extent of dispersion of contaminants, measured vertically downward or in the z-direction.

Parameter Value or Distribution of Values

If site-specific data are available, then the vertical dispersivity can be specified in the input file as a constant value or an empirical or statistical distribution of values.

In the absence of site-specific data, the vertical dispersivity is, by default, calculated from the longitudinal dispersivity using the following equation:

$$\alpha_V = \alpha_L / 160 \qquad (5.14)$$

where:

α_L = longitudinal dispersivity (m)
α_V = vertical dispersivity (m)

Note that in EPACMTP, the input value for α_V is actually the ratio of α_L to α_V. Although the user can define a different value for the ratio of the longitudinal to the vertical dispersivity, the ratio of $\alpha_L/\alpha_V = 160$ is used by default.

Table 5.27 lists the cumulative frequency distribution of horizontal transverse dispersivity that is generated in a default landfill modeling analysis using the regional site-based modeling methodology. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.27 Cumulative Frequency Distribution of Vertical Dispersivity

%	Vertical Dispersivity (m)
0	1.00E-02
10	1.00E-02
25	2.26E-02
50	5.60E-02
75	1.58E-01
80	2.70E-01
85	4.08E-01
90	5.76E-01
95	8.45E-01
100	1.99E+00

Data Sources

By default, the vertical (α_V) dispersivity is calculated by the EPACMTP model as a fraction of the longitudinal dispersivity. The dispersivity relationship described above has been derived based on a review of available data. More recently, Gelhar et al. (1992) have compiled and documented results from a large number of studies in which dispersivity values have been reported. The data presented by Gelhar et al. (1992) show that this default ratio between longitudinal and vertical dispersivities is consistent with published data.

Use In EPACMTP

The vertical dispersivity is an input to the saturated zone transport module; dispersion in the saturated zone generally tends to decrease contaminant concentrations at the receptor well.

5.3.9 Aquifer Temperature (T)

Definition

The aquifer temperature is the long-term average temperature of the ground water within the aquifer. Note that although the temperature of the ground water within the vadose zone is not an explicit model input, this temperature is assumed by EPACMTP to be the same as that of the aquifer.

Parameter Value or Distribution of Values

As modeled in EPACMTP, aquifer temperature affects the transformation rate of constituents that are subject to hydrolysis, through the effect of temperature on reaction rates (see Section 3.3.2.2). In the development of the site data files for each WMU type, information on average annual temperatures in shallow ground-water systems (Todd, 1980) to assign a temperature value to each WMU in the modeling database, based on the unit's geographical location. For each WMU site, the assigned temperature was an average of the upper and lower values for that temperature region, as shown in Figure 5.3. In other words, all WMU's located in the band between 10° and 15° were assigned a temperature value of 12.5 °C.

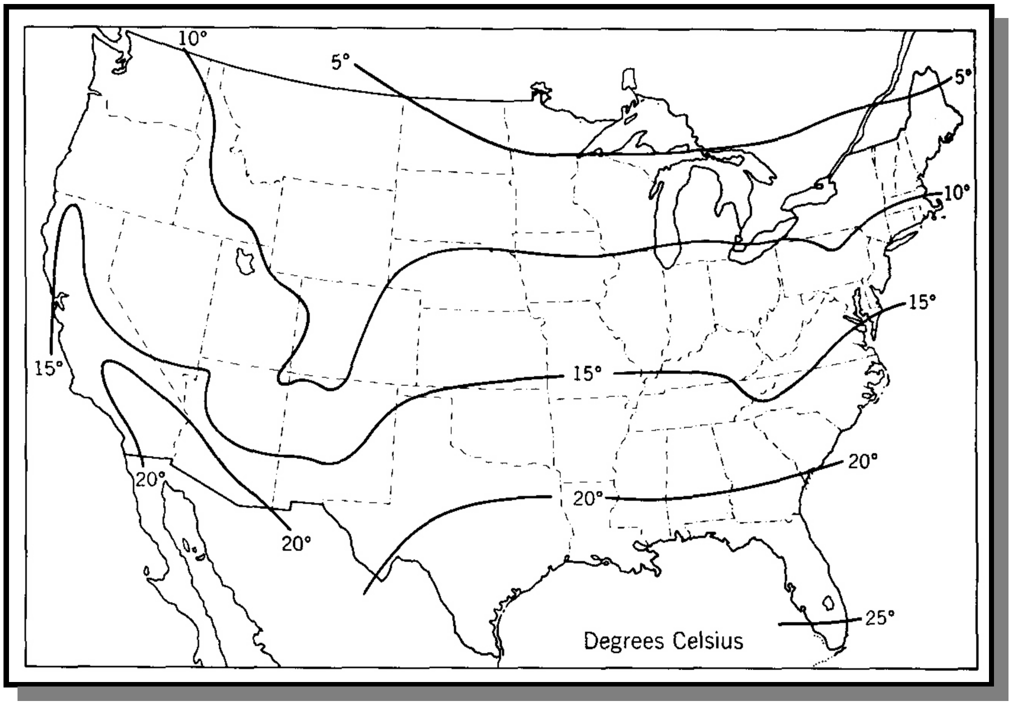

Figure 5.3 Ground-water Temperature Distribution for Shallow Aquifers in the United States (from Todd, 1980)

Data Sources

We used information on average annual temperatures in shallow ground-water systems from Todd (1980) to assign a temperature value to each WMU site in the site data files, based on the unit's geographical location.

Use In EPACMTP

When the EPACMTP model is run using the regional, site-based methodology, the model selects a site at random from those in the site data file for each Monte Carlo realization. For each WMU site, the ground-water temperature was assigned using the data from Todd, (1980) and the unit's geographical location.

In a location-adjusted modeling analysis, a site-specific ground-water temperature can be directly specified in the input file – either as constant value or as a statistical or empirical distribution of values.

The aquifer temperature associated with the modeled site and the specified hydrolysis rate constants are then used by the model to derive the appropriate temperature-dependent first-order hydrolysis rate for organic constituents. Note that although the temperature of the ground water within the vadose zone is not an explicit model input, the EPACMTP model assumes that the soil temperature is the same as that of the aquifer.

5.3.10 Ground-water pH (pH)

Definition

A measure of the acidity or alkalinity of the ground water, pH is measured on a scale of 0 to 14, with 7 representing a neutral state. Values less than 7 are acidic, and values greater than 7 are basic. pH is calculated as the negative logarithm of the concentration of hydrogen ions in a solution. For modeling purposes, the EPACMTP model assumes subsurface pH value is the same in the unsaturated zone and saturated zone.

Parameter Value or Distribution of Values

If site-specific data are available, then the ground-water pH can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of pH values may be used. This pH distribution was obtained through analysis of nearly 25,000 field-measured pH values of uncontaminated ground water obtained from EPA's STORET database (U.S. EPA, 1996). The data are represented by an empirical distribution with low and high values of 3.2 and 9.7, respectively and a median value of 6.8. Because the STORET database has unrealistic extreme values (presumably from errors in instrument calibration or reading, or in data entry), the upper and lower bounds of the distribution were established by reference to reported values in the open literature. The resulting pH distribution is shown in Table 5.28. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.28 Probability distribution of aquifer pH

%	Ground-water pH (standard units)
0	4.32E+00
10	7.49E+00
25	7.30E+00
50	8.91E+00
75	7.84E+00
80	7.43E+00
85	4.65E+00
90	7.42E+00
95	5.74E+00
100	4.87E+00

Note that these values generated for the ground-water pH is assumed to apply to the unsaturated zone as well. The EPACMTP model assumes that the ground-water/aquifer system is well buffered with respect to pH. That is, in the modeling analysis, there is no effect on the ambient pH from the leachate emanating from the base of the WMU. Additionally, the generated pH value is assumed to apply to both the unsaturated zone and saturated zone.

Data Sources

The distribution of pH values shown in Table 5.28 was obtained through analysis of nearly 25,000 field measured pH values of uncontaminated ground water obtained from EPA's STORET database (U.S. EPA, 1996). Note that the upper and lower bounds of this distribution were established by reference to reported values in the open literature.

Use In EPACMTP

The ground-water pH is one of the most important subsurface parameters controlling the mobility of metals. Most metals are more mobile under acidic (low pH) conditions, as compared to neutral or alkaline (pH of 7 or higher) conditions. The pH may also affect the hydrolysis rate of organic constituents; some constituents degrade more rapidly or more slowly as pH varies. The pH of most aquifer systems is slightly acidic, the primary exception being aquifers in solution limestone settings. These may also be referred to as 'karst', 'carbonate' or 'dolomite' aquifers. The ground water in these systems is usually alkaline.

5.3.11 Fractional Organic Carbon Content (f_{oc}^{s})

Definition

The nature and amount of solid matter in the subsurface to which chemical constituents are attracted (the adsorbent) are important in determining the extent to which a constituent's transport through the ground-water pathway is retarded due to adsorption. Particulate organic matter present in the saturated zone (input to EPACMTP as fraction organic carbon) represents one of the dominant adsorbents for sorption of both organic and metal constituents in environmental systems and was one of the geochemical master variables used in the calculation of the non-linear sorption isotherms using the MINTEQA2 model.

Parameter Value or Distribution of Values

If site-specific data are available, then the fractional organic carbon content of the aquifer can be specified in the input file as a constant value or an empirical or statistical distribution of values.

Lacking site-specific data, a default distribution of values may be used. Unfortunately, few if any comprehensive subsurface characterizations of organic carbon content exist. In general, the reported values are low, typically less than 0.01. For the purposes of modeling organic constituents, a low range of values was assumed and the distribution shape was based on the distribution of measured dissolved organic carbon recorded in EPA's STORET data base. The default distribution for fractional organic carbon content is a Johnson SB distribution with a mean and standard deviation in arithmetic space of 4.32×10^{-4} and 0.0456, respectively and upper and lower limits of 0.064 and 0.0, respectively. In the case of metals, the sorption is controlled by complex geochemical interactions which are simulated using MINTEQA2 (see Section 3.3.3.2 and Appendix B), and this distribution of f_{oc} is not used.

A summary of this default distribution is presented in Table 5.29. For a given percentile (%) frequency and value pair in this table, the percentile denotes the relative frequency or likelihood of parameter values in the entire distribution being less than or equal to the corresponding parameter value in the right hand column.

Table 5.29 Probability distribution of fraction organic carbon in the saturated zone

%	Fractional Organic Carbon Content (unitless)
0	6.77E-04
10	4.11E-03
25	8.51E-04
50	1.10E-04
75	4.71E-04
80	7.82E-04
85	3.01E-04
90	9.99E-04
95	5.99E-04
100	7.93E-04

Data Sources

The default distribution for f_{oc} was derived based on professional judgement and the distribution shape was based on the distribution of measured dissolved organic carbon recorded in EPA's STORET database.

Use In EPACMTP

The organic carbon content, f_{oc}, is used to determine the linear distribution coefficient, K_d. This approach is valid only for organic contaminants containing hydrophobic groups since these constituents tend to sorb preferentially on non-polar natural organic compounds in the soil or aquifer. In the case of metals, the organic matter content in the subsurface is one of the controlling master variables used to develop the MINTEQA2-derived isotherms, and EPACMTP uses this organic matter content to select appropriate isotherms to use during the EPACMTP simulation process.

5.3.12 Leading Coefficient of Freundlich Isotherm for Saturated Zone (K_d^s)

Definition

The leading coefficient of the Freundlich isotherm is a constant used to describe the sorptive behavior of a constituent. When the sorption data are plotted as log C versus log S, the intercept of the resulting line is equal to log K^s. In the special case of a linear isotherm, the leading Freundlich coefficient is known as the linear solid-liquid phase distribution coefficient ($\mathbf{K_d^s}$) (commonly called the distribution coefficient).

Parameter Value or Distribution of Values

When modeling organic constituents with EPACMTP, the leading Freundlich coefficient is generally specified as a derived parameter in the input file. If derived, the leading Freundlich coefficient ($\mathbf{K_d^s}$) is automatically assumed linear and calculated by the model according to Equation 5.3b. In this case, f_{oc} is specified in the aquifer-specific input group according to Equation 5.2, and k_{oc} is a constituent-specific input value (see Section 3.3.2.1). However, if site-specific data are available, a constant value or distribution of values could be used for the leading Freundlich coefficient.

When modeling metals transport in the saturated zone with EPACMTP, the leading Freundlich coefficient can be specified as a constant value or as a distribution of values, either based on site-specific data or adsorption data reported in the scientific literature. Another option is to specify sorption according to equations comprising *pH*-based (linear) isotherms. In this case, this input parameter is not used; that is, this record in the input file is ignored by the model. Instead, the $\mathbf{K_d^s}$ (Equation 5.3c) is calculated as a function of *pH* (see Section 3.3.3.1.2).

Alternatively, if tables of non-linear sorption isotherms developed using the MINTEQA2 geochemical model are used to model transport in the unsaturated zone, then a single $\mathbf{K_d^s}$ value is chosen from these tabulated data to be used in the aquifer. As implemented in EPACMTP, the non-linearity of the isotherms is most important in the unsaturated zone where the concentrations are relatively high. Upon reaching the water table and mixing the leachate with ambient ground water, the metal's concentration is considered to be low enough that a linear isotherm can always be used. The appropriate saturated zone $\mathbf{K_d^s}$ value is automatically chosen by the model based on the maximum ground-water concentration under the source. In this case as well, this input parameter is not used; that is, this record in the input file is ignored by the model. Instead, the $\mathbf{K_d^s}$ (Equation 5.3c) is chosen from tabulated data (see Sections 3.3.3.2 and 5.3.13 and Appendix B).

Data Sources

Generally, the $\mathbf{K_d^s}$ for organic constituents is specified as a derived parameter; however, if this option is not appropriate and site-specific data are not available, there are studies in the scientific literature that provide compilations of $\mathbf{K_d^s}$ values that have been measured in the field (for instance, see *Risk Assessment for the Listing Determinations for Inorganic Chemical Manufacturing Wastes*; U.S. EPA, 2000). In this case, the leading Freundlich coefficient would be specified as either a constant value or a distribution of values (and the Freundlich exponent would be set to its default value of 1.0).

The leading Freundlich coefficient for metals is generally superceded by use of either the MINTEQA2-derived sorption data or the pH-based linear isotherms that were developed specifically for use with the EPACMTP model (see Section 3.3.3). However, if neither of these two options is appropriate and site-specific data are not available, there are studies in the scientific literature that provide compilations of K_d's that have been measured in the field (for instance, see Appendix I of U.S. EPA, 2000). In this case, the leading Freundlich coefficient would be specified as either a constant value or a distribution of values.

Use In EPACMTP

The leading Freundlich coefficient (also called the distribution coefficient) is one of the parameters used to calculate the amount by which contaminant transport is retarded relative to the ambient ground-water flow velocity within the aquifer. It is an input to the saturated zone transport module.

5.3.13 Exponent of Freundlich Isotherm for Saturated Zone (η^s)

Definition

The exponent of the Freundlich isotherm is a constant used to describe the sorptive behavior of a constituent. When the sorption data are plotted as log C versus log S, the slope of the resulting line is equal to η^s. In the special case of a linear isotherm, the exponent of the Freundlich isotherm is equal to 1.0.

Parameter Value or Distribution of Values

For modeling organic constituents, the default value of the Freundlich exponent is 1.0, meaning a linear adsorption isotherm is used.

When modeling metals transport in the saturated zone with EPACMTP, the distribution coefficient for metals is generally specified using either tabulated non-linear MINTEQA2 isotherms or pH-based linear isotherms that were developed specifically for use with the EPACMTP model (see Section 3.3.3). In these two cases, the K_d data is either read in from an auxiliary input file or internally calculated, and the Freundlich isotherm coefficient and exponent are not used. If the leading Freundlich coefficient is specified using an empirical distribution of values (e.g., based on reported K_d values in the scientific literature), then the Freundlich isotherm exponent should be set equal to 1.0.

If this parameter is omitted from the data file, it is assigned a default value of 1.0, which is equivalent to specifying a linear sorption isotherm.

In EPACMTP Version 2.0, only the case of $\eta = 1$ is permitted. Non-linear isotherms (see Equation 5.3c) to describe metals transport are used only in the unsaturated zone and are handled using the tabular type of input described in Section 3.3.3.2 and Appendix B.

Data Sources

For modeling organic constituents, the Freundlich isotherm exponent is generally set to its default value of 1.0, and so no specific data source is used to determine the appropriate value for the Freundlich exponent.

For modeling metal constituents, the Freundlich isotherm exponent is not used as an input parameter, and so no specific data source is used (see Section 3.3.3.2). If literature or site-specific data are used to specify a non-linear adsorption isotherm, modeling of the adsorption process is implemented via tabular input describing the relationship in Equation 5.3c.

Use In EPACMTP

The Freundlich exponent is one of the parameters used to calculate the amount by which contaminant transport is retarded relative to the ambient ground-water flow velocity within the aquifer; it is an input to the saturated zone transport module.

5.3.14 Chemical Degradation Rate Coefficient for Saturated Zone (λ_c^s)

Definition

EPACMTP accounts for all transformation processes (both biological and chemical) using a lumped first-order decay coefficient. This overall decay coefficient is the sum of the chemical and biological transformation coefficients. The chemical degradation coefficient for the saturated zone is simply the rate of decay that is caused by chemical reactions (usually hydrolysis) in the saturated zone.

Parameter Value or Distribution of Values

By default, the chemical degradation coefficient in the saturated zone is set to be internally derived using the hydrolysis rate constants and the saturated zone properties according to Equation 3.4. However, if site-specific data are available, this parameter can be specified as a constant value or a distribution of values. In this case, the hydrolysis rate constants can be omitted from the input file.

Data Sources

If this parameter is not derived by the model, then a site-specific data source must be used to determine the appropriate input value.

Use In EPACMTP

The chemical degradation coefficient is used by the model to calculate the amount by which ground-water concentrations are attenuated due to chemical hydrolysis; it is an input to the saturated zone transport module and is one of the parameters required to solve the advection-dispersion equation (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

5.3.15 Biodegradation Rate Coefficient for Saturated Zone (λ_b^s)

Definition

EPACMTP accounts for all transformation processes (both biological and chemical) using a lumped first-order decay coefficient. This overall decay coefficient is the sum of the chemical and biological transformation coefficients. The biological degradation coefficient for the saturated zone is simply the rate of decay that is caused by biological processes in the saturated zone.

Parameter Value or Distribution of Values

By default, the biological degradation coefficient in the saturated zone is set equal to zero. However, if site-specific data are available, this parameter can be specified as a constant value or a distribution of values.

Data Sources

If the input value of this parameter is non-zero, then a site-specific data source must be used to determine the appropriate input value.

Use In EPACMTP

The biological degradation coefficient is used by the model to calculate the amount by which ground-water concentrations are attenuated due to biological processes; it is an input to the saturated zone transport module and is one of the parameters required to solve the advection-dispersion equation (see Sections 3.3.4 and 4.4.4 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a).

6.0 RECEPTOR WELL PARAMETERS

A receptor well is a hypothetical drinking water well that is located downgradient of the waste management unit in consideration. It represents the location at which the potential exposure to the ground water is measured. Discussed in this section are the EPACMTP input parameters which govern the generation and constraining of the receptor well location. These include Monte Carlo parameters that the user can specify. These parameters can be used to apply (or not apply) particular constraints on parameter values or generation methodology.

6.1 RECEPTOR WELL PARAMETERS

The parameters listed below in Table 6.1 are used to define the characteristics of the downgradient receptor well.

Table 6.1 Receptor Well Parameters

Parameter	Symbol	Units	Section	Equation in EPACMTP TBD
Radial Distance to Receptor Well	R_{rw}	m	6.2	4.21, 4.22, 4.25 and 4.26
Angle of Well Off of Plume Centerline	θ_{rw}	degrees	6.3	4.26a
Downgradient Distance to Receptor Well	x_{rw}	m	6.4	4.21, 4.25a and 4.26b
Well Distance From Plume Centerline	y_{rw}	m	6.5	4.22, 4.25b and 4.26c
R_{rw} Origination Method	IWLOC	-	6.5	Section 4.4.3.6
Constraint on Well Distance From Plume Centerline	LYCHK	-	6.5	4.28 as constraint on y_{rw}
Depth of Intake Point Below Watertable	z^*_{rw}	m	6.6	4.29
Constraint on Depth of Intake Point Below Watertable	LZCHK	-	6.6	4.29 as constraint on z^*_{rw}
Averaging Period for Ground-water Concentration at Receptor Well	t_d	yr	6.7	4.108 and 4.109

EPACMTP ultimately represents the receptor well location in a Cartesian coordinate system whose X axis is oriented along the plume centerline for convenience. However, the user can specify the areal receptor well location in either cylindrical (R_{rw},θ_{rw}) or Cartesian (x_{rw},y_{rw}) coordinates and the model will transform the inputs accordingly. It's important to note that the specification of the receptor well depth, z^*_{rw}, is not dependent upon the chosen coordinate system. Figure 6.1 illustrates how the receptor well location is determined using cylindrical coordinates (Figure 6.1a) and Cartesian coordinates (Figure 6.1b).

EPACMTP provides two optional constraints to force receptor well locations into the interior of the dissolved constituent plume; one constraint applies to the areal location of the receptor well (LYCHK), and the other constrains the depth of the receptor well (LZCHK). By default, the receptor well can be located anywhere downgradient of the WMU (radial distance of up to about one mile, with the angle off-center varying uniformly between 0 and 90 degrees) and anywhere within the saturated thickness of the aquifer.

An additional option (IWLOC) provides a receptor well locating methodology which addresses the tendency of WMUs with very large areas (e.g., LAUs) to bias upward the Monte Carlo receptor well concentrations. This option is further described in Section 6.5.

The final parameter discussed in this section is the averaging period for ground water concentration at the receptor well. The averaging period is useful for risk calculations which require an estimate of the exposure concentration over a period of time, say 30 years.

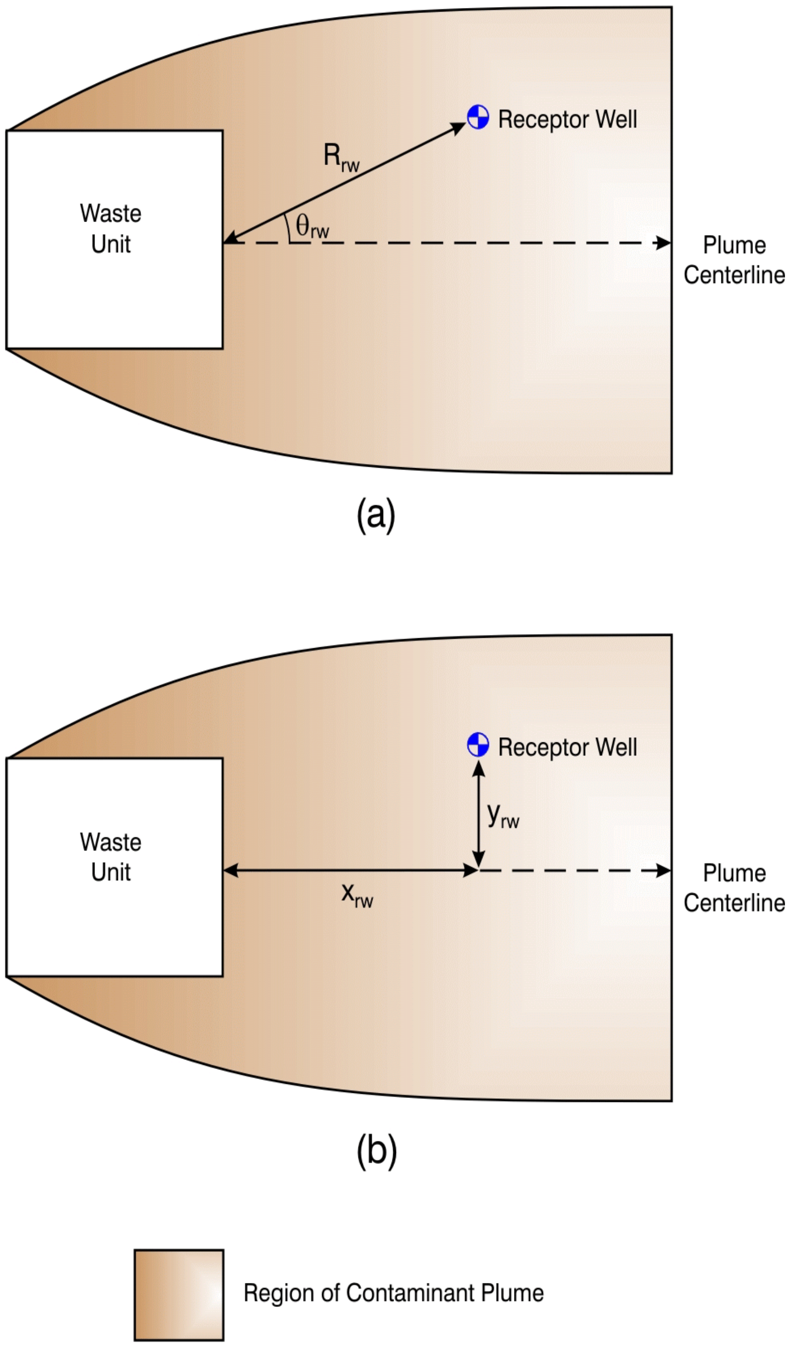

Figure 6.1 Schematic plan view showing procedure for determining the downstream location of the receptor well: (a) well location determined using radial distance, R_{rw}, and angle off center θ_{rw}; and (b) well location generated uniformly within plume limit

6.2 RADIAL DISTANCE TO RECEPTOR WELL (R_{rw})

Definition

The radial distance to the receptor well (m) is measured from the downgradient edge of the WMU to the nearest downgradient receptor well, as depicted in Figure 6.1a.

Parameter Value or Distribution of Values

As shown in Figures 6.1a and 6.1b, the default reference point or origin for determining the receptor well location is midpoint of the downgradient edge of the WMU. EPACMTP provides an alternative receptor well location methodology for determining the reference point and it is controlled by the Monte Carlo control parameter IWLOC. Setting the Monte Carlo control parameter IWLOC equal to zero instructs EPACMTP to use the default reference point for determining the receptor well location. If IWLOC is set equal to one, the alternate location method is used. The alternate method has been included as a means to reduce the bias introduced by WMUs with large areas. When R_{rw} is always measured from the default reference point, receptor well locations are more likely to lay inside the areal extent of the dissolved constituent plume as the size of the WMU increases, biasing exposure concentrations upward. To reduce the potential bias, the reference point in the alternate scenario may be at any point somewhere between the corner and the center of the downgradient edge of the WMU. Section 4.4.3.6 in the *EPACMTP Technical Background Document* (U.S. EPA, 2003a) describes the alternate method in detail. R_{rw} may be specified by any appropriate distribution of values or by a constant value to accommodate site-specific data or analysis-specific assumptions. Lacking site-specific data, R_{rw} is typically determined using the empirical distribution shown in Table 6.2.

Data Sources

In a Monte Carlo simulation, the primary output from the model is the exposure concentration at a receptor well located downgradient from the waste site. Available studies and surveys suggest that on average, multiple downgradient wells are present within the one-mile distance that is typically considered in regulatory applications. To ensure a degree of protection in the modeling analysis, the model computes the concentration at the nearest downgradient well. Information on the downgradient distance to the nearest receptor well can be obtained from the U.S. EPA OSW landfill survey (U.S. EPA, 1993). These data are presented as an empirical distribution in Table 6.2. At most waste sites included in this survey, the direction of ambient ground-water flow was not known exactly; therefore, it cannot be ascertained whether the nearest receptor well is located directly along the plume centerline. To reflect uncertainties and variations in the location of the receptor well in relation to the direction of ambient ground-water flow, the modeled well is typically allowed to be positioned at some varying distance from the plume centerline.

Table 6.2 Cumulative Probability of Distance to Nearest Receptor Well for Landfills (from EPA, 1993)

Cumulative Probability	Radial Distance (m)
0.0	0.6
0.03	13.7
0.04	19.8
0.05	45.7
0.10	103.6
0.15	152.4
0.20	182.9
0.25	243.8
0.30	304.8
0.35	304.8
0.40	365.7
0.45	396.2
0.50	426.7
0.55	457.2
0.60	609.6
0.65	762.0
0.70	804.6
0.75	868.6
0.80	914.4
0.85	1158.2
0.90	1219.1
0.95	1371.5
0.98	1523.9
1.00	1609.3

Use In EPACMTP

The first, and default, option of determining the well location involves determining the Cartesian coordinates of the receptor well as a function of the radial distance (R_w) from the center of the downgradient edge of the WMU and the angle off of thje plume centerline (θ_{rw}), as depicted in Figure 6.1a. If R_{rw} is specified, θ_{rw} must also be specified. EPACMTP will derive x_{rw} and y_{rw} from the cylindrical coordinates (see Section 6.4).

6.3 ANGLE OF WELL OFF OF PLUME CENTERLINE (θ_{rw})

Definition

The first, and default, option of determining the well location involves determining the Cartesian coordinates of the receptor well as a function of the radial distance (R_{rw}) from the center of the downgradient edge of the WMU and the angle off of the plume centerline (θ_{rw}), as depicted in Figure 6.1a. This angle, in conjunction with R_{rw}, defines the receptor well location in the cylindrical coordinates.

Parameter Value or Distribution of Values

θ_{rw} may be specified by any appropriate distribution of values or by a constant value to accommodate site-specific data or analysis-specific assumptions. For example, setting θ_{rw} to zero would constrain the receptor well location to the plume centerline. Lacking site-specific data, to include all potential wells located downstream of the waste units, the angle θ_{rw} is typically taken to be uniformly distributed between 0° and 90°.

Data Sources

In a Monte Carlo simulation, the primary output from the model is the exposure concentration at receptor well located downgradient from the waste site. If site-specific data are unavailable, a default distribution of values may be used. Since multiple downgradient wells are often present within the default one-mile distance, to be protective, the modeled receptor well is taken to be the nearest downgradient well based on an EPA OSW survey of municipal landfills (U.S. EPA, 1993). However, at most waste sites included in this survey, the direction of ambient ground-water flow was not known exactly; therefore, it cannot be ascertained whether the nearest receptor well is located directly along the plume centerline. To reflect uncertainties and variations in the location of the receptor well in relation to the direction of ambient ground-water flow, the modeled well is typically allowed to be positioned at a variable y-distance from the plume centerline.

Thus, to include all hypothetical receptor wells located downstream of the waste units, the angle θ_{rw} is, by default, assumed to be uniformly distributed between 0° and 90°.

Use In EPACMTP

The first, and default, option of determining the well location involves determining the Cartesian coordinates of the receptor well as a function of the radial distance (R_{rw}) from the center of the downgradient edge of the WMU and the angle off of the plume centerline (θ_{rw}), as depicted in Figure 6.1a. If θ_{rw} is specified, R_{rw} must also be specified. EPACMTP will derive x_{rw} and y_{rw} from the cylindrical coordinates (see Section 6.4).

6.4 DOWNGRADIENT DISTANCE TO RECEPTOR WELL (x_{rw})

Definition

The downgradient distance to the receptor well (m) is the distance to the well, as measured from the center of downgradient edge of the WMU along the long-term average ground-water flow path (plume centerline), as depicted in Figure 6.1b.

Parameter Value or Distribution of Values

The first, and default, option of determining the well location involves determining the Cartesian coordinates of the receptor well as a function of the radial distance, R_{rw}, from the center of the downgradient edge of the waste unit, and the angle off-center, θ_{rw}, as depicted in Figure 6.1a. x_{rw} is derived using the following equation:

$$x_{rw} = R_{rw} \cos\ (\theta_{rw}) \tag{6.1}$$

where

x_{rw} = X Cartesian coordinate of the receptor well (m)
R_{rw} = radial distance between waste unit and well (m),
θ_{rw} = angle measured counter-clockwise from the plume centerline (degrees)

The second method incorporated in EPACMTP to determine the receptor well location is to generate a well position directly from the Cartesian coordinates, x_{rw} and y_{rw}. In this case, the Cartesian parameters are specified in the EPACMTP input file, and the cylindrical parameters are ignored (typically these inputs are omitted from the input file). If site-specific data on well location(s) are available, then these data can be used to specify a constant value or an empirical or statistical distribution of values for x_{rw} and y_{rw}.

Alternatively, x_{rw} and y_{rw} can also be used to specify the well location such that the well is located uniformly between the plume centerline and the areal plume boundary, for any given x-distance (Figure 6.1b). This option is described further in Section 6.5 (Well Distance From Plume Centerline (y_w)) .

To reflect uncertainties and variations in the location of the receptor well in relation to the direction of ambient ground-water flow, the modeled well is allowed to be positioned at some varying distance from the plume centerline.

Data Sources

Lacking site-specific data, information on the downgradient distance to the nearest receptor well can be obtained from the U.S. EPA OSW landfill survey (U.S. EPA, 1993). These data are presented as an empirical distribution in Table 6.2.

Use In EPACMTP

The downgradient distance to the receptor well (x_{rw}) is used to represent the location at which the potential exposure concentration to the ground water is measured.

6.5 WELL DISTANCE FROM PLUME CENTERLINE (y_{rw})

Definition

The well distance from the plume centerline (m) is the distance from the plume centerline to the well, measured perpendicular to the plume centerline, as depicted in Figure 6.1b.

Parameter Value or Distribution of Values

The first, and default, option of determining the well location involves determining the Cartesian coordinates of the receptor well as a function of the radial distance, R_{rw}, from the center of the downgradient edge of the waste unit, and the angle off-center, θ_{rw}, as depicted in Figure 6.1a. The parameter y_{rw} is derived using the following equation:

$$y_{rw} = R_{rw} \sin (\theta_{rw}) \tag{6.2}$$

where

y_{rw} = Y Cartesian coordinate of the receptor well (m)
R_{rw} = radial distance between waste unit and well (m),
θ_{rw} = angle measured counter-clockwise from the plume centerline (degrees)

The second method incorporated in EPACMTP to determine the receptor well location is to generate a well position directly from the Cartesian coordinates, x_{rw} and y_{rw}. In this case, the Cartesian parameters are specified in the EPACMTP input file, and the cylindrical parameters are ignored (typically these inputs are omitted from the input file). If site-specific data on well location(s) are available, then these data can be used to specify a constant value or an empirical or statistical distribution of values for x_{rw} and y_{rw}.

Alternatively, x_{rw} and y_{rw} can also be used to estimate the well location such that the well is located uniformly between the plume centerline and the areal plume boundary, for any given x-distance (Figure 6.1b). With this option, x_{rw} is generated from the empirical distribution in Table 6.2. Next, the y_{rw} of the well is generated from a uniform distribution with a minimum value of zero, and a maximum value given by the following equation:

$$y_{rw} \leq y_D + 3[2\alpha_T(x_w + x_{rw})]^{1/2} \tag{6.3}$$

where

y_D = width of the waste unit in the y-direction (m)

x_{rw} = length of the waste unit in the x-direction (m)

α_T = horizontal transverse dispersivity (m)

x_w = length of the WMU in the x-direction (parallel to ground-water flow) (m)

This approximation for the lateral extent of the contaminant plume is based on the assumption that plume spreading in the horizontal-transverse direction is caused by dispersive mixing, which results in a Gaussian profile of the plume cross-section. Use of Equation 6-3 implies that 99.7% of the contaminant mass will be present inside the transverse plume limit.

To select this option, the Monte Carlo control parameter LYCHK should be set to TRUE, the x_{rw} should be specified as an empirical parameter with values as given in Table 6.2, and the y_{rw} should be specified as a uniform distribution with limits of zero and one.

Data Sources

No default data sources are available for y_{rw}. Information on the downstream distance to the nearest receptor well can be obtained from the U.S. EPA OSW landfill survey (U.S. EPA, 1993). These data are presented as an empirical distribution in Table 6.2. At most waste sites included in this survey, the direction of ambient ground-water flow was not known exactly; therefore, it cannot be ascertained whether the nearest receptor well is located directly along the plume centerline. To reflect uncertainties and variations in the location of the receptor well in relation to the direction of ambient ground-water flow, the modeled well is typically allowed to be positioned at some varying distance from the plume centerline if site-specific data are not available.

Use In EPACMTP

Along with the term x_{rw} (downgradient distance to the receptor well), the y_{rw} parameter is used to define the location of a receptor well. The y_{rw} parameter represents the perpendicular distance from the plume centerline at which the potential exposure to the ground water is measured. Setting y_{rw} to zero constrains the receptor well location to the plume centerline.

6.6 DEPTH OF INTAKE POINT BELOW WATERTABLE (z^*_{rw})

Definition

The depth of the intake point below the water table (m) is the depth at which the model calculates the resulting ground-water concentration. Unlike most wells in the real world that have a screened interval of several feet or more, the simulated receptor well in EPACMTP has an intake that is a single point in space, as if the well consisted of a solid casing that was open at the bottom. In this case, the intake point would be the same as the depth of the well (or z^*_{rw}). Note that this depth is measured downwards from the watertable, not from the ground surface.

Parameter Value or Distribution of Values

Three options are available for specifying the vertical position of the well intake point below the water table: uniform distribution, constrained distribution, or constant value.

The first, and default, option is to model the vertical position of the well intake point as being uniformly distributed between the water table (z=0) and the saturated aquifer thickness. This option is selected by specifying the z-position as a uniform distribution with lower and upper limits of 0.0 and 1.0. EPACMTP will multiply this uniformly generated value by the saturated zone thickness to yield the actual receptor well depth below the water table for each Monte Carlo iteration. When the generated value for the vertical position of the receptor well intake point exceeds the saturated thickness of the aquifer (a physically impossible condition), a new well position is generated to ensure that the well depth is always less than the saturated thickness. Conversely, the well depth cannot be less than the minimum depth to the saturated zone.

Alternatively, the vertical position of the observation well can be optionally constrained to lie within the approximate vertical penetration depth of the contaminant plume emanating from the waste unit. This is achieved through the Monte Carlo input variable LZCHK. If LZCHK is set to FALSE, the constraint is not enforced. If LZCHK is set to TRUE, the z^*_{rw} is constrained to lie within the approximate vertical extent of the contaminant plume as defined by:

$$z^*_{rw} \leq 2.5 \left\{ \frac{Q_3^F + Q_4^F}{Q_1^F} B + \left[\alpha_v \, (x_w + x_{rw}) + \alpha_L \left(\frac{Q_3^F + Q_4^F}{Q_1^F} B \right) + \phi_e D^{s^*} \right]^{1/2} \right\} = z^*_{rw\,\max} \tag{6.4}$$

where

$z^*_{rw\,max}$ = Maximum allowable z*-coordinate of the receptor well; that is, the approximate vertical penetration depth of the dissolved constituent plume (m)
Q^F_1-Q^F_4= Components of the ground-water flow field (m^2/yr), see U.S. EPA (2003a), Section 4, Figure 4.7
B = Saturated zone thickness (m)
x_w = Length of source in downstream direction (m)
x_{rw} = Horizontal distance between source and receptor well (m)
α_L = Longitudinal dispersivity (m)
α_v = Vertical dispersivity (m)
ϕ_e = Effective porosity of the aquifer (dimensionless)
D^{s*} = Effective molecular diffusion coefficient (m^2/y)

As a third option, the well position may be fixed at a constant absolute depth or as a constant relative depth (as a constant fractional depth of the saturated thickness).

Data Sources

In the absence of site-specific data for this input, z^*_{rw} is typically defined as a uniformly distributed fraction of the saturated thickness.

Use In EPACMTP

The depth of the intake point below the water table is the depth at which the model calculates the resulting ground-water concentration. It is from this point that a ground-water concentration of a potential contaminant plume would be established.

6.7 AVERAGING PERIOD FOR GROUND-WATER CONCENTRATION AT RECEPTOR WELL (t_d)

Definition

The averaging period for the ground-water concentration at the receptor well (yr) is the time period over which the average concentration is calculated. For instance, if this input is specified as 30 years, then the EPACMTP model would search for the highest 30-year average concentration over the specified modeling period and report this concentration in the output file. This ground-water averaging time should correspond to the exposure duration used in the health-risk calculations for carcinogenic constituents. Up to ten averaging times may be specified.

Parameter Value or Distribution of Values

Usual values of this parameter are 70 years (lifetime exposure), 30 years (high-end residence time), 9 years (average residence time), or 7 years (child exposure) (U.S. EPA, 2000). Although this value is often entered as a constant value, it can also be specified as a statistical or empirical distribution of values.

By default, the exposure period for averaging the receptor well concentration is not provided; in other words, the model only calculates the peak receptor well concentration. The peak receptor well concentration is sometimes used for calculating the resulting health risk for non-carcinogenic constituents or for comparisons to the maximum contaminant levels (MCLs) (The National Drinking Water Standards at 40 CFR 141).

Data Sources

The choice of the averaging period should be consistent with the types of risks to be calculated using the exposure results generated by EPACMTP. The EPA's *Exposure Factors Handbook* (U.S. EPA 1997a-c) contains constituent-specific data on exposure durations for various exposure scenarios.

Use In EPACMTP

EPACMTP always generates a steady state receptor well concentration and a peak concentration. Steady state concentrations correspond to an infinite source analysis; peak concentrations represent the maximum concentration at the well under the finite source scenario. Average concentrations for defined exposure periods are optional results for finite source simulations. If average concentrations are required, up to 10 averaging periods can be specified. If the period of averaging is longer than the period of time for which concentrations are observed at the receptor well, the result will be the average of the available observations.

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APPENDIX A

DETERMINATION OF INFILTRATION AND RECHARGE RATES

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APPENDIX A
DETERMINATION OF INFILTRATION AND RECHARGE RATES

A.1 INFILTRATION AND RECHARGE RATES

EPACMTP requires the input of the rate of downward percolation of water and leachate through the unsaturated zone to the water table. The model distinguishes between two types of percolation as infiltration and recharge:

- **Infiltration** (WMU leakage rate) is defined as water percolating through the WMU – including a liner if present – to the underlying soil.
- **Recharge** is water percolating through the soil to the aquifer outside the WMU.

Infiltration is one of the key parameters affecting the leaching of waste constituents into the subsurface. For a given leachate concentration, the mass of constituents leached is directly proportional to the infiltration rate. In EPACMTP, using a different default liner scenario changes the modeled infiltration rate; more protective liner designs reduce leaching by decreasing the rate of infiltration.

In contrast, recharge introduces pristine water into the aquifer. Increasing recharge therefore tends to result in a greater degree of plume dilution and lower constituent concentrations. High recharge rates may also affect the extent of ground-water mounding and ground-water velocity. The recharge rate is independent of the type and design of the WMU; rather it is a function of the climatic and hydrogeological conditions at the WMU location, such as precipitation, evapotranspiration, surface run-off, and regional soil type.

In developing the EPACMTP model and the accompanying databases, the U.S. EPA used several methodologies to estimate infiltration and recharge. We used the HELP model (Schroeder et al, 1994) to compute recharge rates for all units, as well as infiltration rates for LAUs, and for LFs and WPs with no-liner and single-liner designs. For LFs and WPs, composite liner infiltration rates were compiled from leak-detection-system flow rates reported for actual composite-lined waste units (TetraTech, 2001).

For unlined and single-lined SIs, infiltration through the bottom of the impoundment is calculated internally by EPACMTP, as described in Section 4.3.4 of this document. For composite-lined SIs, we used the Bonaparte (1989) equation to calculate the infiltration rate assuming circular (pin-hole) leaks with a uniform leak size of 6 mm^2, and using the distribution of leak densities (number of leaks per hectare) assembled from the survey of composite-lined units (TetraTech, 2001).

Tables A.1 through A.4 summarize the liner assumptions and infiltration rate calculations for LFs, WPs, SIs, and LAUs. The remainder of this appendix provides background on how we used the HELP model in conjunction with data from climate stations across the United States to develop nationwide recharge and infiltration rate distributions and provides a detailed discussion of how we developed infiltration rates for different default liner designs for each type of WMU.

A.1.1 USING THE HELP MODEL TO DEVELOP RECHARGE AND INFILTRATION RATES

The HELP model is a quasi-two-dimensional hydrologic model for computing water balances of LFs, cover systems, and other solid waste management facilities. The primary purpose of the model is to assist in the comparison of design alternatives. The HELP model uses weather, soil and design data to compute a water balance for LF systems accounting for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. The HELP model can simulate LF systems consisting of various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners.

HELP Versions 3.03 and 3.07 (which include WMU- and liner-specific distributions of infiltration rates) were used to construct the EPACMTP site data files. We started with an existing database of no-liner infiltration rates for LFs, WPs and LAUs. Also existing were recharge rates for 97 climate stations in the lower 48 contiguous United States (ABB, 1995), that are representative of 25 specific climatic regions (developed with HELP version 3.03). We then added five climate stations (located in Alaska, Hawaii, and Puerto Rico) to ensure coverage throughout all of the United States. Figure A.1 shows the locations of the 102 climate stations.

The current version of HELP (version 3.07) was used for the modeling of the additional climate stations for the no-liner scenario. We compared the results of Version 3.07 against Version 3.03 and found that the differences in calculated infiltration rates were insignificant. We also used this comparison to verify a number of counter-intuitive infiltration rates that were generated with HELP Version 3.03. We had observed that for some climate stations located in areas of the country with low precipitation rates, the net infiltration for unlined LFs did not always correlate with the relative permeability of the LF cover. We found some cases in which a less permeable cover resulted in a higher modeled infiltration rate as compared to a more permeable cover. Examples can be seen in the detailed listing of infiltration data that are presented in Tables A.11 to A.14. For instance, Table A.11 shows that for a number of climate stations, including Albuquerque, Denver, and Las Vegas, the modeled infiltration rate for LFs with a silty clay loam (SCL) cover is higher than the values corresponding to silt loam (SLT) and sandy loam (SNL) soil covers. We determined that in all these cases, the HELP modeling results for unlined LFs were correct and could be explained in terms of other water balance components, including surface run-off and evapotranspiration.

Table A.1 Methodology Used to Compute Infiltration for LFs

	No Liner	Single Liner	Composite Liner
Method	HELP model simulations to compute an empirical distribution of infiltration rates for a 2 ft. thick cover of three native soil cover types using nationwide coverage of climate stations. Soil-type specific infiltration rates for a specific site are assigned by using the infiltration rates for respective soil types at the nearest climate station.	HELP model simulations to compute an empirical distribution of infiltration rates through a single clay liner using nationwide coverage of climate stations. Infiltration rates for a specific site were obtained by using the infiltration rate for the nearest climate station.	Compiled from literature sources (TetraTech, 2001) for composite liners
Final Cover	Monte Carlo selection from distribution of soil cover types. 2 ft thick native soil (1 of 3 soil types: silty clay loam, silt loam, and sandy loam) with a range of mean hydraulic conductivities (4.2×10^{-5} cm/s to 7.2×10^{-4} cm/s).	3 ft thick clay cover with a hydraulic conductivity of 1×10^{-7} cm/sec and a 10 ft thick waste layer. On top of the cover, a 1 ft layer of loam to support vegetation and drainage and a 1 ft percolation layer.	No cover modeled; the composite liner is the limiting factor in determining infiltration
Liner Design	No liner	3 ft thick clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec. No leachate collection system. Assumes constant infiltration rate (assumes no increase in hydraulic conductivity of liner) over modeling period.	60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-foot compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. Assumes same infiltration rate (i.e., no increase in hydraulic conductivity of liner) over modeling period.
EPACMTP Infiltration Rate	Monte Carlo selection from HELP generated location- specific values.	Monte Carlo selection from HELP generated location-specific values.	Monte Carlo selection from distribution of leak detection system flow rates.

Table A.2 Methodology Used to Compute Infiltration for SIs

	No Liner	Single Liner	Composite Liner
Method	EPACMTP SI module for infiltration through consolidated sludge and native soil layers with a unit-specific ponding depth from EPA's SI Study (EPA, 2001).	EPACMTP module for infiltration through a layer of consolidated sludge and a single clay liner with unit-specific ponding depth from EPA's SI study.	Bonaparte equation (1989) for pin-hole leaks using distribution of leak densities for units installed with formal CQA programs
Ponding Depth	Unit-specific based on EPA's SI study.	Unit-specific based on EPA's SI study.	Unit-specific based on EPA's SI study.
Liner Design	None. However, barrier to infiltration is provided by layer of consolidated sludge at the bottom of the impoundment, and a layer of clogged native soil below the consolidated sludge. The sludge thickness is assumed to be constant over the modeling period. The hydraulic conductivity of the consolidated sludge is between 1.3×10^{-7} and 1.8×10^{-7} cm/sec. The hydraulic conductivity of the clogged native material is assumed to be 0.1 of the unaffected native material in the vadose zone.	3 ft thick clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec. No leachate collection system. Assumes no increase in hydraulic conductivity of liner over modeling period. Additional barrier is provided by a layer of consolidated sludge at the bottom of the impoundment, see no-liner column.	60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-foot compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. Assumptions: 1) constant infiltration rate (i.e., no increase in hydraulic conductivity of liner) over modeling period; 2) geomembrane liner is limiting factor that determines infiltration rate.
EPACMTP Infiltration Rate	Calculated by EPACMTP based on Monte Carlo selection of unit-specific ponding depth.	Calculated based on Monte Carlo selection of unit-specific ponding depth	Calculated based on Monte Carlo selection of unit-specific ponding depth and distribution of leak densities

Table A.3 Methodology Used to Compute Infiltration for WPs

	No Liner	Single Liner	Composite Liner
Method	HELP model simulations to compute distribution of infiltration rates for a 10 ft. thick layer of waste, using three waste permeabilities (copper slag, coal bottom ash, coal fly ash) and nationwide coverage of climate stations. Waste-type-specific infiltration rates for a specific site are obtained by using the infiltration rates for respective waste types at the nearest climate station.	HELP model simulations to compute distribution of infiltration rates through 10 ft. waste layer using three waste permeabilities and nationwide coverage of climate stations. Infiltration rates for a specific site were obtained by using the infiltration rate for the nearest climate station.	Compiled from literature sources (TetraTech, 2001) for composite liners
Cover	None	None	None
Liner Design	No liner.	3 ft thick clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec, no leachate collection system, and a 10 ft thick waste layer. Assumes no increase in hydraulic conductivity of liner over unit's operational life.	60 mil HDPE layer with either an underlying geosynthetic clay liner with maximum hydraulic conductivity of 5×10^{-9} cm/sec, or a 3-foot compacted clay liner with maximum hydraulic conductivity of 1×10^{-7} cm/sec. 1) same infiltration rate (i.e., no increase in hydraulic conductivity of liner) over unit's operational life; 2) geomembrane is limiting factor in determining infiltration rate.
EPACMTP Infiltration Rate	Monte Carlo selection from HELP generated location-specific values.	Monte Carlo selection from HELP generated location- specific values.	Monte Carlo selection from distribution of leak detection system flow rates

Table A.4 Methodology Used to Compute Infiltration for LAUs

	No Liner	Single Liner	Composite Liner
Method	HELP model simulations to compute an empirical distribution of infiltration rates for a 0.5 ft thick sludge layer, underlain by a 3 ft layer of three types of native soil using nationwide coverage of climate stations. Soil-type specific infiltration rates for a specific site are assigned by using the infiltration rates for respective soil types at the nearest climate station.	N/A	N/A
Liner Design	No liner	N/A	N/A
EPACMTP Infiltration Rate	Monte Carlo selection from HELP generated location specific values.	N/A	N/A

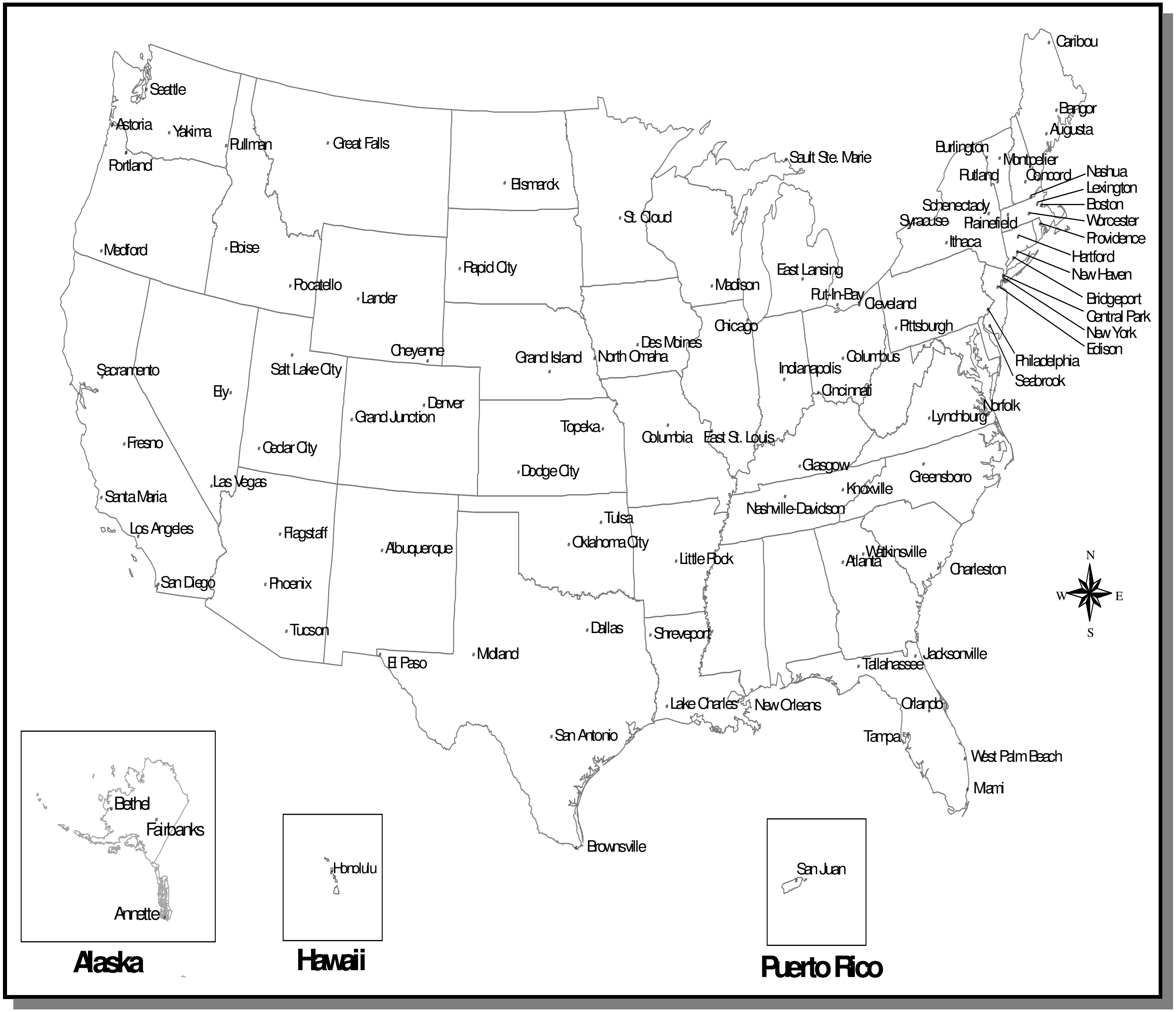

Figure A.1 Locations of HELP Climate Stations

The first 97 climate stations were grouped into 25 climate regions based on ranges of average annual precipitation and pan evaporation, as shown in Table A.5. For each modeled climate station, HELP provides a database of five years of climatic data. We used this climatic data, along with data on the regional soil type and WMU design characteristics, to calculate a water balance for each applicable default liner design as a function of the amount of precipitation that reaches the top surface of the unit, minus the amount of runoff and evapotranspiration. The HELP model then computed the net amount of water that infiltrates through the surface, waste, and liner layers, based on the initial moisture content and the hydraulic conductivity of each layer.

In addition to climate factors and liner designs, the infiltration rates calculated by HELP are affected by LF cover design, permeability of the waste material in WP, and LAU soil type. For every climate station and WMU type (LF, WP and LAU), we calculated three HELP infiltration rates. For a selected WMU type and liner design, the regional site-based modeling process selects randomly from among the HELP-derived infiltration and recharge data, to capture both the nationwide variation in climate conditions, as well as variations in LF soil cover type, WP waste permeability, and LAU soil type.

The factors related to soil type that affect the HELP-generated infiltration and recharge rates are the permeability of the soil used in the LF cover, and – in the case of recharge or for LAUs – the permeability of the soil type in the vicinity of the WMU. We used the same set of soil types (sandy loam, silty loam, and silty clay loam) and soil properties in the infiltration and recharge rate calculations as we did in the unsaturated zone fate and transport simulations (see Table 5.4 in Section 5.2.4).

In the case of uncovered WPs we found that the infiltration rates predicted by the HELP model are sensitive to the permeability of the waste material itself. Based on these results, we simulated WP infiltration rates for three different WP materials: relatively high permeability, moderate permeability, and relatively low permeability. When these rates are used in the EPACMTP modeling, each waste type has an equal likelihood of occurrence.

Table A.5 Grouping of Climate Stations by Average Annual Precipitation and Pan Evaporation (ABB, 1995)

		Climate Region				Climate Region	
City	State	Precipitation (in/yr)	Evaporation (in/yr)	City	State	Precipitation (in/yr)	Evaporation (in/yr)
Boise	ID	< 16	< 30	Columbia	MO	32 - 40	30 - 40
Fresno	CA			Put-in-Bay	OH		
				Madison	WI		
Bismarck	ND	< 16	30 - 40	Columbus	OH		
Denver	CO			Cleveland	OH		
Grand Junction	CO			Des Moines	IA		
Pocatello	ID			E. St. Louis	IL		
Glasgow	MT						
Pullman	WA			Topeka	KS	32 - 40	40 - 50
Yakima	WA						
Cheyenne	WY			Tampa	FL	32 - 40	50 - 60
Lander	WY			San Antonio	TX		
Rapid City	SD	< 16	40 - 50	Portland	ME	40 - 48	< 30
Los Angeles	CA			Hartford	CT		
Sacramento	CA			Syracuse	NY		
San Diego	CA			Worchester	MA		
Santa Maria	CA			Augusta	ME		
Ely	NV			Providence	RI		
Cedar City	UT			Nashua	NH		
				Ithaca	NY		
Albuquerque	NM	< 16	50 - 60	Boston	MA		
				Schenectady	NY		
Las Vegas	NV	< 16	> 60				
Phoenix	AZ			NY City	NY	40 - 48	30 - 40
Tucson	AZ			Lynchburg	VA		
El Paso	TX			Philadelphia	PA		
				Seabrook	NJ		
Medford	OR	16 - 24	30 - 40	Indianapolis	IN		
Great Falls	MT			Cincinnati	OH		
Salt Lake City	UT			Bridgeport	CT		
Grand Island	NE	16 - 24	40 - 50	Jacksonville	FL	40 - 48	40 - 50
				Orlando	FL		

Table A.5 Grouping of Climate Stations by Average Annual Precipitation and Pan Evaporation (ABB, 1995) (continued)

		Climate Region				Climate Region	
City	**State**	**Precipitation (in/yr)**	**Evaporation (in/yr)**	**City**	**State**	**Precipitation (in/yr)**	**Evaporation (in/yr)**
Flagstaff	AZ	16 - 24	50 - 60	Greensboro	NC		
				Watkinsville	GA		
Dodge City	KS	16 - 24	> 60	Norfolk	VA		
Midland	TX			Shreveport	LA		
St. Cloud	MN	24 - 32	< 30	Astoria	OR	> 48	< 30
				New Haven	CT		
E. Lansing	MI	24 - 32	30 - 40	Plainfield	MA		
North Omaha	NE	24 - 32	40 - 50	Nashville	TN	> 48	30 - 40
				Knoxville	TN		
Dallas	TX	24 - 32	50 - 60	Central Park	NY		
Tulsa	OK			Lexington	KY		
Brownsville	TX			Edison	NJ		
Oklahoma City	OK	24 - 32	>60	Atlanta	GA	> 48	40 - 50
				Little Rock	AK		
Bangor	ME	32 - 40	< 30	Tallahassee	FL		
Concord	NH			New Orleans	LA		
Pittsburgh	PA			Charleston	SC		
Portland	OR			W. Palm Beach	FL		
Caribou	ME						
Chicago	IL			Lake Charles	LA	> 48	50 - 60
Burlington	VT			Miami	FL		
Rutland	VT						
Seattle	WA						
Montpelier	VT						
Sault St. Marie	MI						

A.1.2 INFILTRATION RATES FOR UNLINED UNITS

Landfill

We used the HELP model to simulate infiltration through closed LFs for each of the 102 climate station locations shown in Figure A.1. A 2-foot cover was included as the minimum Subtitle D requirement. Three different soil cover types were modeled: sandy loam, silty loam, and silty clay loam soils. Table A.6 presents the hydraulic parameters for these three soil types.

Table A.6 Hydraulic Parameters for the Modeled Soils

Soil Type	HELP Soil Number	Total Porosity (vol/vol)	Field Capacity (vol/vol)	Wilting Point (vol/vol)	Saturated Hydraulic Conductivity (cm/sec)
Sandy Loam	6	0.453	0.190	0.085	0.000720
Silt Loam	9	0.501	0.284	0.135	0.000190
Silty Clay Loam	12	0.471	0.342	0.210	0.000042

Other LF design criteria included:

- A cover crop of “fair” grass — this is the quality of grass cover suggested by the HELP model for LFs where limitations to root zone penetration and poor irrigation techniques may limit grass quality.
- The evaporation zone thickness selected for each location was generally the depth suggested by the model for that location for a fair grass crop; however, the evaporation zone thickness was not allowed to exceed the soil thickness (24 inches).
- The leaf area index (LAI) selected for each location was that of fair grass (2.0) unless the model indicated a lower maximum for that location.
- The LF configuration was based on a one-acre facility with a 2% top slope and a drainage length of 200 feet (one side of a square acre). Runoff was assumed to be possible from 100% of the cover.

Table A.11 presents the LF infiltration rate data for the 102 climate stations. For all four WMU types, the unlined LF infiltration rate for each soil type at each of the 102 climate centers was used as the ambient regional recharge rate for that climatic center and soil type.

Surface Impoundment

We calculated SI infiltration rates using the built-in SI module in EPACMTP (see Section 4.3.4 of this document and Section 2.2.2.3 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)). This means that for EPACMTP, the SI infiltration rate is not really an input parameter, rather the model calculates infiltration rates “on the fly” during the simulation, as a function of impoundment ponding depth and other SI characteristics. For unlined SIs, the primary parameters that control the infiltration rate are the ponding depth in the impoundment, the thickness and permeability of any accumulated sediment layer at the base of the impoundment, and the presence of a ‘clogged’ (i.e., reduced permeability) layer of native soil underneath the impoundment caused by the migration of solids from the impoundment. In addition, EPACMTP checks that the calculated infiltration rate does not result in an unrealistic degree of ground-water mounding (see Section 2.2.5 of the *EPACMTP Technical Background Document* (U.S. EPA, 2003a)).

To create the SI site data file for use with EPACMTP, we used unit-specific data on SI ponding depths from EPA’s *Surface Impoundment Study* (U.S. EPA, 2001). We assumed a fixed sediment layer thickness of 20 cm at the base of the impoundment. The resulting sediment layer permeability has a relatively narrow range of variation between 1.26×10^{-7} and 1.77×10^{-7} cm/s. We assumed that the depth of clogging underneath the impoundment was 0.5 m in all cases, and that saturated hydraulic conductivity of the clogged layer is 10% of that of the native soil underlying the impoundment.

In the event that the SI is reported to have its base below the water table, we calculated the infiltration using Darcy’s law based on the hydraulic gradient across the bottom of the impoundment unit, and the hydraulic conductivity of the consolidated sediment at the bottom of the impoundment unit.

Waste Pile

For the purpose of estimating leaching rates, we considered WPs to be similar to non-covered LFs with a total waste thickness of 10 feet. The infiltration rates for unlined WPs were, therefore, generated with the HELP model using the same general procedures as for LFs, but with the following modifications:

- *No cover*
  We modeled the leachate flux through active, uncovered piles. We modeled the WP surface as having no vegetation. The evaporative zone depth was taken as the suggested HELP model value for the “bare” condition at each climate center. The Leaf Area Index (LAI) was set to zero to eliminate transpiration.

- *Variable waste permeability*
  For uncovered WPs, we found that the infiltration rates predicted by HELP model are sensitive to the permeability of the waste material itself. Based on these results, we simulated WP infiltration rates for

three different WP materials: relatively high permeability, moderate permeability, and relatively low permeability (rather than three different soil types as was done for the LF scenario). The HELP model input parameters for the three waste types are presented in Table A.7.

Table A.7 Moisture Retention Parameters for the Modeled WP Materials

Waste Type	HELP Soil Number	Total Porosity (vol/vol)	Field Capacity (vol/vol)	Wilting Point (vol/vol)	Saturated Hydraulic Conductivity (cm/sec)
Low Permeability	30	0.541	0.187	0.047	0.00005
Moderate Permeability	31	0.578	0.076	0.025	0.00410
High Permeability	33	0.375	0.055	0.020	0.04100

We calculated WP infiltration rates for the 102 climate stations shown in Figure A.1 and the three waste material permeabilities shown in Table A.7. Table A.12 presents the resulting WP infiltration rate values for all climate stations and waste types.

Land Application Unit

LAUs were modeled with HELP using two soil layers. The top layer was taken as six inches in thickness and represented the layer into which the waste was applied. The bottom layer was of the same material type as the top layer and was set at a thickness of 36 inches. Both of these layers were modeled as vertical percolation layers. The same three soil types for LFs were also used for LAUs (see Table A.6).

We assumed the waste applied to the LAU to be a sludge-type material with a high water content. We also assumed a waste application rate of 7.25 inches per year (in/yr) with the waste having a solids content of 20% and a unit weight of 75 lb/ft^3. Assuming that 100% of the water in the waste was available as free water, an excess water amount of 5.8 in/yr, in addition to precipitation, would be available for percolation. HELP model analyses showed that the additional water available for percolation generally would have little effect on the simulated water balance and net infiltration, except for sites located in arid regions of the United States with very little natural precipitation. For more representative waste application rates, the effect disappeared because introducing additional moisture in the simulated water balance results in a commensurate increase in runoff and removal by evapotranspiration. For this reason, the LAU infiltration rate for a given soil type is assumed to be the same as the corresponding LF infiltration rate.

We calculated LAU infiltration rates for the 102 climate stations shown in Figure A.1 and the three soil types shown in Table A.6. Table A.13 presents the resulting LAU infiltration rate values for all climate stations and soil types.

A.1.3 SINGLE-LINED WASTE UNITS

EPACMTP includes infiltration rates for single clay-lined LFs, WPs, and SIs. In the case of LAUs, only unlined units are considered.

Landfill

We calculated infiltration rates for single-lined LFs using version 3.07 of the HELP model. We modeled the LF as a four-layer system, consisting, from top to bottom of:

- 1-foot percolation cover layer;
- 3-foot compacted clay cover with hydraulic conductivity of 1×10^{-7} cm/s ;
- 10-foot thick waste layer; and
- 3-foot thick compacted clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec.

We simulated the cover layer as a loam drainage layer supporting a “fair” cover crop with an evaporative zone depth equal to that associated with a fair cover crop at the climate center. The remaining conditions were identical to those described in Section A.1.2 for unlined LFs. Note that three different soil types were not modeled, since the clay liner is the limiting factor affecting the infiltration rate, not soil type. To avoid changing the standard format of the infiltration rates in the site data file, the clay-lined LF infiltration rates are repeated in each of the three columns that correspond to soil type in the case of unlined LFs. So in the course of a Monte Carlo analysis using the regional site-based modeling methodology for a single-clay lined LF, the soil type is correlated only to recharge rate.

In developing this default distribution of infiltration rates, we used the grouping of climate stations into 25 regions of similar climatic conditions depicted in Table A.5 in order to reduce the number of required HELP simulations. Rather than calculating infiltration rates for each of the 102 individual climate stations, we calculated infiltration rates for the 25 climate regions, and then assigned the same value to each climate station in one group. To ensure a protective result, we chose the climate center with the highest average precipitation in each climate region as representative of that region. We calculated individual infiltration rates for each of the five climate centers in Alaska, Hawaii, and Puerto Rico that were not assigned to a climate region.

During the process of assembling the HELP infiltration values for the EPACMTP model, we realized that the grouping of climate centers into regions for clay-lined units resulted in a number of apparent anomalies in which the suggested infiltration rate for a lined unit would be higher than the unlined infiltration rate at the same climate station. This resulted from the fact that we used the infiltration rate for the climate center with the highest annual precipitation in each region for clay-lined units, but then compared it with a location-specific infiltration value for unlined units. The occurrence of these anomalies was restricted to climate stations in arid parts of the United States, and was noticeable only when the absolute magnitude of infiltration was low. In order to remove these counter-intuitive results, we re-calculated location-specific HELP infiltration rates for clay-lined units at 17 climate stations (Glasgow, MT; Yakima, WA; Lander, WY; Cheyenne, WY; Pullman, WA; Pocatello, ID; Grand Junction, CO; Denver, CO; Great Falls, MT; Salt Lake City, UT; Cedar City, UT; El Paso, TX; Ely, NV; Las Vegas, NV; Rapid City, SD; Phoenix, AZ; and Tucson, AZ). We then incorporated the location-specific infiltration rates for these 17 climate stations into the database of infiltration rates in the site data file, to replace the original regional values. The result is that some of the infiltration rates for the single-clay lined LF scenario are regional values and some are location-specific values. Table A.11 shows the infiltration rate values for clay-lined LFs.

Waste Pile

We calculated infiltration rates for single-lined WPs using the HELP model. We modeled the WP as a two-layer system, consisting, from top to bottom, of:

- 10-foot thick, uncovered, waste layer; and
- 3-foot thick compacted clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec.

Other parameters were set to the same values as in the unlined WP case, including the three default waste material types (see Section A.1.2). We also modeled a bare surface for the evaporative zone depth.

In developing the single-clay lined-WP infiltration rates, we used the same grouping of climate stations in 25 climate regions as previously discussed for LFs. We calculated individual infiltration rates for each of the five climate centers in Alaska, Hawaii, and Puerto Rico that were not assigned to a climate region.

Analogous to the situation encountered for LFs, we found a number of apparent anomalies between WP infiltration rates for unlined as compared to clay-lined WPs, resulting from the use of regional infiltration values for clay-lined units. The occurrence of these anomalies for WPs was also restricted to climate centers in arid parts of the United States, for which the absolute magnitude of infiltration was low. In order to remove these counter-intuitive results, we re-calculated location-specific HELP infiltration rates for clay-lined WP units at 17 climate stations (Glasgow, MT; Yakima, WA; Lander, WY; Cheyenne, WY; Pullman, WA; Pocatello, ID; Grand Junction, CO; Denver, CO; Great Falls, MT; Salt Lake City, UT; Cedar City, UT; El Paso, TX; Ely, NV; Las Vegas, NV; Rapid City, SD; Phoenix, AZ; and Tucson, AZ). We then incorporated the location-specific infiltration rates for these 17 climate stations into the database of infiltration rates in the site data file, to replace the original regional values, and made them part of a distribution package for EPACMTP version 2. The result is that some of the infiltration rates for the single-clay lined WP scenario are regional values and some are location-specific values.

During the process of verifying the HELP-generated infiltration rates for clay-lined units, we also replaced incorrect values for clay-lined WPs assigned to the Lake Charles, LA and Miami, FL climate stations. These two climate stations have high precipitation (Table A.5), but were assigned low infiltration rates. So for these two climate stations, we re-ran the HELP model for the clay-lined WP scenario for each of the three waste permeability values.

Table A.12 shows these finalized infiltration rate values for clay-lined WPs.

Surface Impoundment

For single-lined SIs, infiltration rates were calculated inside of EPACMTP in the same manner as described in the Section A.1.2 for unlined units, with the exception that we added a 3-foot compacted clay liner with a hydraulic conductivity of 1×10^{-7} cm/s at the bottom of the WMU, and we did not include the effect of clogged native material due to the filtering effects of the liner.

A.1.4 INFILTRATION RATES FOR COMPOSITE-LINED UNITS

We conducted an information collection effort that involved searching the available literature for data that quantify liner integrity and leachate infiltration through composite liners (TetraTech, 2001). We then assembled these data and applied them to develop the following methodologies for modeling infiltration from composite-lined units:

Landfill and Waste Pile

We treated composite-lined LFs and WPs as being the same for the purpose of determining infiltration rates. For these WMU's, we developed an infiltration rate distribution from actual leak detection system (LDS) flow rates reported for clay composite-lined LF cells, and incorporated them into an EPACMTP input file.

We based the distribution of composite-lined LF and WP infiltration rates on available monthly average LDS flow rates from 27 LF cells reported by TetraTech (2001). The data and additional detail for the 27 LF cells are provided in Appendix D, Table D.5 of the *IWEM Technical Background Document* (U.S. EPA, 2003c). The data included monthly average LDS flow rates for 22 operating LF cells and 5 closed LF cells. The 27 LF cells are located in eastern United States: 23 in the northeastern region, 1 in the mid-Atlantic region, and 3 in the southeastern region. Each of the LF cells is underlain by a geomembrane/geosynthetic clay liner which consists of a geomembrane of thickness between 1 and 1.5 mm (with the majority, 22 of 27, being 1.5 mm thick), overlying a geosynthetic clay layer of reported thickness of 6 mm. The geomembrane is a flexible membrane layer made from HDPE. The geosynthetic clay liner is a composite barrier consisting of two geotextile outer layers with a uniform core of bentonite clay to form a hydraulic barrier. The liner system is underlain by a LDS.

We decided in this case to use a subset of the reported flow rates compiled by TetraTech (2001) in developing the composite liner infiltration rates for EPACMTP. We did not include LDS flow rates for geomembrane/compacted clay composite-lined LF cells in our distribution. For compacted clay liners (including composite geomembrane/ compacted clay liners), there is the potential for water to be released during the consolidation of the clay liner and yield an unknown contribution of water to LDS flow, such that it is very difficult to determine how much of the LDS flow is due to liner leakage, versus how much is due to clay consolidation. We also decided in this case to not use LDS flow rates from three geomembrane/geosynthetic clay lined-cells. For one cell, flow rate data were available for the cell's operating period and the cell's post-closure period. The average flow rate for the cell was 26 liters/hectare/day when the cell was operating and 59 liters/hectare/day when the cell was closed. We believe these flow rates, which were among the highest reported, are difficult to interpret because the flow rate from the closed cell was over twice the flow rate from the open cell, a pattern inconsistent with the other open cell/closed cell data pairs we reviewed. For the two other cells, additional verification of the data may be needed in order to fully understand the reported flow rates.

The resulting cumulative probability distribution of infiltration rates for composite-lined LFs and WPs for use in this application is based on the 27 remaining data points is presented in Table A.8. Note that over 50% of the values are zero; that is, they have no measurable infiltration.

Table A.8 Cumulative Frequency Distribution of Infiltration Rate for Composite-Lined LFs and WPs

Percentile	0	10	25	50	75	90	100
Infiltration Rate (m/yr)	0.0	0.0	0.0	0.0	7.30×10^{-5}	1.78×10^{-4}	4.01×10^{-4}

Surface Impoundment

For the surface impoundment scenario, the EPACMTP model derives a value for leakage through circular defects (pin holes) in a composite liner using the following equation developed by Bonaparte et al. (1989):

$$Q = 0.21 a^{0.1} h^{0.9} K_s^{0.74} \tag{A.1}$$

where:

Q = steady-state rate of leakage through a single hole in the liner (m^3/s)
a = area of hole in the geomembrane (m^2)
h = head of liquid on top of geomembrane (m)

K_s = hydraulic conductivity of the low-permeability soil underlying the geomembrane (m/s)

This equation is applicable to cases where there is good contact between the geomembrane and the underlying compacted clay liner. In the course of a Monte Carlo analysis using the regional site-based modeling methodology, the EPACMTP model derives the infiltration rate for each SI unit in the nationwide database included in the site data file using the above equation. This methodology uses the unit-specific ponding depth data (corresponding to h in the above equation) from the recent *Surface Impoundment Study* (U.S. EPA, 2001) in combination with a distribution of leak densities (expressed as number of leaks per hectare) compiled from 26 leak density values reported in TetraTech (2001). The leak densities are based on liners installed with formal Construction Quality Assurance (CQA) programs.

The 26 sites with leak density data are mostly located outside the United States: 3 in Canada, 7 in France, 14 in United Kingdom, and 2 with unknown locations. The WMUs at these sites (8 LFs, 4 SIs, and 14 unknown) are underlain by a layer of geomembrane of thickness varying from 1.14 to 3 mm. The majority of the geomembranes are made from HDPE (23 of 26) with the remaining 3 made from prefabricated bituminous geomembrane or polypropylene. One of the sites has a layer of compacted clay liner beneath the geomembrane, however, for the majority of the sites (25 of 26) material types below the geomembrane layer are not reported. The leak density data above were used for SIs. The leak density distribution is shown in Table A.9. Table D.6, Appendix D of the *IWEM Technical Background Document* (U.S. EPA, 2003c) provides additional detail.

To use the Bonaparte equation, the EPACMTP model assumes a uniform leak size of 6 millimeters squared (mm^2). This leak size is the middle of a range of hole sizes reported by Rollin et al. (1999), who found that 25 percent of holes were less than 2 mm^2, 50 percent of holes were 2 to 10 mm^2, and 25 percent of holes were greater than 10 mm^2. Additionally, the model assumes that the geomembrane is underlain by a compacted clay liner whose hydraulic conductivity is 1×10^{-7} cm/s.

In order to ascertain the plausibility of the leak density data, we conducted an infiltration rate calculation to estimate the range of infiltration resulting from the leaks in geomembrane. Because of the absence of documented infiltration data for SIs, for comparison purposes we used the infiltration data for LFs, described previously under the LF and WP sections, as a surrogate infiltration data set. Because the comparison was made on the basis of LF data, we set the head of liquid above the geomembrane to 0.3 m (1 foot) which is a typical maximum design head for LFs. Calculation results are shown in Table D.6, Appendix D of the *IWEM Technical Background Document* (U.S. EPA, 2003c). These results indicate that the calculated leakage rates, based on the assumptions of above-geomembrane head, hole dimension, hydraulic conductivity of the barrier underneath the geomembrane, and good contact between the geomembrane and the barrier, agree favorably with the observed LF flow rates reported in Table D.5, Appendix D of the *IWEM Technical Background Document* (U.S. EPA, 2003c). This result provided confidence that the leak density data could be used as a reasonable basis for calculating infiltration rates using actual SI ponding depths. The empirical distribution of composite-lined infiltration rates for SIs is part of the EPACMTP input file, if example input files for the composite-lined scenario are to be included in a distribution package.

In order to use these data in EPACMTP, the user is required to specify the unit's ponding depth. EPACMTP will then determine the unit's infiltration distribution using the Bonaparte equation and the leak density distribution in Table A.9. The resulting frequency distribution of calculated infiltration rates for composite-lined SIs that are generated using the standard regional site-based modeling methodology is presented in Table A.10.

Table A.9 Cumulative Frequency Distribution of Leak Density for Composite-Lined SIs

Percentile	0	10	20	30	40	50	60	70	80	90	100
Leak density (No. Leaks/ha)	0	0	0	0	0.7	0.915	1.36	2.65	4.02	4.77	12.5

Table A.10 Cumulative Frequency Distribution of Infiltration Rate for Composite-Lined SIs

Percentile	0	10	25	50	75	90	100
Infiltration Rate (m/yr)	0.0	0.0	0.0	1.34×10^{-5}	1.34×10^{-4}	3.08×10^{-4}	4.01×10^{-3}

Table A.11 HELP-Derived Landfill Infiltration Rates

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
	City	State	Silt Loam	Sandy Loam	Silty Clay	Silt Loam	Sandy Loam	Silty Clay
1	Fresno	CA	0.0307	0.0368	0.0381	0.0046	0.0046	0.0046
2	Boise	ID	0.0008	0.0094	0.0038	0.0046	0.0046	0.0046
3	Denver	CO	0.0008	0.0008	0.0036	0.0000	0.0000	0.0000
4	Grand Junction	CO	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000
5	Pocatello	ID	0.0000	0.0000	0.0000	0.0006	0.0006	0.0006
6	Glasgow	MT	0.0099	0.0074	0.0099	0.0001	0.0001	0.0001
7	Bismarck	ND	0.0239	0.0300	0.0196	0.0188	0.0188	0.0188
8	Pullman	WA	0.0069	0.0132	0.0084	0.0002	0.0002	0.0002
9	Yakima	WA	0.0000	0.0023	0.0003	0.0001	0.0001	0.0001

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
	City	**State**	**Silt Loam**	**Sandy Loam**	**Silty Clay**	**Silt Loam**	**Sandy Loam**	**Silty Clay**
10	Cheyenne	WY	0.0005	0.0013	0.0086	0.0000	0.0000	0.0000
11	Lander	WY	0.0033	0.0053	0.0094	0.0001	0.0001	0.0001
12	Los Angeles	CA	0.0787	0.0950	0.0699	0.0013	0.0013	0.0013
13	Sacramento	CA	0.1024	0.0876	0.0945	0.0013	0.0013	0.0013
14	San Diego	CA	0.0221	0.0340	0.0241	0.0013	0.0013	0.0013
15	Santa Maria	CA	0.0947	0.1151	0.0841	0.0013	0.0013	0.0013
16	Ely	NV	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000
17	Rapid City	SD	0.0005	0.0071	0.0033	0.0001	0.0001	0.0001
18	Cedar City	UT	0.0000	0.0008	0.0000	0.0001	0.0001	0.0001
19	Albuquerque	NM	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000
20	Las Vegas	NV	0.0000	0.0000	0.0018	0.0001	0.0001	0.0001
21	Phoenix	AZ	0.0000	0.0003	0.0003	0.0000	0.0000	0.0000
22	Tucson	AZ	0.0000	0.0003	0.0005	0.0000	0.0000	0.0000
23	El Paso	TX	0.0076	0.0130	0.0081	0.0001	0.0001	0.0001
24	Medford	OR	0.2073	0.2309	0.2096	0.0432	0.0432	0.0432
25	Great Falls	MT	0.0036	0.0069	0.0074	0.0001	0.0001	0.0001
26	Salt Lake City	UT	0.0130	0.0269	0.0185	0.0005	0.0005	0.0005
27	Grand Island	NE	0.0442	0.0627	0.0323	0.0196	0.0196	0.0196
28	Flagstaff	AZ	0.0239	0.0630	0.0226	0.0241	0.0241	0.0241
29	Dodge City	KS	0.0135	0.0345	0.0226	0.0094	0.0094	0.0094
30	Midland	TX	0.0180	0.0254	0.0135	0.0094	0.0094	0.0094
31	St. Cloud	MN	0.0602	0.0831	0.0554	0.0342	0.0342	0.0342
32	E. Lansing	MI	0.1090	0.1452	0.1102	0.0374	0.0374	0.0374
33	North Omaha	NE	0.0671	0.0795	0.0536	0.0291	0.0291	0.0291
34	Tulsa	OK	0.0686	0.1006	0.0465	0.0241	0.0241	0.0241
35	Brownsville	TX	0.0549	0.1049	0.0384	0.0241	0.0241	0.0241
36	Dallas	TX	0.0599	0.1067	0.0531	0.0241	0.0241	0.0241
37	Oklahoma City	OK	0.0612	0.0942	0.0389	0.0246	0.0246	0.0246
38	Concord	NH	0.1585	0.2057	0.1372	0.0432	0.0432	0.0432
39	Pittsburgh	PA	0.0894	0.1313	0.0792	0.0432	0.0432	0.0432
40	Portland	OR	0.4171	0.4387	0.3927	0.0432	0.0432	0.0432
41	Caribou	ME	0.1082	0.1491	0.0886	0.0432	0.0432	0.0432

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
	City	**State**	**Silt Loam**	**Sandy Loam**	**Silty Clay**	**Silt Loam**	**Sandy Loam**	**Silty Clay**
42	Chicago	IL	0.0798	0.1138	0.0620	0.0432	0.0432	0.0432
43	Burlington	VT	0.1359	0.1781	0.1166	0.0432	0.0432	0.0432
44	Bangor	ME	0.1471	0.2045	0.1227	0.0432	0.0432	0.0432
45	Rutland	VT	0.1212	0.1598	0.1008	0.0432	0.0432	0.0432
46	Seattle	WA	0.4384	0.4582	0.4077	0.0432	0.0432	0.0432
47	Montpelier	VT	0.1062	0.1483	0.0879	0.0432	0.0432	0.0432
48	Sault St. Marie	MI	0.1651	0.2101	0.1435	0.0432	0.0432	0.0432
49	Put-in-Bay	OH	0.0508	0.1003	0.0495	0.0409	0.0409	0.0409
50	Madison	WI	0.0912	0.1400	0.0686	0.0409	0.0409	0.0409
51	Columbus	OH	0.0765	0.1158	0.0663	0.0409	0.0409	0.0409
52	Cleveland	OH	0.0780	0.1212	0.0823	0.0409	0.0409	0.0409
53	Des Moines	IA	0.1143	0.1641	0.1156	0.0409	0.0409	0.0409
54	E. St. Louis	IL	0.1435	0.1676	0.0704	0.0409	0.0409	0.0409
55	Columbia	MO	0.1529	0.1989	0.1224	0.0409	0.0409	0.0409
56	Topeka	KS	0.1049	0.1483	0.0762	0.0350	0.0350	0.0350
57	Tampa	FL	0.0658	0.1031	0.0475	0.0253	0.0253	0.0253
58	San Antonio	TX	0.1095	0.1646	0.0820	0.0253	0.0253	0.0253
59	Hartford	CT	0.1709	0.2228	0.1405	0.0445	0.0445	0.0445
60	Syracuse	NY	0.2545	0.3251	0.2118	0.0445	0.0445	0.0445
61	Worchester	MA	0.2022	0.2591	0.1697	0.0445	0.0445	0.0445
62	Augusta	ME	0.2116	0.2700	0.1674	0.0445	0.0445	0.0445
63	Providence	RI	0.2131	0.2863	0.1753	0.0445	0.0445	0.0445
64	Portland	ME	0.2294	0.2840	0.1872	0.0445	0.0445	0.0445
65	Nashua	NH	0.2268	0.2812	0.1943	0.0445	0.0445	0.0445
66	Ithaca	NY	0.1684	0.2136	0.1392	0.0445	0.0445	0.0445
67	Boston	MA	0.2332	0.2383	0.1542	0.0445	0.0445	0.0445
68	Schenectady	NY	0.1473	0.1928	0.1224	0.0445	0.0445	0.0445
69	Lynchburg	VA	0.3081	0.3612	0.2570	0.0444	0.0444	0.0444
70	New York City	NY	0.2436	0.2944	0.1969	0.0444	0.0444	0.0444
71	Philadelphia	PA	0.2007	0.2609	0.1641	0.0444	0.0444	0.0444
72	Seabrook	NJ	0.1814	0.2428	0.1427	0.0444	0.0444	0.0444
73	Indianapolis	IN	0.1300	0.1862	0.1064	0.0444	0.0444	0.0444

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
	City	**State**	**Silt Loam**	**Sandy Loam**	**Silty Clay**	**Silt Loam**	**Sandy Loam**	**Silty Clay**
74	Cincinnati	OH	0.1554	0.2210	0.1539	0.0444	0.0444	0.0444
75	Bridgeport	CT	0.1953	0.2464	0.1615	0.0444	0.0444	0.0444
76	Orlando	FL	0.1016	0.1697	0.0805	0.0362	0.0362	0.0362
77	Greensboro	NC	0.3256	0.3896	0.2705	0.0362	0.0362	0.0362
78	Jacksonville	FL	0.1511	0.2106	0.1102	0.0362	0.0362	0.0362
79	Watkinsville	GA	0.2891	0.3556	0.2332	0.0362	0.0362	0.0362
80	Norfolk	VA	0.2643	0.3857	0.1798	0.0362	0.0362	0.0362
81	Shreveport	LA	0.2296	0.2939	0.1842	0.0362	0.0362	0.0362
82	Astoria	OR	1.0762	1.1494	0.9647	0.0526	0.0526	0.0526
83	New Haven	CT	0.3520	0.4628	0.2855	0.0526	0.0526	0.0526
84	Plainfield	MA	0.1900	0.2540	0.1521	0.0526	0.0526	0.0526
85	Knoxville	TN	0.4107	0.4460	0.3543	0.0486	0.0486	0.0486
86	Central Park	NY	0.3363	0.4171	0.2738	0.0486	0.0486	0.0486
87	Lexington	KY	0.3294	0.3970	0.2700	0.0486	0.0486	0.0486
88	Edison	NJ	0.3122	0.3914	0.2492	0.0486	0.0486	0.0486
89	Nashville	TN	0.4674	0.5395	0.3769	0.0486	0.0486	0.0486
90	Little Rock	AK	0.3531	0.4336	0.2824	0.0477	0.0477	0.0477
91	Tallahassee	FL	0.5913	0.7308	0.4564	0.0477	0.0477	0.0477
92	New Orleans	LA	0.5893	0.7445	0.4503	0.0477	0.0477	0.0477
93	Charleston	SC	0.2609	0.3287	0.2123	0.0477	0.0477	0.0477
94	W. Palm Beach	FL	0.2611	0.3490	0.1783	0.0477	0.0477	0.0477
95	Atlanta	GA	0.3416	0.3993	0.2822	0.0477	0.0477	0.0477
96	Lake Charles	LA	0.3647	0.4641	0.2817	0.0492	0.0492	0.0492
97	Miami	FL	0.1450	0.2201	0.1019	0.0492	0.0492	0.0492
98	Annette	AK	1.6833	1.8354	1.4610	0.0338	0.0338	0.0338
99	Bethel	AK	0.0564	0.0721	0.0554	0.0295	0.0295	0.0295
100	Fairbanks	AK	0.0104	0.0234	0.0117	0.0094	0.0094	0.0094
101	Honolulu	HI	0.0523	0.0945	0.0366	0.0048	0.0048	0.0048
102	San Juan	PR	0.1267	0.1923	0.0945	0.0193	0.0193	0.0193

Table A.12 HELP-derived Waste Pile Infiltration Rates

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
	City	State	Low	Med	High	Low	Med	High
			Silt Loam	Sandy Loam	Silty Clay	Silt Loam	Sandy Loam	Silty Clay Loam
1	Fresno	CA	0.0206	0.0422	0.0963	0.0136	0.0434	0.0606
2	Boise	ID	0.0053	0.0003	0.0318	0.0136	0.0434	0.0606
3	Denver	CO	0.0130	0.0366	0.0958	0.0020	0.0013	0.0037
4	Grand Junction	CO	0.0053	0.0003	0.0178	0.0046	0.0017	0.0020
5	Pocatello	ID	0.0069	0.0020	0.0579	0.0059	0.0015	0.0319
6	Glasgow	MT	0.0056	0.0043	0.0554	0.0005	0.0002	0.0234
7	Bismarck	ND	0.0056	0.0003	0.0356	0.0124	0.0689	0.0950
8	Pullman	WA	0.0112	0.0259	0.1001	0.0093	0.0143	0.0344
9	Yakima	WA	0.0053	0.0003	0.0104	0.0049	0.0047	0.0284
10	Cheyenne	WY	0.0053	0.0003	0.0140	0.0014	0.0003	0.0071
11	Lander	WY	0.0058	0.0008	0.0544	0.0042	0.0012	0.0200
12	Los Angeles	CA	0.0792	0.1331	0.1885	0.0000	0.0556	0.0718
13	Sacramento	CA	0.0699	0.1509	0.1991	0.0000	0.0556	0.0718
14	San Diego	CA	0.0361	0.0658	0.0658	0.0000	0.0556	0.0718
15	Santa Maria	CA	0.0856	0.1234	0.1732	0.0000	0.0556	0.0718
16	Ely	NV	0.0056	0.0135	0.0752	0.0059	0.0011	0.0036
17	Rapid City	SD	0.0053	0.0003	0.0102	0.0010	0.0011	0.0192
18	Cedar City	UT	0.0056	0.0003	0.0259	0.0048	0.0008	0.0053
19	Albuquerque	NM	0.0056	0.0003	0.0097	0.0016	0.0151	0.0074
20	Las Vegas	NV	0.0206	0.0231	0.0556	0.0052	0.0018	0.0080
21	Phoenix	AZ	0.0053	0.0003	0.0351	0.0047	0.0020	0.0008
22	Tucson	AZ	0.0064	0.0003	0.0279	0.0064	0.0075	0.0017
23	El Paso	TX	0.0053	0.0003	0.0330	0.0058	0.0026	0.0067
24	Medford	OR	0.2261	0.2497	0.2990	0.1262	0.1328	0.1313
25	Great Falls	MT	0.0132	0.0259	0.0899	0.0019	0.0047	0.0334
26	Salt Lake City	UT	0.0091	0.0193	0.0747	0.0091	0.0105	0.0368
27	Grand Island	NE	0.0284	0.0963	0.2050	0.0422	0.1347	0.1342
28	Flagstaff	AZ	0.0170	0.0404	0.1016	0.0105	0.1228	0.1234
29	Dodge City	KS	0.0295	0.1011	0.1902	0.0033	0.1063	0.1193
30	Midland	TX	0.0381	0.0757	0.1283	0.0033	0.1063	0.1193

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
			Low	**Med**	**High**	**Low**	**Med**	**High**
	City	**State**	**Silt Loam**	**Sandy Loam**	**Silty Clay**	**Silt Loam**	**Sandy Loam**	**Silty Clay Loam**
31	St. Cloud	MN	0.0513	0.1516	0.2418	0.0264	0.1262	0.1255
32	E. Lansing	MI	0.0602	0.1361	0.2197	0.0481	0.1153	0.1114
33	North Omaha	NE	0.0439	0.1618	0.2771	0.0202	0.1264	0.1265
34	Tulsa	OK	0.0907	0.2471	0.3452	0.0050	0.1329	0.1318
35	Brownsville	TX	0.0457	0.2268	0.3256	0.0050	0.1329	0.1318
36	Dallas	TX	0.1067	0.2578	0.3543	0.0050	0.1329	0.1318
37	Oklahoma City	OK	0.0851	0.2423	0.3386	0.0075	0.1310	0.1298
38	Concord	NH	0.1410	0.2570	0.3147	0.1125	0.1273	0.1266
39	Pittsburg	PA	0.1100	0.2131	0.2944	0.1125	0.1273	0.1266
40	Portland	OR	0.1003	0.1880	0.2705	0.1125	0.1273	0.1266
41	Caribou	ME	0.1016	0.1758	0.2372	0.1125	0.1273	0.1266
42	Chicago	IL	0.1158	0.2126	0.2725	0.1125	0.1273	0.1266
43	Burlington	VT	0.4663	0.5331	0.5631	0.1125	0.1273	0.1266
44	Bangor	ME	0.0820	0.1717	0.2852	0.1125	0.1273	0.1266
45	Rutland	VT	0.4486	0.5060	0.5370	0.1125	0.1273	0.1266
46	Seattle	WA	0.0485	0.1676	0.2685	0.1125	0.1273	0.1266
47	Montpelier	VT	0.1252	0.2098	0.3160	0.1125	0.1273	0.1266
48	Sault St. Marie	MI	0.1283	0.2116	0.2858	0.1125	0.1273	0.1266
49	Put-in-Bay	OH	0.0617	0.2022	0.3048	0.0688	0.1325	0.1321
50	Madison	WI	0.0790	0.1717	0.2606	0.0688	0.1325	0.1321
51	Columbus	OH	0.0559	0.1481	0.2527	0.0688	0.1325	0.1321
52	Cleveland	OH	0.0889	0.1821	0.2680	0.0688	0.1325	0.1321
53	Des Moines	IA	0.1232	0.2634	0.3907	0.0688	0.1325	0.1321
54	E. St. Louis	IL	0.0897	0.2512	0.3546	0.0688	0.1325	0.1321
55	Columbia	MO	0.1547	0.3101	0.4277	0.0688	0.1325	0.1321
56	Topeka	KS	0.0841	0.2469	0.3620	0.0174	0.1305	0.1302
57	Tampa	FL	0.1168	0.2954	0.4026	0.0200	0.1339	0.1333
58	San Antonio	TX	0.1059	0.2715	0.3724	0.0200	0.1339	0.1333
59	Hartford	CT	0.1496	0.2611	0.3444	0.1193	0.1286	0.1279
60	Syracuse	NY	0.2487	0.4100	0.4844	0.1193	0.1286	0.1279
61	Worchester	MA	0.1473	0.2751	0.3622	0.1193	0.1286	0.1279

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
			Low	**Med**	**High**	**Low**	**Med**	**High**
	City	**State**	**Silt Loam**	**Sandy Loam**	**Silty Clay**	**Silt Loam**	**Sandy Loam**	**Silty Clay Loam**
62	Augusta	ME	0.1692	0.3216	0.4209	0.1193	0.1286	0.1279
63	Providence	RI	0.1821	0.3482	0.4610	0.1193	0.1286	0.1279
64	Portland	ME	0.1765	0.3335	0.4148	0.1193	0.1286	0.1279
65	Nashua	NH	0.1773	0.3312	0.4267	0.1193	0.1286	0.1279
66	Ithaca	NY	0.1806	0.3132	0.3861	0.1193	0.1286	0.1279
67	Boston	MA	0.2090	0.3254	0.3922	0.1193	0.1286	0.1279
68	Schenectady	NY	0.1770	0.2786	0.3622	0.1193	0.1286	0.1279
69	Lynchburg	VA	0.2830	0.4590	0.5654	0.1062	0.1336	0.1332
70	New York City	NY	0.1234	0.2690	0.3818	0.1062	0.1336	0.1332
71	Philadelphia	PA	0.1577	0.3406	0.4709	0.1062	0.1336	0.1332
72	Seabrook	NJ	0.1783	0.3096	0.4133	0.1062	0.1336	0.1332
73	Indianapolis	IN	0.2121	0.3988	0.5184	0.1062	0.1336	0.1332
74	Cincinnati	OH	0.1773	0.3526	0.4757	0.1062	0.1336	0.1332
75	Bridgeport	CT	0.2113	0.3691	0.4717	0.1062	0.1336	0.1332
76	Orlando	FL	0.3061	0.4839	0.5941	0.0804	0.1273	0.1266
77	Greensboro	NC	0.2426	0.4666	0.5903	0.0804	0.1273	0.1266
78	Jacksonville	FL	0.2591	0.4455	0.5710	0.0804	0.1273	0.1266
79	Watkinsville	GA	0.2992	0.4544	0.5535	0.0804	0.1273	0.1266
80	Norfolk	VA	0.1694	0.3835	0.4737	0.0804	0.1273	0.1266
81	Shreveport	LA	0.1996	0.4087	0.5263	0.0804	0.1273	0.1266
82	Astoria	OR	0.9865	1.2136	1.2637	0.1316	0.1355	0.1350
83	New Haven	CT	0.3561	0.5423	0.5098	0.1316	0.1355	0.1350
84	Plainfield	MA	0.1910	0.3033	0.3950	0.1316	0.1355	0.1350
85	Knoxville	TN	0.2804	0.4521	0.5733	0.1255	0.1352	0.1349
86	Central Park	NY	0.3045	0.4897	0.6066	0.1255	0.1352	0.1349
87	Lexington	KY	0.4039	0.5415	0.6421	0.1255	0.1352	0.1349
88	Edison	NJ	0.3000	0.5286	0.6525	0.1255	0.1352	0.1349
89	Nashville	TN	0.4173	0.6144	0.7435	0.1255	0.1352	0.1349
90	Little Rock	AK	0.3332	0.5288	0.6414	0.1184	0.1351	0.1347
91	Tallahassee	FL	0.5024	0.8486	0.9792	0.1184	0.1351	0.1347
92	New Orleans	LA	0.3018	0.5380	0.6683	0.1184	0.1351	0.1347
93	Charleston	SC	0.2794	0.4829	0.5832	0.1184	0.1351	0.1347

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)			Single Clay Liner Infiltration Rate (m/yr)		
			Low	Med	High	Low	Med	High
	City	State	Silt Loam	Sandy Loam	Silty Clay	Silt Loam	Sandy Loam	Silty Clay Loam
94	W. Palm Beach	FL	0.5126	0.8219	0.9581	0.1184	0.1351	0.1347
95	Atlanta	GA	0.2553	0.5641	0.6904	0.1184	0.1351	0.1347
96	Lake Charles	LA	0.1615	0.4227	0.5331	0.0489	0.0558	0.0927
97	Miami	FL	0.3891	0.6066	0.7201	0.0489	0.0558	0.0927
98	Annette	AK	1.5373	1.8146	1.8789	0.1352	0.1357	0.1354
99	Bethel	AK	0.0502	0.0725	0.1225	0.0352	0.0364	0.0660
100	Fairbanks	AK	0.0077	0.0167	0.0777	0.0098	0.0118	0.0407
101	Honolulu	HI	0.0501	0.1083	0.1983	0.0323	0.0494	0.0871
102	San Juan	PR	0.1498	0.2883	0.4442	0.0637	0.0793	0.1114

Table A.13 HELP-derived Land Application Unit Infiltration Rates

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)		
	City	State	Silt Loam	Sandy Loam	Silty Clay Loam
1	Fresno	CA	0.0307	0.0368	0.0381
2	Boise	ID	0.0008	0.0094	0.0038
3	Denver	CO	0.0008	0.0008	0.0036
4	Grand Junction	CO	0.0000	0.0000	0.0003
5	Pocatello	ID	0.0000	0.0000	0.0000
6	Glasgow	MT	0.0099	0.0074	0.0099
7	Bismarck	ND	0.0239	0.0300	0.0196
8	Pullman	WA	0.0069	0.0132	0.0084
9	Yakima	WA	0.0000	0.0023	0.0003
10	Cheyenne	WY	0.0005	0.0013	0.0086
11	Lander	WY	0.0033	0.0053	0.0094
12	Los Angeles	CA	0.0787	0.0950	0.0699
13	Sacramento	CA	0.1024	0.0876	0.0945
14	San Diego	CA	0.0221	0.0340	0.0241
15	Santa Maria	CA	0.0947	0.1151	0.0841
16	Ely	NV	0.0000	0.0000	0.0003
17	Rapid City	SD	0.0005	0.0071	0.0033
18	Cedar City	UT	0.0000	0.0008	0.0000
19	Albuquerque	NM	0.0000	0.0000	0.0003
20	Las Vegas	NV	0.0000	0.0000	0.0018
21	Phoenix	AZ	0.0000	0.0003	0.0003
22	Tucson	AZ	0.0000	0.0003	0.0005
23	El Paso	TX	0.0076	0.0130	0.0081
24	Medford	OR	0.2073	0.2309	0.2096
25	Great Falls	MT	0.0036	0.0069	0.0074
26	Salt Lake City	UT	0.0130	0.0269	0.0185
27	Grand Island	NE	0.0442	0.0627	0.0323
28	Flagstaff	AZ	0.0239	0.0630	0.0226
29	Dodge City	KS	0.0135	0.0345	0.0226
30	Midland	TX	0.0180	0.0254	0.0135
31	St. Cloud	MN	0.0602	0.0831	0.0554
32	E. Lansing	MI	0.1090	0.1452	0.1102
33	North Omaha	NE	0.0671	0.0795	0.0536
34	Tulsa	OK	0.0686	0.1006	0.0465
35	Brownsville	TX	0.0549	0.1049	0.0384

Climate Center Index	Climate Center		No Liner Infiltration Rate (m/yr)		
	City	State	Silt Loam	Sandy Loam	Silty Clay Loam
36	Dallas	TX	0.0599	0.1067	0.0531
37	Oklahoma City	OK	0.0612	0.0942	0.0389
38	Concord	NH	0.1585	0.2057	0.1372
39	Pittsburg	PA	0.0894	0.1313	0.0792
40	Portland	OR	0.4171	0.4387	0.3927
41	Caribou	ME	0.1082	0.1491	0.0886
42	Chicago	IL	0.0798	0.1138	0.0620
43	Burlington	VT	0.1359	0.1781	0.1166
44	Bangor	ME	0.1471	0.2045	0.1227
45	Rutland	VT	0.1212	0.1598	0.1008
46	Seattle	WA	0.4384	0.4582	0.4077
47	Montpelier	VT	0.1062	0.1483	0.0879
48	Sault St. Marie	MI	0.1651	0.2101	0.1435
49	Put-in-Bay	OH	0.0508	0.1003	0.0495
50	Madison	WI	0.0912	0.1400	0.0686
51	Columbus	OH	0.0765	0.1158	0.0663
52	Cleveland	OH	0.0780	0.1212	0.0823
53	Des Moines	IA	0.1143	0.1641	0.1156
54	E. St. Louis	IL	0.1435	0.1676	0.0704
55	Columbia	MO	0.1529	0.1989	0.1224
56	Topeka	KS	0.1049	0.1483	0.0762
57	Tampa	FL	0.0658	0.1031	0.0475
58	San Antonio	TX	0.1095	0.1646	0.0820
59	Hartford	CT	0.1709	0.2228	0.1405
60	Syracuse	NY	0.2545	0.3251	0.2118
61	Worchester	MA	0.2022	0.2591	0.1697
62	Augusta	ME	0.2116	0.2700	0.1674
63	Providence	RI	0.2131	0.2863	0.1753
64	Portland	ME	0.2294	0.2840	0.1872
65	Nashua	NH	0.2268	0.2812	0.1943
66	Ithaca	NY	0.1684	0.2136	0.1392
67	Boston	MA	0.2332	0.2383	0.1542
68	Schenectady	NY	0.1473	0.1928	0.1224
69	Lynchburg	VA	0.3081	0.3612	0.2570
70	New York City	NY	0.2436	0.2944	0.1969
71	Philadelphia	PA	0.2007	0.2609	0.1641
72	Seabrook	NJ	0.1814	0.2428	0.1427

Climate Center Index	**Climate Center**		**No Liner Infiltration Rate (m/yr)**		
	City	**State**	**Silt Loam**	**Sandy Loam**	**Silty Clay Loam**
73	Indianapolis	IN	0.1300	0.1862	0.1064
74	Cincinnati	OH	0.1554	0.2210	0.1539
75	Bridgeport	CT	0.1953	0.2464	0.1615
76	Orlando	FL	0.1016	0.1697	0.0805
77	Greensboro	NC	0.3256	0.3896	0.2705
78	Jacksonville	FL	0.1511	0.2106	0.1102
79	Watkinsville	GA	0.2891	0.3556	0.2332
80	Norfolk	VA	0.3122	0.0000	0.2685
81	Shreveport	LA	0.2296	0.2939	0.1842
82	Astoria	OR	1.0762	1.1494	0.9647
83	New Haven	CT	0.3520	0.4628	0.2855
84	Plainfield	MA	0.1900	0.2540	0.1521
85	Knoxville	TN	0.4107	0.4460	0.3543
86	Central Park	NY	0.3363	0.4171	0.2738
87	Lexington	KY	0.3294	0.3970	0.2700
88	Edison	NJ	0.3122	0.3914	0.2492
89	Nashville	TN	0.4674	0.5395	0.3769
90	Little Rock	AK	0.3531	0.4336	0.2824
91	Tallahassee	FL	0.5913	0.7308	0.4564
92	New Orleans	LA	0.5893	0.7445	0.4503
93	Charleston	SC	0.2609	0.3287	0.2123
94	W. Palm Beach	FL	0.2611	0.3490	0.1783
95	Atlanta	GA	0.3416	0.3993	0.2822
96	Lake Charles	LA	0.3647	0.4641	0.2817
97	Miami	FL	0.1450	0.2201	0.1019
98	Annette	AK	1.8049	1.9771	1.5159
99	Bethel	AK	0.1849	0.1981	0.1781
100	Fairbanks	AK	0.1463	0.1483	0.1445
101	Honolulu	HI	0.0541	0.0983	0.0363
102	San Juan	PR	0.1491	0.2164	0.1049

Table A.14 HELP-derived Regional Recharge Rates

Climate Center Index	Climate Center		Ambient Regional Recharge Rate (m/yr)		
			Soil Type		
	City	State	Silt Loam	Sandy Loam	Silty Clay Loam
1	Fresno	CA	0.0307	0.0368	0.0381
2	Boise	ID	0.0008	0.0094	0.0038
3	Denver	CO	0.0008	0.0008	0.0036
4	Grand Junction	CO	0.0000	0.0000	0.0003
5	Pocatello	ID	0.0000	0.0000	0.0000
6	Glasgow	MT	0.0099	0.0074	0.0099
7	Bismarck	ND	0.0239	0.0300	0.0196
8	Pullman	WA	0.0069	0.0132	0.0084
9	Yakima	WA	0.0000	0.0023	0.0003
10	Cheyenne	WY	0.0005	0.0013	0.0086
11	Lander	WY	0.0033	0.0053	0.0094
12	Los Angeles	CA	0.0787	0.0950	0.0699
13	Sacramento	CA	0.1024	0.0876	0.0945
14	San Diego	CA	0.0221	0.0340	0.0241
15	Santa Maria	CA	0.0947	0.1151	0.0841
16	Ely	NV	0.0000	0.0000	0.0003
17	Rapid City	SD	0.0005	0.0071	0.0033
18	Cedar City	UT	0.0000	0.0008	0.0000
19	Albuquerque	NM	0.0000	0.0000	0.0003
20	Las Vegas	NV	0.0000	0.0000	0.0018
21	Phoenix	AZ	0.0000	0.0003	0.0003
22	Tucson	AZ	0.0000	0.0003	0.0005
23	El Paso	TX	0.0076	0.0130	0.0081
24	Medford	OR	0.2073	0.2309	0.2096
25	Great Falls	MT	0.0036	0.0069	0.0074
26	Salt Lake City	UT	0.0130	0.0269	0.0185
27	Grand Island	NE	0.0442	0.0627	0.0323
28	Flagstaff	AZ	0.0239	0.0630	0.0226
29	Dodge City	KS	0.0135	0.0345	0.0226
30	Midland	TX	0.0180	0.0254	0.0135
31	St. Cloud	MN	0.0602	0.0831	0.0554
32	E. Lansing	MI	0.1090	0.1452	0.1102
33	North Omaha	NE	0.0671	0.0795	0.0536
34	Tulsa	OK	0.0686	0.1006	0.0465
35	Brownsville	TX	0.0549	0.1049	0.0384

Climate Center Index	Climate Center		Ambient Regional Recharge Rate (m/yr)		
			Soil Type		
	City	State	Silt Loam	Sandy Loam	Silty Clay Loam
36	Dallas	TX	0.0599	0.1067	0.0531
37	Oklahoma City	OK	0.0612	0.0942	0.0389
38	Concord	NH	0.1585	0.2057	0.1372
39	Pittsburg	PA	0.0894	0.1313	0.0792
40	Portland	OR	0.4171	0.4387	0.3927
41	Caribou	ME	0.1082	0.1491	0.0886
42	Chicago	IL	0.0798	0.1138	0.0620
43	Burlington	VT	0.1359	0.1781	0.1166
44	Bangor	ME	0.1471	0.2045	0.1227
45	Rutland	VT	0.1212	0.1598	0.1008
46	Seattle	WA	0.4384	0.4582	0.4077
47	Montpelier	VT	0.1062	0.1483	0.0879
48	Sault St. Marie	MI	0.1651	0.2101	0.1435
49	Put-in-Bay	OH	0.0508	0.1003	0.0495
50	Madison	WI	0.0912	0.1400	0.0686
51	Columbus	OH	0.0765	0.1158	0.0663
52	Cleveland	OH	0.0780	0.1212	0.0823
53	Des Moines	IA	0.1143	0.1641	0.1156
54	E. St. Louis	IL	0.1435	0.1676	0.0704
55	Columbia	MO	0.1529	0.1989	0.1224
56	Topeka	KS	0.1049	0.1483	0.0762
57	Tampa	FL	0.0658	0.1031	0.0475
58	San Antonio	TX	0.1095	0.1646	0.0820
59	Hartford	CT	0.1709	0.2228	0.1405
60	Syracuse	NY	0.2545	0.3251	0.2118
61	Worchester	MA	0.2022	0.2591	0.1697
62	Augusta	ME	0.2116	0.2700	0.1674
63	Providence	RI	0.2131	0.2863	0.1753
64	Portland	ME	0.2294	0.2840	0.1872
65	Nashua	NH	0.2268	0.2812	0.1943
66	Ithaca	NY	0.1684	0.2136	0.1392
67	Boston	MA	0.2332	0.2383	0.1542
68	Schenectady	NY	0.1473	0.1928	0.1224
69	Lynchburg	VA	0.3081	0.3612	0.2570
70	New York City	NY	0.2436	0.2944	0.1969
71	Philadelphia	PA	0.2007	0.2609	0.1641

Climate Center Index	Climate Center		Ambient Regional Recharge Rate (m/yr)		
			Soil Type		
	City	State	Silt Loam	Sandy Loam	Silty Clay Loam
72	Seabrook	NJ	0.1814	0.2428	0.1427
73	Indianapolis	IN	0.1300	0.1862	0.1064
74	Cincinnati	OH	0.1554	0.2210	0.1539
75	Bridgeport	CT	0.1953	0.2464	0.1615
76	Orlando	FL	0.1016	0.1697	0.0805
77	Greensboro	NC	0.3256	0.3896	0.2705
78	Jacksonville	FL	0.1511	0.2106	0.1102
79	Watkinsville	GA	0.2891	0.3556	0.2332
80	Norfolk	VA	0.3122	0.0000	0.2685
81	Shreveport	LA	0.2296	0.2939	0.1842
82	Astoria	OR	1.0762	1.1494	0.9647
83	New Haven	CT	0.3520	0.4628	0.2855
84	Plainfield	MA	0.1900	0.2540	0.1521
85	Knoxville	TN	0.4107	0.4460	0.3543
86	Central Park	NY	0.3363	0.4171	0.2738
87	Lexington	KY	0.3294	0.3970	0.2700
88	Edison	NJ	0.3122	0.3914	0.2492
89	Nashville	TN	0.4674	0.5395	0.3769
90	Little Rock	AK	0.3531	0.4336	0.2824
91	Tallahassee	FL	0.5913	0.7308	0.4564
92	New Orleans	LA	0.5893	0.7445	0.4503
93	Charleston	SC	0.2609	0.3287	0.2123
94	W. Palm Beach	FL	0.2611	0.3490	0.1783
95	Atlanta	GA	0.3416	0.3993	0.2822
96	Lake Charles	LA	0.3647	0.4641	0.2817
97	Miami	FL	0.1450	0.2201	0.1019
98	Annette	AK	1.6833	1.8354	1.4610
99	Bethel	AK	0.0564	0.0721	0.0554
100	Fairbanks	AK	0.0104	0.0234	0.0117
101	Honolulu	HI	0.0523	0.0945	0.0366
102	San Juan	PR	0.1267	0.1923	0.0945

A.1.5 DETERMINATION OF RECHARGE RATES

We estimated recharge rates for the three primary soil types across the United States (SNL, SLT, and SCL) and ambient climate conditions at 102 climate stations through the use of the HELP water-balance model as summarized in Sections A.1.1 and A.1.2. We assumed the ambient regional recharge rate for a given climate center and soil type (for all four WMU types) is the same as the corresponding unlined LF infiltration rate. Table A.14 presents the resulting regional recharge rates for all climate stations and soil types.

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APPENDIX B

NON-LINEAR SORPTION ISOTHERMS CALCULATED USING THE MINTEQA2 MODEL

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APPENDIX B
NON-LINEAR SORPTION ISOTHERMS CALCULATED USING THE MINTEQA2 MODEL

1.0 INTRODUCTION

This appendix describes the development of concentration-dependent metal partition coefficients for use in EPACMTP. In the subsurface, metal contaminants undergo reactions with ligands in the pore water and with surface sites on the solid aquifer or soil matrix material. Reactions in which the metal is bound to the solid matrix are referred to as sorption reactions and metal that is bound to the solid is said to be sorbed. The ratio of the concentration of metal sorbed to the concentration in the mobile aqueous phase at equilibrium is referred to as the partition coefficient (K_d). During contaminant transport, sorption to the solid matrix results in retardation of the contaminant front. Thus, transport models such as EPACMTP incorporate the contaminant partition coefficient into the overall retardation factor (the ratio of the average linear particle velocity to the velocity of that portion of the plume where the contaminant is at 50 percent dilution). Using K_d in EPACMTP transport modeling implies the assumption that local equilibrium between the solutes and the sorbents is attained. This implies that the rate of sorption reactions is fast relative to advective-dispersive transport of the contaminant.

EPACMTP incorporates the option of using tables of non-linear sorption isotherms. These isotherms reflect the tendency of K_d to decrease as the total metal concentration in the system increases. The non-linear isotherms available for use in EPACMTP are specified in terms of the dissolved metal concentration and the corresponding sorbed concentration at a series of total metal concentrations. The isotherms were estimated using the geochemical speciation model, MINTEQA2. For a particular metal, K_d values in a soil or aquifer are dependent upon the metal concentration and various geochemical characteristics of the soil or aquifer and the associated pore water. Geochemical parameters that have the greatest influence on the magnitude of K_d include the pH of the system and the nature and concentration of sorbents associated with the soil or aquifer matrix. In the subsurface beneath a disposal facility, the concentration of leachate constituents may also influence K_d. Although the dependence of metal partitioning on the total metal concentration and on pH and other geochemical characteristics is apparent from partitioning studies reported in the scientific literature, K_d values for many metals are not available for the range of metal concentrations or geochemical conditions needed in risk assessment modeling. For this reason, we chose to use an equilibrium speciation model, MINTEQA2, to estimate partition coefficients. Using a speciation model allows K_d values to be estimated for a range of total metal concentrations in various model systems designed to depict natural variability in those geochemical characteristics that most influence metal partitioning.

MINTEQA2

We produced the non-linear sorption isotherms for metals by using MINTEQA2[1], a geochemical speciation model maintained and distributed by the U.S. EPA. From input data consisting of total concentrations of chemical constituents, MINTEQA2 calculates the fraction of a contaminant metal that is dissolved, adsorbed, and precipitated at equilibrium (see Figure B.1). The total concentrations of major and minor ions, trace metals and other chemicals are specified in terms of key species known as components. MINTEQA2 automatically includes an extensive database of solution species and solid phase species representing reaction products of two or more of the components. The model does not automatically include sorption reactions, but these can be included in the calculations if supplied by the user. When sorption reactions are included, the dimensionless partition coefficient can be calculated from the ratio of the sorbed metal concentration to the dissolved metal concentration at equilibrium. The dimensionless partition coefficient is converted to K_d with units of liters per kilogram (L/kg) by normalizing by the mass of soil (in kilograms) with which one liter of pore water is equilibrated (the phase ratio). An isotherm is generated when the equilibrium metal distribution between sorbed and dissolved fractions is estimated for a series of total metal concentrations.

Progress in accounting for sorption in equilibrium calculations over the past decade has resulted in the development of coherent databases of sorption reactions for particular sorbents. These databases include acid-base sorption reactions and reactions for major ions in aquatic systems (Ca, Mg, SO_4, etc.). Including such reactions along with those representing sorption of trace metals makes it possible to estimate sorption in systems of varying pH and composition. Examples of coherent databases of sorption reactions include that for the hydrous ferric oxide surface presented by Dzombak and Morel (1990) and a similar database for goethite presented by Mathur (1995).

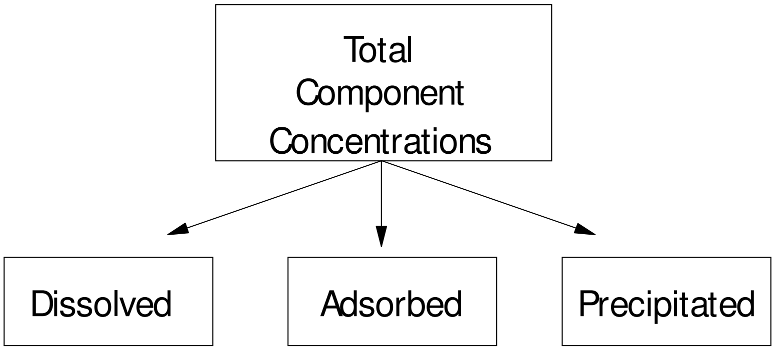

Figure B.1 MINTEQA2 Computes the Equilibrium Distribution of Metal.

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[1] The version of MINTEQA2 used in this modeling was modified from version 4.02.

2.0 MODEL INPUT DATA AND PROCEDURE

Expected natural variability in K_d for a particular metal was included in the MINTEQA2 modeling by including variability in important input parameters upon which K_d depends. The input parameters for which variability was incorporated include ground-water composition, pH, concentration of sorbents, concentration of leachate organic matter (LOM), and concentration of metal.

The ground-water chemistry exerts an important influence on metal partition coefficients. The major ions present in ground water may compete with trace metals for sorption sites. Also, inorganic ligands may complex with some metals reducing their tendency to sorb. For the purposes of this model, we assumed that the influence of ground-water composition on metal sorption can be adequately represented by dividing the universe of ground-water compositional types into two categories: carbonate and non-carbonate. Further, we assumed that the influence of pH can be represented by depicting each of these two ground water types at a number of equilibrium pH values within its natural range of variability. Furthermore, the depiction of each ground-water chemistry at multiple pH values can be accomplished by titrating the natural ground-water chemistry with a mineral acid or base.

The influence of variability in sorption capacity of soil and aquifer materials was included in the K_d estimates by equilibrating the ground-water systems with various concentrations of commonly occurring natural sorbents. Two common sorbents in soil and ground-water systems are ferric oxyhydroxide and particulate organic matter (POM). Although other sorbents such as clay minerals, carbonate minerals, hydrous aluminum and manganese oxides, and silica may sorb metals in the subsurface, representation of ferric oxyhydroxide and particulate organic matter in the model is sufficient to provide a reasonable assessment of the sorption capacity of most natural ground-water systems.

Leachate organic matter present as various well-characterized acids may influence the propensity for metal sorption. The influence of leachate organic matter on metal sorption is characterized by including representative acids present at concentration levels that span the expected range.

2.1 METALS OF INTEREST

The metal contaminants whose partition coefficients have been estimated using MINTEQA2 include arsenic (As), antimony (Sb), barium (Ba), beryllium (Be), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), fluoride (F), mercury (Hg), manganese (Mn), molybdenum (Mo), lead (Pb), nickel (Ni), selenium (Se), silver (Ag), thallium (Tl), vanadium (V), and zinc (Zn).

Several of these metals occur naturally in more than one oxidation state. The modeling described here is restricted to the oxidation states that are most likely to occur in waste systems or most likely to be mobile in ground-water waste systems. For arsenic, chromium, and selenium, partition coefficients were estimated for two oxidation states. These were: As(III) and As(V), Cr(III) and Cr(VI), and Se(IV) and Se(VI). For antimony, molybdenum, thallium, and vanadium, only one oxidation state was modeled although multiple oxidation states occur. For all four of these metals, the choice of which state to model was dictated by practical aspects such as availability of sorption reactions and by subjective assessment of the appropriate oxidation state. The oxidation states modeled were Sb(V) (there were no sorption reactions available for Sb(III)), Mo(VI) (molybdate seems the most relevant form from literature reports), thallium (I) (this form is more frequently cited in the literature as having environmental implications), and V(V) (vanadate; sorption reactions were not available for other forms).

2.2 GROUND-WATER COMPOSITION

The extent of metal sorption in a ground-water system is dependent upon the chemical characteristics of the pore water solution and the interactions between all solutes and the sorbing sites present on the exposed surfaces of the soil and aquifer matrix material. In EPACMTP, partition coefficients were estimated separately for two ground-water compositional types, one with composition representative of a carbonate-terrain system and one representative of a non-carbonate system. The two ground-water compositional types are correlated with the hydrogeologic environment parameter in EPACMTP. In EPACMTP, this parameter may take on one of thirteen values, each indicative of a particular ground-water type (see Table B.1). Issues of practicality limit to just two the number of ground-water types for which separate partition coefficients can be estimated. The broadest division that may be made of the thirteen ground-water types in EPACMTP is carbonate and non-carbonate. Thus, these are the two broad types for which coefficients were estimated. The carbonate type corresponds to the "solution limestone" hydrogeologic environment setting in EPACMTP (hydrogeologic environment parameter = 12). The other twelve possible hydrogeologic settings in EPACMTP are represented by the non-carbonate ground-water type.

Table B.1 Settings For The Hydrogeologic Environment Parameter In EPACMTP

Hydrogeologic Environment Parameter	Environment (Ground-Water Type) Represented
1	Metamorphic and Igneous
2	Bedded Sedimentary Rock
3	Till Over Sedimentary Rock
4	Sand and Gravel
5	Alluvial Basins Valleys and Fans
6	River Valleys and Floodplains with Overbank Deposits
7	River Valleys and Floodplains without Overbank Deposit
8	Outwash
9	Till and Till Over Outwash
10	Unconsolidated and Semi-consolidated Shallow Aquifers
11	Coastal Beaches
12	Solution Limestone
13	Others (unclassified hydrogeologic environments)

For both ground-water types, we selected from the literature a representative, charge-balanced ground-water chemistry specified in terms of major ion concentrations and natural pH. The carbonate system was represented by a well sample reported for a limestone aquifer (Freeze and Cherry, 1979). This ground water had a natural pH of 7.5 and was saturated with respect to calcite. The non-carbonate system was represented by a sample reported from an unconsolidated sand and gravel aquifer with a natural pH of 7.4 (White et al., 1963). An unconsolidated sand and gravel aquifer was selected to represent the non-carbonate compositional type because it is the most frequently occurring of the twelve (non-carbonate) hydrogeologic environments in EPACMTP. The composition of both the carbonate and non-carbonate representative ground-water samples is shown in Table B.2. These compositions were used in MINTEQA2 to estimate partition coefficients for carbonate and non-carbonate ground-water types. When EPACMTP is used in site-specific or monte carlo mode, the choice of the hydrogeologic environment by the user (or the monte carlo routine) dictates the set of partition coefficients (carbonate or non-carbonate) that should be accessed.

Table B.2 Composition Of Representative Ground Waters

Constituent Chemical	Concentrations (mg/L) Carbonate Ground water	Non-carbonate Ground water
Ca	55	49
Mg	28	13
SO_4	20	27
HCO_3	265	384
Na	3.1	105
Cl	10	34
K	1.5	3.0
NO_3	---	7.8
F	---	0.3
SiO_2	---	21
pH	7.5	7.4
Temp	18 C	14 C
Other	Equilibrium with calcite	---

2.3 MODEL ADSORBENTS

Two types of adsorbents were represented in the MINTEQA2 equilibrium modeling: ferric oxide and particulate organic matter. Ferric oxides (and hydroxides) and particulate organic matter are among the most important sorbents in natural systems. The former may be present as amorphous substances or crystalline minerals such as hematite, goethite, or ferrihydrite dispersed in soil as discrete particles or as coatings on particles of other materials. In recent years, databases of equilibrium sorption reactions for hydrous ferric oxide and goethite have been compiled from studies described in the literature (Dzombak and Morel, 1990; Mathur, 1995). Both of the databases cited were designed for use with the MIT Two-Layer sorption model, also called the diffuse-layer model (DLM; Dzombak and Morel, 1990).

Owing to the complexity and variability of natural organic substances, the science of modeling surface reactions on particulate organic matter is less advanced than for sorption onto hydrous metal oxides. The modeling described here assumes that reactions on POM are analogous to those on dissolved organic matter (DOM); a DOM model was adapted for the POM calculation. This model, the Gaussian distribution model (Dobbs et. al., 1989), assumes that organic matter is a complex mixture of substances exhibiting highly variable binding affinities for metals. Reactions are represented like conventional pure substance reactions except that the usual single equilibrium constant is replaced by a distribution of constants (log K values). The distribution of log K is assumed to be Gaussian in shape. This model is also supplied with a database of reactions, including acid-base and major ion reactions, each with its mean log K for depicting the Gaussian distribution.

When included in equilibrium models, these databases of sorption reactions provide a means of including competition for sorption sites among major ground-water ions such as Ca, Mg, and SO_4 and contaminant metal constituents. More importantly, by including in equilibrium calculations the acid-base reactions for these surfaces, the dependence of trace metal sorption on pH can be reflected in the model.

2.3.1 Goethite Sorbent

Mineralogically, we assumed the ferric oxide sorbent to be goethite (α-FeOOH). Goethite is a common form of ferric oxide in soils. The database of sorption reactions for goethite reported by Mathur (1995) was used with the diffuse-layer sorption model in MINTEQA2 to represent the interactions of protons, major ions, and contaminant metals with the ferric oxide surface (hereafter referred to as FeOx for brevity).

The concentration of sorption sites used in the MINTEQA2 model runs was based on a measurement of ferric iron extractable from soil samples using hydroxylamine hydrochloride as reported in EPRI(1986). This method of Fe extraction is intended to provide a measure of the exposed ferric oxide present as mineral coatings and discrete particles and available for surface reactions with solutes in the associated pore water. The variability in ferric oxide sorbent concentration represented by the variability in extractable Fe from these samples was included in the modeling by selecting low, medium and high extractable Fe concentrations corresponding to the 17th, 50th and 83rd percentiles of the sample measurements. The extractable Fe weight percentages used in the modeling are shown in Table B.3.

Table B.3 Concentration Levels For Goethite Sorbent

Concentration Level	Weight Percent Fe (extractable)	FeOOH Sorbent Concentration (g/L)
Unsaturated zone		
Low	0.0182	1.325
Medium	0.0729	5.309
High	0.1190	8.667
Saturated zone		
Low	0.0182	1.032
Medium	0.0729	4.136
High	0.1190	6.751

Although the same distribution of extractable Fe sorbent was used in modeling the saturated and unsaturated zones, the actual concentration of sorbing sites corresponding to the low, medium, and high FeOx settings in MINTEQA2 was different in the two zones because the assumed ratio of soil mass to solution volume (the phase ratio) was different. For both zones, the phase ratio was calculated as the mean soil bulk density divided by the mean water content (product of mean porosity and mean water saturation). In EPACMTP, the mean soil bulk density and mean porosity are

1.6 kg/L and 45 percent, respectively. The mean water saturation in the unsaturated zone is 77.7 percent. The water saturation in the saturated zone is, of course, 100 percent. Thus, the phase ratio for the unsaturated zone is 4.57 kg/L and for the saturated zone is 3.56 kg/L. We used these values and the molar mass ratio of goethite to Fe to convert the weight percent extractable Fe to the mass of goethite appropriate for one liter of pore water solution (see Table B.3).

The specific surface area and site density used in the diffuse-layer adsorption model were as prescribed by Mathur(1995) for goethite. These values along with the molar concentration of FeOx sorbing sites are shown in Table B.4. The complete database of goethite sorption reactions used in MINTEQA2, including acid-base surface reactions and reactions for major ions, is shown in Table B.5. The reactions shown in Table B.5 have been reformulated for use in MINTEQA2. The reformulation step is necessary in order to present the reaction to MINTEQA2 in a manner consistent with its database conventions and its predetermined set of reactants (components). The MINTEQA2 conventions include the requirement that all reactions be written as formation reactions. In some cases, the reformulation may have involved adding ancillary reactions to those presented by Mathur. The addition of ancillary reactions is necessary if the original reaction is not written in terms of MINTEQA2 components. All ancillary reactions used to reformulate the Mathur goethite reactions were obtained directly from the MINTEQA2 (v4.02) thermodynamic database.

Table B.4 Model Parameters For The Goethite Sorbent

Parameter	Model Value
Specific surface area (m^2/g)	60
Site density (moles of sites per mole Fe)	0.018
Unsaturated zone: Site concentration (mol/L)	
Low	2.680×10^{-4}
Medium	1.074×10^{-3}
High	1.753×10^{-3}
Saturated zone: *Site concentration (mol/L)*	
Low	2.087×10^{-4}
Medium	8.365×10^{-4}
High	1.365×10^{-3}

Table B.5 Goethite Sorption Reactions Used In MINTEQA2

Goethite Sorption Reaction	Intrinsic Equilibrium Constant
$\equiv FeOH_2^+ \rightleftharpoons \equiv FeOH^o + H^+$	$\log K_{a1}$ = 6.93
$\equiv FeOH^o \rightleftharpoons \equiv FeO^- + H^+$	$\log K_{a2}$ = -9.65
$\equiv FeOH^o + Ca^{2+} \rightleftharpoons \equiv FeOCa^+ + H^+$	$\log K_1$ = -6.48
$\equiv FeOH^o + Ca^{2+} \rightleftharpoons \equiv FeOHCa^{2+}$	$\log K_2$ = 3.98
$\equiv FeOH^o + Ca^{2+} + H^+ \rightleftharpoons \equiv FeOCa^+ + H_2O$	$\log K_3$ = 12.26
$\equiv FeOH^o + Mg^{2+} \rightleftharpoons \equiv FeOMg^+ + H^+$	$\log K_1$ = -3.02
$\equiv FeOH^o + Mg^{2+} \rightleftharpoons \equiv FeOHMg^{2+}$	$\log K_2$ = 5.24
$\equiv FeOH^o + Ba^{2+} \rightleftharpoons \equiv FeOBa^+ + H^+$	$\log K_1$ = -5.62
$\equiv FeOH^o + Ba^{2+} \rightleftharpoons \equiv FeOHBa^{2+}$	$\log K_2$ = 3.43
$\equiv FeOH^o + Cu^{2+} \rightleftharpoons \equiv FeOCu^+ + H^+$	$\log K_1$ = 1.39
$\equiv FeOH^o + Cu^{2+} \rightleftharpoons \equiv FeOHCu^{2+}$	$\log K_2$ = 8.92
$\equiv FeOH^o + Cd^{2+} \rightleftharpoons \equiv FeOCd^+ + H^+$	$\log K_1$ = -1.96
$\equiv FeOH^o + Cd^{2+} \rightleftharpoons \equiv FeOHCd^{2+}$	$\log K_2$ = 6.28
$\equiv FeOH^o + Zn^{2+} \rightleftharpoons \equiv FeOZn^+ + H^+$	$\log K_1$ = -0.96
$\equiv FeOH^o + Zn^{2+} \rightleftharpoons \equiv FeOHZn^{2+}$	$\log K_2$ = 7.50
$\equiv FeOH^o + Pb^{2+} \rightleftharpoons \equiv FeOPb^+ + H^+$	$\log K_1$ = 0.44
$\equiv FeOH^o + Pb^{2+} \rightleftharpoons \equiv FeOHPb^{2+}$	$\log K_2$ = 8.25
$\equiv FeOH^o + Ni^{2+} \rightleftharpoons \equiv FeONi^+ + H^+$	$\log K_1$ = -1.96
$\equiv FeOH^o + Ni^{2+} \rightleftharpoons \equiv FeOHNi^{2+}$	$\log K_2$ = 6.38
$\equiv FeOH^o + Co^{2+} \rightleftharpoons \equiv FeOCo^+ + H^+$	$\log K_1$ = -0.79
$\equiv FeOH^o + Co^{2+} \rightleftharpoons \equiv FeOHCo^{2+}$	$\log K_2$ = 7.28
$\equiv FeOH^o + Hg(OH)_2^o \rightleftharpoons \equiv FeOHgOH^o + H_2O$	$\log K_0$ = 2.86
$\equiv FeOH^o + Hg(OH)_2^o + H^+ \rightleftharpoons \equiv FeOHg^+ + 2\ H_2O$	$\log K_1$ = 10.03
$\equiv FeOH^o + Hg(OH)_2^o + 2H^+ \rightleftharpoons \equiv FeOHHg^{2+} + 2\ H_2O$	$\log K_2$ = 18.58
$\equiv FeOH^o + Hg(OH)_2^o + H^+ + Cl^- \rightleftharpoons \equiv FeOHgCl^o + 2\ H_2O$	$\log K_4$ = 13.51
$\equiv FeOH^o + Ag^+ \rightleftharpoons \equiv FeOAg + H^+$	$\log K_1$ = -4.11
$\equiv FeOH^o + Ag^+ \rightleftharpoons \equiv FeOHAg^+$	$\log K_2$ = 4.74
$\equiv FeOH^o + Mn^{2+} \rightleftharpoons \equiv FeOMn^+ + H^+$	$\log K_1$ = -2.66
$\equiv FeOH^o + Mn^{2+} \rightleftharpoons \equiv FeOHMn^{2+}$	$\log K_2$ = 5.99
$\equiv FeOH^o + Be^{2+} \rightleftharpoons \equiv FeOBe^+ + H^+$	$\log K_1$ = 2.69
$\equiv FeOH^o + Be^{2+} \rightleftharpoons \equiv FeOHBe^{2+}$	$\log K_2$ = 10.61
$\equiv FeOH^o + Tl^+ \rightleftharpoons \equiv FeOTl^o + H^+$	$\log K_1$ = -5.37
$\equiv FeOH^o + Tl^+ \rightleftharpoons \equiv FeOHTl^+$	$\log K_2$ = 3.66
$\equiv FeOH^o + Cr(OH)_2^+ \rightleftharpoons \equiv FeOCrOH^+ + H_2O$	$\log K_1$ = 8.07

Table B.5 Goethite Sorption Reactions Used In MINTEQA2 (continued)

Goethite Sorption Reaction	Intrinsic Equilibrium Constant
$\equiv FeOH^o + Cr(OH)_2^+ + H^+ \rightleftharpoons \equiv FeOHCrOH^{+2} + H_2O$	$\log K_2 = 16.07$
$\equiv FeOH^o + H_3AsO_3^o \rightleftharpoons \equiv FeH_2AsO_3^o + H_2O$	$\log K_1 = 4.33$
$\equiv FeOH^o + H_3AsO_4^o \rightleftharpoons \equiv FeH_2AsO_4^o + H_2O$	$\log K_1 = 6.87$
$\equiv FeOH^o + H_3AsO_4^o \rightleftharpoons \equiv FeHAsO_4^- + H^+ + H_2O$	$\log K_2 = -0.89$
$\equiv FeOH^o + H_3AsO_4^o \rightleftharpoons \equiv FeOHAsO_4^{3-} + 3H^+$	$\log K_4 = -11.09$
$\equiv FeOH^o + VO_2^+ + H_2O \rightleftharpoons \equiv FeH_2VO_4^o + H^+$	$\log K_1 = 2.35$
$\equiv FeOH^o + VO_2^+ + H_2O \rightleftharpoons \equiv FeHVO_4^- + 2H^+$	$\log K_2 = -5.91$
$\equiv FeOH^o + VO_2^+ + 2H_2O \rightleftharpoons \equiv FeOHVO_4^{3-} + 4H^+$	$\log K_4 = -17.53$
$\equiv FeOH^o + Sb(OH)_6^- + H^+ \rightleftharpoons \equiv FeOH_2Sb(OH)_6^o$	$\log K_1 = 11.94$
$\equiv FeOH^o + Sb(OH)_6^- \rightleftharpoons \equiv FeOHSb(OH)_6^-$	$\log K_2 = 5.76$
$\equiv FeOH^o + SO_4^{2-} + 2H^+ \rightleftharpoons \equiv FeHSO_4^o + H_2O$	$\log K_1 = 12.89$
$\equiv FeOH^o + SO_4^{2-} + H^+ \rightleftharpoons \equiv FeSO_4^- + H_2O$	$\log K_2 = 6.74$
$\equiv FeOH^o + SO_4^{2-} \rightleftharpoons \equiv FeOSO_4^{3-} + H^+$	$\log K_4 = -6.26$
$\equiv FeOH^o + HSeO_3^- + H^+ \rightleftharpoons \equiv FeHSeO_3^o + H_2O$	$\log K_1 = 3.25$
$\equiv FeOH^o + HSeO_3^- \rightleftharpoons \equiv FeSeO_3^- + H_2O$	$\log K_2 = 2.09$
$\equiv FeOH^o + HSeO_3^- \rightleftharpoons \equiv FeOSeO_3^{3-} + 2H^+$	$\log K_4 = -14.25$
$\equiv FeOH^o + SeO_4^{2-} + 2H^+ \rightleftharpoons \equiv FeHSeO_4^o + H_2O$	$\log K_1 = 11.65$
$\equiv FeOH^o + SeO_4^{2-} + H^+ \rightleftharpoons \equiv FeSeO_4^- + H_2O$	$\log K_2 = 6.54$
$\equiv FeOH^o + CrO_4^{2-} + 2H^+ \rightleftharpoons \equiv FeHCrO_4^o + H_2O$	$\log K_1 = 17.11$
$\equiv FeOH^o + CrO_4^{2-} + H^+ \rightleftharpoons \equiv FeCrO_4^- + H_2O$	$\log K_2 = 11.17$
$\equiv FeOH^o + CrO_4^{2-} \rightleftharpoons \equiv FeOHCrO_4^{2-}$	$\log K_3 = 4.05$
$\equiv FeOH^o + MoO_4^{2-} + 2H^+ \rightleftharpoons \equiv FeHMoO_4^o + H_2O$	$\log K_1 = 14.65$
$\equiv FeOH^o + MoO_4^{2-} + H^+ \rightleftharpoons \equiv FeMoO_4^- + H_2O$	$\log K_2 = 8.18$
$\equiv FeOH^o + F^- + H^+ \rightleftharpoons \equiv FeOH_2F^o$	$\log K_1 = 9.20$
$\equiv FeOH^o + F^- \rightleftharpoons \equiv FeOHF^-$	$\log K_2 = 1.59$

2.3.2 Particulate Organic Matter Sorbent

We obtained the concentration of the second adsorbent, particulate organic matter, from organic matter distributions already present in EPACMTP. EPACMTP includes frequency distributions for organic matter for three soil types in the unsaturated zone: silty clay loam, sandy loam, and silty loam. The silty loam soil type is intermediate in weight percent organic matter in comparison with the other two and is the most frequently occurring soil type. Therefore, low, medium, and high POM content levels for the MINTEQA2 modeling in the unsaturated zone were established as the 7.5, 50, and 92.5 percentiles of the silty loam organic matter distribution. In the saturated zone, the EPACMTP distribution of organic matter is identical to that for the sandy loam soil type of the unsaturated zone. Low, medium, and high POM content levels in MINTEQA2 modeling of the saturated zone were established as the 7.5, 50, and 92.5 percentile levels, respectively, of this distribution.

As was the case for the goethite sorbent, the concentration of POM included in the MINTEQA2 modeling was determined from the low, medium, and high content levels (expressed in weight percent POM) and the mass of soil appropriate for one liter of pore water solution (see section 2.3.1). Thus, phase ratios of 4.57 kg/L in the unsaturated zone and 3.56 kg/L in the saturated zone were used to compute the POM concentration for MINTEQA2 model runs.

We obtained a dissolved organic carbon (DOC) distribution for the saturated zone from the U.S. EPA STORET database. This distribution is based on 1343 ground-water samples and is approximated by a log normal distribution with a median $\log_e$ DOC of 1.974 (corresponding to 7.2 mg C per liter) and $\log_e$ standard deviation of 1.092. Assuming DOM is approximately 50 percent organic carbon, the DOC values are multiplied by two to approximate DOM concentrations. The MINTEQA2 modeling employed low, medium and high concentrations for DOM corresponding to the 7.5, 50.0, and 92.5 percentiles, respectively, of this approximated DOM distribution. An important point to note is that POM and DOM were not treated as independent variables in the MINTEQA2 modeling: the high DOM value was associated with the high POM value, the medium DOM with the medium POM, etc.

Because no directly measured data were available for describing the variation in DOM concentration in the unsaturated zone, we assumed that high, medium, and low DOM concentrations reflected a constant ratio of POM content (in weight percent) to DOM concentration. The constant ratio was arbitrarily chosen as the ratio of the median DOM (mg/L) from the saturated zone distribution to the median value of POM (weight percent) from the saturated zone distribution. This ratio, 194.6, was applied to the low, medium, and high weight percent POM values of the unsaturated zone to obtain DOM concentrations at the low, medium, and high levels. The weight percent POM and concentration (mg/L) of both POM and DOM is shown in Table B.6 for all three concentration levels in both zones.

For both POM and DOM, we assumed a site density of 1.2×10^{-6} moles of sites per mg organic matter. The site concentrations for organic matter in both zones are listed in Table B.7.

Table B.6 POM And DOM Concentration Levels

	POM wt%	POM Concentration (mg/L)	DOM Concentration (mg/L)
Unsaturated zone			
Low	0.034	1553.8	6.6
Medium	0.105	4798.5	20.4
High	0.325	14852.5	63.20
Saturated zone			
Low	0.020	712.0	3.00
Medium	0.074	2634.4	14.40
High	0.275	9790.0	69.38

Table B.7 Site Concentrations For POM And DOM Components In MINTEQA2

	POM Site Concentration (mol/L)	DOM Site Concentration (mol/L)
Unsaturated zone		
Low	1.865×10^{-3}	7.896×10^{-6}
Medium	5.758×10^{-3}	2.439×10^{-5}
High	1.782×10^{-2}	7.548×10^{-5}
Saturated zone		
Low	8.544×10^{-4}	3.600×10^{-6}
Medium	3.161×10^{-3}	1.728×10^{-5}
High	1.175×10^{-2}	8.326×10^{-5}

We used a specialized sub-model within MINTEQA2 for calculations involving the POM and DOM. This sub-model, called the Gaussian distribution model, assumes that natural organic matter is a mixture of various functional groups having a mean log K for binding protons and metals, and a standard deviation in log K (Dobbs et al., 1989). This is in contrast to all other reactants in MINTEQA2 which are implicitly treated as pure substances with a single equilibrium constant for a particular metal. A database of DOM reactions proposed by Susetyo et al. (1991) for the metals Ba, Cd, Cr(III), Cu, Pb, Ni, and Zn and for protons and various other MINTEQA2 components is included with version 4.02 of the model. Adsorption of metals onto POM was included in the model calculations by assuming that the reactions were identical to those for metal complexation with DOM. Table B.8 shows Gaussian organic matter reactions used in MINTEQA2 for this work. Although the Gaussian model was proposed for metal-DOM reactions, we used it here to account for metal-POM reactions as well. The only difference between the method of calculation for metal-DOM and metal-POM species in MINTEQA2 was that POM species were excluded from contributing to the ionic strength.

For the metals Ag, Co, Hg, and Tl, it was necessary to estimate the mean log K for DOM and POM binding for use in MINTEQA2. The mean log K values for Ag, Co, and Tl were derived from a linear free-energy relationship based upon to known mean log K values for several metals, their first hydrolysis constants, and their log K values for complexation with acetate. For Hg, the mean log K was estimated from a linear regression based on binding constants for humic and fulvic acid as given by Tipping (1994).

Table B.8 POM And DOM Reactions Included In MINTEQA2 Modeling

Organic Matter (OM) Reaction	Mean log K	Standard Deviation	Species Charge
$OM + H^+ \rightleftharpoons OM\text{-}H$	3.87	1.7	-1.8
$OM + Ca^{2+} \rightleftharpoons OM\text{-}Ca$	2.9	1.7	-0.8
$OM + Mg^{2+} \rightleftharpoons OM\text{-}Mg$	1.9	1.7	-0.8
$OM + Ba^{2+} \rightleftharpoons OM\text{-}Ba$	3.1	1.7	-0.8
$OM + Be^{2+} \rightleftharpoons OM\text{-}Be$	3.5	1.7	-0.8
$OM + Cd^{2+} \rightleftharpoons OM\text{-}Cd$	3.3	1.7	-0.8
$OM + Cr(OH)_2^+ + 2H^+ \rightleftharpoons OM\text{-}Cr + 2H_2O$	15.22	1.7	0.2
$OM + Cu^{2+} \rightleftharpoons OM\text{-}Cu$	4.9	1.7	-0.8
$OM + Ni^{2+} \rightleftharpoons OM\text{-}Ni$	3.3	1.7	-0.8
$OM + Pb^{2+} \rightleftharpoons OM\text{-}Pb$	5.2	1.7	-0.8
$OM + Zn^{2+} \rightleftharpoons OM\text{-}Zn$	3.5	1.7	-0.8
$OM + Hg(OH)_2^{o} + 2H^+ \rightleftharpoons OM\text{-}Hg + 2H_2O$	15.2	1.7	-0.8
$OM + Co^{2+} \rightleftharpoons OM\text{-}Co$	3.3	1.7	-0.8
$OM + Ag^+ \rightleftharpoons OM\text{-}Ag$	2.0	1.7	-1.8
$OM + Tl^+ \rightleftharpoons OM\text{-}Tl$	1.0	1.7	-1.8
$OM + Mn^{2+} \rightleftharpoons OM\text{-}Mn$	3.0	1.7	-0.8

2.4 LEACHATE ORGANIC MATTER

In addition to the metal contaminants, the leachate exiting a landfill may contain elevated concentrations of leachate organic matter. This organic matter may consist of various compounds including organic acids that represent primary disposed waste or that result from the breakdown of more complex organic substances. Many organic acids found in landfill leachate have significant metal-complexing capacity that may influence metal mobility. In an effort to incorporate in the K_d modeling the solubilizing effect of organic acids, we included three representative monoprotic acids as components. Data presented by Gintautas et al. (1993) were used to select and quantify the three representative organic acids. Gintautas examined leachates from six landfills from across the U.S. Their analyses indicated the presence of over 30 different acids–most were carboxylic. The three acids chosen to represent the complex mixture of leachate acids in the MINTEQA2 modeling were acetic acid, propionic acid, and butyric acid. These were selected based on structure-activity relationships, comparison of equilibrium constants, and relative concentrations in the leachates analyzed by Gintautas.

In the MINTEQA2 modeling, low, medium, and high concentration levels for the representative acids were established based on the lowest, the average, and the highest measured TOC among the six landfill leachates. The same set of three acids was used in both the unsaturated and saturated zones. In the latter, their concentrations were one-seventh of their unsaturated zone concentrations. This reduction in the leachate acid concentration was applied to account in a rudimentary way for the effects of dispersion and diffusion in the mixing zone. The factor of one-seventh resulted from flow model tests to estimate an "average" dilution factor in the mixing zone. Table B.9 gives the low, medium, and high concentrations used in the MINTEQA2 modeling for each of the three acids in each zone.

The MINTEQA2 thermodynamic database includes complexation reactions between each of the three representative acids and many of the contaminant metals of interest. Acid-base and major ion reactions are also included. Some metals, especially those that behave as anions in aqueous solution (e.g., arsenite, arsenate, chromate, etc.) do not complex with these acids.

Table B.9 Model Concentrations Of Representative Leachate Acids

Concentration Level	Acetic acid (mg/L)	Propionic acid (mg/L)	Butyric acid (mg/L)
Unsaturated zone			
Low	24.80	14.61	15.68
Medium	111.00	64.30	67.94
High	274.60	158.60	169.00
Saturated zone			
Low	3.54	2.09	2.24
Medium	15.86	9.19	9.71
High	39.23	22.66	24.14

2.5 MINTEQA2 MODELING PROCEDURE

The MINTEQA2 modeling was conducted separately for each of the twenty-two contaminant metals. For each metal, the modeling was performed separately for each zone (unsaturated and saturated) for each of the two ground waters. Thus, results were produced in four main categories: the carbonate ground-water unsaturated zone, the carbonate ground-water saturated zone; the non-carbonate ground-water unsaturated zone, and the non-carbonate ground-water saturated zone. Within each of these four categories, we followed a similar modeling procedure. The modeling procedure consisted of three steps, each involving execution of the MINTEQA2 model. First, the sorbents were pre-equilibrated with the ground water at the natural ground-water pH. Second, the pre-equilibrated ground-water sorbent systems were titrated to different pH's of interest. Finally, leachate organic acids and the contaminant metal were added to the pre-equilibrated, pH-adjusted systems. In this last step, the metal salt was added to each system at a series of forty-four total concentrations as in a titration and the model computed the equilibrium distribution at each titration point to produce an isotherm.

2.5.1 Pre-equilibration With Sorbents

The goethite and POM sorbents were pre-equilibrated with the ground water at all nine combinations of their concentration levels. Because the sorbents adsorb some of the non-contaminant ions present as ground-water constituents (calcium, magnesium, sulfate, fluoride), we assume the representative compositions used for both the carbonate and non-carbonate ground waters reflect dissolved concentrations at equilibrium with an unknown sorbed concentration. The purpose of the pre-equilibration step is to estimate this unknown sorbed concentration so that it may be included in subsequent model runs. The method of discovering the sorbed totals for each of the ground-water constituents that undergoes sorption was trial and error. Specifically, MINTEQA2 was executed repeatedly with adjusted total concentrations of these sorbing constituents until the equilibrium dissolved concentration for each was equal to the measured dissolved concentrations reported for the ground water. This trial and error pre-equilibration method was performed separately for each of nine possible combinations of the FeOx and POM sorbent concentrations (e.g., low FeOx, low POM; low FeOx, medium POM;from Table B.4).

The pre-equilibration step was conducted at the natural pH of each ground water, and calcite was imposed as an equilibrium mineral for the carbonate ground-water type. Small additions of inert ions (Na^+ or NO_3^-) were added to maintain charge balance.

2.5.2 Titrating Systems To New pH Values

The nine pre-equilibrated systems were titrated to target pH's that span the pH range commonly observed for that ground-water type. Rather than imposing target pH's as equilibrium constraints in the model, we used acids and bases to titrate to the pH targets. The titrants for pH adjustment were NaOH to raise the pH and HNO_3 to lower the pH. For the carbonate ground water, the pH was assumed to range from 7.0

to 8.0. Since the natural pH of the carbonate ground water was 7.5, the acid and base were used to lower and raise the pH to 7.0 and 8.0, respectively, resulting in three pH values for this ground water. Since this was done for each of the nine pre-equilibrated systems, the outcome of this titration step was twenty-seven variants of the carbonate ground-water system exhibiting various concentration levels of the sorbent and various pH values. Equilibrium with calcite was maintained in all of these carbonate systems.

For the non-carbonate ground water, the pH of interest was assumed to span the range 4.5 to 8.2. Each of the nine pre-equilibrated non-carbonate systems was titrated to nine target pH's within this range: 4.5, 5.1, 5.6, 6.0, 6.3, 6.6, 6.9, 7.4, and 8.2. Since the natural pH of the non-carbonate ground water was 7.4, the base was used only to titrate to pH 8.2. The lower pH's were attained by titrating with the acid. The outcome of the titration step for the non-carbonate ground water was eighty-one variants of the non-carbonate ground-water system exhibiting various concentration levels of the sorbent and various pH values.

2.5.3 Addition Of Leachate Acids And Contaminant Metal

Each of the pre-equilibrated, pH-adjusted systems were equilibrated with the three concentration levels of leachate organic acids (see Table B.9). As before, the equilibrium pH was not imposed as a constraint in MINTEQA2, so the addition of the leachate acid impacted the calculated equilibrium pH. Because there were three concentration levels for the leachate organic acids, this step resulted in 81 leachate-ground-water systems for each zone (unsaturated and saturated) for the carbonate ground water and 243 leachate-ground-water systems for each zone for the non-carbonate ground water .

The contaminant metal was added in the same step as the leachate organic acids. The metal was added as a metal salt at a series of forty-four total concentrations spanning the range 0.001 mg/L to 10,000 mg/L of metal. The choice of chemical species by which the metal was introduced was predicated on the desire to maintain charge balance and to avoid species that would exert a great influence on the equilibrium pH. In some cases, we introduced a fictitious substance to accomplish these goals. The equilibrium distribution was calculated at each of the forty-four total metal concentrations to produce an isotherm of sorbed metal versus metal concentration.

3.0 RESULTS

As shown in Figure B.1, MINTEQA2 computes the equilibrium distribution of metal among three categories: dissolved, sorbed, and precipitated. The concentration in the first two of these categories along with the corresponding total metal concentration define the non-linear isotherm. All three concentrations (dissolved, sorbed, and precipitated) are made available for use in EPACMTP, but the precipitated concentration is not used. The ratio of the equilibrium sorbed and dissolved concentrations recorded in the isotherm is the dimensionless K_d. For the sorbed fraction, the concentration recorded in the isotherm is the amount of metal sorbed *from* one liter of solution. Of course, this amount is also sorbed *onto* the mass of soil with which one liter was equilibrated. This mass is the phase ratio: 4.57 kg/L for the unsaturated zone and 3.56 kg/L for the saturated zone. The K_d in units of L/kg is thus computed by normalizing the dimensionless K_d by the appropriate phase ratio.

For each metal, the modeling resulted in 243 isotherms for the non-carbonate ground water for the unsaturated zone, and 81 isotherms for the carbonate ground water for the unsaturated zone. We produced a like number of isotherms for each ground water for the saturated zone. Each isotherm corresponds to particular concentration levels of FeOx and POM sorbents, pH, and leachate organic matter concentration. In monte carlo or site-specific mode, EPACMTP selects the appropriate isotherm based on the conditions being modeled. Isotherms were produced for Ag, As(III), As(V), Ba, Be, Cd, Co, Cr(III), Cr(VI), Cu, F, Hg, Mn(II), Mo(V), Ni, Pb, Sb(V), Se(IV), Se(VI), Tl(I), V(V), and Zn.

3.1 EXAMPLE ISOTHERMS

Example isotherms for Cr(VI) are shown in Figure B.2. This figure shows K_d versus total Cr(VI) concentration for the non-carbonate ground water saturated zone at various pH values. The isotherms plotted are for the medium concentration level of FeOx and POM sorbents and the low concentration level of leachate organic matter. Because chromate behaves as an anion in ground water, its adsorption is enhanced at low pH relative to high pH. This behavior is reversed for metals that behave as cations.

Figure B.3 shows the impact of FeOx concentration level on the K_d values of lead. As expected, sorption is enhanced at the higher FeOx concentrations resulting in larger K_d values. The example shown is for the unsaturated zone of the carbonate ground water with the low concentration levels of POM and leachate organic acids. The pH corresponds to the lowest setting for the carbonate systems: 7.0.

The impact of varying the POM concentration level differs among the various metals. The effect of POM concentration level also depends on the pH. The variable impact of POM is due to two factors: the absence of organic matter reactions for anionic metals and the concurrent influence of DOM for those metals for which organic matter reactions are included. In the MINTEQA2 modeling procedure we used, increasing the POM sorbent concentration is always accompanied by a proportional increase in the DOM concentration. The overall impact on the amount of metal sorbed depends on the relative competition among all constituents in the systems for these two substances. The "winner" of this relative competition (POM or DOM) shifts with pH because both substances undergo acid-base reactions. Figure B.4 shows the impact of varying the POM/DOM concentration level on lead sorption for the non-carbonate ground water unsaturated zone with medium FeOx concentration level and low leachate organic matter concentration level at pH 6.3.

The influence of the leachate organic matter concentration level is illustrated in Figure B.5 for copper sorption. The LOM level is represented in the model by particular concentrations of three representative leachate organic acids. The acids exert two modes of influence on metal sorption: (1) they lower the pH, reducing sorption of cations and enhancing sorption of anions; (2) for those metals that complex these acids, metal sorption is reduced through competition. The latter effect is generally restricted to metals that behave as cations. The results shown in Figure B.5 correspond to high concentration levels of FeOx and POM sorbents in the unsaturated zone for the carbonate ground water. The pH is 7.0.

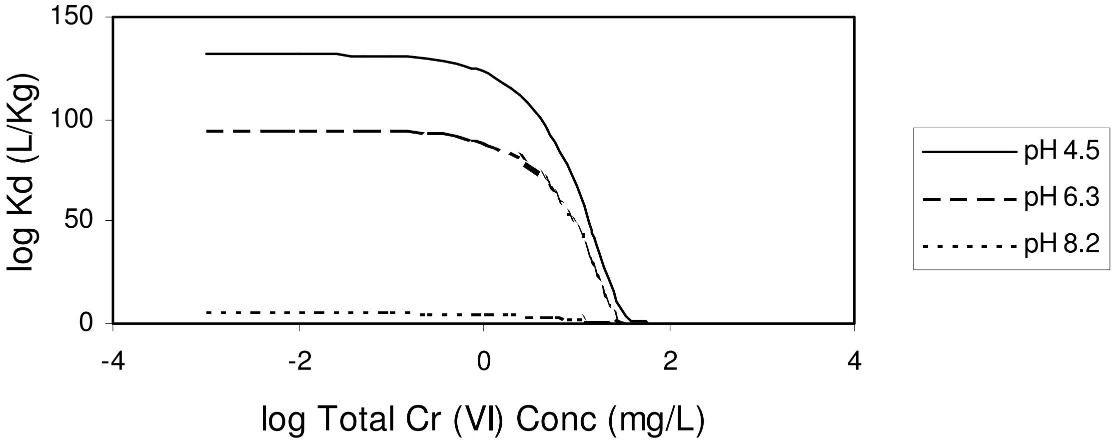

Figure B.2 Cr(VI) Isotherms Illustrating Influence of pH.

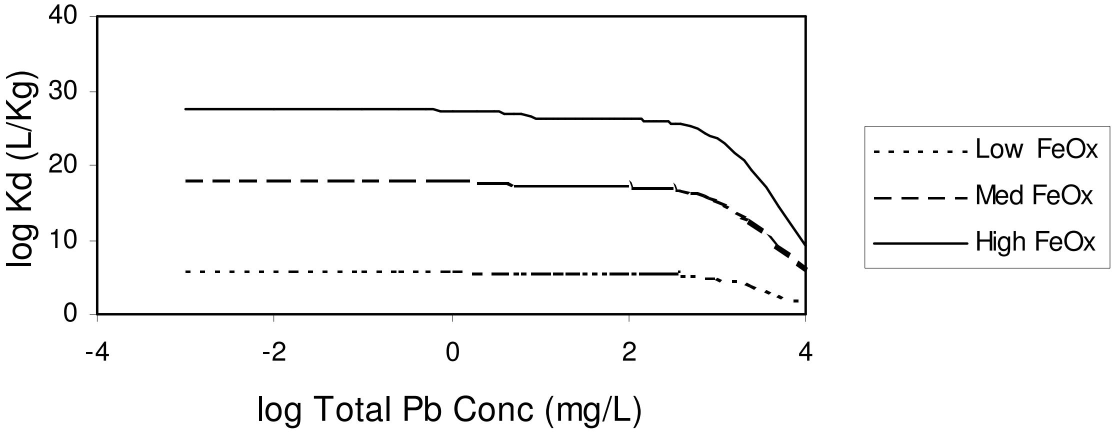

Figure B.3 Pb Isotherms Illustrating Influence of FeOx Sorbent Concentration.

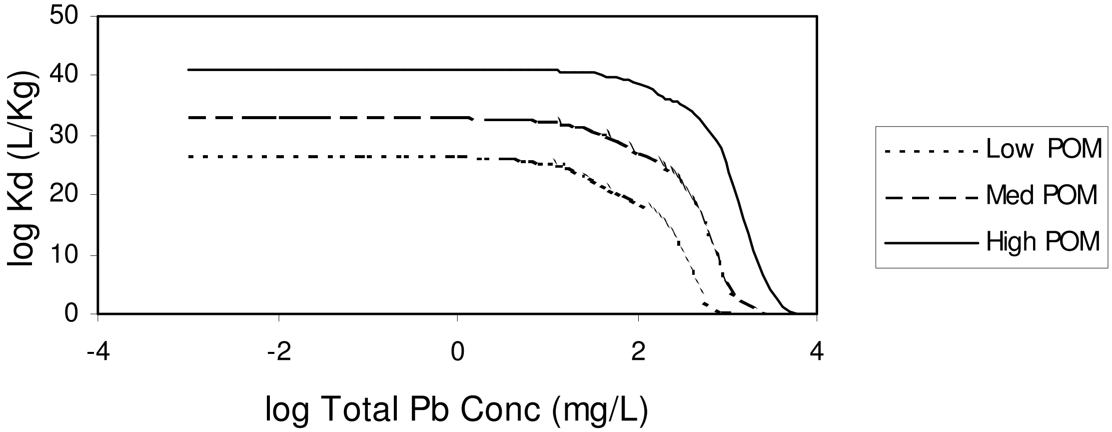

Figure B.4 Pb Isotherms Illustrating Influence of POM/DOM Concentration.

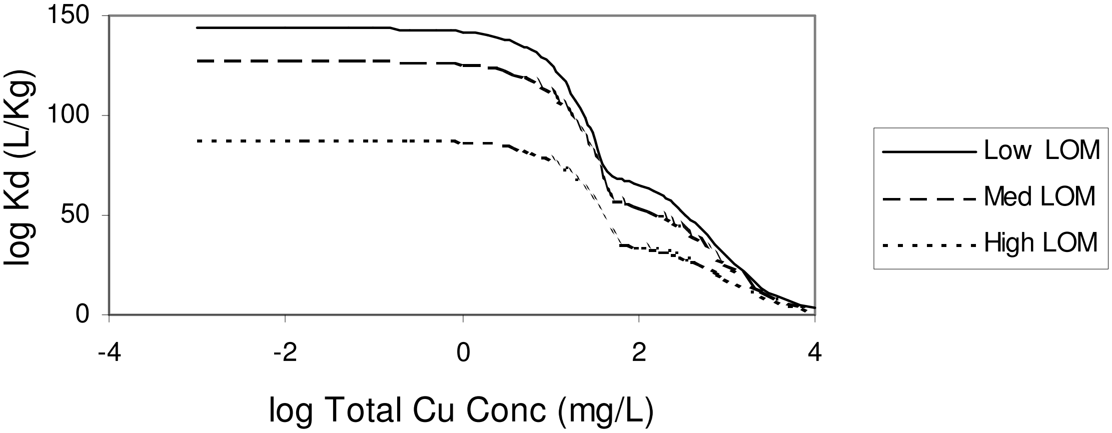

Figure B.5 Cu Isotherms Illustrating Influence of LOM Concentration.

4.0 ASSUMPTIONS AND LIMITATIONS

There are many assumptions inherent in the use of a speciation model to estimate partition coefficients. Some of these must be acknowledged to result in limitations on the utility of the model results. Undoubtedly, the results are better for some metals than for others. Various modeling assumptions and limitations we used are presented below. These are organized as those resulting from the manner in which the ground-water composition, the sorbents, and the leachate were characterized, and certain broader, more general issues. The discussion is limited to pointing out each assumption or limitation. Although the direction of possible error in the estimated K_d values is apparent from some of these limitations, it would seem to be impossible to quantify the uncertainty in the estimated K_d values.

4.1 GROUND-WATER CHARACTERIZATION ISSUES

- The categorization of all ground waters into two types, carbonate and non-carbonate, is quite broad. The non-carbonate category is especially broad, and sorption behavior among different ground-water compositions that might fall into this category could be quite variable. We did not account for this variability in the current approach.

- Although the pre-equilibration step is helpful in more realistically establishing appropriate major ion concentrations, it is somewhat artificial in the sense that sorbents are not correlated with ground water. Both the FeOx and POM sorbents were represented as general concentration distributions; the concentration levels used do not correlate specifically to the ground-water compositions used.

- Both ground waters were artificially adjusted to different pH's of interest by titrating with an acid or base. The degree to which this procedure can result in model ground-water compositions that adequately represent true variability in factors that impact K_d is unknown.

4.2 SORBENT CHARACTERIZATION ISSUES

- Only two sorbents are represented in the model systems. Other sorbents are important in some circumstances including clays, hydrous aluminum and manganese oxides, calcite, and silica. Failure to include all potential sorbents could result in underestimation of sorption.

- The ferric oxide was accounted in the modeling as goethite. Other ferric oxides may be important in ground water, including hydrous ferric oxide (HFO). HFO has a higher specific surface area and greater reactivity for some metals than does goethite. The degree of sorption may be underestimated for some metals in systems where HFO is the dominant form of ferric oxide. Also, equilibrium constants for adsorption onto goethite were unavailable for some metals; estimates were used.

- The data used to quantify the FeOx and POM sorbents (and the DOM) is sparse. The degree to which the true variability in concentration levels of these sorbents has been captured in the modeling is unknown.

- There is no provision in the modeling to account for occlusion of sorbents. Both ferric oxide and organic matter may form coatings over other surfaces. Failure to account for occlusion could result in overestimating the available sorption sites.

- The ferric oxide (goethite) sorbent is included in all model runs. This implies that it is ubiquitous. However, there are natural ground-water conditions that preclude the formation of ferric oxide precipitates. As illustrated in Figure B.6, goethite is not the stable iron solid phase at conditions of low pH and low E_h. The approximate pH-E_h window of applicability for the model results is outlined by dashes in this figure. The selection of specific pH targets limits the pH range (4.5 to 8.2). But no explicit E_h was defined in the model (wavy lines at top and bottom of window in Figure B.6). The "implied" E_h minimum could be considered as the level where ferric oxide ceases to be the stable iron phase. Within the pH range of interest, this implies that the lower left corner of the window shown in Figure B.6 is inconsistent with the use of goethite as a sorbing phase. Including the goethite sorbent where it cannot exist could obviously lead to overestimating sorption. The omission of the stable iron phases siderite and pyrite as model sorbents serves to compensate for this flaw, although the extent of this compensation is unknown. The main point of the diagram is not to point out the stability fields of specific iron minerals but to show the applicability window for our modeling (framed by pH and Eh) with reference to the general picture of iron sulfide, carbonate, and hydroxide (or oxide) minerals.

- The Gaussian model for estimating metal interactions with organic matter was developed for dissolved organic matter. It has not been tested for estimating the degree of metal sorption onto POM. Also, mean log K values for some metals have not been measured; estimates were used.

4.3 LEACHATE CHARACTERIZATION ISSUES

- The concentration levels for leachate organic matter were based on a limited sampling from six municipal landfills. Municipal landfills may have leachate organic content that is significantly different from that of hazardous waste units. Hazardous waste leachates may show more variability in total organic carbon concentration and in the nature of the organic species present.

- Other leachate constituents may be present at elevated concentrations, but these are not accounted for. Some of these (e.g., Ca, Mg, SO_4, Cl, etc.) may reduce the amount of metal sorption by competing for adsorption sites (especially Ca) or by complexing metals so that a greater fraction is retained in solution (especially SO_4 and Cl). Failure to include these effects could result in overestimating sorption of some metals.

- Leachate from highly alkaline wastes was not included in the modeling. Highly alkaline leachates may result in elevation of the ground-water pH above the upper bound for which isotherms have been computed. Sorption tends to increase with pH for many metals up to about pH 8 to 9. Above this level, formation of metal hydroxy solution species may inhibit sorption for some metals.

- The metal was introduced as a metal salt. The metal species was chosen to avoid impact on the pH, but some pH effect is unavoidable. Arbitrary changes in pH due to the choice of metal species may have induced undesired changes in K_d, especially at high total metal concentrations.

- Methylated forms of metal were not accounted for in this modeling. Mercury and arsenic are known to undergo methylation in the environment.

4.4 OTHER ISSUES

- The system redox potential was not explicitly defined in the modeling. All species that might undergo oxidation-reduction reactions were constrained to remain in the form in which they were entered in the model. This restriction applied to major ions such as sulfate and to all trace metals. The impact on K_d is unknown, but is expected to be metal-specific.

- All contaminant metals were introduced separately and individually in the modeling. The possible simultaneous presence of multiple metals is unaccounted for. The impact on K_d is not expected to be great except at high metal concentrations were competition for sorption sites may result in less sorption for some metals than suggested by this modeling.

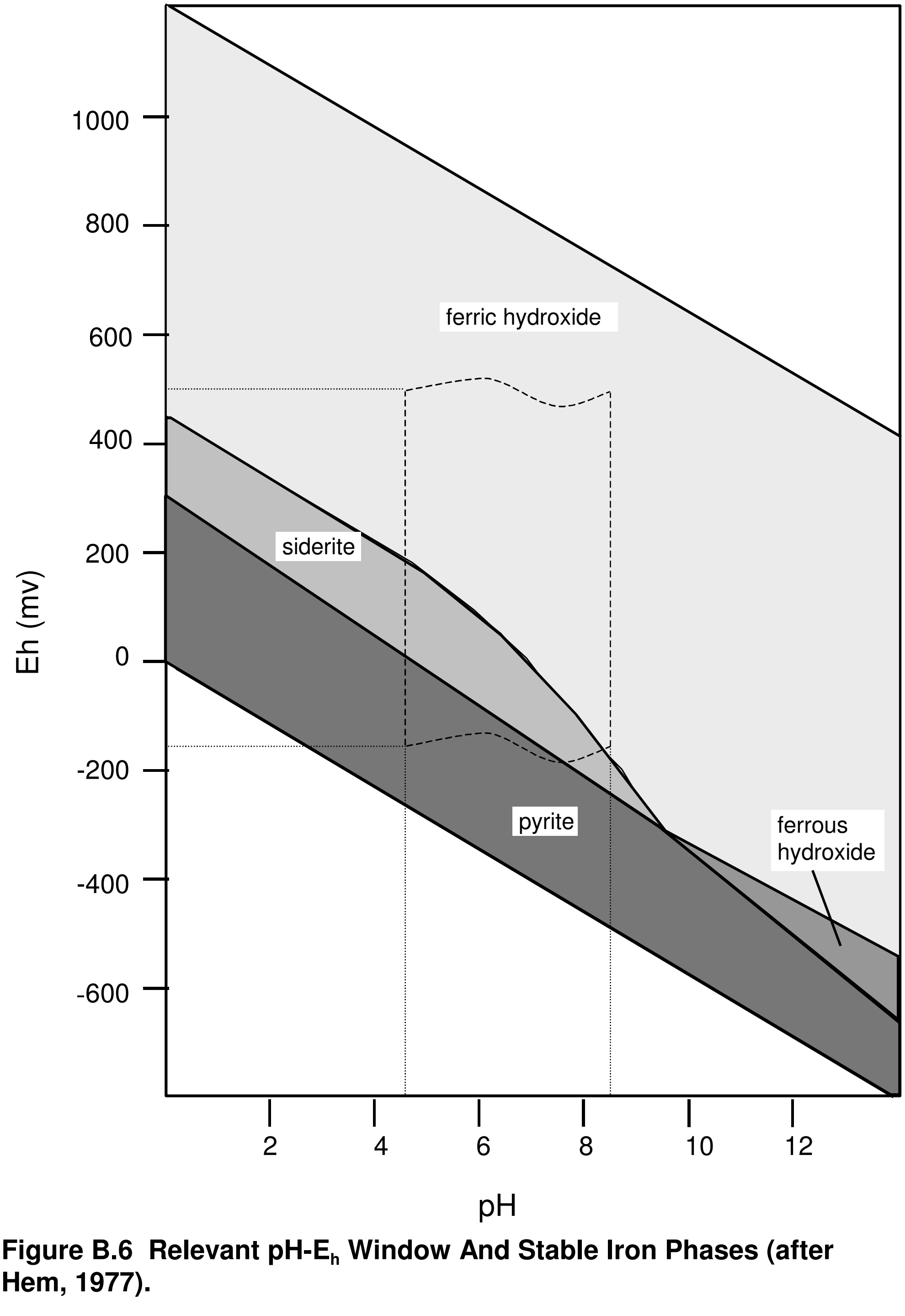

Figure B.6 Relevant pH-E_h Window And Stable Iron Phases (after Hem, 1977).

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APPENDIX C

PHYSICAL AND CHEMICAL PROPERTIES FOR ORGANIC CONSTITUENTS

CAS	Constituent Name	Molecular Weight (g/mol) (a)	Solubility (mg/L) (b)	Log Koc (log[mL/g]) (c)	Hydrolysis Rate Constants (c)			Diffusion Coefficient in Water (Di) (m2/yr) (d)
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
83-32-9	Acenaphthene	154.2	4.24	3.75	0	0	0	
75-07-0	Acetaldehyde [Ethanal]	44.1	1.0E+06 (e)	-0.21 (h)	0	0	0	0.0426
67-64-1	Acetone (2-propanone)	58.1	1.0E+06 (e)	-0.59	0	0	0	0.0363
75-05-8	Acetonitrile (methyl cyanide)	41.1	1.0E+06 (e)	-0.71	0	0	45	0.0445
98-86-2	Acetophenone	120.2	6.13E+03	1.26	0	0	0	
107-02-8	Acrolein	56.1	2.13E+05	-0.22		6.7E+08		0.0385
79-06-1	Acrylamide	71.1	6.4E+05	-0.99	31.5	0.018	0	0.0397
79-10-7	Acrylic acid [propenoic acid]	72.1	1.0E+06 (e)	-1.84	0	0	0	0.0378
107-13-1	Acrylonitrile	53.1	7.4E+04	-0.09	500	0	5.2E+03	0.0388
309-00-2	Aldrin	364.9	0.18	6.18	0	0	0	0.0184
107-18-6	Allyl alcohol	58.1	1.0E+06 (e)	1.47 (e)	0	0	0	
62-53-3	Aniline (benzeneamine)	93.1	3.6E+04	0.60	0	0	0	0.0319
120-12-7	Anthracene	178.2	4.3E-02	4.21	0	0	0	
7440-36-0	Antimony	121.8						
7440-38-2	Arsenic	74.9						
7440-39-3	Barium	137.3						
56-55-3	Benz{a}anthracene	228.3	9.4E-03	5.34	0	0	0	0.0186 (i)
71-43-2	Benzene	78.1	1.75E+03	1.80	0	0	0	0.0325
92-87-5	Benzidine	184.2	500.0	1.26	0	0	0	0.0239
50-32-8	Benzo{a}pyrene	252.3	1.62E-03	5.80	0	0	0	0.0208
205-99-2	Benzo{b}fluoranthene	252.3	1.5E-03	5.80	0	0	0	0.0174 (i)
100-51-6	Benzyl alcohol	108.1	4.0E+04	0.78	0	0	0	
100-44-7	Benzyl chloride	126.6	525.00	2.84	0	410	0	0.0278
7440-41-7	Beryllium	9.0						
111-44-4	Bis(2-chloroethyl)ether	143.0	1.72E+04	0.80	0	0.23	0	0.0275
39638-32-9	Bis(2-chloroisopropyl)ether	171.1	1.31E+03	2.39	0		0	0.0233
117-81-7	Bis(2-ethylhexyl)phthalate	390.6	0.34	7.13	0	0	1.4E+03	0.0132
75-27-4	Bromodichloromethane	163.8	6.74E+03	1.77			5.0E+04	0.0337

CAS	Constituent Name	Molecular Weight (g/mol) (a)	Solubility (mg/L) (b)	Log Koc (log[mL/g]) (c)	Hydrolysis Rate Constants (c)			Diffusion Coefficient in Water (Di) (m2/yr) (d)
					Acid Catalyzed (Ka) (1/mol/yr)	Neutral (Kn) (1/yr)	Base Catalyzed (Kb) (1/mol/yr)	
74-83-9	Bromomethane	94.9	1.52E+04	0.76	0	9.46	0	0.0426
106-99-0	Butadiene 1,3-	54.1	735.00	2.06 (e)				0.0325
71-36-3	Butanol n-	74.1	7.4E+04	0.50	0	0	0	
85-68-7	Butyl benzyl phthalate	312.4	2.69	4.23	0	0	1.2E+05	
88-85-7	Butyl-4,6-dinitrophenol,2-sec-(Dinoseb)	240.2	52.00	2.02	0	0	0	
7440-43-9	Cadmium	112.4						
75-15-0	Carbon disulfide	76.1	1.19E+03	1.84	0	0	31500	0.041
56-23-5	Carbon tetrachloride	153.8	793.00	2.41	0	0.017	0	0.0308
57-74-9	Chlordane	409.8	0.06	5.89	0	0	37.7	0.0172
126-99-8	Chloro-1,3-butadiene 2-(Chloroprene)	88.5	1.74E+03	1.74	0	0	0	0.0315
106-47-8	Chloroaniline p-	127.6	5.3E+03	1.61	0	0	0	
108-90-7	Chlorobenzene	112.6	472.00	2.58	0	0	0	0.0299
510-15-6	Chlorobenzilate	325.2	11.10	4.04	0	0	2.8E+06	0.0173
124-48-1	Chlorodibromomethane	208.3	2.6E+03	1.91			2.5E+04	0.0334
75-00-3	Chloroethane [Ethyl chloride]	64.5	5.68E+03	0.51	0	0	0	0.0366
67-66-3	Chloroform	119.4	7.92E+03	1.58	0	1.0E-04	2740	0.0344
74-87-3	Chloromethane	50.5	5.33E+03	0.91				0.0429
95-57-8	Chlorophenol 2-	128.6	2.2E+04	1.82	0	0	0	0.0299
107-05-1	Chloropropene 3- (Allyl Chloride)	76.5	3.37E+03	1.13	0	40	0	0.0341
16065-83-1	Chromium (III) (Chromic Ion)	52.0						
18540-29-9	Chromium (VI)	52.0						
218-01-9	Chrysene	228.3	1.6E-03	5.34	0	0	0	0.0213
7440-48-4	Cobalt	58.9						
7440-50-8	Copper	63.5						
108-39-4	Cresol m-	108.1	2.27E+04	1.76	0	0	0	0.0294
95-48-7	Cresol o-	108.1	2.6E+04	1.76	0	0	0	0.0311

CAS	Constituent Name	Molecular Weight (g/mol) (a)	Solubility (mg/L) (b)	Log Koc (log[mL/g]) (c)	Hydrolysis Rate Constants (c)			Diffusion Coefficient in Water (Di) (m2/yr) (d)
					Acid Catalyzed (Ka) (1/mol/yr)	Neutral (Kn) (1/yr)	Base Catalyzed (Kb) (1/mol/yr)	
106-44-5	Cresol p-	108.1	2.15E+04	1.76	0	0	0	0.0291
1319-77-3	Cresols	324.4	2.34E+04	2.12	0	0	0	0.0299
98-82-8	Cumene	120.2	61.30	3.40	0	0	0	0.0248
108-93-0	Cyclohexanol	100.2	4.3E+04 (e)	1.11 (g)	0	0	0	0.0295
108-94-1	Cyclohexanone	98.1	5.0E+03	1.82	0	0	0	
72-54-8	DDD	320.0	0.09	5.89	0	0.025	2.2E+04	
72-55-9	DDE	318.0	0.12	6.64	0	0	0	
50-29-3	DDT p,p'-	354.5	0.03	6.59	0	0.06	3.1E+05	0.014
2303-16-4	Diallate	270.2	40.00	4.17	0	0.1	8.0E+03	
53-70-3	Dibenz{a,h}anthracene	278.4	0.00	6.52	0	0	0	0.019
96-12-8	Dibromo-3-chloropropane 1,2-	236.3	1.23E+03	1.94	0	4.0E-03	1.2E+05	0.0281
95-50-1	Dichlorobenzene 1,2-	147.0	156.00	3.08	0	0	0	0.0281
106-46-7	Dichlorobenzene 1,4-	147.0	73.80	3.05	0	0	0	0.0274
91-94-1	Dichlorobenzidine 3,3'-	253.1	3.11	3.32	0	0	0	0.0173 (i)
75-71-8	Dichlorodifluoromethane (Freon 12)	120.9	280.00	2.16				0.0341
75-34-3	Dichloroethane 1,1-	99.0	5.06E+03	1.46	0	1.13E-02	0.378	0.0334
107-06-2	Dichloroethane 1,2-	99.0	8.52E+03	1.13	0	9.61E-03	54.7	0.0344
75-35-4	Dichloroethylene 1,1-	96.9	2.25E+03	1.79	0	0	0	0.0347
156-59-2	Dichloroethylene cis-1,2-	96.9	3.5E+03	1.70	0	0	0	
156-60-5	Dichloroethylene trans-1,2-	96.9	6.3E+03	1.60	0	0	0	
120-83-2	Dichlorophenol 2,4-	163.0	4.5E+03	2.49	0	0	0	
94-75-7	Dichlorophenoxyacetic acid 2,4-(2,4-D)	221.0	677.00	0.68	0	0	0	
78-87-5	Dichloropropane 1,2-	113.0	2.8E+03	1.67	0	0	0	0.0307
542-75-6	Dichloropropene 1,3-(mixture of isomers)	111.0	2.8E+03	1.43				0.0319
10061-01-5	Dichloropropene cis-1,3-	111.0	2.72E+03	1.80	0	40	0	0.0322
10061-02-6	Dichloropropene trans-1,3-	111.0	2.72E+03	1.80	0	40	0	0.0319

CAS	Constituent Name	Molecular Weight (g/mol) (a)	Solubility (mg/L) (b)	Log Koc (log[mL/g]) (c)	Hydrolysis Rate Constants (c)			Diffusion Coefficient in Water (Di) (m2/yr) (d)
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
60-57-1	Dieldrin	380.9	0.20	5.08	0	6.30E-02	0	0.019
84-66-2	Diethyl phthalate	222.2	1.08E+03	1.99	0	0	3.1E+05	
56-53-1	Diethylstilbestrol	268.4	0.10	4.09	0	0	0	
60-51-5	Dimethoate	229.2	2.5E+04	0.13	0	1.68	4.48E+06	
119-90-4	Dimethoxybenzidine 3,3'-	0.0	60.00	1.49	0	0	0	
68-12-2	Dimethyl formamide N,N- [DMF]	73.1	1.0E+06 (g)	-0.99 (h)	0	0	0	0.0353
57-97-6	Dimethylbenz{a}anthracene 7,12-	256.3	2.50E-02	6.64	0	0	0	0.0172 (i)
119-93-7	Dimethylbenzidine 3,3'-	212.3	1.3E+03	2.55	0	0	0	
105-67-9	Dimethylphenol 2,4-	122.2	7.87E+03	2.29	0	0	0	
84-74-2	Di-n-butyl phthalate	278.3	11.20	4.37	0	0	1.8E+06	
99-65-0	Dinitrobenzene 1,3-	168.1	861.00	1.31	0	0	0	
51-28-5	Dinitrophenol 2,4-	184.1	2.79E+03	-0.09	0	0	0	
121-14-2	Dinitrotoluene 2,4-	182.1	270.00	1.68	0	0	0	0.0249
606-20-2	Dinitrotoluene 2,6-	182.1	182.00	1.40	0	0	0	
117-84-0	Di-n-octyl phthalate	390.6	0.02	7.60	0	0	5.2E+05	
123-91-1	Dioxane 1,4-	88.1	1.0E+06 (e)	-0.81	0	0	0	0.0331
122-39-4	Diphenylamine	169.2	35.70	3.30	0	0	0	
122-66-7	Diphenylhydrazine 1,2-	184.2	68.00	2.82	0	0	0	0.0229
298-04-4	Disulfoton	274.4	16.30	2.94	0	2.3	5.4E+04	
115-29-7	Endosulfan (Endosulfan I and II,mixture)	406.9	0.51	3.55				
72-20-8	Endrin	380.9	0.25	4.60	0	0.055	0	
106-89-8	Epichlorohydrin	92.5	6.59E+04	-0.53	2.5E+04		30.9	0.035
106-88-7	Epoxybutane 1,2-	72.1	9.5E+04 (e)	0.90 (e)				0.0331
110-80-5	Ethoxyethanol 2-	90.1	1.0E+06 (e)	-0.54	0	0	0	0.0308
111-15-9	Ethoxyethanol acetate 2-	132.2	2.29E+05 (g)	0.70 (g)	0	0	0	0.0252
141-78-6	Ethyl acetate	88.1	8.03E+04	0.35	3.5E+03		4.8E-03	3.4E+06

CAS	Constituent Name	Molecular Weight (g/mol) (a)	Solubility (mg/L) (b)	Log Koc (log[mL/g]) (c)	Hydrolysis Rate Constants (c)			Diffusion Coefficient in Water (Di) (m2/yr) (d)
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
60-29-7	Ethyl ether	74.1	5.68E+04	0.55	0	0	0	
97-63-2	Ethyl methacrylate	114.1	3.67E+03	1.27	0	0	1.1E+06	
62-50-0	Ethyl methanesulfonate	124.2	6.3E+03	-0.27	0	1.25E+03	0	
100-41-4	Ethylbenzene	106.2	169.00	3.00	0	0	0	0.0267
106-93-4	Ethylene dibromide (1,2-Dibromoethane)	187.9	4.18E+03	1.42	0	0.63	0	0.0331
107-21-1	Ethylene glycol	62.1	1.0E+06 (e)	-1.50	0	0	0	0.0429
75-21-8	Ethylene oxide	44.1	1.0E+06 (e)	-1.10	2.9E+05		21	0.046
96-45-7	Ethylene thiourea	102.2	6.2E+04	0.00	0	0	0	0.0319 (i)
206-44-0	Fluoranthene	202.3	0.21	4.63	0	0	0	
16984-48-8	Fluoride	19.0						
50-00-0	Formaldehyde	30.0	5.5E+05	-1.30	0	0	0	0.0549
64-18-6	Formic acid	46.0	1.0E+06 (e)	-2.70	0	0	0	
98-01-1	Furfural	96.1	1.1E+05	0.80 (j)	0	0	0	0.0337
319-85-7	HCH beta-	290.8	0.24	3.43	0	0	0	0.0233
58-89-9	HCH (Lindane) gamma-	290.8	6.80	3.40	0	1.05	1.7E+06	0.023
319-84-6	HCH alpha-	290.8	2.00	3.43	0	0	0	0.0232
76-44-8	Heptachlor	373.3	0.18	5.21	0	61	0	0.018
1024-57-3	Heptachlor epoxide	389.3	0.20	4.90	0	0.063	0	0.0176
87-68-3	Hexachloro-1,3-butadiene	260.8	3.23	4.46	0	0	0	0.0222
118-74-1	Hexachlorobenzene	284.8	0.01	5.41	0	0	0	0.0248
77-47-4	Hexachlorocyclopentadiene	272.8	1.80	4.72	0	24.8	0	0.0228
55684-94-1	Hexachlorodibenzofurans [HxCDFs]	374.9	8.25E-06 (f)	7.00	0	0	0	0.0133 (i)
34465-46-8	Hexachlorodibenzo-p-dioxins [HxCDDs]	390.9	4.0E-06 (f)	6.38 (g)	0	0	0	0.013 (i)
67-72-1	Hexachloroethane	236.7	50.00	3.61	0	0	0	0.028
70-30-4	Hexachlorophene	406.9	140.00	5.00	0	0	0	
110-54-3	Hexane n-	86.2	12.40	2.95 (k)	0	0	0	0.0256

CAS	**Constituent Name**	**Molecular Weight (g/mol) (a)**	**Solubility (mg/L) (b)**	**Log Koc (log[mL/g]) (c)**	**Hydrolysis Rate Constants (c)**			**Diffusion Coefficient in Water (Di) (m2/yr) (d)**
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
7783-06-4	Hydrogen Sulfide	34.1	437.00		0	0	0	
193-39-5	Indeno{1,2,3-cd}pyrene	276.3	2.2E-05	6.26	0	0	0	0.0164 (i)
78-83-1	Isobutyl alcohol	74.1	8.5E+04	0.44	0	0	0	
78-59-1	Isophorone	138.2	1.2E+04	1.90	0	0	0	0.0238
143-50-0	Kepone	490.6	7.60	4.15	0	0	0	
7439-92-1	Lead	207.2						
7439-96-5	Manganese	54.9						
7439-97-6	Mercury	200.6	0.06					0.0949
126-98-7	Methacrylonitrile	67.1	25400.00	0.22	500	0	5.2E+03	0.0334
67-56-1	Methanol	32.0	1.0E+06 (e)	-1.08	0	0	0	0.052
72-43-5	Methoxychlor	345.7	0.05	4.90	0	0.69	1.2E+04	
109-86-4	Methoxyethanol 2-	76.1	1.0E+06 (e)	0.95 (e)	0	0	0	0.0347
110-49-6	Methoxyethanol acetate 2-	118.1	1.0E+06 (m)		0	0	0	0.0275
78-93-3	Methyl ethyl ketone	72.1	2.23E+05	-0.03	0	0	0	0.0322
108-10-1	Methyl isobutyl ketone	100.2	1.9E+04	0.87	0	0	0	0.0264
80-62-6	Methyl methacrylate	100.1	1.5E+04	0.74	0	0	0	0.0292
298-00-0	Methyl parathion	263.2	55.00	2.47		2.8		
1634-04-4	Methyl tert-butyl ether [MTBE]	88.1	5.13E+04 (e)	1.05 (e)	0	0	0	0.0272
56-49-5	Methylcholanthrene 3-	268.4	0.00	7.00	0	1.7E-02	0	0.0194
74-95-3	Methylene bromide (Dibromomethane)	173.8	1.19E+04	1.21	0	0	0	
75-09-2	Methylene Chloride (Dichloromethane)	84.9	1.3E+04	0.93	0	1.0E-03	0.6	0.0394
7439-98-7	Molybdenum	95.9						
91-20-3	Naphthalene	128.2	31.00	3.11	0	0	0	0.0264
7440-02-0	Nickel	58.7						
98-95-3	Nitrobenzene	123.1	2.09E+03	1.51	0	0	0	0.0298
79-46-9	Nitropropane 2-	89.1	1.7E+04	0.23	0	0	0	0.0322
55-18-5	Nitrosodiethylamine N-	102.1	9.3E+04	-0.03	0	0	0	0.0288

CAS	**Constituent Name**	**Molecular Weight (g/mol) (a)**	**Solubility (mg/L) (b)**	**Log Koc (log[mL/g]) (c)**	**Hydrolysis Rate Constants (c)**			**Diffusion Coefficient in Water (Di) (m2/yr) (d)**
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
62-75-9	Nitrosodimethylamine N-	74.1	1.0E+06 (e)	0.45	0	0	0	0.0363
924-16-3	Nitroso-di-n-butylamine N-	158.2	1.27E+03	2.09	0	0	0	0.0215
621-64-7	Nitroso-di-n-propylamine N-	130.2	9.89E+03	1.03	0	0	0	0.0245
86-30-6	Nitrosodiphenylamine N-	198.2	35.10	2.84	0	0	0	0.0227
10595-95-6	Nitrosomethylethylamine N-	88.1	1.97E+04	1.03	0	0	0	0.0315
100-75-4	Nitrosopiperidine N-	114.1	7.65E+04	-0.02	0	0	0	0.029
930-55-2	Nitrosopyrrolidine N-	100.1	1.0E+06 (e)	-0.57	0	0	0	0.0319
152-16-9	Octamethyl pyrophosphoramide	286.3	1.0E+06 (m)	-0.51	1.9E+03			
56-38-2	Parathion (ethyl)	291.3	6.54	3.15	0	2.4	3.7E+06	
608-93-5	Pentachlorobenzene	250.3	1.33	5.39	0	0	0	
30402-15-4	Pentachlorodibenzofurans [PeCDFs]	340.4	2.40E-04 (f)	4.93 (g)	0	0	0	0.0142 (i)
36088-22-9	Pentachlorodibenzo-p-dioxins [PeCDDs]	356.4	1.18E-04 (f)	6.3 (g)	0	0	0	0.0138 (i)
82-68-8	Pentachloronitrobenzene (PCNB)	295.3	0.55	4.57	0	0	0	
87-86-5	Pentachlorophenol	266.3	1.95E+03	3.06	0	0	0	0.0253
108-95-2	Phenol	94.1	8.28E+04	1.23	0	0	0	0.0325
62-38-4	Phenyl mercuric acetate	336.7	2.0E+03	0.00	0	0	0	
108-45-2	Phenylenediamine 1,3-	108.1	2.55E+06	-0.30	0	0	0	
298-02-2	Phorate	260.4	50.00	2.64	0	62	0	
85-44-9	Phthalic anhydride	148.1	6.2E+03	1.56 (e)	0	4.9E+05	0	0.0308
1336-36-3	Polychlorinated biphenyls (Aroclors)		0.07	6.19	0	0	0	0.0189
23950-58-5	Pronamide	256.1	32.80	2.63	59	0	610	
75-56-9	Propylene oxide [1,2-Epoxypropane]	58.1	4.05E+05 (e)	1.40 (e)	0	0	0	0.0382
129-00-0	Pyrene	202.3	0.14	4.92	0	0	0	
110-86-1	Pyridine	79.1	1.0E+06 (e)	0.34	0	0	0	0.0344
94-59-7	Safrole	162.2	810.67	2.34	0	0	0	

CAS	**Constituent Name**	**Molecular Weight (g/mol) (a)**	**Solubility (mg/L) (b)**	**Log Koc (log[mL/g]) (c)**	**Hydrolysis Rate Constants (c)**			**Diffusion Coefficient in Water (Di) (m2/yr) (d)**
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
7782-49-2	Selenium	79.0						
7440-22-4	Silver	107.9						
57-24-9	Strychnine and salts	334.4	160.00	1.90	0	0	0	
100-42-5	Styrene	104.2	310.00	2.84	0	0	0	0.0278
95-94-3	Tetrachlorobenzene 1,2,4,5-	215.9	0.60	4.28	0	0	0	
51207-31-9	Tetrachlorodibenzofuran 2,3,7,8-	306.0	6.92E-04 (f)	6.62	0	0	0	0.0153 (i)
1746-01-6	Tetrachlorodibenzo-p-dioxin 2,3,7,8-	322.0	7.91E-06 (f)	6.10	0	0	0	0.0148 (i)
630-20-6	Tetrachloroethane 1,1,1,2-	167.8	1.1E+03	2.71	0	0.0137	1.13E+04	0.0287
79-34-5	Tetrachloroethane 1,1,2,2-	167.8	2.97E+03	2.07	0	5.1E-03	1.59E+07	0.0293
127-18-4	Tetrachloroethylene	165.8	200.00	2.21	0	0	0	0.0298
58-90-2	Tetrachlorophenol 2,3,4,6-	231.9	100.00	2.32	0	0	0	
3689-24-5	Tetraethyl dithiopyrophosphate (Sulfotep)	322.3	25.00	3.51	0	84	9.0E+06	
7440-28-0	Thallium	204.4						
137-26-8	Thiram [Thiuram]	240.4	30.00	2.83 (e)	0	0	0	
108-88-3	Toluene	92.1	526.00	2.43	0	0	0	0.0291
95-80-7	Toluenediamine 2,4-	122.2	3.37E+04	0.02	0	0	0	0.0282 (i)
95-53-4	Toluidine o-	107.2	1.66E+04	1.24	0	0	0	0.029
106-49-0	Toluidine p-	107.2	782.00	1.24	0	0	0	
8001-35-2	Toxaphene (chlorinated camphenes)		0.74	4.31	0	0.07	2.8E+04	0.0173
75-25-2	Tribromomethane (Bromoform)	252.7	3.1E+03	2.05			1.0E+04	0.0328
76-13-1	Trichloro-1,2,2-trifluoro-ethane 1,1,2-	187.4	170.00	2.97	0	0	0	0.0271
120-82-1	Trichlorobenzene 1,2,4-	181.4	34.60	3.96	0	0	0	0.0265
71-55-6	Trichloroethane 1,1,1-	133.4	1.33E+03	2.16	0	0.64	2.4E+06	0.0303
79-00-5	Trichloroethane 1,1,2-	133.4	4.42E+03	1.73	0	2.73E-05	4.95E+04	0.0315
79-01-6	Trichloroethylene (Trichloroethylene 1,1,2-)	131.4	1.1E+03	2.10	0	0	0	0.0322

CAS	**Constituent Name**	**Molecular Weight (g/mol) (a)**	**Solubility (mg/L) (b)**	**Log Koc (log[mL/g]) (c)**	**Hydrolysis Rate Constants (c)**			**Diffusion Coefficient in Water (Di) (m2/yr) (d)**
					Acid Catalyzed (Ka) (1/mol/yr)	**Neutral (Kn) (1/yr)**	**Base Catalyzed (Kb) (1/mol/yr)**	
75-69-4	Trichlorofluoromethane (Freon 11)	137.4	1.1E+03	2.11	0	0	0	0.0319
95-95-4	Trichlorophenol 2,4,5-	197.4	1.2E+03	2.93	0	0	0	
88-06-2	Trichlorophenol 2,4,6-	197.4	800.00	2.25	0	0	0	0.0255
93-72-1	Trichlorophenoxy)propionic acid 2-(2,4,5-	269.5	140.00	1.74	0	0	0	
93-76-5	Trichlorophenoxyacetic acid 2,4,5-	255.5	268.30	1.43	0	0	0	
96-18-4	Trichloropropane 1,2,3-	147.4	1.75E+03	1.66	0	1.7E-02	3.6E+03	0.0291
121-44-8	Triethylamine	101.2	5.5E+04 (e)	1.31 (l)	0	0	0	0.0247
99-35-4	Trinitrobenzene (Trinitrobenzene 1,3,5-)	213.1	350.00	1.05	0	0	0	
126-72-7	Tris(2,3-dibromopropyl)phosphate	697.6	8.00	3.19	0	8.8E-02	3.0E+05	
7440-62-2	Vanadium	50.9						
108-05-4	Vinyl acetate	86.1	2.0E+04	0.45	0	0	0	0.0315
75-01-4	Vinyl chloride	62.5	2.76E+03	1.04	0	0	0	0.0378
108-38-3	Xylene m-	106.2	161.00	3.09	0	0	0	0.0267
95-47-6	Xylene o-	106.2	178.00	3.02	0	0	0	0.027
106-42-3	Xylene p-	106.2	185.00	3.12	0	0	0	0.0267
1330-20-7	Xylenes (total)	318.5	175.00	3.08	0	0	0	0.0268
7440-66-6	Zinc	65.4						

Note: Data sources for chemical property values are indicated in the column headings; exceptions are noted in parentheses for individual chemical values.

Data sources:

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b. U.S. EPA, 1997b. Superfund Chemical Data Matrix (SCDM). SCDMWIN 1.0 (SCDM Windows User's Version), Version 1. Office of Solid Waste and Emergency Response, Washington DC: GPO. http://www.epa.gov/superfund/resources/scdm/index.htm. Accessed July 2001

c. Kollig, H. P. (ed.), 1993. Environmental fate consultants for organic chemicals under consideration for EPA's hazardous waste identification projects. Environmental Research Laboratory, Office of R&D, U.S. EPA, Athens, GA.

d. Calculated based on Water 9. U.S. EPA, 2001. Office of Air Quality Planning and Standards, Research Triangle Park, NC. http://www.epa.gov/ttn/chief/software/water/index.html. Accessed July 2001

e. Syracuse Research Corporation (SRC), 1999. CHEMFATE Chemical Search, Environmental Science Center, Syracuse, NY. http://esc.syrres.com/efdb/Chemfate.htm. Accessed July 2001.

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g. USNLM (U.S. National Library of Medicine), 2001. Hazardous Substances Data Bank (HSDB). http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen/HSDB. Accessed July 2001.

h. MI DEQ. Environmental response Division Operational Memorandum #18 (Opmemo 18): Part 201 Generic Cleanup Criteria Tables, Revision 1, State of Michigan, Department of Environmental Quality. http://www.deq.state.mi.us/erd/opmemo18/index.html.

i. Calculated based on U.S. EPA, 1987. Process Coefficients and Models for Simulating Toxic Organics and Heavy Metals in Surface Waters. Office of Research and Development. Washington, DC: US Government Printing Office (GPO).

j. U.S. EPA, 1999. Region III Soil-to-Groundwater SSLs. Region III, Philadelphia, PA. http://www.epa.gov/reg3hwmd/risk/ssl.pdf

k. U.S. EPA, 2000. Physical-chemical Data.http://www.epa.gov/Rgeion9/waste/sfund/prg/index.htm

l. Calculated from octanol-water partition coefficient using regression equation log[Koc] = 1.029 x log[Kow] - 0.18; presented in Table 10.2 of G. deMarsily, 1986. Quantitative Hydrogeology. Academic Press

m. Lyman, W.J., W.F. Reehl, and D.H. Rosenblatt, 1990. Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds. Washington, DC: American Chemical Society.

APPENDIX D

WMU AND HYDROGEOLOGIC ENVIRONMENT DATABASES

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LIST OF TABLES

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
1	3.04E+04	-999	12.5	1	69	1.00
2	2.97E+04	3.12	22.5	5	92	1.00
3	1.35E+04	0.67	22.5	4	58	1.00
4	4.05E+04	1.47	17.5	4	93	1.00
5	2.02E+04	3.85	12.5	2	51	1.00
6	4.45E+05	7.68	12.5	12	85	1.00
7	3.84E+04	0.86	12.5	4	74	1.00
8	1.11E+05	2.08	12.5	2	39	1.00
9	3.24E+04	4.30	12.5	5	51	1.00
10	1.21E+04	0.74	22.5	4	58	1.00
11	6.15E+05	1.02	7.5	2	32	1.00
12	1.63E+04	-999	17.5	13	90	1.00
13	2.02E+04	-999	12.5	12	42	19.63
14	3.04E+04	-999	12.5	1	69	19.63
15	1.21E+04	-999	22.5	4	81	2.69
16	8.09E+04	-999	17.5	2	36	2.69
17	2.02E+03	-999	17.5	1	95	2.69
18	6.07E+04	3.17	12.5	2	39	2.69
19	6.07E+04	0.76	17.5	13	34	2.69
20	1.21E+04	0.68	12.5	12	54	2.69
21	9.31E+03	-999	17.5	1	95	2.69
22	8.09E+03	1.22	17.5	12	89	2.69
23	2.02E+05	1.31	17.5	12	95	2.69
24	3.24E+04	7.67	17.5	4	89	2.69
25	4.05E+04	-999	17.5	5	13	2.69
26	4.86E+03	1.36	12.5	2	39	2.69
27	2.02E+02	-999	7.5	4	43	2.69
28	4.05E+03	4.09	7.5	2	66	2.69
29	2.02E+03	4.42	12.5	4	36	2.69
30	5.06E+03	-999	17.5	2	36	2.69
31	2.02E+04	-999	22.5	12	78	2.69
32	4.86E+04	1.19	17.5	12	85	2.69
33	1.21E+04	6.82	17.5	4	95	2.69
34	6.07E+04	1.78	17.5	5	89	1.00
35	1.09E+05	1.52	12.5	2	74	1.00
36	1.21E+05	-999	12.5	9	42	1.00
37	2.43E+04	1.01	22.5	4	91	1.00
38	1.42E+05	0.69	12.5	4	71	1.00
39	4.05E+03	1.23	12.5	4	39	1.00
40	6.88E+04	1.83	12.5	12	54	1.00
41	3.04E+04	-999	12.5	5	51	1.00
42	3.35E+05	-999	12.5	4	52	1.00
43	2.71E+03	3.05	7.5	4	45	1.00
44	6.07E+04	3.00	7.5	13	49	1.00
45	2.02E+06	2.83	12.5	12	88	1.00
46	1.42E+04	1.17	22.5	4	96	1.00
47	1.42E+04	-999	12.5	2	39	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
48	8.09E+03	7.90	17.5	13	34	1.00
49	8.09E+04	0.55	7.5	4	60	1.00
50	4.05E+04	2.86	17.5	12	85	1.00
51	5.26E+04	2.05	7.5	2	32	1.00
52	2.02E+04	0.98	12.5	8	32	1.00
53	1.01E+05	2.45	12.5	4	52	1.00
54	3.97E+04	2.38	12.5	2	39	1.00
55	1.11E+05	7.47	17.5	12	95	1.00
56	1.34E+04	0.84	12.5	9	73	1.00
57	4.86E+04	-999	12.5	1	71	1.00
58	1.27E+05	1.01	12.5	12	50	1.00
59	9.47E+04	1.75	12.5	1	71	1.00
60	6.07E+04	0.87	12.5	4	71	1.00
61	3.32E+05	5.24	17.5	5	13	1.00
62	2.23E+04	2.02	12.5	5	56	1.00
63	6.96E+04	-999	17.5	12	95	1.00
64	6.07E+04	-999	17.5	1	77	1.00
65	6.88E+04	3.32	12.5	8	75	1.00
66	4.05E+03	2.05	17.5	4	93	1.00
67	5.26E+05	3.64	12.5	4	49	1.00
68	2.87E+04	1.93	17.5	2	36	1.00
69	4.05E+04	7.65	12.5	2	39	1.00
70	7.28E+04	-999	7.5	8	48	1.00
71	1.72E+05	-999	12.5	4	72	1.00
72	1.01E+04	5.37	17.5	12	95	1.00
73	3.14E+04	4.83	12.5	5	3	1.00
74	1.07E+05	5.56	12.5	4	51	1.00
75	5.06E+04	1.77	12.5	2	39	1.00
76	6.92E+04	5.09	17.5	4	23	1.00
77	1.42E+05	-999	12.5	12	71	1.00
78	1.94E+04	1.28	12.5	12	69	1.00
79	7.16E+04	3.93	12.5	9	32	1.00
80	9.31E+04	-999	17.5	12	85	1.00
81	3.24E+05	1.84	12.5	12	42	1.00
82	3.72E+05	-999	12.5	2	69	1.00
83	1.21E+03	3.15	17.5	5	34	1.00
84	4.17E+03	2.78	17.5	2	95	1.00
85	2.51E+05	-999	12.5	12	73	1.00
86	1.35E+05	6.55	12.5	9	42	1.00
87	1.66E+03	7.98	12.5	9	73	1.00
88	1.35E+05	4.09	22.5	4	81	1.00
89	8.09E+04	1.53	12.5	5	40	1.00
90	2.55E+05	7.79	12.5	2	71	1.00
91	4.57E+04	-999	12.5	1	71	1.00
92	3.24E+03	-999	12.5	2	39	1.00
93	2.10E+05	1.26	7.5	13	68	1.00
94	5.67E+04	2.51	12.5	2	52	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
95	5.67E+02	1.29	22.5	12	91	1.00
96	5.54E+05	0.53	12.5	5	26	1.00
97	2.43E+04	4.09	12.5	4	39	1.00
98	9.79E+05	0.54	12.5	12	49	1.00
99	5.26E+04	1.13	17.5	2	95	1.00
100	2.19E+05	3.12	12.5	2	71	1.00
101	2.83E+04	2.34	12.5	2	39	1.00
102	8.09E+03	-999	17.5	1	95	1.00
103	2.27E+05	-999	12.5	12	42	1.00
104	4.05E+03	2.95	12.5	2	53	1.00
105	8.50E+04	2.18	22.5	12	93	1.00
106	7.08E+04	-999	12.5	9	42	1.00
107	2.02E+04	6.71	12.5	12	42	1.00
108	2.43E+04	0.82	7.5	4	66	1.25
109	8.09E+03	-999	17.5	12	95	1.25
110	3.28E+03	1.52	12.5	12	69	1.25
111	1.34E+05	1.99	7.5	13	4	1.25
112	1.62E+04	3.07	12.5	2	88	1.25
113	3.64E+04	1.19	17.5	1	77	1.25
114	4.05E+05	-999	12.5	9	73	1.25
115	2.02E+05	1.31	12.5	12	55	1.25
116	8.09E+02	-999	7.5	13	68	16.22
117	3.24E+04	-999	22.5	12	57	1.00
118	4.86E+04	1.58	22.5	4	92	1.00
119	8.50E+02	-999	12.5	12	50	1.00
120	4.86E+04	-999	22.5	12	91	1.00
121	5.14E+05	-999	7.5	13	5	1.00
122	3.12E+06	-999	22.5	4	92	1.00
123	8.09E+04	-999	12.5	12	71	1.00
124	1.30E+04	1.98	17.5	12	95	1.00
125	2.02E+04	-999	22.5	12	57	1.00
126	4.17E+03	-999	22.5	12	93	1.00
127	2.02E+03	-999	17.5	4	29	1.00
128	1.41E+06	-999	22.5	5	92	1.00
129	1.17E+04	0.65	22.5	13	96	1.00
130	6.07E+04	-999	17.5	4	81	1.00
131	2.23E+05	-999	12.5	2	39	22.01
132	4.05E+04	3.96	22.5	4	92	2.55
133	4.05E+02	-999	17.5	2	36	2.55
134	8.09E+04	-999	17.5	2	89	2.55
135	2.27E+04	5.41	12.5	5	33	2.55
136	2.02E+02	1.36	22.5	13	92	2.55
137	2.14E+05	4.82	7.5	8	31	2.55
138	1.54E+05	-999	22.5	12	78	2.55
139	2.71E+04	0.99	7.5	2	31	1.00
140	8.09E+05	8.18	12.5	2	39	1.00
141	1.00E+06	2.35	22.5	4	58	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
142	7.08E+05	4.24	12.5	5	26	1.00
143	7.16E+05	2.14	17.5	13	90	1.00
144	2.02E+04	-999	12.5	2	52	1.00
145	2.54E+05	2.09	17.5	4	80	1.00
146	1.01E+05	-999	12.5	6	89	1.00
147	2.02E+04	-999	22.5	12	58	1.00
148	5.26E+04	1.01	12.5	2	28	1.00
149	5.26E+02	2.03	22.5	4	96	1.00
150	1.86E+05	1.72	12.5	4	27	1.00
151	6.07E+04	-999	12.5	1	72	1.00
152	2.23E+04	1.36	12.5	5	4	1.00
153	1.72E+06	-999	12.5	2	39	1.00
154	1.21E+05	0.65	22.5	2	91	1.00
155	2.63E+05	-999	12.5	13	73	1.00
156	1.86E+05	-999	12.5	12	73	1.00
157	5.67E+04	-999	12.5	12	42	1.00
158	7.69E+05	3.75	12.5	8	55	1.00
159	1.21E+05	4.36	12.5	2	39	1.00
160	1.62E+06	-999	12.5	5	51	1.00
161	8.09E+03	2.62	12.5	1	63	1.00
162	3.44E+04	6.26	12.5	4	72	1.00
163	6.27E+05	6.55	12.5	2	39	1.00
164	2.23E+04	1.26	17.5	2	93	1.00
165	2.43E+04	1.21	17.5	13	77	1.00
166	4.45E+04	-999	12.5	5	29	1.00
167	1.50E+04	1.58	17.5	12	95	1.00
168	1.97E+06	-999	22.5	4	96	1.00
169	1.21E+06	6.00	12.5	12	49	1.00
170	1.24E+06	2.81	7.5	2	32	1.00
171	2.02E+06	3.96	22.5	4	81	1.00
172	5.10E+05	-999	12.5	2	51	1.00
173	4.86E+04	0.55	12.5	4	40	1.00
174	3.24E+04	-999	22.5	4	92	1.00
175	5.54E+05	-999	12.5	13	56	1.00
176	8.09E+05	7.26	22.5	5	22	1.00
177	8.09E+03	-999	17.5	12	89	1.00
178	2.51E+04	0.96	7.5	1	31	1.00
179	1.62E+06	6.14	7.5	13	49	1.00
180	1.62E+05	-999	7.5	2	11	1.00
181	6.75E+04	1.95	12.5	12	20	1.00
182	2.59E+05	0.76	17.5	4	92	1.00
183	2.67E+05	4.20	17.5	13	34	1.00
184	1.62E+05	7.06	22.5	4	58	1.00
185	2.23E+05	6.32	12.5	2	51	1.00
186	4.65E+03	0.66	7.5	2	7	1.00
187	1.01E+06	-999	12.5	13	73	1.00
188	8.05E+05	1.64	12.5	5	74	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
189	1.86E+06	4.55	12.5	5	51	1.00
190	1.18E+06	6.66	22.5	4	36	1.00
191	2.02E+03	1.32	17.5	2	36	1.00
192	9.92E+04	5.01	12.5	2	85	1.00
193	7.16E+05	2.14	17.5	5	90	1.00
194	1.23E+05	4.29	7.5	4	10	1.00
195	1.46E+04	-999	12.5	9	42	1.00
196	1.66E+05	-999	17.5	4	95	1.00
197	1.62E+04	-999	17.5	4	93	1.00
198	7.08E+05	4.24	12.5	5	26	1.00
199	9.29E+04	-999	17.5	2	89	1.00
200	5.26E+05	3.55	22.5	4	36	1.00
201	1.48E+06	-999	17.5	4	81	1.00
202	6.48E+03	0.51	12.5	12	71	1.00
203	2.02E+04	6.55	12.5	12	87	1.00
204	4.87E+05	-999	12.5	4	51	1.00
205	5.46E+04	5.11	7.5	5	10	1.00
206	1.66E+05	5.99	12.5	8	55	1.00
207	1.21E+05	5.28	17.5	13	34	1.00
208	4.05E+03	1.32	12.5	12	69	1.38
209	1.69E+06	4.98	17.5	4	93	1.38
210	1.25E+05	3.32	12.5	12	54	1.38
211	5.67E+04	1.32	12.5	13	73	1.38
212	2.02E+03	-999	22.5	5	12	1.38
213	4.53E+05	8.04	7.5	4	7	1.38
214	4.05E+03	-999	22.5	4	81	1.38
215	4.05E+04	4.91	12.5	12	19	1.38
216	2.02E+04	-999	7.5	13	10	1.38
217	1.82E+05	3.64	12.5	2	39	1.38
218	1.21E+05	-999	22.5	4	92	1.00
219	8.50E+02	-999	17.5	13	77	7.56
220	9.31E+02	-999	17.5	1	79	7.56
221	2.83E+04	-999	22.5	4	58	1.05
222	7.29E+02	2.36	17.5	4	89	1.00
223	1.42E+04	3.27	17.5	4	80	1.00
224	8.09E+04	4.11	12.5	5	74	1.00
225	8.09E+04	1.23	12.5	12	69	1.00
226	1.66E+04	5.39	12.5	1	77	1.00
227	8.90E+04	1.39	17.5	13	29	1.00
228	2.02E+04	-999	22.5	4	58	1.00
229	8.90E+03	1.23	22.5	4	96	1.00
230	3.24E+04	1.33	12.5	6	73	1.00
231	5.67E+04	2.63	17.5	2	30	1.00
232	4.05E+04	-999	22.5	12	57	1.00
233	6.48E+04	2.76	12.5	4	88	1.00
234	5.67E+02	0.88	17.5	4	89	1.81
235	1.11E+04	-999	12.5	12	85	1.81

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
236	7.90E+04	-999	12.5	12	55	1.81
237	4.45E+02	1.12	12.5	13	16	1.81
238	4.05E+03	2.45	12.5	5	39	1.81
239	1.62E+04	-999	17.5	12	95	1.81
240	1.01E+04	-999	12.5	12	54	1.81
241	4.86E+04	-999	12.5	1	88	1.81
242	4.86E+04	-999	12.5	4	71	1.81
243	1.05E+05	-999	17.5	13	34	1.81
244	1.38E+03	3.57	22.5	12	93	1.81
245	1.11E+04	2.20	12.5	4	72	1.81
246	1.94E+04	-999	12.5	12	89	1.00
247	7.69E+04	3.70	17.5	12	89	1.00
248	2.94E+04	-999	17.5	5	13	1.00
249	3.64E+03	3.64	17.5	1	85	1.00
250	4.05E+02	6.55	12.5	1	72	1.00
251	2.02E+04	-999	22.5	4	92	1.00
252	3.80E+04	0.52	22.5	4	35	1.00
253	2.12E+03	-999	17.5	5	89	1.00
254	6.75E+04	1.10	17.5	4	79	1.00
255	4.43E+03	1.03	17.5	12	85	1.00
256	2.63E+04	-999	12.5	4	74	1.00
257	2.02E+04	-999	12.5	13	26	1.00
258	4.25E+04	2.44	17.5	4	93	1.00
259	2.02E+04	-999	22.5	12	57	1.00
260	2.83E+04	3.51	12.5	12	69	1.00
261	6.88E+04	1.20	12.5	4	72	1.00
262	2.02E+04	1.27	22.5	4	81	1.00
263	3.89E+04	3.47	17.5	12	89	1.00
264	2.43E+04	2.97	17.5	12	85	1.00
265	2.63E+05	1.35	17.5	4	89	1.00
266	8.09E+04	1.31	22.5	4	96	1.00
267	1.38E+04	1.14	22.5	4	81	1.00
268	5.22E+03	1.08	12.5	12	49	1.00
269	6.39E+05	-999	12.5	2	87	1.00
270	2.02E+04	0.65	12.5	5	34	1.00
271	1.01E+04	-999	7.5	4	60	1.00
272	7.04E+04	-999	12.5	9	42	1.00
273	3.64E+04	0.68	22.5	12	78	1.00
274	8.09E+03	-999	22.5	12	93	1.00
275	3.24E+04	-999	17.5	13	90	1.00
276	9.29E+04	-999	17.5	4	29	1.00
277	4.04E+04	1.06	12.5	5	40	1.00
278	6.21E+04	1.02	12.5	13	26	1.00
279	5.79E+03	0.80	22.5	4	92	1.00
280	2.02E+04	3.54	22.5	4	81	1.00
281	6.52E+03	1.27	12.5	2	51	1.00
282	8.13E+04	-999	22.5	4	96	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
283	5.26E+04	-999	17.5	5	13	1.00
284	2.12E+06	-999	22.5	5	92	1.00
285	6.07E+04	0.65	17.5	13	81	1.00
286	9.31E+04	2.67	22.5	4	92	1.00
287	2.67E+04	-999	22.5	4	35	1.00
288	4.00E+04	0.69	12.5	4	51	1.00
289	4.05E+04	-999	17.5	5	13	1.00
290	2.23E+04	-999	22.5	12	78	1.00
291	2.02E+04	4.09	7.5	13	5	1.00
292	6.88E+04	8.02	22.5	4	96	1.00
293	3.72E+04	1.33	17.5	4	89	1.00
294	4.35E+04	4.22	17.5	12	89	1.00
295	6.07E+04	2.73	12.5	2	69	1.00
296	8.62E+04	-999	12.5	5	87	1.00
297	6.07E+04	-999	17.5	13	81	1.38
298	2.79E+03	1.98	22.5	6	92	1.38
299	4.05E+03	1.82	17.5	1	77	1.38
300	1.21E+03	-999	12.5	4	72	29.81
301	8.09E+03	-999	22.5	4	92	29.81
302	1.21E+04	-999	12.5	8	42	29.81
303	8.09E+04	4.09	12.5	4	52	29.81
304	1.86E+03	-999	12.5	9	56	29.81
305	8.09E+01	3.03	17.5	1	77	29.81
306	2.02E+03	1.23	22.5	4	91	29.81
307	2.02E+04	-999	22.5	5	21	29.81
308	3.72E+03	0.89	7.5	8	45	29.81
309	8.09E+03	-999	22.5	4	92	29.81
310	2.43E+02	2.05	17.5	12	85	29.81
311	9.31E+02	7.12	12.5	8	46	29.81
312	1.01E+04	-999	12.5	12	73	29.81
313	1.01E+04	-999	22.5	12	57	29.81
314	2.02E+04	1.02	12.5	12	39	29.81
315	8.09E+03	0.61	12.5	5	3	29.81
316	8.09E+01	-999	22.5	12	58	29.81
317	1.62E+05	-999	17.5	13	77	9.25
318	4.05E+04	2.45	22.5	4	92	9.25
319	2.02E+02	-999	17.5	13	1	9.25
320	1.01E+03	-999	17.5	1	95	9.25
321	1.21E+04	-999	22.5	12	57	9.25
322	1.62E+03	-999	12.5	4	19	9.25
323	2.63E+04	4.56	17.5	4	79	9.25
324	6.07E+04	5.46	12.5	13	86	9.25
325	4.05E+03	0.82	12.5	12	42	9.25
326	2.02E+03	-999	17.5	4	89	9.25
327	8.09E+03	-999	17.5	5	34	9.25
328	2.47E+04	-999	12.5	1	84	9.25
329	4.05E+04	-999	12.5	4	74	9.25

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
330	6.07E+03	-999	17.5	12	89	9.25
331	8.90E+04	4.09	17.5	5	21	9.25
332	4.45E+02	1.38	12.5	13	29	9.25
333	2.43E+04	3.07	17.5	4	80	9.25
334	6.07E+03	5.73	12.5	4	39	9.25
335	4.05E+03	0.74	17.5	13	34	9.25
336	2.83E+02	2.60	7.5	13	66	9.25
337	2.43E+04	5.11	12.5	2	51	9.25
338	4.05E+01	0.91	22.5	12	76	9.25
339	2.83E+04	4.09	12.5	12	73	9.25
340	4.05E+04	1.32	17.5	13	36	9.25
341	6.07E+04	-999	17.5	1	95	9.25
342	4.05E+03	2.05	17.5	2	36	9.25
343	4.05E+03	1.23	7.5	4	5	9.25
344	9.31E+02	3.69	12.5	2	88	9.25
345	2.02E+02	-999	12.5	9	73	9.25
346	3.90E+04	3.98	7.5	2	31	9.25
347	8.09E+03	-999	17.5	12	85	9.25
348	1.14E+04	0.79	17.5	12	95	9.25
349	6.07E+04	-999	7.5	12	48	9.25
350	2.23E+04	0.77	12.5	4	88	9.25
351	3.04E+03	2.73	17.5	1	79	9.25
352	8.09E+03	-999	17.5	1	79	9.25
353	1.21E+03	-999	22.5	12	57	9.25
354	8.09E+03	-999	17.5	4	95	9.25
355	8.09E+03	-999	17.5	1	95	9.25
356	1.01E+04	0.92	12.5	8	56	9.25
357	4.05E+03	-999	22.5	4	81	9.25
358	4.86E+04	1.26	12.5	2	52	9.25
359	4.05E+01	-999	17.5	5	90	9.25
360	2.43E+04	-999	12.5	8	55	1.00
361	8.09E+03	-999	17.5	4	80	1.00
362	6.07E+03	1.09	22.5	4	12	1.00
363	4.05E+04	-999	22.5	13	12	1.00
364	1.43E+04	1.45	17.5	5	13	1.00
365	1.16E+04	-999	12.5	2	39	1.00
366	8.82E+03	2.38	12.5	5	51	1.00
367	4.05E+04	3.17	12.5	4	51	1.00
368	8.09E+03	6.60	12.5	2	52	1.00
369	4.46E+04	3.97	17.5	1	79	1.00
370	4.05E+03	5.11	22.5	4	96	1.00
371	1.42E+04	-999	22.5	4	12	1.00
372	1.09E+04	4.55	7.5	13	66	1.00
373	3.72E+04	4.46	12.5	5	40	1.00
374	2.55E+04	2.79	7.5	4	60	1.00
375	4.45E+05	5.58	17.5	2	36	1.00
376	2.43E+05	6.82	7.5	4	68	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
377	6.07E+03	6.87	7.5	13	66	1.00
378	6.07E+03	4.09	12.5	4	72	1.00
379	8.09E+03	0.61	17.5	12	89	1.00
380	8.09E+03	3.27	22.5	2	58	1.00
381	5.77E+04	2.77	17.5	1	77	1.00
382	3.24E+05	7.16	7.5	12	50	1.00
383	3.75E+04	-999	12.5	1	61	1.00
384	4.25E+02	-999	7.5	13	66	1.00
385	4.86E+05	-999	7.5	8	48	1.00
386	5.67E+04	1.05	17.5	10	79	1.00
387	1.26E+05	-999	22.5	4	12	1.00
388	8.09E+03	0.59	12.5	1	61	1.00
389	2.83E+04	3.11	7.5	2	50	1.00
390	2.63E+05	3.78	12.5	12	42	1.00
391	1.62E+05	4.50	17.5	4	79	1.00
392	1.38E+03	3.01	12.5	2	71	1.00
393	1.62E+05	2.56	17.5	5	21	1.00
394	1.05E+05	-999	12.5	12	49	1.00
395	1.02E+04	3.83	12.5	4	39	1.00
396	4.45E+03	3.95	12.5	12	71	1.00
397	1.82E+04	7.07	12.5	2	66	1.00
398	3.24E+04	0.77	12.5	13	72	1.00
399	3.84E+05	6.46	12.5	4	51	1.00
400	4.86E+04	5.11	12.5	12	39	1.00
401	2.23E+05	5.28	22.5	4	14	1.00
402	2.23E+04	1.12	12.5	12	54	1.00
403	5.67E+04	-999	12.5	2	55	1.00
404	1.01E+05	5.24	17.5	2	36	1.00
405	4.05E+03	-999	22.5	12	58	1.00
406	1.01E+04	-999	17.5	5	13	1.00
407	3.91E+04	2.93	17.5	4	89	1.00
408	1.01E+04	-999	17.5	5	34	1.00
409	9.31E+04	1.78	17.5	12	85	1.00
410	1.67E+04	2.18	12.5	4	39	1.00
411	1.62E+04	-999	12.5	12	49	1.00
412	8.09E+04	-999	17.5	4	79	1.00
413	1.21E+04	-999	12.5	2	39	1.00
414	1.16E+04	-999	12.5	5	39	1.00
415	2.79E+04	2.20	17.5	13	90	1.00
416	2.31E+04	-999	12.5	2	39	1.00
417	1.63E+04	3.81	22.5	13	36	1.00
418	8.09E+03	-999	12.5	2	39	1.33
419	1.27E+04	-999	12.5	12	77	1.33
420	4.45E+04	-999	17.5	4	30	1.33
421	2.59E+03	8.31	12.5	4	52	1.33
422	4.86E+03	3.20	12.5	5	26	1.33
423	8.09E+03	0.82	17.5	2	89	1.33

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
424	2.02E+03	-999	17.5	13	36	1.33
425	5.26E+02	1.87	12.5	2	52	1.33
426	3.48E+04	-999	7.5	13	39	1.33
427	5.26E+04	-999	7.5	5	10	1.33
428	2.17E+05	0.53	12.5	5	87	1.33
429	4.05E+04	-999	17.5	12	95	1.33
430	1.21E+05	2.18	17.5	13	34	1.33
431	7.35E+04	6.76	12.5	4	74	1.33
432	2.23E+04	4.46	17.5	12	95	1.33
433	8.09E+03	-999	22.5	2	36	1.33
434	4.05E+03	-999	22.5	4	92	1.33
435	4.05E+04	-999	12.5	2	54	1.33
436	1.21E+05	-999	12.5	5	56	1.33
437	1.05E+05	5.35	12.5	2	53	1.33
438	3.72E+03	1.13	12.5	2	51	1.33
439	3.44E+04	-999	17.5	4	81	1.33
440	2.43E+04	-999	17.5	2	30	1.33
441	8.09E+03	-999	12.5	12	85	1.33
442	6.07E+04	-999	17.5	5	54	1.33
443	2.02E+04	2.05	12.5	13	72	1.33
444	4.05E+03	-999	17.5	1	95	1.33
445	5.26E+03	-999	17.5	5	12	1.33
446	2.43E+05	3.48	12.5	9	73	1.33
447	2.83E+02	-999	22.5	12	57	1.33
448	7.53E+04	0.79	17.5	13	37	1.33
449	1.21E+04	-999	22.5	12	58	1.33
450	6.07E+03	-999	12.5	1	72	1.33
451	1.21E+04	-999	7.5	12	53	1.33
452	4.86E+03	0.81	12.5	2	39	1.33
453	8.09E+03	-999	12.5	12	49	1.33
454	1.98E+05	-999	12.5	12	71	1.33
455	4.86E+04	5.11	12.5	2	88	1.33
456	4.05E+04	-999	12.5	2	50	1.33
457	8.09E+03	-999	12.5	4	74	1.33
458	3.36E+03	-999	7.5	2	53	1.33
459	2.02E+06	-999	7.5	2	53	1.33
460	6.07E+03	-999	22.5	2	58	1.33
461	9.07E+04	5.11	12.5	13	73	1.33
462	3.24E+03	-999	22.5	4	12	1.33
463	2.02E+04	-999	12.5	12	42	1.33
464	4.05E+04	-999	7.5	8	65	1.33
465	1.01E+05	1.28	17.5	4	79	1.33
466	3.34E+04	7.93	17.5	12	85	1.33
467	3.24E+05	2.64	17.5	2	36	1.33
468	7.45E+03	-999	17.5	12	95	1.33
469	1.05E+05	0.97	12.5	12	88	1.33
470	3.24E+04	-999	17.5	13	37	1.33

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
471	2.70E+04	2.28	17.5	13	34	1.33
472	3.24E+05	1.53	17.5	4	30	1.33
473	4.86E+04	-999	12.5	13	68	1.33
474	3.04E+04	4.58	12.5	13	56	1.33
475	2.43E+04	-999	17.5	13	37	1.33
476	1.86E+04	-999	12.5	2	51	1.33
477	1.56E+05	2.92	12.5	13	56	1.33
478	4.86E+05	0.53	7.5	2	17	1.33
479	4.05E+04	1.31	12.5	2	51	1.33
480	2.32E+04	3.56	17.5	13	13	1.00
481	1.66E+05	-999	7.5	13	3	1.00
482	2.02E+04	-999	12.5	12	69	1.00
483	1.21E+05	0.55	17.5	2	30	1.00
484	5.46E+04	3.54	12.5	4	74	7.48
485	1.49E+05	4.45	7.5	13	50	7.48
486	1.92E+04	1.49	22.5	4	92	7.48
487	1.82E+04	1.27	12.5	8	46	7.48
488	6.07E+03	6.78	12.5	4	74	7.48
489	1.30E+05	-999	17.5	5	90	7.48
490	3.44E+04	-999	12.5	7	29	7.48
491	3.64E+04	1.59	12.5	5	24	7.48
492	5.18E+04	2.56	22.5	4	96	1.00
493	5.26E+04	1.06	17.5	4	79	1.00
494	1.34E+05	6.20	7.5	1	44	1.00
495	5.87E+04	0.56	17.5	4	93	1.00
496	3.52E+05	2.63	7.5	1	31	1.00
497	2.19E+05	-999	22.5	4	92	1.00
498	7.08E+04	-999	22.5	4	96	1.00
499	7.32E+04	-999	7.5	4	31	1.00
500	4.05E+05	0.63	22.5	13	81	1.00
501	3.84E+04	1.94	7.5	2	50	1.00
502	1.75E+04	2.52	22.5	12	92	1.00
503	1.79E+05	2.83	12.5	12	69	1.00
504	8.09E+04	-999	17.5	4	92	1.00
505	1.84E+05	3.15	17.5	12	89	1.00
506	4.05E+04	2.89	17.5	1	95	1.00
507	2.52E+06	1.77	17.5	13	34	1.00
508	1.21E+05	-999	17.5	4	93	1.00
509	1.58E+05	2.35	7.5	2	31	1.00
510	1.36E+04	1.42	17.5	2	87	1.00
511	6.88E+03	3.95	22.5	12	78	1.00
512	1.05E+05	7.87	22.5	12	78	1.00
513	7.01E+04	2.00	22.5	12	91	1.00
514	2.02E+05	-999	17.5	12	85	1.00
515	1.92E+06	0.79	17.5	4	93	1.00
516	2.43E+04	-999	22.5	4	92	1.00
517	1.62E+05	-999	17.5	4	92	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
518	1.21E+05	2.18	7.5	4	50	1.00
519	1.82E+05	0.84	7.5	13	43	1.00
520	1.24E+04	1.94	17.5	4	90	1.00
521	1.62E+05	-999	17.5	2	80	1.00
522	3.72E+05	1.32	22.5	12	78	1.00
523	1.78E+05	4.65	12.5	2	28	1.00
524	8.09E+04	-999	12.5	2	66	1.00
525	9.31E+04	4.66	7.5	8	41	1.00
526	1.09E+05	7.58	7.5	8	62	1.00
527	6.56E+04	3.27	7.5	2	50	1.00
528	5.38E+04	7.38	7.5	2	50	1.00
529	1.49E+05	7.80	17.5	4	95	1.00
530	1.46E+05	1.32	17.5	4	95	1.00
531	1.21E+05	2.38	17.5	12	95	1.00
532	1.62E+05	3.07	7.5	4	45	1.00
533	5.80E+04	2.47	22.5	4	92	1.00
534	1.52E+04	-999	22.5	4	92	1.00
535	2.29E+04	-999	12.5	5	24	1.00
536	2.02E+03	-999	12.5	4	52	1.00
537	9.15E+04	3.62	22.5	4	96	1.00
538	8.09E+04	-999	17.5	4	93	1.00
539	2.53E+04	6.55	12.5	13	40	1.00
540	8.09E+03	2.86	12.5	2	40	1.00
541	2.43E+04	0.83	12.5	12	39	1.00
542	2.38E+04	5.22	12.5	2	82	1.00
543	2.70E+04	-999	17.5	1	85	1.00
544	1.62E+04	2.86	7.5	2	31	1.00
545	4.86E+04	4.33	7.5	1	47	1.00
546	1.23E+05	2.68	17.5	4	89	1.00
547	2.02E+05	-999	12.5	4	51	1.00
548	4.05E+04	3.60	12.5	8	46	1.00
549	1.62E+05	6.14	22.5	12	91	1.00
550	1.25E+05	2.65	17.5	2	81	1.00
551	1.21E+05	2.21	17.5	4	93	1.00
552	2.02E+04	1.15	7.5	4	25	1.00
553	6.48E+04	4.06	7.5	2	50	1.00
554	4.33E+04	3.29	22.5	4	81	1.00
555	1.42E+05	3.04	17.5	4	80	1.00
556	6.07E+04	6.55	7.5	1	62	1.00
557	3.72E+05	-999	17.5	4	81	1.00
558	1.19E+06	2.61	7.5	2	50	1.00
559	6.07E+05	6.34	17.5	4	92	1.00
560	1.21E+05	3.14	12.5	4	52	1.00
561	3.64E+04	2.43	12.5	12	54	1.00
562	1.62E+05	1.23	12.5	8	32	1.00
563	2.02E+04	-999	7.5	1	31	1.00
564	6.48E+04	1.79	17.5	5	89	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
565	9.96E+04	1.93	17.5	5	81	1.00
566	5.06E+04	0.93	7.5	4	25	1.00
567	1.42E+05	1.17	17.5	4	81	1.00
568	8.09E+04	-999	7.5	2	48	1.00
569	2.02E+05	2.95	12.5	1	9	1.00
570	2.83E+05	5.84	7.5	1	44	1.00
571	2.02E+04	1.23	12.5	4	82	1.00
572	6.07E+05	1.85	17.5	5	81	1.00
573	1.98E+05	1.82	22.5	12	78	1.00
574	7.28E+05	2.73	17.5	1	85	1.00
575	6.68E+04	2.16	22.5	12	78	1.00
576	4.05E+05	0.52	12.5	4	74	1.00
577	1.35E+04	1.43	17.5	2	87	1.00
578	2.02E+05	0.82	7.5	2	50	1.00
579	5.67E+04	4.24	12.5	1	63	1.00
580	1.62E+05	2.86	12.5	13	24	1.00
581	2.83E+04	-999	17.5	1	95	1.00
582	1.23E+06	-999	17.5	2	80	1.00
583	1.62E+05	2.66	22.5	4	91	1.00
584	1.08E+04	-999	12.5	2	71	1.00
585	2.63E+04	2.97	7.5	4	50	1.00
586	1.92E+04	1.49	22.5	4	92	1.00
587	2.02E+05	1.38	12.5	8	32	1.00
588	3.97E+05	5.62	12.5	4	66	1.00
589	3.37E+04	-999	17.5	5	90	1.00
590	3.24E+04	5.16	17.5	4	93	1.00
591	1.34E+05	2.29	7.5	1	31	1.00
592	1.21E+05	2.86	12.5	13	40	1.00
593	1.66E+05	-999	22.5	12	78	1.00
594	5.67E+05	4.09	17.5	4	95	1.33
595	2.37E+04	1.58	17.5	5	90	1.33
596	6.07E+04	4.09	17.5	4	95	1.33
597	8.90E+04	2.10	17.5	5	90	1.33
598	4.86E+04	2.73	7.5	2	50	1.33
599	4.86E+04	4.48	12.5	1	69	1.33
600	3.31E+04	1.71	17.5	12	92	1.33
601	1.05E+06	0.90	7.5	13	48	1.33
602	1.42E+04	4.68	12.5	12	84	1.33
603	3.24E+05	4.09	7.5	8	32	1.33
604	9.31E+02	1.32	17.5	2	89	4.42
605	8.09E+03	-999	17.5	12	95	4.42
606	1.01E+04	0.65	12.5	2	4	4.42
607	1.38E+04	1.06	17.5	13	34	4.42
608	8.09E+03	-999	17.5	12	89	4.42
609	1.63E+05	-999	22.5	5	21	4.42
610	4.86E+02	0.71	12.5	5	40	4.42
611	7.08E+04	5.28	12.5	9	73	4.42

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
612	1.66E+03	2.59	22.5	12	58	4.42
613	4.05E+03	-999	7.5	4	60	4.42
614	4.05E+04	8.18	12.5	8	9	1.00
615	2.02E+03	7.39	12.5	4	40	1.00
616	1.78E+05	2.79	17.5	4	29	1.00
617	1.13E+04	2.57	12.5	1	9	1.00
618	4.05E+03	-999	17.5	12	89	1.00
619	7.49E+04	-999	17.5	2	89	1.00
620	9.66E+04	-999	22.5	4	58	1.00
621	5.67E+03	7.95	12.5	12	73	1.00
622	4.05E+04	-999	12.5	2	54	1.00
623	4.05E+04	-999	22.5	2	21	1.00
624	1.21E+05	-999	7.5	4	43	1.00
625	2.02E+04	0.82	12.5	1	8	1.00
626	1.01E+05	-999	12.5	5	26	1.00
627	4.45E+04	4.69	12.5	8	46	1.00
628	1.54E+04	4.55	12.5	8	42	1.00
629	5.36E+04	0.93	22.5	2	22	1.00
630	7.69E+04	1.63	17.5	12	89	1.00
631	4.05E+04	-999	17.5	1	95	1.00
632	1.36E+04	-999	17.5	2	87	1.00
633	1.62E+04	3.58	12.5	12	49	1.00
634	1.13E+04	2.59	12.5	8	9	1.00
635	1.62E+04	-999	17.5	4	93	1.00
636	8.09E+03	2.32	12.5	12	72	1.00
637	8.09E+03	-999	12.5	5	51	1.00
638	1.75E+04	-999	12.5	5	26	1.00
639	8.26E+04	-999	12.5	8	8	1.00
640	1.62E+04	5.11	7.5	4	25	1.00
641	8.50E+04	1.21	7.5	4	60	1.00
642	2.00E+04	-999	12.5	4	20	1.00
643	3.04E+05	0.91	22.5	4	58	1.00
644	2.02E+04	-999	17.5	1	95	1.00
645	1.21E+04	-999	12.5	12	54	1.00
646	1.30E+05	2.56	12.5	6	89	1.00
647	5.40E+04	6.14	22.5	12	91	1.00
648	9.61E+04	-999	22.5	4	58	1.00
649	7.89E+05	3.36	17.5	4	90	1.00
650	2.02E+05	3.27	12.5	2	52	1.36
651	1.06E+04	-999	12.5	12	71	1.36
652	2.43E+04	0.55	12.5	5	40	1.36
653	2.02E+03	-999	7.5	4	83	30.19
654	2.02E+03	-999	22.5	2	22	30.19
655	1.21E+05	-999	22.5	12	91	30.19
656	1.21E+02	0.68	17.5	4	36	30.19
657	1.82E+04	1.36	17.5	13	13	11.28
658	7.90E+04	3.88	22.5	12	91	11.28

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
659	1.42E+04	3.10	17.5	1	77	1.00
660	4.05E+04	2.05	12.5	7	29	1.00
661	1.00E+04	8.25	12.5	6	73	1.00
662	7.49E+02	0.92	17.5	4	23	1.00
663	5.26E+04	7.40	17.5	13	13	1.00
664	2.27E+05	7.31	12.5	6	73	1.00
665	2.63E+04	-999	12.5	1	5	1.00
666	5.46E+04	3.15	12.5	6	74	1.00
667	8.09E+03	-999	12.5	5	9	1.00
668	1.48E+04	1.67	17.5	4	89	1.00
669	4.98E+03	-999	17.5	5	90	1.00
670	6.48E+04	0.80	17.5	1	77	1.00
671	4.86E+03	-999	12.5	12	87	1.00
672	3.89E+05	1.49	22.5	4	96	1.00
673	3.64E+05	-999	7.5	2	32	1.37
674	2.43E+04	2.73	12.5	8	83	1.37
675	2.32E+04	-999	22.5	4	92	1.37
676	1.42E+05	-999	17.5	2	36	1.37
677	4.05E+04	4.09	22.5	12	93	1.37
678	6.07E+04	-999	12.5	2	39	24.00
679	9.11E+04	-999	12.5	13	24	24.00
680	2.79E+03	-999	17.5	12	85	1.89
681	9.31E+02	-999	17.5	5	13	1.89
682	2.95E+03	3.34	12.5	2	51	1.89
683	1.62E+05	0.87	17.5	12	85	1.89
684	4.65E+04	1.58	12.5	4	66	1.89
685	8.09E+03	-999	7.5	2	60	1.89
686	1.67E+04	3.47	12.5	12	87	1.00
687	1.42E+05	-999	22.5	12	76	1.00
688	3.52E+03	1.96	12.5	4	66	1.00
689	4.69E+03	1.59	12.5	5	3	1.00
690	2.19E+04	-999	17.5	4	20	1.00
691	1.01E+05	1.32	17.5	5	13	1.27
692	4.05E+03	-999	12.5	2	69	1.27
693	2.83E+04	0.88	22.5	4	96	1.00
694	1.66E+04	-999	12.5	12	69	1.00
695	4.05E+03	-999	22.5	12	92	1.00
696	9.41E+03	0.88	12.5	5	19	1.00
697	4.05E+03	1.06	22.5	4	81	1.00
698	2.27E+04	0.99	17.5	13	37	1.00
699	2.43E+03	2.94	22.5	4	58	1.00
700	1.38E+03	-999	22.5	4	35	1.00
701	2.02E+03	-999	17.5	4	81	1.00
702	8.34E+02	3.97	17.5	4	29	1.00
703	1.62E+04	0.99	22.5	4	96	1.00
704	2.02E+04	-999	12.5	5	27	1.00
705	8.36E+03	-999	7.5	4	7	1.00

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (° C)	HG Environment	Nearest Climate Center	Site Weighting
706	2.43E+04	-999	17.5	5	34	1.00
707	4.05E+03	3.27	7.5	2	31	1.00
708	1.63E+04	3.38	22.5	4	92	1.00
709	7.28E+04	2.05	12.5	12	54	1.00
710	2.43E+04	1.32	12.5	8	46	1.00
711	4.18E+04	5.74	12.5	12	54	1.00
712	3.64E+04	2.05	22.5	4	92	1.00
713	4.05E+04	0.98	12.5	4	74	1.00
714	3.04E+04	-999	12.5	8	46	1.00
715	3.04E+05	-999	22.5	4	96	1.00
716	1.62E+04	0.85	17.5	4	23	1.00
717	3.84E+04	-999	17.5	4	80	1.00
718	2.02E+03	1.33	17.5	4	29	1.00
719	2.36E+04	1.18	17.5	13	29	1.00
720	6.21E+02	-999	12.5	2	19	1.00
721	1.01E+05	5.73	12.5	12	73	1.00
722	1.62E+04	-999	17.5	4	95	1.00
723	8.09E+04	-999	17.5	4	20	1.00
724	1.42E+04	1.04	12.5	5	26	1.00
725	4.05E+04	-999	17.5	4	93	1.17
726	4.05E+03	2.05	12.5	2	39	1.17
727	4.65E+04	-999	12.5	5	40	1.17
728	3.24E+02	-999	12.5	2	52	1.17
729	8.09E+03	-999	17.5	4	95	1.17
730	1.52E+05	3.27	7.5	13	68	10.23
731	5.67E+04	2.63	17.5	2	30	10.23
732	2.48E+03	-999	7.5	1	47	10.23
733	1.11E+04	-999	12.5	2	50	1.00
734	2.43E+04	1.91	12.5	2	71	1.00
735	1.66E+05	7.98	12.5	8	32	1.00
736	1.02E+06	0.65	12.5	5	51	1.00
737	1.36E+05	-999	12.5	5	34	1.00
738	1.21E+04	1.09	17.5	1	95	1.00
739	8.09E+04	-999	12.5	12	42	1.00
740	3.10E+04	0.94	12.5	2	52	1.00
741	1.62E+04	-999	7.5	8	32	1.00
742	1.62E+04	-999	17.5	2	90	1.36
743	2.02E+05	1.74	17.5	5	13	1.36
744	1.01E+05	-999	17.5	5	23	1.36
745	1.82E+04	2.83	12.5	5	74	1.36
746	6.07E+02	-999	22.5	2	36	1.36
747	1.82E+04	3.00	17.5	4	93	1.36
748	1.78E+04	0.83	12.5	2	39	1.36
749	4.05E+04	2.36	7.5	4	60	1.36
750	7.90E+04	-999	7.5	12	42	1.36
751	3.34E+04	4.46	12.5	9	74	1.36
752	3.04E+04	2.02	22.5	4	96	1.36

Table D.1 Nationwide Database of Landfill Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (° C)	HG Environment	Nearest Climate Center	Site Weighting
753	4.05E+03	-999	12.5	2	54	1.36
754	3.72E+03	-999	12.5	12	49	1.36
755	2.43E+04	2.14	12.5	2	74	1.36
756	2.31E+05	-999	7.5	2	32	1.00
757	1.86E+04	0.79	17.5	12	89	1.00
758	1.62E+04	1.32	12.5	12	69	1.00
759	1.82E+04	-999	12.5	13	40	1.00
760	8.09E+04	0.53	22.5	4	96	1.00
761	5.26E+04	-999	22.5	4	96	1.00
762	4.25E+04	-999	22.5	4	96	1.00
763	7.69E+03	1.08	12.5	5	51	1.00
764	1.62E+04	2.86	12.5	2	39	1.00
765	5.67E+04	4.38	22.5	12	91	1.00
766	2.63E+05	0.76	22.5	4	96	1.00
767	8.09E+03	1.02	17.5	1	77	1.00
768	3.64E+04	-999	17.5	4	93	1.00
769	5.95E+04	2.27	17.5	2	93	1.00
770	2.32E+04	1.28	17.5	4	80	1.00
771	1.58E+05	-999	12.5	4	72	1.00
772	2.83E+04	-999	17.5	4	80	1.00
773	8.50E+04	2.92	22.5	2	36	1.00
774	1.21E+05	-999	17.5	4	89	6.82
775	2.43E+05	-999	17.5	4	93	6.82
776	1.82E+04	1.24	17.5	1	85	1.00
777	1.62E+04	2.05	12.5	12	69	1.00
778	1.27E+04	3.34	17.5	1	79	1.00
779	6.07E+03	-999	17.5	1	85	1.00
780	4.29E+04	1.48	17.5	12	85	1.00
781	1.52E+05	1.82	17.5	1	85	1.00
782	1.01E+04	3.14	17.5	1	95	1.00
783	7.97E+03	-999	17.5	4	93	1.00
784	8.09E+03	-999	17.5	4	79	1.00
785	8.09E+03	-999	17.5	1	79	1.00
786	2.43E+05	-999	17.5	12	95	1.00
787	8.09E+03	0.82	7.5	1	31	3.09
788	1.34E+03	1.98	7.5	4	84	3.09
789	6.48E+04	1.84	7.5	8	44	1.00
790	1.21E+04	-999	7.5	8	62	1.36

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
1	6.31E+02	2.13	0.00	0.2	12.5	110	50	1	6	4	7.02
2	9.39E+03	1.22	0.00	0.2	17.5	5000	50	1	5	12	25.16
3	9.75E+03	2.44	0.00	0.2	17.5	5000	50	1	5	12	25.16
4	2.20E+04	2.44	0.00	0.2	17.5	5000	50	1	5	12	25.16
5	2.93E+04	3.54	5.98	0.2	17.5	5000	50	1	5	12	25.16
6	8.83E+02	0.61	1.22	0.2	12.5	120	50	2	10	72	22.33
7	5.81E+03	0.61	1.22	0.2	12.5	110	50	2	10	72	22.33
8	1.68E+03	6.25	7.32	0.2	12.5	900	7	3	2	56	29.82
9	2.59E+05	0.76	1.52	0.2	17.5	1450	22	1	1	85	7.21
10	3.60E+05	10.97	9.30	0.2	17.5	100	42	3	1	77	6.81
11	6.56E+04	6.10	8.53	0.2	17.5	625	50	3	1	77	6.81
12	4.05E+05	5.33	14.48	0.2	17.5	75	50	3	1	77	6.81
13	1.25E+05	8.53	2.29	0.2	17.5	960	50	3	1	77	6.81
14	3.24E+05	5.33	12.04	0.2	17.5	125	50	3	1	77	6.81
15	6.60E+04	8.84	9.60	0.2	17.5	775	50	3	1	77	6.81
16	2.59E+05	6.10	7.32	0.2	17.5	350	50	3	1	77	6.81
17	2.93E+03	-999	0.00	0.2	17.5	150	50	3	10	80	123.12
18	2.69E+03	3.66	4.57	0.2	17.5	1600	50	3	10	91	238.79
19	1.67E+04	3.66	4.57	0.2	17.5	1600	50	3	10	91	238.79
20	2.69E+03	3.66	4.57	0.2	17.5	1600	50	3	10	91	238.79
21	5.40E+02	-999	0.00	0.2	12.5	5000	41	2	8	42	21.14
22	4.05E+03	3.66	4.57	0.2	17.5	5000	23	3	1	77	3.61
23	1.17E+04	3.20	3.81	0.2	17.5	5000	50	3	1	77	3.61
24	4.05E+03	3.66	6.10	0.2	17.5	5000	23	3	1	77	3.61
25	3.72E+04	1.68	8.23	0.2	17.5	5000	50	3	1	77	3.61
26	2.42E+03	1.25	3.94	0.2	22.5	20	24	3	10	96	21.82
27	3.07E+03	1.83	2.19	0.2	22.5	55	22	3	10	96	21.82

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
28	7.66E+02	2.29	2.29	0.2	22.5	5000	47	1	10	81	25.05
29	1.52E+02	0.76	1.37	0.2	22.5	5000	17	1	10	81	25.05
30	5.81E+02	1.83	0.00	0.2	17.5	190	50	1	6	34	28.76
31	2.32E+03	1.52	2.44	0.2	12.5	115	50	1	2	42	117.25
32	7.90E+03	0.61	1.52	0.2	12.5	40	27	3	2	42	117.25
33	1.62E+04	3.51	1.95	0.2	22.5	5000	50	3	10	96	1.01
34	1.62E+04	3.51	1.95	0.2	22.5	5000	50	3	10	96	1.01
35	1.21E+04	4.27	1.37	0.2	17.5	410	50	3	6	54	1.70
36	4.80E+05	4.80	1.30	0.2	17.5	90	50	3	6	54	1.70
37	1.21E+05	6.10	1.68	0.2	17.5	50	50	3	6	54	1.70
38	1.49E+05	4.57	0.00	0.2	17.5	65	50	3	6	54	1.70
39	7.69E+03	4.27	0.46	0.2	17.5	65	50	3	6	54	1.70
40	1.02E+05	4.57	2.59	0.2	17.5	65	50	3	6	54	1.70
41	2.00E+03	1.07	0.61	0.2	7.5	120	50	1	7	66	7.21
42	2.58E+03	2.44	1.07	0.2	7.5	130	50	1	7	66	7.21
43	2.58E+03	2.44	1.07	0.2	7.5	145	50	1	7	66	7.21
44	2.53E+03	2.74	1.07	0.2	7.5	145	50	1	7	66	7.21
45	1.21E+05	3.12	0.00	0.2	17.5	85	50	1	7	91	1.01
46	2.75E+05	-999	0.00	0.2	17.5	300	50	1	7	91	1.01
47	1.11E+06	0.34	0.00	0.2	17.5	85	50	1	7	91	1.01
48	3.54E+02	-999	0.00	0.2	12.5	20	50	1	2	71	7.02
49	4.87E+02	0.68	0.00	0.2	12.5	20	50	1	2	71	7.02
50	6.07E+03	4.18	3.87	0.2	12.5	695	50	3	9	49	23.04
51	1.42E+04	1.52	0.00	0.2	12.5	330	50	3	9	49	23.04

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
52	6.07E+03	4.18	3.87	0.2	12.5	710	50	3	9	49	23.04
53	1.42E+04	3.66	1.83	0.2	12.5	620	50	3	9	49	23.04
54	1.35E+03	3.66	1.83	0.2	12.5	575	50	3	9	49	23.04
55	1.35E+03	3.66	1.83	0.2	12.5	590	50	3	9	49	23.04
56	2.02E+04	4.13	3.61	0.2	12.5	530	50	3	9	49	23.04
57	6.06E+03	1.52	0.40	0.2	7.5	20	50	2	6	25	7.67
58	6.04E+03	1.63	0.38	0.2	7.5	60	50	2	6	25	7.67
59	4.05E+05	2.43	0.00	0.2	12.5	25	50	3	7	54	7.02
60	1.01E+06	2.58	0.00	0.2	12.5	25	50	3	7	54	7.02
61	1.62E+03	2.28	0.00	0.2	12.5	5000	57	3	7	54	7.02
62	2.02E+02	2.74	0.00	0.2	12.5	5000	50	3	7	54	7.02
63	6.97E+02	2.28	5.72	0.2	12.5	20	50	1	2	39	21.25
64	1.04E+03	0.03	0.52	0.2	22.5	1520	50	2	4	78	26.72
65	1.49E+03	1.22	1.83	0.2	12.5	20	31	3	12	6	23.20
66	1.39E+02	0.30	1.98	0.2	12.5	20	50	3	12	6	23.20
67	1.23E+03	1.47	0.00	0.2	12.5	90	5	3	12	6	23.20
68	2.79E+01	0.61	0.00	0.2	12.5	140	50	3	12	6	23.20
69	5.06E+04	1.49	3.63	0.2	17.5	1200	50	1	10	93	7.27
70	1.62E+03	0.46	2.74	0.2	17.5	1100	55	1	10	93	7.27
71	1.62E+03	1.74	0.61	0.2	17.5	750	55	1	10	93	7.27
72	4.86E+03	0.46	6.10	0.2	17.5	930	65	1	10	93	7.27
73	4.86E+03	-999	4.45	0.2	17.5	1600	65	1	10	93	7.27
74	1.82E+04	1.07	3.51	0.2	17.5	1700	65	1	10	93	7.27

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
75	4.05E+03	1.98	2.59	0.2	17.5	5000	50	1	10	93	7.27
76	1.86E+03	-999	0.00	0.2	17.5	5000	5	1	10	93	7.27
77	6.99E+03	1.31	2.23	0.2	17.5	700	50	1	10	93	7.27
78	9.68E+03	1.07	8.08	0.2	17.5	1100	50	1	10	93	7.27
79	5.26E+04	3.89	2.44	0.2	17.5	5000	36	1	10	93	7.27
80	4.45E+04	4.43	1.83	0.2	17.5	1900	35	1	10	93	7.27
81	9.31E+03	1.37	2.44	0.2	17.5	700	65	1	10	93	7.27
82	5.30E+03	2.18	0.91	0.2	7.5	5000	16	3	4	48	7.67
83	5.23E+03	4.57	2.74	0.2	7.5	5000	50	3	4	48	7.67
84	4.46E+03	3.05	1.22	0.2	7.5	5000	50	3	4	48	7.67
85	3.57E+03	0.61	1.52	0.2	7.5	5000	50	3	4	48	7.67
86	8.88E+03	4.27	2.74	0.2	7.5	5000	50	3	4	48	7.67
87	8.76E+03	3.05	3.05	0.2	7.5	5000	50	3	4	48	7.67
88	4.06E+03	2.13	1.52	0.2	7.5	5000	50	3	4	48	7.67
89	1.74E+05	4.55	3.51	0.2	22.5	200	50	3	6	96	6.81
90	1.29E+05	2.26	1.07	0.2	22.5	50	50	3	6	96	6.81
91	1.86E+04	3.35	4.27	0.2	17.5	255	32	3	7	90	7.21
92	1.53E+03	1.37	2.90	0.2	17.5	180	27	3	7	90	7.21
93	2.63E+05	0.30	1.07	0.2	17.5	1220	50	3	10	89	6.81
94	1.94E+04	3.05	3.66	0.2	17.5	5000	50	3	10	89	6.81
95	1.62E+04	4.05	5.18	0.2	17.5	5000	50	3	10	89	6.81
96	3.48E+04	3.05	3.66	0.2	17.5	5000	50	3	10	89	6.81
97	1.21E+03	3.12	3.66	0.2	17.5	5000	50	3	10	89	6.81

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
98	1.21E+03	5.49	3.05	0.2	17.5	0	50	1	10	89	6.81
99	8.58E+05	1.52	1.52	0.2	17.5	1550	50	3	10	89	6.81
100	6.11E+04	4.57	5.94	0.2	17.5	1020	50	3	10	89	6.81
101	2.67E+04	3.05	0.30	0.2	17.5	1380	50	3	10	89	6.81
102	6.07E+04	5.11	4.88	0.2	17.5	1900	50	3	10	89	6.81
103	1.01E+04	4.49	5.18	0.2	17.5	5000	50	3	10	89	6.81
104	6.14E+04	1.83	3.05	0.2	17.5	1620	50	3	10	89	6.81
105	1.54E+05	4.57	1.83	0.2	17.5	1100	50	3	10	89	6.81
106	6.19E+04	5.44	6.48	0.2	17.5	1960	50	3	10	89	6.81
107	8.09E+04	-999	1.07	0.2	17.5	240	50	1	10	81	21.82
108	2.30E+02	3.35	3.05	0.2	12.5	180	27	1	6	39	23.20
109	2.09E+03	1.53	0.00	0.2	12.5	800	50	2	2	71	29.06
110	2.02E+05	2.29	2.90	0.2	17.5	140	50	1	10	93	3.40
111	8.09E+03	2.44	3.05	0.2	17.5	975	50	1	10	93	3.40
112	8.09E+03	2.74	2.13	0.2	17.5	895	50	1	10	93	3.40
113	4.86E+04	2.74	3.66	0.2	17.5	910	50	1	10	93	3.40
114	8.09E+03	2.44	3.35	0.2	17.5	950	50	1	10	93	3.40
115	2.31E+04	3.05	3.96	0.2	17.5	845	50	1	10	93	3.40
116	2.02E+05	5.18	5.49	0.2	17.5	25	50	1	10	93	3.40
117	6.48E+03	4.85	0.00	0.2	17.5	360	50	1	10	93	3.40
118	1.70E+05	4.57	6.71	0.2	17.5	500	50	1	10	93	3.40
119	1.01E+03	2.44	2.74	0.2	17.5	270	50	1	10	93	3.40
120	2.43E+04	4.57	4.88	0.2	17.5	820	50	1	10	93	3.40

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
121	1.39E+03	3.05	3.12	0.2	12.5	180	50	3	6	6	7.21
122	1.39E+03	4.57	5.49	0.2	12.5	230	50	3	6	6	7.21
123	5.57E+03	4.57	5.49	0.2	12.5	265	50	3	6	6	7.21
124	5.57E+02	3.81	4.66	0.2	12.5	230	50	3	6	6	7.21
125	4.06E+03	3.68	4.66	0.2	12.5	270	50	3	6	6	7.21
126	2.83E+04	-999	1.52	0.2	12.5	180	50	1	4	46	7.67
127	1.01E+04	0.30	6.10	0.2	12.5	605	50	1	4	46	7.67
128	1.42E+04	0.30	3.20	0.2	12.5	590	50	1	4	46	7.67
129	8.09E+03	3.35	1.98	0.2	12.5	320	50	1	4	46	7.67
130	2.02E+04	0.91	3.96	0.2	12.5	180	50	1	4	46	7.67
131	2.83E+03	1.73	3.35	0.2	12.5	330	50	1	4	46	7.67
132	7.43E+01	1.52	2.44	0.2	12.5	1800	13	3	2	69	21.54
133	2.86E+05	1.22	0.00	0.2	22.5	150	50	2	10	92	6.81
134	1.30E+05	1.67	0.00	0.2	22.5	280	52	1	10	96	21.43
135	7.49E+04	1.98	0.30	0.2	7.5	30	60	2	8	42	3.61
136	5.26E+03	1.60	2.44	0.2	7.5	290	60	2	8	42	3.61
137	4.73E+04	0.76	1.83	0.2	7.5	30	60	2	8	42	3.61
138	7.49E+04	2.74	0.00	0.2	7.5	30	60	2	8	42	3.61
139	3.68E+04	1.37	1.83	0.2	7.5	30	60	2	8	42	3.61
140	5.02E+02	1.07	0.00	0.2	17.5	455	30	1	5	13	21.25
141	1.19E+04	1.45	1.22	0.2	17.5	160	50	1	2	90	6.81
142	1.39E+03	1.22	2.74	0.2	17.5	340	50	3	2	90	6.81
143	4.61E+03	0.15	1.83	0.2	17.5	950	50	3	2	90	6.81

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
144	8.71E+02	1.52	2.44	0.2	17.5	560	50	3	2	90	6.81
145	5.96E+04	4.57	5.49	0.2	17.5	470	50	3	2	90	6.81
146	1.33E+03	1.52	5.49	0.2	17.5	480	50	3	2	90	6.81
147	3.43E+03	1.52	3.51	0.2	17.5	600	50	3	2	90	6.81
148	1.45E+05	2.29	2.29	0.2	17.5	100	50	3	2	90	6.81
149	6.01E+03	1.52	3.66	0.2	17.5	700	50	1	2	90	6.81
150	5.30E+02	1.22	1.22	0.2	7.5	110	20	2	9	49	20.59
151	1.30E+02	1.22	1.22	0.2	7.5	20	27	2	9	49	20.59
152	7.80E+02	1.22	1.22	0.2	7.5	110	20	2	9	49	20.59
153	7.80E+02	1.22	1.22	0.2	7.5	110	20	2	9	49	20.59
154	9.14E+02	-999	0.30	0.2	12.5	20	15	2	8	59	7.02
155	2.93E+03	1.52	2.44	0.2	17.5	1300	50	3	2	37	19.70
156	2.69E+03	1.52	2.44	0.2	17.5	1330	50	3	2	37	19.70
157	1.99E+03	-999	1.52	0.2	17.5	1480	17	3	2	37	19.70
158	2.28E+03	-999	1.52	0.2	17.5	1455	17	3	2	37	19.70
159	1.36E+03	1.68	1.68	0.2	17.5	1450	50	3	12	89	7.39
160	8.38E+03	4.57	6.10	0.2	17.5	1180	50	3	12	89	7.39
161	3.48E+03	2.29	4.42	0.2	17.5	5000	50	3	12	89	7.39
162	8.09E+05	3.05	0.00	0.2	22.5	1500	50	3	6	81	6.81
163	2.38E+01	4.57	4.88	0.2	22.5	1575	4	1	7	81	23.36
164	1.38E+03	4.57	3.05	0.2	22.5	1270	50	3	10	96	3.61
165	1.39E+03	0.61	3.66	0.2	22.5	1340	50	3	10	96	3.61
166	2.06E+02	0.76	1.37	0.2	17.5	95	50	3	10	80	26.72

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
167	5.26E+02	0.64	0.00	0.2	17.5	20	65	1	2	15	1.01
168	2.02E+03	2.44	3.05	0.2	17.5	20	65	3	2	15	1.01
169	2.63E+04	-999	4.42	0.2	22.5	215	50	3	10	96	7.67
170	6.07E+03	0.58	1.22	0.2	22.5	1645	50	3	10	96	7.67
171	7.08E+05	1.22	2.44	0.2	22.5	35	50	3	10	96	7.67
172	2.83E+05	0.91	1.83	0.2	22.5	35	50	3	10	96	7.67
173	4.25E+05	1.37	2.29	0.2	22.5	35	50	3	10	96	7.67
174	3.64E+04	2.44	3.05	0.2	22.5	20	50	3	10	96	7.67
175	1.50E+04	1.98	0.30	0.2	22.5	1440	50	3	10	96	7.67
176	1.13E+04	-999	0.00	0.2	17.5	20	47	1	1	85	11.83
177	1.13E+04	-999	0.00	0.2	17.5	30	47	1	1	85	11.83
178	5.55E+03	-999	2.13	0.2	17.5	1800	50	1	2	6	11.52
179	3.33E+03	-999	1.98	0.2	17.5	2000	50	1	2	6	11.52
180	5.14E+05	2.74	3.96	0.2	17.5	5000	50	3	6	90	6.81
181	5.06E+03	1.37	2.13	0.2	17.5	5000	50	3	6	90	6.81
182	7.28E+03	0.84	2.06	0.2	17.5	1500	50	3	6	90	6.81
183	4.05E+05	1.14	4.50	0.2	17.5	5000	50	3	6	90	6.81
184	6.07E+04	1.70	4.11	0.2	17.5	5000	22	3	6	90	6.81
185	1.21E+04	4.11	5.18	0.2	17.5	5000	50	3	6	90	6.81
186	1.21E+04	5.26	6.02	0.2	17.5	5000	50	3	6	90	6.81
187	2.14E+05	3.21	3.96	0.2	17.5	475	47	3	6	90	6.81
188	1.21E+04	5.49	6.10	0.2	12.5	60	50	1	4	46	6.81
189	2.43E+05	4.57	5.18	0.2	12.5	40	50	1	4	46	6.81

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
190	4.05E+04	3.51	0.00	0.2	12.5	90	50	2	5	82	6.81
191	6.27E+04	5.05	9.51	0.2	22.5	150	50	2	4	76	7.21
192	3.04E+04	-999	4.72	0.2	22.5	330	16	2	4	76	7.21
193	2.67E+04	-999	5.64	0.2	22.5	315	16	2	4	76	7.21
194	9.29E+03	1.37	3.96	0.2	22.5	1700	24	3	10	92	23.20
195	1.45E+03	2.26	2.44	0.2	22.5	1600	50	3	10	92	23.20
196	5.38E+03	2.77	3.66	0.2	22.5	1260	50	3	10	92	23.20
197	5.38E+03	2.77	3.96	0.2	22.5	1140	50	3	10	92	23.20
198	8.99E+02	1.83	3.66	0.2	22.5	1080	50	3	10	92	23.20
199	8.99E+02	1.83	3.66	0.2	22.5	1080	50	3	10	92	23.20
200	1.19E+03	3.66	5.03	0.2	17.5	395	50	1	10	79	7.21
201	6.07E+03	1.37	2.29	0.2	17.5	130	50	1	10	79	7.21
202	2.20E+03	3.96	4.72	0.2	17.5	395	50	1	10	79	7.21
203	1.19E+03	3.66	5.03	0.2	17.5	395	50	1	10	79	7.21
204	8.36E+03	1.52	3.35	0.2	17.5	500	50	1	10	79	7.21
205	4.49E+04	1.22	1.07	0.2	17.5	550	50	1	10	79	7.21
206	1.41E+03	3.49	3.89	0.2	17.5	480	50	1	10	79	7.21
207	3.18E+03	3.57	3.96	0.2	17.5	480	50	1	10	79	7.21
208	1.76E+03	1.68	1.72	0.2	17.5	660	50	1	10	79	7.21
209	1.19E+03	3.66	5.03	0.2	17.5	395	50	1	10	79	7.21
210	4.41E+03	2.16	0.61	0.2	12.5	850	65	3	2	73	21.82
211	1.30E+04	1.71	1.92	0.2	12.5	695	8	3	2	73	21.82
212	8.82E+03	0.30	0.30	0.2	22.5	150	50	2	11	94	26.72

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
213	8.76E+03	0.30	0.30	0.2	22.5	90	50	2	11	94	26.72
214	2.02E+05	3.66	2.13	0.2	17.5	335	50	2	10	80	3.40
215	1.21E+03	1.83	3.66	0.2	17.5	600	30	2	10	80	3.40
216	2.02E+03	-999	0.00	0.2	17.5	65	50	1	10	80	3.40
217	4.69E+05	2.97	2.67	0.2	17.5	115	50	1	10	80	3.40
218	2.02E+05	3.66	2.13	0.2	17.5	435	50	2	10	80	3.40
219	1.55E+03	1.10	2.74	0.2	12.5	270	50	2	7	66	117.25
220	2.68E+03	2.13	1.83	0.2	12.5	270	50	2	7	66	117.25
221	2.21E+03	3.05	3.66	0.2	27.5	1800	50	3	6	102	7.67
222	3.19E+03	2.13	0.00	0.2	27.5	656	50	3	6	102	7.67
223	1.90E+03	3.05	3.66	0.2	27.5	1800	50	3	6	102	7.67
224	1.90E+03	3.05	3.66	0.2	27.5	1800	50	3	6	102	7.67
225	3.24E+04	1.37	0.15	0.2	7.5	850	50	3	9	62	6.81
226	3.24E+04	1.98	0.61	0.2	7.5	755	50	2	9	62	6.81
227	3.16E+04	5.33	2.13	0.2	7.5	320	50	2	9	62	6.81
228	2.79E+03	3.96	5.79	0.2	17.5	320	50	3	12	89	21.25
229	2.87E+04	1.37	2.74	0.2	17.5	1580	50	1	12	89	21.25
230	5.04E+03	3.66	0.00	0.2	17.5	1500	50	1	12	89	21.25
231	5.04E+03	3.66	0.00	0.2	17.5	1560	50	1	12	89	21.25
232	2.18E+04	1.68	3.05	0.2	17.5	1750	50	1	12	89	21.25
233	9.29E+02	1.83	0.91	0.2	22.5	505	18	3	10	92	7.67
234	2.37E+04	1.83	1.22	0.2	22.5	505	50	3	10	92	7.67
235	2.42E+03	1.68	2.35	0.2	17.5	350	50	1	2	15	23.20

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
236	2.98E+04	0.88	3.26	0.2	17.5	400	50	1	2	15	23.20
237	2.83E+03	1.89	2.26	0.2	17.5	350	50	1	2	15	23.20
238	3.12E+04	2.07	2.83	0.2	17.5	350	50	1	2	15	23.20
239	6.07E+03	0.81	0.00	0.2	17.5	580	57	1	2	15	23.20
240	4.86E+03	1.01	0.00	0.2	17.5	580	55	1	2	15	23.20
241	6.48E+03	1.11	0.00	0.2	17.5	580	55	1	2	15	23.20
242	1.07E+04	2.06	2.06	0.2	17.5	350	50	1	2	15	23.20
243	2.36E+03	1.86	2.53	0.2	17.5	350	50	1	2	15	23.20
244	1.62E+04	3.81	4.57	0.2	12.5	200	50	1	1	69	26.72
245	3.12E+01	1.22	0.00	0.2	12.5	30	12	2	4	46	26.72
246	5.20E+01	0.24	0.28	0.2	22.5	5000	7	2	4	57	63.12
247	1.42E+03	3.45	5.18	0.2	12.5	30	50	3	9	39	21.25
248	1.21E+04	1.22	1.98	0.2	7.5	75	50	2	4	42	3.40
249	1.21E+04	0.30	0.91	0.2	7.5	25	50	2	4	42	3.40
250	1.80E+05	-999	0.00	0.2	22.5	95	50	1	10	91	6.81
251	6.61E+03	5.64	0.00	0.2	22.5	720	50	2	10	91	6.81
252	7.93E+04	3.05	3.81	0.2	22.5	565	50	1	10	91	6.81
253	4.82E+05	1.22	2.29	0.2	22.5	670	50	2	10	91	6.81
254	1.92E+04	3.05	4.27	0.2	22.5	40	50	2	10	91	6.81
255	1.92E+04	3.05	4.27	0.2	22.5	40	50	2	10	91	6.81
256	5.67E+03	0.15	1.68	0.2	22.5	5000	37	3	10	96	7.21
257	5.67E+03	0.38	1.91	0.2	22.5	5000	37	3	10	96	7.21
258	1.37E+04	-999	0.00	0.2	22.5	60	50	3	10	96	1.01

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
259	1.86E+05	0.63	0.00	0.2	22.5	250	95	3	10	96	1.01
260	2.16E+05	-999	0.00	0.2	22.5	85	50	3	10	96	1.01
261	1.57E+05	-999	0.00	0.2	22.5	385	50	3	10	96	1.01
262	1.12E+05	-999	0.00	0.2	22.5	700	50	3	10	96	1.01
263	1.09E+05	2.11	0.00	0.2	22.5	710	75	3	10	96	1.01
264	1.70E+05	-999	0.00	0.2	22.5	240	50	3	10	96	1.01
265	4.74E+02	2.13	4.57	0.2	17.5	180	50	3	10	93	7.21
266	2.01E+03	1.83	3.05	0.2	22.5	5000	50	3	10	58	7.39
267	2.01E+03	1.83	3.05	0.2	22.5	5000	50	3	10	58	7.39
268	4.01E+02	-999	0.00	0.2	17.5	360	50	3	2	34	229.99
269	9.17E+01	-999	0.00	0.2	17.5	360	50	3	2	34	229.99
270	2.60E+01	-999	0.00	0.2	17.5	360	50	3	2	34	229.99
271	4.01E+02	-999	0.00	0.2	17.5	360	50	3	2	34	229.99
272	4.01E+02	-999	0.00	0.2	17.5	360	50	3	2	34	229.99
273	3.52E+04	2.05	2.90	0.2	12.5	400	50	3	5	24	117.97
274	4.05E+03	2.12	3.58	0.2	12.5	350	50	3	5	24	117.97
275	1.62E+04	4.39	6.16	0.2	17.5	5000	50	2	5	20	7.02
276	1.78E+04	0.91	1.83	0.2	17.5	5000	27	2	5	20	7.02
277	3.67E+03	3.05	1.52	0.2	7.5	140	37	1	6	25	7.67
278	4.30E+03	4.21	7.92	0.2	12.5	1260	47	1	12	73	21.25
279	6.31E+03	2.50	5.79	0.2	12.5	1260	50	1	12	73	21.25
280	2.02E+04	-999	0.00	0.2	12.5	1260	50	1	12	73	21.25
281	9.30E+00	1.83	3.05	0.2	12.5	130	14	2	8	61	21.25

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
282	5.89E+04	3.35	4.57	0.2	12.5	310	50	3	6	6	7.21
283	5.65E+04	3.35	4.57	0.2	12.5	110	47	3	6	6	7.21
284	1.69E+04	4.27	0.00	0.2	7.5	1480	50	1	9	44	38.99
285	4.58E+04	1.83	3.66	0.2	7.5	1620	50	1	9	44	38.99
286	1.17E+04	1.98	3.66	0.2	7.5	190	50	1	9	44	38.99
287	2.02E+03	-999	1.07	0.2	7.5	190	50	1	9	44	38.99
288	6.07E+03	-999	1.07	0.2	7.5	180	65	1	9	44	38.99
289	1.68E+05	6.25	5.33	0.2	7.5	1360	50	1	9	44	38.99
290	2.84E+03	1.37	1.83	0.2	7.5	20	50	1	9	44	38.99
291	7.53E+02	0.93	0.00	0.2	7.5	20	50	1	9	44	38.99
292	1.33E+05	4.27	3.35	0.2	7.5	1040	50	1	9	44	38.99
293	6.97E+03	2.39	0.00	0.2	17.5	1220	50	3	6	90	7.86
294	4.46E+03	3.84	5.18	0.2	17.5	1510	50	3	6	90	7.86
295	1.34E+04	3.20	0.00	0.2	12.5	220	50	2	7	66	10.30
296	3.67E+02	1.42	0.61	0.2	12.5	50	50	2	4	86	29.82
297	2.47E+04	3.83	3.81	0.2	7.5	240	50	2	9	44	6.81
298	8.63E+04	5.48	3.35	0.2	7.5	130	50	2	9	44	6.81
299	1.01E+03	3.25	2.97	0.2	7.5	40	50	2	9	43	7.02
300	7.28E+04	0.50	1.46	0.2	7.5	5000	30	3	9	43	7.02
301	5.26E+04	1.29	2.74	0.2	7.5	5000	50	3	9	43	7.02
302	5.34E+03	0.91	4.27	0.2	7.5	455	50	3	9	43	7.02
303	8.90E+03	5.49	3.35	0.2	17.5	710	18	1	10	81	6.81
304	5.50E+03	3.44	0.00	0.2	17.5	950	50	1	10	81	6.81

Table D.2 Nationwide Database of Surface Impoundment Sites

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305	3.69E+03	4.65	4.53	0.2	17.5	1100	50	1	10	81	6.81
306	2.79E+05	1.22	0.00	0.2	17.5	905	22	3	10	81	6.81
307	2.47E+05	3.05	2.13	0.2	17.5	1100	50	1	10	81	6.81
308	4.86E+06	2.44	0.00	0.2	17.5	125	50	3	10	81	6.81
309	3.64E+04	1.52	0.61	0.2	17.5	720	50	1	10	81	6.81
310	9.71E+03	2.74	0.00	0.2	17.5	1500	50	1	10	81	6.81
311	1.21E+04	1.01	0.79	0.2	17.5	950	50	1	10	81	6.81
312	2.47E+05	4.57	0.46	0.2	17.5	1540	50	3	10	81	6.81
313	1.76E+03	1.83	0.00	0.2	7.5	460	50	1	4	100	36.31
314	3.59E+03	1.22	0.00	0.2	7.5	480	50	1	4	100	36.31
315	3.26E+03	1.68	0.76	0.2	7.5	500	50	1	4	100	36.31
316	3.52E+03	-999	0.91	0.2	7.5	60	22	3	7	10	7.67
317	5.07E+02	2.44	2.44	0.2	7.5	75	50	3	7	10	7.67
318	1.00E+03	-999	2.44	0.2	7.5	20	22	3	7	10	7.67
319	1.28E+03	-999	2.04	0.2	7.5	20	22	3	7	10	7.67
320	1.17E+05	2.74	3.66	0.2	7.5	5000	50	3	7	10	7.67
321	1.32E+03	2.08	1.99	0.2	7.5	75	50	3	7	10	7.67
322	1.11E+03	1.27	0.61	0.2	17.5	90	24	3	2	89	7.27
323	9.96E+02	5.49	6.10	0.2	17.5	190	47	2	5	12	7.21
324	1.23E+03	0.91	1.22	0.2	17.5	5000	50	1	2	95	23.04
325	8.36E+01	-999	6.10	0.2	17.5	5000	50	1	2	95	23.04
326	9.29E+01	-999	6.10	0.2	17.5	5000	50	1	2	95	23.04
327	1.24E+03	0.91	1.22	0.2	17.5	5000	50	1	2	95	23.04

Table D.2 Nationwide Database of Surface Impoundment Sites

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328	7.43E+02	-999	1.07	0.2	22.5	150	50	3	6	96	3.61
329	1.23E+03	3.35	3.96	0.2	22.5	340	50	3	10	96	3.61
330	1.24E+03	-999	1.98	0.2	22.5	120	50	3	6	96	3.61
331	2.92E+03	4.27	2.44	0.2	22.5	90	7	3	10	96	3.61
332	2.92E+03	4.27	2.44	0.2	22.5	90	7	3	10	96	3.61
333	5.34E+02	0.19	1.22	0.2	22.5	1330	50	3	6	96	3.61
334	2.42E+03	1.22	2.90	0.2	22.5	130	17	3	10	96	3.61
335	1.67E+03	0.30	1.22	0.2	22.5	190	17	3	10	96	3.61
336	2.92E+03	4.27	2.44	0.2	22.5	20	7	3	10	96	3.61
337	2.79E+04	13.72	33.53	0.2	12.5	1315	50	3	6	51	21.25
338	3.72E+04	7.47	4.57	0.2	12.5	40	50	3	6	51	21.25
339	3.72E+04	8.69	5.79	0.2	12.5	230	50	3	6	51	21.25
340	2.79E+04	6.10	3.66	0.2	12.5	330	50	3	6	51	21.25
341	6.97E+04	0.38	6.40	0.2	12.5	65	50	3	6	51	21.25
342	2.14E+04	3.05	4.57	0.2	22.5	370	75	3	10	96	1.01
343	2.33E+03	2.97	3.05	0.2	12.5	1080	50	2	10	71	64.39
344	1.77E+03	3.58	3.66	0.2	12.5	1000	50	2	10	71	64.39
345	3.04E+03	1.83	2.74	0.2	17.5	700	50	2	10	71	29.82
346	1.03E+03	-999	7.62	0.2	12.5	260	50	3	9	56	127.91
347	7.24E+02	-999	4.57	0.2	12.5	240	50	3	9	56	127.91
348	3.90E+02	0.07	0.00	0.2	22.5	260	50	2	10	92	229.99
349	8.90E+03	1.07	8.08	0.2	12.5	440	17	1	2	39	5.31
350	3.90E+03	2.13	3.84	0.2	17.5	85	50	2	2	13	22.33

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
351	4.07E+04	3.66	1.71	0.2	17.5	840	50	1	10	6	3.61
352	2.18E+04	3.81	2.01	0.2	17.5	1120	22	1	10	6	3.61
353	1.16E+03	-999	0.00	0.2	17.5	590	13	3	1	79	137.50
354	2.92E+03	-999	0.00	0.2	7.5	330	27	1	9	66	7.02
355	2.02E+04	2.44	1.52	0.2	22.5	1115	50	2	4	78	6.81
356	4.86E+04	11.46	7.47	0.2	22.5	1115	50	2	4	78	6.81
357	4.86E+04	11.46	7.47	0.2	22.5	1100	50	2	4	78	6.81
358	4.86E+04	11.46	7.47	0.2	22.5	970	50	2	4	78	6.81
359	4.86E+04	11.46	7.47	0.2	22.5	1360	50	2	4	78	6.81
360	2.83E+04	3.66	4.88	0.2	22.5	220	50	2	4	78	6.81
361	3.84E+04	2.44	1.52	0.2	22.5	960	50	2	4	78	6.81
362	4.86E+04	11.46	7.47	0.2	22.5	1400	50	2	4	78	6.81
363	8.09E+03	9.07	0.00	0.2	22.5	240	50	2	4	78	6.81
364	4.05E+03	18.15	0.00	0.2	22.5	410	50	2	4	78	6.81
365	2.23E+04	3.30	0.00	0.2	22.5	505	50	2	4	78	6.81
366	1.62E+04	1.83	2.44	0.2	22.5	1295	50	2	4	78	6.81
367	2.83E+04	3.05	3.35	0.2	22.5	635	50	2	4	78	6.81
368	7.73E+05	3.66	0.00	0.2	22.5	295	50	2	4	78	6.81
369	7.47E+03	4.02	5.37	0.2	22.5	395	50	2	4	78	6.81
370	2.02E+04	3.66	4.88	0.2	22.5	255	50	2	4	78	6.81
371	4.86E+04	11.46	7.47	0.2	22.5	1650	50	2	4	78	6.81
372	3.48E+05	3.35	0.30	0.2	22.5	115	50	2	4	78	6.81
373	4.86E+04	11.46	7.47	0.2	22.5	1380	50	2	4	78	6.81

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
374	2.43E+04	3.05	4.27	0.2	22.5	495	50	2	4	78	6.81
375	4.05E+04	4.86	7.47	0.2	22.5	815	50	2	4	78	6.81
376	4.86E+04	11.46	7.47	0.2	22.5	985	50	2	4	78	6.81
377	4.86E+04	11.46	7.47	0.2	22.5	1155	50	2	4	78	6.81
378	4.86E+04	5.18	0.61	0.2	22.5	1380	50	2	4	78	6.81
379	4.86E+04	11.46	7.47	0.2	22.5	1500	50	2	4	78	6.81
380	4.86E+04	11.46	7.47	0.2	22.5	1540	50	2	4	78	6.81
381	2.14E+05	2.90	3.35	0.2	22.5	40	50	2	4	78	6.81
382	1.62E+03	-999	0.00	0.2	17.5	40	50	1	5	13	19.70
383	1.62E+03	-999	0.00	0.2	17.5	110	50	1	5	13	19.70
384	1.62E+05	-999	0.00	0.2	17.5	5000	50	1	5	13	19.70
385	1.21E+04	-999	0.00	0.2	17.5	340	50	1	5	13	19.70
386	5.26E+03	-999	0.00	0.2	17.5	200	50	1	5	13	19.70
387	5.26E+03	-999	0.00	0.2	17.5	200	50	2	5	13	19.70
388	5.26E+04	-999	0.00	0.2	17.5	410	50	1	5	13	19.70
389	1.83E+04	0.38	1.60	0.2	12.5	1075	50	1	6	56	38.75
390	2.15E+04	0.87	1.55	0.2	12.5	1100	50	1	6	56	38.75
391	1.70E+03	1.78	1.25	0.2	12.5	1125	50	1	6	56	38.75
392	8.09E+03	1.68	4.18	0.2	17.5	485	50	3	10	80	3.40
393	9.71E+02	2.44	0.00	0.2	17.5	120	50	3	10	80	3.40
394	1.58E+05	1.98	2.13	0.2	17.5	215	50	3	10	80	3.40
395	7.69E+04	2.44	3.54	0.2	17.5	20	50	3	10	80	3.40
396	6.84E+05	1.22	2.56	0.2	17.5	405	50	1	10	80	3.40

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
397	1.58E+05	4.88	2.07	0.2	17.5	1350	50	3	10	80	3.40
398	8.09E+03	1.68	4.48	0.2	17.5	350	50	3	10	80	3.40
399	2.67E+05	3.66	2.99	0.2	17.5	245	50	3	10	80	3.40
400	1.21E+04	1.68	4.39	0.2	17.5	40	50	3	10	80	3.40
401	5.11E+03	2.13	3.05	0.2	7.5	70	50	3	4	42	6.81
402	5.11E+03	1.83	3.05	0.2	7.5	80	50	3	4	42	6.81
403	5.11E+03	0.61	3.05	0.2	7.5	80	50	3	4	42	6.81
404	1.84E+04	6.72	0.00	0.2	17.5	370	50	3	2	15	7.67
405	2.07E+04	1.22	2.13	0.2	17.5	445	50	3	2	15	7.67
406	4.37E+05	1.28	0.09	0.2	17.5	60	50	3	2	15	7.67
407	5.26E+04	0.77	0.00	0.2	17.5	460	50	3	2	15	7.67
408	7.53E+03	1.52	1.83	0.2	17.5	445	50	3	2	15	7.67
409	2.95E+05	0.58	1.40	0.2	17.5	30	50	3	2	15	7.67
410	1.16E+03	1.83	2.44	0.2	12.5	360	5	3	7	89	38.75
411	7.29E+03	2.29	6.55	0.2	12.5	140	37	3	7	89	38.75
412	1.86E+03	-999	2.59	0.2	12.5	130	20	3	7	89	38.75
413	9.80E+00	1.14	2.29	0.2	17.5	60	50	3	1	77	10.91
414	4.65E+03	1.76	3.96	0.2	12.5	185	50	3	9	42	7.67
415	1.86E+04	2.13	3.66	0.2	12.5	220	50	3	9	42	7.67
416	1.86E+04	2.29	3.81	0.2	12.5	220	50	3	9	42	7.67
417	7.28E+04	16.11	0.00	0.2	22.5	40	50	2	4	76	3.61
418	2.38E+04	4.27	2.90	0.2	7.5	1180	50	2	8	31	29.82
419	2.38E+04	4.27	2.90	0.2	7.5	1170	50	2	8	31	29.82

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
420	1.77E+03	2.13	3.05	0.2	12.5	20	29	2	7	84	6.81
421	1.63E+03	1.68	2.59	0.2	12.5	20	29	2	7	84	6.81
422	1.95E+03	1.22	2.74	0.2	12.5	40	29	2	7	84	6.81
423	3.72E+03	1.95	3.32	0.2	12.5	40	29	2	7	84	6.81
424	2.91E+04	-999	3.05	0.2	17.5	5000	32	3	5	13	28.76
425	2.91E+04	3.05	3.05	0.2	17.5	5000	32	3	5	13	28.76
426	1.30E+03	-999	0.00	0.2	7.5	300	15	1	5	3	164.74
427	1.77E+04	0.94	2.44	0.2	17.5	5000	50	1	6	90	117.25
428	5.57E+02	2.04	0.00	0.2	17.5	5000	50	1	6	90	117.25
429	1.94E+02	1.91	1.78	0.2	12.5	40	50	1	2	39	23.36
430	1.30E+03	-999	0.00	0.2	12.5	170	50	1	2	39	23.36
431	6.69E+02	0.46	0.00	0.2	17.5	810	50	3	12	89	6.81
432	2.91E+04	3.66	2.74	0.2	17.5	1115	50	3	12	89	6.81
433	3.86E+03	1.83	7.32	0.2	17.5	575	50	3	12	89	6.81
434	4.65E+05	2.74	2.44	0.2	17.5	105	50	3	12	89	6.81
435	2.31E+05	4.57	4.57	0.2	17.5	270	50	3	12	89	6.81
436	1.01E+05	4.57	3.96	0.2	17.5	795	50	3	12	89	6.81
437	6.96E+03	5.18	3.81	0.2	17.5	565	50	3	12	89	6.81
438	6.96E+03	5.18	3.81	0.2	17.5	525	50	3	12	89	6.81
439	7.81E+03	2.44	0.00	0.2	7.5	900	50	2	4	98	7.67
440	5.95E+03	1.27	0.00	0.2	7.5	550	50	2	6	25	7.67
441	1.63E+03	2.07	0.00	0.2	7.5	300	50	2	6	25	7.67
442	2.69E+03	1.89	0.00	0.2	7.5	300	50	2	6	25	7.67

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
443	1.74E+02	0.46	1.52	0.2	17.5	420	14	3	2	95	216.36
444	6.09E+02	0.15	1.07	0.2	17.5	420	14	3	2	95	216.36
445	1.21E+03	1.83	2.44	0.2	27.5	550	50	2	6	102	7.21
446	1.39E+04	4.26	3.67	0.2	12.5	210	50	2	10	72	117.25
447	1.78E+03	2.74	3.05	0.2	12.5	610	50	2	10	72	117.25
448	2.01E+03	1.83	1.53	0.2	12.5	670	50	2	10	72	117.25
449	3.58E+03	0.30	3.90	0.2	12.5	440	50	2	10	72	117.25
450	3.09E+03	1.30	0.00	0.2	12.5	500	50	2	10	72	117.25
451	1.24E+03	1.45	0.00	0.2	12.5	40	50	2	10	72	117.25
452	1.24E+03	0.02	0.00	0.2	12.5	30	50	2	10	72	117.25
453	1.39E+04	3.89	3.38	0.2	12.5	320	50	2	10	72	117.25
454	1.74E+03	2.74	3.05	0.2	12.5	600	50	2	10	72	117.25
455	6.88E+03	2.44	2.51	0.2	12.5	280	50	2	10	72	117.25
456	2.85E+02	1.30	4.18	0.2	12.5	280	50	2	10	72	123.57
457	2.86E+02	1.81	4.18	0.2	12.5	280	50	2	10	72	123.57
458	2.36E+05	0.91	0.00	0.2	22.5	300	50	2	4	76	3.61
459	7.70E+03	-999	0.00	0.2	22.5	700	50	2	4	76	3.61
460	2.88E+04	-999	0.00	0.2	22.5	0	50	2	4	76	3.61
461	1.35E+05	0.91	0.00	0.2	22.5	0	50	2	4	76	3.61
462	5.71E+04	0.91	0.00	0.2	22.5	40	50	2	4	76	3.61
463	5.32E+05	0.91	0.00	0.2	22.5	20	50	2	4	76	3.61
464	6.19E+04	0.91	0.00	0.2	22.5	20	50	2	4	76	3.61
465	2.16E+05	0.91	0.00	0.2	22.5	200	50	2	4	76	3.61

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
466	1.01E+05	1.29	0.00	0.2	22.5	5000	50	2	4	76	3.61
467	8.10E+04	-999	0.00	0.2	22.5	0	50	2	4	76	3.61
468	6.13E+02	3.10	4.63	0.2	17.5	190	50	3	1	79	38.75
469	2.02E+02	-999	0.00	0.2	12.5	395	27	1	5	3	1.01
470	2.31E+05	-999	0.00	0.2	12.5	65	38	2	7	3	1.01
471	5.30E+03	0.61	0.15	0.2	22.5	600	50	2	10	92	7.21
472	4.27E+03	0.61	1.83	0.2	22.5	800	50	2	10	92	7.21
473	5.64E+03	1.83	1.83	0.2	22.5	840	50	2	10	92	7.21
474	4.16E+03	0.61	1.86	0.2	22.5	740	50	2	10	92	7.21
475	2.79E+03	4.54	0.27	0.2	22.5	640	50	2	10	92	7.21
476	6.04E+02	1.22	0.46	0.2	22.5	640	50	2	10	92	7.21
477	9.75E+03	0.30	0.46	0.2	22.5	440	50	2	10	92	7.21
478	1.86E+03	1.77	0.30	0.2	22.5	500	50	2	10	92	7.21
479	1.02E+03	0.73	0.27	0.2	22.5	530	50	2	10	92	7.21
480	8.36E+02	0.01	0.00	0.2	22.5	5000	17	1	10	92	164.74
481	7.04E+03	0.76	2.29	0.2	7.5	220	50	2	2	7	7.67
482	4.06E+04	2.44	3.96	0.2	7.5	240	50	2	2	7	7.67
483	7.28E+02	0.30	0.61	0.2	7.5	800	50	2	2	7	7.67
484	1.09E+03	0.15	1.52	0.2	7.5	740	50	2	2	7	7.67
485	2.31E+03	0.61	4.27	0.2	7.5	600	50	2	2	7	7.67
486	6.42E+02	1.43	0.91	0.2	7.5	216	50	2	2	7	7.67
487	3.93E+04	0.61	1.22	0.2	7.5	1220	50	2	2	7	7.67
488	1.46E+03	3.05	5.18	0.2	7.5	900	50	2	2	7	7.67

Table D.2 Nationwide Database of Surface Impoundment Sites

Site Number	Area (m2)	Operating Depth (m)	Base Depth Below Grade (m)	Total Thickness of Sediment (m)	Soil/GW Temp. (˚ C)	Distance to Nearest SW Body (m)	Operating Life/Leaching Duration (yr)	Soil Type	HG Environment	Nearest Climate Center	Site Weighting
489	2.22E+04	0.23	0.99	0.2	7.5	810	50	2	2	7	7.67
490	2.33E+04	1.83	2.13	0.2	7.5	1390	50	1	2	7	7.67
491	1.44E+03	1.22	1.83	0.2	7.5	624	50	2	2	7	7.67
492	1.86E+03	0.30	0.61	0.2	7.5	230	50	2	2	7	7.67
493	4.33E+03	0.91	2.59	0.2	7.5	500	50	2	2	7	7.67
494	7.28E+02	0.91	2.74	0.2	7.5	710	50	2	2	7	7.67
495	3.99E+04	3.96	4.27	0.2	7.5	1080	50	2	2	7	7.67
496	4.69E+04	1.98	2.90	0.2	7.5	960	50	2	2	7	7.67
497	2.02E+02	2.13	1.83	0.2	22.5	5000	27	2	4	94	26.72
498	1.52E+03	0.00	0.00	0.2	17.5	5000	12	2	4	34	25.16
499	1.19E+03	3.20	4.27	0.2	17.5	5000	50	3	1	77	20.95
500	7.41E+03	-999	0.00	0.2	12.5	240	50	3	6	6	216.36
501	1.81E+03	-999	0.00	0.2	12.5	190	50	3	6	6	216.36
502	5.16E+04	-999	0.06	0.2	12.5	150	50	3	6	6	216.36
503	7.00E+01	0.06	0.76	0.2	22.5	480	6	3	10	96	7.02

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (° C)	HG Environment	Nearest Climate Center	Site Weighting
1	1.01E+02	1.71E-01	12.5	2	39	10
2	3.78E+02	1.60E+00	12.5	12	69	10
3	1.21E+02	7.46E+00	17.5	4	90	1
4	1.21E+02	2.10E-01	12.5	12	54	1
5	4.45E+02	2.52E+01	12.5	12	53	1
6	8.09E+01	2.23E-01	17.5	1	79	1
7	5.20E+03	4.79E-02	12.5	2	52	1
8	8.09E+01	7.27E+00	12.5	5	74	1
9	1.35E+03	3.47E-01	22.5	4	58	1
10	3.24E+02	1.40E+01	12.5	12	85	1
11	1.21E+03	9.32E-02	17.5	12	89	1
12	6.07E+02	3.73E-02	12.5	12	42	1
13	6.20E+05	9.65E-07	12.5	12	69	1
14	1.21E+02	2.62E+00	7.5	2	32	1
15	2.43E+02	6.90E-01	17.5	13	90	1
16	6.75E+00	1.34E+02	22.5	4	92	1
17	6.07E+02	5.13E-02	12.5	2	53	1
18	4.05E+01	1.68E+00	17.5	4	95	1
19	2.10E+03	1.38E-01	12.5	12	32	20
20	3.64E+02	1.49E-01	12.5	8	82	20
21	8.09E+01	6.71E-01	12.5	12	42	20
22	4.05E+03	4.47E-02	12.5	4	66	20
23	4.05E+01	2.24E-01	17.5	5	1	20
24	4.86E+03	5.03E-01	17.5	12	93	3
25	4.05E+01	2.22E-02	22.5	4	91	3
26	1.21E+02	8.95E+00	12.5	4	56	3
27	2.02E+01	3.69E+01	12.5	2	71	3
28	2.02E+04	1.12E-03	17.5	4	79	3
29	2.02E+01	1.34E+01	22.5	4	81	3
30	5.58E+03	-9.99E+02	7.5	2	32	3
31	1.21E+02	2.24E+01	12.5	9	51	3
32	1.62E+02	2.01E+01	17.5	5	12	3
33	5.58E+03	1.05E-02	12.5	12	71	3
34	2.02E+01	-9.99E+02	12.5	5	26	3
35	3.24E+04	1.23E+00	12.5	4	74	3
36	2.02E+01	2.24E+01	12.5	12	51	3
37	2.02E+01	4.65E+00	22.5	4	79	3
38	1.21E+02	2.24E+00	12.5	2	66	3
39	2.43E+02	5.22E+00	12.5	2	53	3
40	2.02E+03	8.95E-02	12.5	2	71	3
41	2.02E+01	2.15E+00	12.5	2	66	3
42	2.43E+04	8.76E-02	22.5	4	92	3
43	8.09E+01	1.23E+00	12.5	2	88	3
44	1.01E+03	3.56E-01	17.5	4	80	3

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
45	4.05E+01	4.47E+00	12.5	12	42	3
46	1.08E+02	1.01E+01	17.5	1	95	3
47	4.05E+01	1.01E+00	12.5	4	66	3
48	1.62E+02	2.10E+00	7.5	2	32	3
49	1.21E+03	1.12E+00	12.5	9	42	3
50	4.05E+01	3.13E+01	12.5	8	42	3
51	8.09E+01	1.85E-02	12.5	4	74	3
52	1.01E+03	1.79E+01	12.5	2	59	3
53	2.02E+01	3.95E-02	7.5	5	3	3
54	2.02E+01	1.10E+01	12.5	2	71	3
55	2.02E+02	1.12E-01	12.5	2	88	3
56	1.86E+04	9.75E-03	7.5	4	60	3
57	8.09E+01	4.92E-01	12.5	9	51	3
58	8.09E+01	3.95E-02	12.5	5	29	3
59	2.63E+04	-9.99E+02	12.5	4	52	3
60	2.02E+01	3.95E-02	17.5	4	80	3
61	4.05E+01	3.80E-01	12.5	2	71	3
62	1.62E+02	7.92E-01	7.5	2	48	3
63	2.02E+02	1.86E-01	12.5	12	85	3
64	2.02E+01	1.34E+02	17.5	12	89	3
65	4.05E+02	3.35E-02	22.5	4	58	3
66	2.83E+02	9.59E-01	7.5	12	32	3
67	6.88E+02	2.63E+00	12.5	4	39	3
68	9.31E+02	3.65E-01	17.5	2	58	3
69	2.02E+01	1.32E+02	12.5	12	85	3
70	2.02E+01	4.04E-01	12.5	2	74	3
71	4.05E+01	5.37E+00	12.5	12	50	3
72	2.79E+03	-9.99E+02	12.5	4	51	3
73	4.05E+01	6.98E+01	12.5	4	51	3
74	2.43E+03	7.46E-02	12.5	2	52	3
75	2.02E+01	8.95E+00	17.5	13	34	3
76	1.00E+05	1.36E-01	12.5	5	26	1
77	2.02E+01	1.97E+01	12.5	12	42	1
78	8.99E+03	1.79E+01	12.5	9	42	1
79	2.43E+02	2.24E+01	22.5	4	81	1
80	4.05E+03	3.36E-01	22.5	4	91	1
81	4.05E+02	1.23E+00	12.5	4	71	1
82	1.08E+02	3.75E+01	12.5	6	74	1
83	2.70E+01	4.59E+01	12.5	2	66	1
84	2.02E+01	1.23E+02	17.5	4	95	1
85	2.02E+02	8.95E+00	12.5	12	42	1
86	8.63E+02	5.77E+00	17.5	12	85	1
87	1.16E+04	7.40E+00	12.5	12	49	1
88	4.05E+03	2.24E-01	12.5	5	69	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
89	7.45E+04	3.65E-01	12.5	4	52	1
90	9.31E+02	1.46E-01	12.5	4	66	1
91	9.44E+01	5.59E+00	17.5	12	95	1
92	4.05E+04	1.79E-02	17.5	1	95	1
93	4.28E+03	1.16E+00	12.5	12	88	1
94	2.02E+01	8.95E+00	12.5	12	52	1
95	5.61E+03	2.53E+00	22.5	4	81	1
96	1.62E+02	3.50E+01	12.5	4	72	1
97	1.21E+04	5.97E+00	12.5	12	49	1
98	5.58E+03	1.22E-01	12.5	2	66	1
99	2.02E+02	2.91E+00	12.5	2	66	1
100	2.02E+03	1.40E-01	7.5	13	66	1
101	2.02E+01	5.38E-01	17.5	2	36	1
102	6.07E+05	1.19E+00	12.5	2	69	1
103	1.11E+03	4.88E-02	12.5	2	52	1
104	1.34E+03	1.48E-01	22.5	4	96	1
105	8.09E+01	5.60E-01	12.5	8	32	1
106	2.10E+03	7.74E-01	12.5	2	74	1
107	4.05E+01	7.05E+00	12.5	12	42	1
108	4.05E+01	2.24E+02	12.5	2	69	1
109	1.21E+02	9.69E+01	17.5	12	95	1
110	4.05E+01	1.73E-02	12.5	1	71	1
111	8.09E+01	1.17E+01	7.5	2	50	1
112	1.62E+02	8.18E+00	12.5	2	39	1
113	1.01E+02	1.61E+01	12.5	1	75	1
114	4.05E+03	1.12E-02	17.5	4	93	1
115	2.33E+02	4.86E+00	12.5	4	74	1
116	9.44E+03	2.08E+00	17.5	12	95	1
117	4.05E+03	8.05E-02	12.5	12	71	1
118	2.02E+01	1.34E+02	7.5	8	32	1
119	2.02E+02	5.37E+01	12.5	2	66	1
120	5.67E+04	8.63E-04	12.5	4	52	1
121	2.43E+02	3.54E+01	12.5	9	51	1
122	4.05E+01	3.27E+02	12.5	4	72	1
123	1.42E+02	-9.99E+02	12.5	12	42	1
124	5.67E+04	1.64E-02	12.5	5	3	1
125	1.62E+02	1.29E+00	12.5	12	42	1
126	1.89E+02	4.15E+01	12.5	4	51	1
127	2.02E+01	1.68E+02	7.5	12	48	1
128	2.16E+04	2.80E+00	7.5	2	32	1
129	6.48E+02	1.96E+00	12.5	12	71	1
130	2.02E+01	1.66E+01	12.5	2	74	1
131	2.02E+03	5.22E+00	17.5	12	89	1
132	1.21E+04	8.95E-01	12.5	13	82	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
133	8.09E+01	-9.99E+02	12.5	12	42	1
134	1.56E+02	2.67E+01	12.5	12	42	1
135	2.10E+03	1.08E-01	7.5	4	47	1
136	4.05E+04	5.59E-02	12.5	9	42	1
137	4.05E+01	5.59E+00	12.5	6	73	1
138	6.27E+03	7.16E-04	22.5	4	81	1
139	1.21E+04	-9.99E+02	12.5	2	66	1
140	4.05E+01	1.68E-01	12.5	13	71	1
141	2.43E+02	3.36E+02	12.5	2	52	1
142	6.48E+02	-9.99E+02	12.5	2	66	1
143	1.01E+04	4.75E-01	12.5	2	52	1
144	2.02E+01	6.44E+01	7.5	4	84	1
145	4.05E+03	8.05E-02	12.5	12	71	1
146	1.86E+03	8.75E-01	12.5	2	39	1
147	3.97E+03	5.24E-02	12.5	2	52	1
148	1.21E+02	-9.99E+02	12.5	4	27	1
149	4.45E+02	6.10E+00	12.5	2	52	1
150	1.52E+03	7.27E-01	12.5	9	42	1
151	7.45E+03	1.80E+00	12.5	4	72	1
152	8.09E+03	5.59E-01	12.5	2	39	1
153	3.91E+02	1.93E+00	7.5	13	45	1
154	4.05E+01	-9.99E+02	12.5	1	75	1
155	1.42E+03	4.79E+00	12.5	2	71	1
156	8.09E+01	1.39E-01	12.5	9	42	1
157	1.25E+03	1.67E+00	7.5	2	32	1
158	6.07E+01	9.32E+00	17.5	12	89	1
159	9.20E+02	1.18E+02	12.5	9	42	1
160	3.64E+02	4.97E-01	12.5	12	51	1
161	9.31E+02	2.43E-01	12.5	12	51	1
162	9.31E+02	1.95E+00	12.5	2	39	1
163	8.09E+01	3.99E+00	12.5	12	69	1
164	6.88E+02	3.29E-01	7.5	12	45	1
165	8.09E+02	9.02E-01	7.5	13	4	1
166	1.51E+04	5.71E-01	7.5	4	60	1
167	5.22E+03	3.69E-02	7.5	8	32	1
168	4.05E+03	4.03E+00	12.5	2	74	1
169	4.05E+03	2.07E-01	17.5	4	95	1
170	4.05E+03	1.12E-02	22.5	12	57	1
171	2.02E+02	2.24E-01	17.5	13	90	1
172	2.70E+03	2.51E-01	7.5	12	48	1
173	5.58E+03	7.29E-02	12.5	5	40	1
174	4.45E+02	5.08E-01	17.5	5	12	1
175	9.75E+03	1.58E+00	17.5	2	37	1
176	1.01E+03	1.23E-05	12.5	8	9	1
177	3.24E+02	8.11E-02	17.5	5	34	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
178	6.07E+03	2.98E-02	12.5	12	50	1
179	4.05E+01	1.33E-01	22.5	12	76	1
180	4.05E+01	5.60E-01	22.5	4	92	1
181	2.02E+03	6.71E-02	7.5	13	5	1
182	2.02E+03	1.57E-01	22.5	5	92	1
183	1.47E+06	4.88E-01	22.5	12	57	1
184	1.82E+03	4.65E-02	17.5	13	29	1
185	9.31E+02	1.23E-01	17.5	13	29	1
186	1.01E+05	8.95E-02	22.5	4	92	1
187	2.02E+04	2.06E+00	12.5	1	71	1
188	1.42E+06	1.92E+00	22.5	12	57	1
189	6.07E+02	1.12E+01	22.5	4	92	1
190	1.15E+06	4.29E-01	22.5	4	92	1
191	2.02E+01	1.45E+00	12.5	13	71	1
192	3.04E+05	5.22E-01	22.5	12	57	1
193	4.05E+03	2.24E-03	17.5	4	30	1
194	2.83E+02	1.59E-02	17.5	2	77	1
195	2.02E+01	5.28E+00	12.5	12	51	1
196	4.45E+02	4.06E-02	17.5	4	90	1
197	8.09E+04	2.24E-02	12.5	4	48	1
198	2.02E+03	4.47E-01	17.5	2	36	1
199	2.02E+02	4.47E-01	17.5	12	79	1
200	2.02E+01	4.93E-03	17.5	4	90	22
201	2.79E+03	6.43E-04	12.5	8	55	22
202	8.09E+01	8.38E-02	17.5	1	95	3
203	1.01E+01	9.86E-03	22.5	4	81	3
204	9.96E+03	4.55E-01	12.5	5	33	3
205	4.05E+01	6.73E-01	17.5	12	90	3
206	8.09E+01	2.71E-02	17.5	4	69	3
207	2.09E+04	1.64E+00	12.5	2	39	3
208	2.02E+01	4.14E+00	17.5	4	90	3
209	2.02E+01	1.13E-01	12.5	13	19	3
210	9.31E+02	7.50E-04	17.5	4	90	3
211	8.50E+02	5.87E-05	12.5	5	56	1
212	3.64E+02	3.35E+00	12.5	1	67	1
213	1.05E+03	2.31E-03	12.5	4	71	1
214	3.04E+03	3.06E-01	17.5	4	69	1
215	9.31E+02	2.34E-02	17.5	12	89	1
216	8.09E+01	1.73E-02	22.5	12	78	1
217	2.02E+01	1.23E-01	17.5	5	12	1
218	1.94E+03	1.03E+00	12.5	12	73	1
219	1.01E+01	-9.99E+02	22.5	12	78	1
220	1.39E+04	2.87E-05	17.5	5	13	1
221	1.01E+01	2.71E-01	7.5	5	3	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
222	3.04E+04	1.41E+01	12.5	5	69	1
223	4.05E+02	1.84E-01	12.5	9	42	1
224	2.02E+02	6.71E+00	12.5	12	42	1
225	2.02E+01	2.47E-01	17.5	5	12	1
226	2.48E+05	-9.99E+02	22.5	4	96	1
227	1.01E+04	-9.99E+02	17.5	1	69	1
228	8.09E+01	1.40E+01	12.5	12	42	1
229	1.50E+04	5.76E-01	12.5	2	39	1
230	4.05E+01	1.12E+01	17.5	5	21	1
231	2.02E+03	2.01E-01	7.5	5	10	1
232	1.50E+03	2.66E-01	7.5	1	64	1
233	2.02E+04	2.17E+00	12.5	4	56	1
234	4.05E+03	4.19E+00	12.5	12	19	1
235	4.05E+01	8.29E-01	17.5	13	13	1
236	2.02E+01	1.13E-01	17.5	13	77	8
237	2.02E+03	2.24E-02	17.5	4	95	1
238	8.09E+03	1.12E-03	22.5	4	58	1
239	1.62E+02	4.05E+01	12.5	5	74	1
240	4.05E+01	2.35E+01	12.5	4	72	1
241	1.86E+03	3.04E-02	12.5	4	73	1
242	1.35E+01	1.11E-01	12.5	12	51	1
243	1.13E+03	4.99E+00	12.5	12	50	1
244	2.02E+01	2.96E-01	12.5	2	88	1
245	1.01E+06	1.34E+00	22.5	12	57	1
246	8.09E+01	1.58E+00	12.5	1	65	1
247	4.05E+01	6.76E-01	22.5	4	92	1
248	5.40E+03	4.19E-02	12.5	5	40	2
249	3.72E+03	1.22E-02	12.5	2	54	2
250	1.13E+03	7.93E-04	17.5	1	79	2
251	6.75E+02	6.04E-02	12.5	4	51	2
252	6.88E+02	8.55E-01	12.5	2	51	2
253	9.29E+03	2.26E-02	12.5	12	54	2
254	6.07E+01	1.49E-01	12.5	5	56	2
255	4.05E+03	1.79E+00	12.5	2	33	2
256	1.62E+04	1.68E+01	17.5	4	74	2
257	4.05E+01	2.71E-02	12.5	8	46	2
258	9.31E+02	2.92E+00	17.5	5	12	2
259	1.62E+04	5.59E-02	17.5	4	79	2
260	1.21E+02	3.58E-01	22.5	4	81	2
261	1.21E+02	2.24E+00	22.5	12	57	2
262	2.02E+01	1.78E-01	17.5	13	90	1
263	2.02E+03	4.47E-02	12.5	12	55	1
264	4.45E+02	5.08E+00	22.5	5	92	1
265	4.86E+03	4.66E-02	12.5	13	20	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
266	3.62E+04	1.90E+00	17.5	1	89	1
267	1.00E+04	2.84E-02	17.5	5	74	1
268	1.52E+03	5.67E-01	12.5	4	74	1
269	1.94E+06	6.52E-01	22.5	4	20	1
270	1.30E+06	1.82E+01	22.5	12	57	1
271	2.91E+05	1.55E+00	22.5	12	57	1
272	4.65E+04	5.44E-02	22.5	4	92	1
273	4.05E+03	4.47E-02	7.5	8	32	1
274	2.63E+02	1.55E-01	12.5	2	66	1
275	2.99E+04	1.36E+00	17.5	12	89	1
276	1.21E+04	8.96E-04	17.5	12	87	1
277	1.21E+02	4.59E+00	22.5	4	81	1
278	7.64E+04	3.26E-01	22.5	4	20	1
279	4.05E+03	2.24E-02	12.5	13	72	1
280	4.25E+05	2.66E+00	17.5	2	80	1
281	4.46E+04	1.52E-02	12.5	1	71	1
282	9.31E+02	1.22E-01	22.5	4	92	1
283	8.09E+03	9.86E-05	22.5	4	35	1
284	4.99E+05	3.45E+00	22.5	12	78	1
285	1.89E+05	9.59E-01	7.5	13	5	1
286	1.42E+02	8.10E-03	17.5	4	74	1
287	2.06E+03	2.19E-01	12.5	13	86	1
288	5.03E+04	1.08E-01	17.5	5	13	1
289	2.02E+03	1.01E-01	22.5	4	96	1
290	4.05E+01	3.08E+00	12.5	4	74	1
291	4.45E+04	9.97E-01	17.5	1	95	1
292	1.30E+03	1.75E-01	22.5	12	93	1
293	4.05E+01	3.92E+00	22.5	4	35	30
294	2.02E+01	-9.99E+02	12.5	9	42	30
295	4.05E+01	-9.99E+02	22.5	4	81	30
296	4.05E+02	4.44E-03	12.5	2	71	30
297	2.02E+01	4.47E+00	17.5	5	12	30
298	2.02E+01	5.03E-01	7.5	4	75	30
299	4.05E+03	5.60E-03	12.5	12	54	30
300	2.02E+03	6.71E-02	22.5	4	92	30
301	6.75E+00	1.18E-01	22.5	13	92	30
302	2.02E+01	8.88E-02	22.5	12	57	30
303	2.43E+02	6.99E-03	7.5	2	48	30
304	1.21E+03	1.89E-03	17.5	12	95	30
305	6.88E+02	-9.99E+02	22.5	4	92	30
306	4.17E+03	8.69E+00	7.5	8	32	30
307	2.02E+01	4.49E-01	17.5	13	37	30
308	1.62E+02	1.05E-01	7.5	2	32	30
309	2.02E+01	1.78E-01	17.5	4	90	30

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
310	8.09E+01	5.59E+00	12.5	13	74	30
311	5.67E+02	1.60E-01	17.5	2	36	30
312	4.05E+01	3.36E+00	12.5	12	42	30
313	2.02E+01	8.93E-01	7.5	2	43	30
314	3.72E+03	2.43E+00	12.5	12	85	30
315	4.05E+03	8.88E-04	7.5	2	31	30
316	1.21E+02	8.39E-01	12.5	8	46	30
317	8.09E+01	1.01E+02	22.5	4	14	30
318	1.21E+04	7.46E-01	17.5	2	58	30
319	4.45E+02	6.10E-01	17.5	1	69	30
320	7.01E+02	8.60E-02	17.5	4	90	30
321	2.02E+03	1.68E-03	12.5	1	71	30
322	4.05E+02	8.88E-03	17.5	12	79	30
323	2.02E+01	1.97E-02	17.5	5	12	30
324	2.02E+01	1.79E+01	12.5	5	69	30
325	1.01E+04	2.24E-03	22.5	12	57	30
326	4.05E+01	3.92E-01	12.5	5	19	30
327	2.02E+01	3.58E+00	17.5	4	90	30
328	2.02E+01	2.24E+00	7.5	12	48	30
329	2.02E+01	6.90E-02	12.5	9	42	30
330	8.09E+01	1.68E-01	12.5	8	46	30
331	4.05E+01	3.92E+00	7.5	13	49	30
332	2.02E+01	9.37E-02	12.5	4	74	30
333	2.02E+01	3.16E-01	12.5	2	53	30
334	2.02E+03	5.57E-03	22.5	4	92	9
335	8.09E+01	1.01E-01	17.5	12	95	9
336	2.02E+01	8.93E-01	17.5	4	77	9
337	2.02E+02	2.80E-01	22.5	12	91	9
338	4.05E+01	2.33E+01	12.5	12	42	9
339	4.65E+02	8.75E-01	17.5	2	36	9
340	4.05E+02	6.71E-02	17.5	5	13	9
341	2.02E+01	-9.99E+02	12.5	2	71	9
342	1.01E+03	3.31E-02	17.5	12	89	9
343	4.05E+01	2.79E-01	12.5	4	66	9
344	4.05E+02	4.19E-02	7.5	1	44	9
345	4.05E+03	1.12E-02	17.5	4	90	9
346	3.72E+03	1.52E-02	12.5	2	31	9
347	2.02E+03	5.37E-02	12.5	1	71	9
348	4.45E+02	6.59E-02	17.5	12	95	9
349	2.02E+02	4.44E-03	17.5	4	36	9
350	2.02E+03	7.74E-01	22.5	4	92	9
351	2.02E+01	2.91E+00	7.5	5	3	9
352	4.05E+03	8.39E+00	17.5	4	79	9
353	2.14E+05	9.96E-01	17.5	8	74	9
354	6.88E+02	6.58E+00	12.5	12	32	9

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
355	2.02E+01	4.47E+00	7.5	12	48	9
356	2.02E+01	8.88E-02	17.5	1	79	9
357	4.05E+03	2.24E-02	22.5	12	91	9
358	3.52E+04	2.35E-01	12.5	4	84	9
359	9.31E+02	1.82E-02	22.5	12	93	9
360	4.05E+01	1.23E+01	22.5	12	97	9
361	6.07E+03	-9.99E+02	12.5	12	72	9
362	3.44E+03	4.95E-01	12.5	13	32	9
363	4.45E+02	7.63E-01	22.5	12	91	9
364	6.75E+02	2.49E-02	22.5	12	97	9
365	8.09E+01	1.12E+01	12.5	12	87	9
366	6.07E+03	7.46E-03	17.5	5	14	9
367	2.43E+02	2.79E-02	22.5	11	57	9
368	2.43E+02	1.49E-01	22.5	4	96	9
369	1.21E+03	2.24E-01	12.5	8	54	9
370	8.09E+03	4.14E-02	17.5	13	20	9
371	6.07E+03	2.98E-01	12.5	4	66	9
372	2.79E+03	8.11E-03	7.5	4	31	9
373	1.35E+01	2.80E+01	12.5	5	26	9
374	9.31E+02	8.75E+00	12.5	12	42	9
375	2.02E+01	4.44E-02	12.5	1	8	9
376	3.56E+03	6.36E-02	17.5	4	92	9
377	1.62E+04	4.19E-03	17.5	1	77	9
378	8.09E+03	6.16E-06	17.5	5	12	9
379	1.21E+02	1.49E+00	12.5	2	59	9
380	1.21E+04	2.24E+00	7.5	4	25	9
381	9.31E+02	4.87E-02	12.5	4	13	9
382	2.02E+01	2.80E+00	17.5	2	36	9
383	3.64E+02	1.99E-01	7.5	2	32	9
384	5.67E+02	2.00E-01	22.5	4	35	9
385	8.09E+03	3.36E-01	17.5	1	69	9
386	4.05E+01	2.68E+01	17.5	4	90	9
387	1.01E+01	4.44E-02	17.5	5	13	9
388	1.01E+01	1.17E+01	22.5	4	92	9
389	4.45E+02	5.08E+00	7.5	1	65	9
390	8.09E+01	6.71E-01	22.5	4	81	9
391	2.02E+01	1.33E-01	12.5	2	71	9
392	1.42E+02	1.60E+01	22.5	12	78	9
393	8.09E+01	1.12E-01	7.5	4	6	9
394	8.09E+03	5.59E-01	12.5	8	82	9
395	6.07E+03	1.12E+01	12.5	4	51	9
396	8.09E+01	-9.99E+02	7.5	2	45	9
397	2.02E+03	1.40E-02	17.5	1	79	9
398	4.05E+01	3.35E-01	12.5	5	26	9

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
399	1.21E+03	3.70E-03	12.5	9	42	9
400	4.65E+03	1.94E-02	12.5	4	19	9
401	1.01E+03	2.24E-02	22.5	12	76	9
402	6.07E+02	1.86E+00	12.5	4	65	9
403	6.07E+02	9.32E-01	7.5	4	10	9
404	1.21E+02	1.40E-01	17.5	5	53	9
405	1.21E+03	1.49E-02	17.5	2	74	9
406	4.05E+01	2.24E-01	17.5	5	1	9
407	2.83E+02	-9.99E+02	12.5	4	72	9
408	1.38E+03	1.97E+00	17.5	12	95	9
409	2.83E+03	3.20E+00	22.5	2	58	1
410	6.88E+02	1.32E-01	17.5	5	12	9
411	8.09E+01	1.68E-01	12.5	4	51	9
412	4.05E+01	5.37E+00	22.5	5	14	9
413	8.09E+03	3.49E-03	17.5	4	69	1
414	4.05E+01	3.35E-01	12.5	8	46	1
415	4.05E+01	3.22E+00	17.5	13	34	1
416	8.50E+02	9.86E-02	12.5	6	51	1
417	4.05E+01	1.79E+01	17.5	5	12	1
418	2.47E+03	1.28E-01	12.5	12	74	1
419	1.42E+02	1.46E+02	12.5	2	71	1
420	8.90E+03	2.24E-05	17.5	8	74	1
421	2.02E+02	2.46E+00	12.5	8	63	1
422	4.05E+01	2.24E+00	12.5	4	72	1
423	1.62E+02	5.59E+01	12.5	9	42	1
424	5.40E+01	1.40E+01	22.5	4	58	1
425	2.27E+04	5.99E-01	7.5	8	32	1
426	8.09E+01	1.39E-01	22.5	4	81	1
427	4.05E+01	3.58E+00	7.5	12	45	1
428	2.63E+02	9.06E-01	17.5	5	34	1
429	4.05E+01	1.23E+01	17.5	5	1	1
430	1.21E+04	1.87E-03	12.5	4	65	1
431	2.02E+02	1.79E+00	12.5	2	74	1
432	1.21E+03	5.44E+00	12.5	12	49	1
433	4.86E+02	3.54E+00	17.5	1	77	1
434	3.64E+02	4.97E-01	12.5	1	61	1
435	4.05E+01	1.04E+02	12.5	4	51	1
436	1.01E+04	1.21E+00	17.5	2	74	1
437	2.23E+04	7.32E-01	12.5	4	39	1
438	8.09E+01	7.94E-01	12.5	9	51	1
439	2.02E+02	1.68E+01	12.5	12	49	1
440	1.62E+04	4.19E-01	22.5	12	78	1
441	4.65E+02	1.70E+00	17.5	5	12	1
442	2.02E+03	2.68E-01	12.5	12	71	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
443	1.38E+03	2.21E-01	12.5	2	69	1
444	1.27E+03	1.67E+00	17.5	1	69	1
445	8.09E+01	2.80E-01	22.5	12	78	1
446	4.05E+01	2.80E+01	17.5	5	13	1
447	6.07E+01	4.00E+01	17.5	5	13	1
448	4.05E+04	1.12E-02	22.5	5	12	1
449	1.13E+03	7.19E-02	12.5	2	74	1
450	1.21E+04	1.64E+00	22.5	12	97	1
451	1.50E+03	1.81E+00	12.5	12	42	1
452	3.34E+04	4.26E-02	17.5	4	79	1
453	8.09E+01	1.01E+00	12.5	4	45	1
454	2.23E+02	3.76E-01	12.5	12	85	1
455	8.09E+01	2.80E+00	22.5	12	97	1
456	6.75E+01	-9.99E+02	7.5	2	66	1
457	2.02E+01	2.24E+01	12.5	2	39	1
458	4.05E+01	1.70E+01	7.5	2	48	1
459	8.50E+02	7.99E-01	22.5	4	91	1
460	2.06E+03	8.77E+00	12.5	12	49	1
461	4.05E+01	8.50E+00	12.5	4	51	1
462	2.02E+01	1.79E+00	12.5	5	74	1
463	4.05E+01	1.37E+01	17.5	1	69	1
464	3.64E+02	3.84E-03	12.5	12	87	1
465	1.21E+03	5.59E+00	22.5	12	78	1
466	4.45E+02	1.42E+00	12.5	2	39	1
467	3.64E+02	1.37E-04	12.5	2	45	1
468	2.02E+02	2.01E+00	17.5	5	34	1
469	5.26E+03	5.68E-01	12.5	12	69	1
470	2.02E+05	1.12E-01	12.5	1	71	1
471	2.02E+01	3.28E+00	7.5	2	32	1
472	2.43E+02	2.79E-01	7.5	8	32	1
473	1.11E+04	1.61E-04	17.5	13	34	1
474	2.02E+01	8.95E+00	12.5	2	56	1
475	7.69E+04	2.05E-01	12.5	12	49	1
476	8.09E+03	7.27E-01	12.5	5	56	1
477	3.24E+04	2.32E+00	12.5	5	33	1
478	2.02E+01	-9.99E+02	12.5	4	66	1
479	7.28E+04	8.08E-01	12.5	12	74	1
480	4.05E+03	1.80E-01	17.5	12	89	1
481	4.45E+02	1.14E+01	17.5	5	12	1
482	2.02E+04	7.40E-05	17.5	1	89	1
483	2.02E+01	2.24E-01	22.5	4	81	1
484	1.38E+03	6.58E+00	12.5	4	66	1
485	1.21E+02	-9.99E+02	22.5	4	35	1
486	2.02E+01	8.95E+00	17.5	2	58	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
487	1.86E+03	2.43E-01	17.5	4	90	1
488	1.01E+01	1.79E+00	12.5	4	71	1
489	4.05E+04	4.47E-01	12.5	2	66	1
490	4.05E+03	2.24E-01	12.5	4	39	1
491	2.02E+03	8.38E-04	22.5	13	36	1
492	1.21E+02	1.86E+03	22.5	5	12	1
493	1.35E+05	1.45E+00	17.5	4	90	1
494	4.05E+01	2.33E+01	17.5	5	12	1
495	1.13E+03	6.23E+00	17.5	5	12	1
496	4.05E+01	6.99E+00	17.5	2	36	1
497	1.62E+04	5.59E-01	12.5	4	39	1
498	2.02E+03	2.91E+00	12.5	4	72	1
499	4.05E+01	5.18E+00	17.5	1	95	1
500	2.51E+05	1.49E-01	12.5	13	56	1
501	4.45E+02	2.44E+01	17.5	5	34	1
502	1.42E+04	5.11E-01	12.5	2	86	1
503	1.21E+04	2.98E-01	12.5	2	66	1
504	4.05E+03	4.44E-04	17.5	4	90	1
505	2.83E+02	8.53E-01	12.5	2	66	1
506	1.94E+04	1.40E-01	12.5	5	29	1
507	4.05E+03	2.80E+00	7.5	4	31	29
508	1.62E+02	8.42E+00	17.5	1	95	29
509	2.02E+01	1.78E-01	12.5	2	86	29
510	4.05E+01	3.22E+01	7.5	2	48	7
511	2.02E+01	3.95E-02	12.5	4	66	7
512	2.02E+01	8.95E+01	17.5	5	12	7
513	4.05E+03	1.96E+00	12.5	13	40	1
514	3.24E+02	2.80E-02	12.5	4	52	7
515	7.28E+02	9.32E-01	17.5	1	98	1
516	1.38E+03	5.26E-01	7.5	1	64	1
517	4.05E+03	3.69E-01	17.5	4	93	1
518	6.07E+03	1.88E+01	12.5	2	2	1
519	6.88E+02	3.29E-01	7.5	4	31	1
520	1.62E+04	3.02E-01	22.5	4	81	1
521	6.27E+03	3.61E+00	12.5	12	69	1
522	2.91E+03	3.26E+00	12.5	8	42	1
523	1.25E+05	3.19E-02	22.5	12	91	1
524	1.01E+04	1.23E-01	17.5	12	93	1
525	6.58E+03	9.11E-02	7.5	4	31	1
526	4.65E+03	2.98E-02	17.5	4	90	1
527	3.08E+03	2.21E+01	22.5	4	92	1
528	1.62E+04	-9.99E+02	7.5	1	62	1
529	2.43E+04	7.46E-01	7.5	2	32	1
530	2.83E+02	1.28E-01	12.5	2	56	1
531	4.45E+02	1.53E+00	17.5	5	53	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
532	9.11E+03	2.14E-01	22.5	4	92	1
533	8.73E+04	1.80E-03	12.5	2	45	1
534	2.19E+03	1.92E-03	7.5	2	48	1
535	2.27E+03	1.20E+00	17.5	4	69	1
536	4.52E+04	1.84E-07	7.5	1	64	1
537	1.42E+02	1.33E+01	12.5	2	45	1
538	6.21E+02	9.73E-01	7.5	2	48	1
539	5.06E+02	5.49E+01	12.5	2	66	1
540	4.11E+02	4.77E+00	7.5	1	62	1
541	1.01E+05	3.36E-02	17.5	4	69	1
542	4.86E+02	1.67E+02	7.5	2	48	1
543	4.05E+01	3.36E+01	12.5	4	66	1
544	2.37E+04	6.69E-01	7.5	1	44	1
545	6.75E+04	1.79E-01	22.5	4	92	1
546	9.31E+02	1.34E+00	12.5	8	46	1
547	6.07E+04	3.73E-01	22.5	12	91	1
548	4.05E+03	5.03E-02	17.5	5	90	1
549	4.05E+04	7.94E-02	12.5	5	40	1
550	1.86E+03	2.58E+00	12.5	8	82	1
551	7.28E+02	9.32E-01	17.5	1	98	1
552	1.62E+04	1.75E-01	17.5	4	90	1
553	5.58E+03	1.35E+00	12.5	5	40	1
554	1.89E+02	2.40E+01	7.5	13	48	1
555	2.02E+03	4.70E-01	22.5	4	96	1
556	8.09E+01	5.55E-02	12.5	5	33	30
557	2.02E+01	1.12E+00	17.5	5	12	30
558	2.02E+02	6.21E-02	17.5	1	79	30
559	2.02E+01	2.47E-03	12.5	4	72	30
560	2.02E+01	3.95E-02	7.5	8	49	4
561	2.83E+02	1.60E-01	7.5	2	32	4
562	4.05E+01	9.86E-03	22.5	4	81	4
563	2.06E+03	2.19E+00	22.5	4	92	4
564	4.45E+02	2.03E+00	17.5	12	95	4
565	9.31E+02	3.65E-01	17.5	12	95	4
566	2.02E+01	4.93E-02	7.5	8	32	4
567	4.05E+01	8.38E-02	7.5	5	3	4
568	2.02E+01	1.13E-01	12.5	2	66	4
569	2.35E+04	3.57E-02	17.5	5	12	4
570	2.02E+01	6.71E+00	12.5	12	42	4
571	2.39E+04	5.00E-01	17.5	13	56	4
572	1.21E+03	2.24E+01	17.5	12	89	4
573	1.29E+06	1.94E-08	22.5	2	21	4
574	1.52E+03	2.98E+00	12.5	2	40	4
575	2.02E+01	3.60E-01	12.5	5	40	4

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
576	4.17E+03	3.91E-01	22.5	13	30	4
577	8.09E+01	2.12E+00	7.5	2	45	4
578	2.02E+01	2.96E-02	12.5	2	86	4
579	4.25E+02	3.85E-01	17.5	13	90	4
580	1.01E+01	2.24E+00	12.5	8	42	4
581	2.02E+01	5.37E+01	17.5	5	12	4
582	9.31E+02	1.17E+01	12.5	4	74	1
583	8.09E+02	2.52E-01	17.5	1	69	1
584	1.01E+03	3.13E+00	12.5	1	31	1
585	2.23E+02	2.03E+00	12.5	12	45	1
586	7.28E+02	3.11E-02	17.5	12	95	1
587	1.38E+03	3.29E-01	12.5	5	40	1
588	2.31E+03	2.75E+00	17.5	12	93	1
589	2.02E+06	1.57E+00	22.5	5	22	1
590	1.38E+03	1.32E-01	7.5	1	65	1
591	7.61E+03	6.82E-01	12.5	5	69	1
592	2.02E+03	5.03E-02	12.5	13	40	1
593	7.28E+02	6.21E-01	12.5	4	45	1
594	1.74E+03	1.95E-01	17.5	5	90	1
595	3.44E+03	1.32E-01	12.5	8	9	1
596	8.09E+04	2.01E-02	12.5	5	26	1
597	2.57E+04	5.53E+00	22.5	2	22	1
598	8.90E+02	2.85E+00	17.5	2	74	1
599	8.94E+03	3.54E-01	12.5	1	31	1
600	8.38E+03	1.08E-02	17.5	4	93	1
601	3.43E+04	4.30E+00	17.5	4	22	1
602	2.43E+02	5.51E-02	7.5	2	45	1
603	4.86E+03	2.80E-01	12.5	12	72	1
604	1.01E+03	1.97E-01	12.5	2	71	1
605	2.31E+03	3.92E+00	12.5	8	9	1
606	4.05E+03	1.23E-05	12.5	5	40	1
607	5.26E+02	3.66E-01	17.5	4	90	1
608	2.02E+03	4.47E-01	12.5	13	20	1
609	3.56E+05	1.53E-01	17.5	13	90	1
610	4.05E+03	5.59E-02	17.5	4	23	1
611	5.06E+00	3.35E-01	12.5	12	42	1
612	8.50E+02	5.93E+00	12.5	8	46	1
613	4.45E+02	9.41E-03	12.5	12	48	1
614	2.02E+01	1.33E-01	12.5	2	66	1
615	9.31E+02	2.92E-02	17.5	5	53	30
616	2.02E+01	2.22E-01	12.5	2	88	30
617	2.02E+03	2.24E-01	7.5	4	83	30
618	4.65E+02	3.60E-01	17.5	13	53	30
619	2.02E+01	2.71E-02	12.5	8	53	30

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
620	2.02E+01	4.14E-01	12.5	12	72	30
621	6.75E+00	1.48E-01	22.5	4	96	30
622	2.43E+02	7.40E-03	17.5	5	53	11
623	3.04E+03	1.12E+00	12.5	12	49	11
624	4.05E+01	3.45E-02	7.5	12	48	11
625	2.02E+01	4.47E+01	22.5	4	96	11
626	6.88E+02	2.20E-01	17.5	4	30	11
627	2.02E+01	2.24E+00	12.5	5	40	11
628	1.01E+05	8.95E-04	7.5	5	10	11
629	5.26E+03	3.10E-01	22.5	5	92	11
630	6.07E+03	1.86E-03	17.5	2	90	11
631	2.02E+01	1.97E-02	7.5	12	48	11
632	9.31E+02	1.95E+00	12.5	13	74	1
633	4.86E+04	9.32E-02	22.5	11	94	1
634	5.67E+02	8.81E-05	12.5	2	88	1
635	2.02E+01	2.15E+01	17.5	4	77	1
636	3.72E+03	6.08E-03	17.5	12	95	1
637	4.05E+01	3.36E+01	7.5	12	48	1
638	4.45E+02	4.98E+00	17.5	4	90	1
639	1.21E+04	2.44E-01	7.5	12	48	1
640	1.86E+03	7.29E+00	12.5	12	42	1
641	1.62E+03	2.77E-03	17.5	1	79	1
642	3.64E+02	6.82E-02	12.5	9	51	1
643	2.59E+04	3.32E-01	22.5	13	92	1
644	3.24E+03	2.21E+00	12.5	12	48	1
645	8.09E+03	1.68E-03	22.5	12	76	1
646	1.21E+02	1.68E+00	12.5	12	69	24
647	4.05E+03	5.59E-02	12.5	2	86	2
648	2.02E+01	1.12E+00	12.5	8	46	2
649	5.67E+02	1.48E-01	12.5	2	53	2
650	2.43E+02	2.34E-02	7.5	5	3	2
651	4.05E+02	6.66E-03	22.5	4	96	2
652	8.09E+01	3.32E-01	17.5	5	13	1
653	2.02E+01	2.47E-02	12.5	1	71	1
654	2.02E+01	5.59E+00	12.5	4	88	1
655	1.13E+03	3.99E-01	17.5	13	20	1
656	4.45E+02	-9.99E+02	17.5	5	12	1
657	1.82E+03	5.74E-01	12.5	1	69	1
658	1.01E+01	4.44E-02	22.5	4	96	1
659	3.36E+03	3.37E-02	12.5	1	83	1
660	2.02E+01	4.44E-02	7.5	13	68	24
661	1.38E+03	2.96E-01	12.5	2	74	24
662	3.24E+03	3.48E-03	12.5	2	85	24
663	2.02E+03	3.58E-01	12.5	2	83	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
664	6.48E+02	1.47E-01	12.5	9	42	1
665	4.09E+03	1.66E-01	17.5	5	12	1
666	4.05E+04	4.47E-01	12.5	4	66	1
667	2.23E+02	1.52E-01	17.5	1	95	1
668	2.43E+02	1.19E-02	12.5	5	26	1
669	2.43E+02	3.73E+00	17.5	4	80	1
670	6.07E+03	2.42E-02	12.5	12	74	1
671	4.05E+01	2.68E+01	12.5	4	72	1
672	2.02E+02	8.88E-03	17.5	5	100	1
673	1.82E+02	7.46E+00	22.5	4	96	1
674	2.02E+03	1.13E-03	22.5	12	92	1
675	5.67E+02	3.20E+00	17.5	5	37	1
676	4.05E+03	1.80E-01	12.5	5	4	1
677	4.05E+01	3.23E+00	12.5	2	66	1
678	1.21E+02	6.71E-01	22.5	12	76	1
679	7.43E+03	1.68E-02	7.5	4	25	1
680	2.02E+01	8.38E-02	17.5	5	12	1
681	1.62E+02	1.68E-01	7.5	4	68	1
682	7.28E+02	1.55E-01	12.5	12	54	1
683	1.38E+03	3.26E-03	22.5	4	81	1
684	2.53E+02	3.91E-01	12.5	8	82	1
685	1.62E+04	3.50E-02	12.5	2	45	1
686	2.09E+04	3.03E-02	12.5	12	54	1
687	4.05E+01	5.18E-02	17.5	12	95	1
688	2.83E+02	2.51E+00	17.5	13	13	1
689	3.04E+03	7.40E-04	17.5	4	23	1
690	1.54E+04	4.12E-02	7.5	2	7	1
691	4.05E+02	1.12E+00	12.5	4	72	1
692	4.05E+03	7.22E-01	22.5	4	81	1
693	5.40E+02	1.12E+00	12.5	2	66	1
694	1.01E+04	1.58E-04	17.5	13	90	1
695	9.31E+02	9.73E-01	12.5	5	26	1
696	9.31E+02	2.07E-01	12.5	5	26	1
697	1.42E+02	9.59E-01	12.5	2	66	1
698	1.42E+02	1.60E-01	17.5	4	95	1
699	4.45E+02	1.02E+00	17.5	13	81	1
700	3.72E+03	1.02E-01	7.5	4	31	1
701	1.38E+03	1.69E-02	17.5	4	95	1
702	8.09E+04	3.36E-03	17.5	4	92	1
703	1.38E+03	4.13E-03	12.5	2	45	1
704	6.07E+02	4.44E-03	12.5	5	4	1
705	8.09E+01	6.71E-01	12.5	5	74	1
706	4.05E+01	1.23E-03	17.5	13	37	1
707	4.05E+01	2.07E-01	12.5	5	26	1
708	4.05E+03	7.84E-03	22.5	4	96	1

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (° C)	HG Environment	Nearest Climate Center	Site Weighting
709	2.02E+04	4.47E-01	12.5	2	66	1
710	4.05E+01	1.12E+00	12.5	2	87	1
711	9.31E+02	9.73E-01	17.5	13	56	1
712	2.02E+03	8.88E-04	12.5	12	74	1
713	5.67E+02	6.39E+00	22.5	4	96	1
714	4.45E+02	2.03E-01	12.5	5	26	1
715	2.02E+01	2.46E+00	12.5	2	69	1
716	2.02E+03	4.47E-02	17.5	13	90	1
717	4.05E+01	2.24E-01	17.5	1	95	1
718	4.05E+01	1.23E-02	17.5	4	30	1
719	2.02E+03	8.95E-02	17.5	5	53	1
720	6.75E+00	1.12E+00	17.5	5	12	1
721	4.05E+03	4.47E-01	7.5	13	45	1
722	2.02E+01	8.88E-02	7.5	2	48	30
723	1.01E+01	1.97E-02	17.5	5	12	10
724	4.05E+01	8.39E+01	12.5	2	69	10
725	2.43E+02	-9.99E+02	12.5	4	63	10
726	2.02E+01	9.86E-03	17.5	5	12	10
727	2.02E+01	3.49E+01	12.5	4	56	10
728	2.02E+01	5.59E+00	7.5	13	45	10
729	2.02E+01	7.45E-01	17.5	5	12	10
730	2.83E+02	6.38E-02	12.5	12	54	1
731	2.02E+02	4.32E+01	17.5	1	89	1
732	8.09E+01	3.50E+00	12.5	12	51	1
733	9.31E+02	8.75E-01	12.5	4	51	1
734	5.06E+01	2.22E-02	12.5	4	45	1
735	8.50E+02	1.44E-01	12.5	4	72	1
736	4.05E+01	5.59E+01	22.5	5	92	31
737	2.02E+01	1.23E-01	22.5	4	92	31
738	2.02E+01	1.33E-01	17.5	2	36	31
739	2.02E+01	1.68E-01	17.5	4	34	31
740	2.02E+01	3.95E-02	17.5	5	21	31
741	1.21E+03	3.73E-02	7.5	1	64	7
742	2.02E+01	-9.99E+02	12.5	2	32	7
743	4.05E+01	1.68E+00	12.5	4	51	7
744	4.65E+02	5.93E-01	12.5	8	46	7
745	2.02E+01	9.86E-03	17.5	5	12	7
746	2.43E+02	1.16E-01	12.5	12	49	7
747	1.66E+03	6.82E-01	17.5	4	80	7
748	1.21E+03	1.49E+00	7.5	4	31	7
749	8.09E+01	5.60E-01	17.5	1	95	7
750	4.45E+02	2.75E+00	12.5	12	49	7
751	4.45E+02	1.64E-02	12.5	5	40	7
752	2.02E+01	8.88E-02	22.5	4	81	7

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
753	2.02E+01	2.24E+00	17.5	5	14	7
754	2.02E+03	1.16E+00	22.5	12	93	7
755	4.05E+01	4.02E-01	12.5	12	42	7
756	6.48E+02	4.89E+00	17.5	5	12	1
757	1.10E+02	8.68E-01	12.5	4	74	1
758	1.21E+03	2.49E-01	17.5	1	95	1
759	1.62E+02	6.04E+01	12.5	2	52	1
760	1.62E+02	1.51E+01	12.5	12	49	1
761	4.05E+01	1.40E+02	12.5	12	49	1
762	4.05E+01	1.40E+02	12.5	12	49	1
763	4.05E+03	2.10E-01	12.5	6	73	1
764	8.09E+01	6.71E-01	12.5	9	51	1
765	1.21E+02	4.25E+01	7.5	2	45	1
766	2.83E+02	1.28E+01	7.5	1	64	1
767	1.94E+04	7.50E+00	12.5	2	52	1
768	2.02E+03	1.72E+01	7.5	2	32	1
769	8.09E+02	1.34E+01	12.5	8	63	1
770	2.43E+02	1.98E+00	7.5	2	32	1
771	1.01E+02	4.47E+00	7.5	12	48	1
772	8.09E+01	7.05E-01	12.5	2	59	1
773	2.02E+01	2.22E-01	12.5	1	53	1
774	1.82E+02	1.53E+01	12.5	8	42	1
775	4.05E+01	5.67E-02	12.5	4	51	1
776	2.08E+03	6.52E-01	22.5	4	81	1
777	2.02E+01	8.88E-02	17.5	4	90	1
778	8.09E+01	2.24E+00	22.5	4	92	1
779	4.05E+01	2.91E-01	12.5	12	49	1
780	6.75E+01	4.47E+01	12.5	5	40	1
781	4.05E+01	4.24E+00	17.5	4	34	1
782	2.02E+02	2.58E-01	12.5	5	74	1
783	5.06E+00	8.38E-02	12.5	4	72	1
784	4.05E+01	2.80E+00	17.5	1	77	1
785	8.09E+01	5.55E-02	17.5	4	95	1
786	9.31E+02	3.16E-01	12.5	12	52	1
787	4.05E+01	5.60E-01	12.5	1	71	1
788	2.22E+04	4.49E-02	12.5	9	63	1
789	8.09E+01	2.52E-01	17.5	2	36	1
790	8.09E+01	1.99E+00	7.5	13	68	1
791	9.31E+02	4.38E-01	17.5	5	13	1
792	4.05E+01	2.46E+01	7.5	13	32	1
793	9.11E+04	3.69E-01	7.5	2	32	1
794	2.02E+01	3.95E-02	12.5	12	42	22
795	2.02E+01	6.90E-01	12.5	12	42	2
796	6.88E+02	5.53E-02	12.5	2	71	2

Table D.3 Nationwide Database of Waste Pile Sites

Site Number	**Area (m2)**	**Depth (m)**	**Soil/GW Temperature (˚ C)**	**HG Environment**	**Nearest Climate Center**	**Site Weighting**
797	2.02E+01	2.68E+01	17.5	4	95	2
798	2.02E+01	3.36E+01	12.5	4	39	2
799	1.21E+02	7.46E-01	12.5	4	66	2
800	8.09E+01	7.64E-02	12.5	2	52	2
801	4.05E+01	7.89E-02	17.5	5	12	2
802	3.24E+02	3.50E+00	12.5	5	74	1
803	5.95E+03	2.71E-01	22.5	4	81	1
804	1.01E+01	1.04E-01	7.5	12	45	1
805	1.40E+06	8.41E-06	7.5	8	62	31
806	2.02E+01	4.44E-02	12.5	1	71	31
807	4.05E+01	1.01E-01	12.5	4	61	7
808	2.02E+03	4.44E-04	17.5	1	95	7
809	2.83E+02	3.20E+00	17.5	1	79	7
810	2.02E+01	5.57E-01	17.5	12	89	7
811	2.83E+02	8.00E-02	12.5	1	63	1
812	8.09E+01	4.70E+01	17.5	1	95	1
813	8.09E+01	6.29E-01	17.5	1	89	1
814	1.01E+04	1.18E-01	12.5	12	72	1
815	2.83E+02	2.21E-01	17.5	12	85	1
816	2.33E+03	1.94E-02	17.5	1	77	1
817	8.09E+01	5.55E-03	12.5	2	42	1
818	6.52E+03	2.92E-01	12.5	1	69	1
819	1.49E+04	8.53E-04	12.5	1	69	1
820	8.09E+01	3.08E-02	17.5	1	69	1
821	4.05E+01	1.23E-02	17.5	5	12	29
822	4.05E+03	-9.99E+02	7.5	1	31	3
823	2.02E+01	2.91E+00	7.5	12	48	3
824	2.02E+01	2.22E-01	22.5	12	58	3
825	4.05E+03	1.54E-01	12.5	2	85	1
826	2.02E+03	1.12E+00	7.5	8	62	1
827	2.29E+02	2.63E-01	12.5	2	66	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
1	4.05E+05	9.65E-01	12.5	1	2	1
2	2.43E+04	5.75E-05	12.5	2	2	30
3	4.45E+06	7.11E-01	12.5	2	2	1
4	1.01E+04	2.82E-02	12.5	5	2	1
5	4.05E+03	3.76E-02	7.5	2	3	1
6	6.07E+04	1.71E+00	7.5	5	3	24
7	4.86E+05	1.68E+00	12.5	1	5	1
8	2.02E+04	9.31E-02	7.5	1	7	10
9	4.05E+03	1.86E+00	7.5	1	7	1
10	2.10E+05	9.68E-03	7.5	1	7	11
11	1.01E+03	1.87E-03	7.5	4	7	1
12	2.02E+03	9.49E-02	12.5	1	8	30
13	6.48E+05	4.07E-01	12.5	1	8	11
14	1.94E+06	7.85E-01	12.5	8	9	1
15	1.05E+06	7.09E-01	12.5	8	9	1
16	9.31E+03	1.63E-02	17.5	5	13	1
17	4.05E+03	4.46E-03	17.5	5	13	1
18	8.09E+06	3.02E-04	17.5	5	13	30
19	5.58E+03	5.29E-03	17.5	5	13	30
20	4.05E+01	5.65E-01	17.5	5	13	30
21	6.07E+03	3.10E-01	17.5	5	13	11
22	6.07E+04	6.82E-01	17.5	5	13	11
23	4.05E+05	3.58E-01	17.5	5	13	11
24	1.01E+05	2.98E-01	17.5	5	13	1
25	4.05E+05	1.12E+00	17.5	5	13	1
26	1.21E+06	1.43E-01	17.5	5	13	1
27	1.26E+06	2.47E-01	17.5	5	13	1
28	3.24E+05	8.38E-02	17.5	5	13	1
29	4.05E+03	4.46E-03	17.5	5	15	30
30	5.10E+05	3.91E-01	12.5	4	20	1
31	1.21E+05	6.06E-01	17.5	5	20	1
32	4.05E+03	5.59E-02	22.5	5	21	11
33	9.31E+04	5.62E-01	17.5	4	23	1
34	6.48E+03	4.40E-02	17.5	4	23	1
35	1.21E+04	1.86E-02	17.5	5	23	1
36	1.09E+05	2.84E-01	17.5	5	23	1
37	4.05E+01	-9.99E+02	7.5	1	25	20
38	8.09E+07	1.12E-05	7.5	4	25	16
39	4.32E+04	-9.99E+02	7.5	4	25	1
40	1.27E+05	9.68E-03	12.5	2	29	1
41	2.83E+04	1.99E-03	12.5	7	29	1
42	1.90E+05	6.98E-01	17.5	2	30	1
43	4.61E+05	1.30E-04	17.5	4	30	1
44	9.71E+05	2.43E-02	17.5	4	30	1
45	6.68E+06	4.51E-01	17.5	4	30	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
46	5.71E+04	1.12E-02	7.5	2	31	1
47	8.50E+04	1.59E+00	7.5	2	31	30
48	1.62E+05	2.80E-03	7.5	2	31	30
49	2.43E+04	2.47E-05	7.5	2	31	30
50	1.17E+05	1.48E-03	7.5	4	31	30
51	4.05E+05	1.11E-03	12.5	8	31	1
52	3.74E+05	2.03E+00	12.5	8	31	1
53	4.45E+04	4.07E-03	7.5	2	32	9
54	2.43E+05	5.58E-01	7.5	2	32	1
55	2.43E+05	3.10E-01	7.5	8	32	11
56	3.24E+05	9.60E-01	7.5	8	32	1
57	1.72E+05	8.41E-05	7.5	8	32	1
58	1.90E+04	3.17E-03	12.5	2	33	1
59	6.48E+05	2.80E-03	12.5	5	33	1
60	8.46E+05	3.34E-03	17.5	2	34	1
61	2.36E+05	3.99E-03	17.5	2	34	1
62	3.24E+04	5.03E-03	22.5	4	35	1
63	2.79E+04	4.09E-02	22.5	4	35	1
64	1.42E+03	2.08E-02	22.5	4	35	1
65	8.50E+02	2.66E-01	22.5	4	35	1
66	2.10E+03	2.37E-06	17.5	5	37	3
67	6.48E+05	1.44E-01	12.5	2	39	2
68	1.13E+04	8.81E-08	7.5	1	40	1
69	1.21E+05	6.20E-02	7.5	12	41	11
70	4.05E+03	2.22E-04	12.5	2	42	1
71	3.44E+05	6.51E-04	12.5	12	42	1
72	4.05E+03	2.91E-03	12.5	12	42	1
73	8.09E+03	2.33E-03	12.5	12	42	1
74	1.78E+04	4.23E-03	12.5	12	42	1
75	2.02E+01	5.42E-02	12.5	12	42	30
76	4.45E+02	-9.99E+02	12.5	12	42	1
77	2.02E+05	1.33E-05	12.5	12	42	1
78	2.23E+06	3.72E-04	12.5	12	42	2
79	1.21E+04	7.46E-01	12.5	6	42	1
80	3.04E+05	4.53E-04	12.5	8	42	29
81	5.91E+04	-9.99E+02	12.5	8	42	1
82	1.70E+05	1.66E-02	12.5	8	42	30
83	9.31E+05	3.11E-03	12.5	8	42	1
84	5.74E+04	1.15E+00	12.5	9	42	1
85	2.02E+05	4.49E-05	12.5	9	42	1
86	2.43E+05	3.25E-05	12.5	9	42	24
87	4.17E+04	7.50E-02	12.5	9	42	2
88	1.01E+05	6.26E-04	7.5	2	45	11
89	1.34E+05	1.24E+00	7.5	2	45	1
90	9.31E+02	1.63E-01	12.5	8	46	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
91	4.65E+05	6.31E-01	12.5	8	46	11
92	4.45E+04	4.33E-03	12.5	8	46	1
93	2.43E+04	5.97E-02	12.5	8	46	1
94	2.02E+04	6.71E-01	12.5	1	100	22
95	1.21E+04	7.44E-01	7.5	2	48	30
96	3.84E+05	1.47E-01	7.5	2	48	11
97	6.31E+05	6.92E-02	7.5	2	48	11
98	3.35E+05	5.62E-03	7.5	2	48	1
99	1.74E+06	6.49E-01	7.5	2	48	1
100	3.24E+06	1.17E-02	7.5	4	48	1
101	3.71E+04	2.54E-04	7.5	12	48	1
102	4.86E+04	7.76E-03	7.5	12	48	11
103	2.71E+05	-9.99E+02	12.5	12	48	1
104	8.09E+03	2.17E-03	12.5	12	49	1
105	9.11E+05	4.08E-04	12.5	12	49	30
106	9.71E+04	1.05E-03	12.5	12	49	1
107	5.67E+05	3.09E-01	7.5	2	50	30
108	3.76E+05	1.85E-01	7.5	2	50	11
109	5.91E+04	1.24E-03	12.5	2	50	1
110	2.68E+05	4.92E-03	12.5	12	50	1
111	8.09E+05	2.24E-03	12.5	12	50	1
112	9.11E+05	5.17E-03	12.5	2	51	30
113	1.82E+05	4.55E-02	12.5	4	51	11
114	2.02E+06	6.90E-01	12.5	4	51	1
115	7.57E+05	5.44E-03	12.5	12	51	1
116	3.69E+05	3.20E-04	12.5	9	51	1
117	2.79E+03	3.57E-05	12.5	2	52	3
118	2.02E+01	1.88E+00	12.5	2	52	30
119	2.02E+04	1.07E-02	12.5	4	52	3
120	2.02E+04	2.03E-01	12.5	4	52	1
121	8.78E+05	3.90E-03	12.5	12	52	11
122	2.23E+04	1.01E-03	7.5	12	53	11
123	7.59E+04	7.89E-05	17.5	5	53	1
124	1.01E+06	2.68E-05	17.5	5	53	30
125	2.02E+06	2.13E-03	17.5	5	53	11
126	2.63E+04	5.31E-05	12.5	12	54	1
127	3.72E+03	9.25E-03	12.5	12	54	1
128	8.09E+04	1.40E-04	12.5	12	54	30
129	1.01E+05	4.47E-02	12.5	12	54	1
130	4.05E+04	7.52E-02	12.5	12	54	1
131	2.43E+06	1.45E-04	12.5	4	55	1
132	1.01E+05	6.02E-04	12.5	4	55	1
133	2.02E+04	2.33E-03	12.5	2	56	2
134	8.09E+05	3.50E-04	12.5	5	56	1
135	1.09E+05	1.76E-03	22.5	12	57	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
136	4.05E+01	5.57E-01	17.5	2	58	1
137	3.64E+06	1.02E+00	17.5	2	58	1
138	1.62E+04	2.02E-03	22.5	2	58	9
139	1.21E+04	-9.99E+02	22.5	4	58	1
140	8.09E+03	6.71E-02	12.5	1	63	1
141	1.01E+06	2.68E-03	12.5	5	64	1
142	1.62E+05	5.03E-04	12.5	5	64	1
143	2.43E+04	2.05E-07	12.5	5	64	1
144	3.24E+03	2.80E-03	12.5	4	66	11
145	1.28E+06	2.45E-03	12.5	4	66	1
146	9.31E+02	9.72E-02	7.5	4	68	1
147	4.05E+04	9.31E-03	7.5	4	68	30
148	4.05E+04	2.24E-03	12.5	1	69	1
149	4.05E+04	4.02E-04	12.5	1	69	1
150	1.21E+04	2.33E-03	12.5	1	69	1
151	3.22E+04	4.70E-01	12.5	12	69	1
152	4.05E+04	9.31E-04	12.5	12	69	16
153	1.01E+04	8.93E-02	12.5	12	69	11
154	8.09E+05	1.90E-03	12.5	12	69	1
155	2.10E+03	9.68E-02	12.5	12	69	24
156	2.02E+05	6.83E-01	12.5	5	69	1
157	9.15E+05	8.24E-04	17.5	1	69	1
158	2.83E+04	6.71E-03	17.5	1	69	1
159	1.30E+05	7.30E-02	17.5	1	69	1
160	8.09E+04	3.48E-04	17.5	1	69	2
161	4.05E+04	2.79E-01	17.5	1	69	1
162	1.54E+05	1.71E-01	17.5	1	69	1
163	1.01E+05	2.66E-05	17.5	4	69	1
164	1.21E+05	6.86E-01	12.5	1	71	1
165	1.01E+05	7.52E-03	12.5	1	71	1
166	2.19E+05	6.89E-03	12.5	1	71	1
167	2.02E+04	3.35E-03	12.5	2	71	1
168	1.21E+03	7.40E-04	12.5	2	71	30
169	1.32E+05	4.29E-01	12.5	2	71	11
170	1.19E+05	2.47E-09	12.5	12	71	1
171	2.43E+05	7.44E-05	12.5	1	72	30
172	1.54E+05	2.33E-01	12.5	1	72	1
173	5.67E+02	3.17E-03	12.5	4	72	1
174	4.05E+03	4.50E-04	12.5	4	72	1
175	9.31E+02	-9.99E+02	12.5	4	72	1
176	2.91E+05	6.46E-01	12.5	4	72	1
177	8.09E+01	-9.99E+02	12.5	4	72	2
178	1.62E+05	3.08E-08	17.5	4	72	1
179	2.79E+03	2.70E-01	12.5	4	73	1
180	7.28E+05	2.17E-01	12.5	6	73	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
181	8.09E+03	4.89E-03	12.5	6	73	1
182	9.31E+02	1.98E-01	12.5	9	73	1
183	2.02E+04	2.47E-05	12.5	2	74	30
184	1.42E+05	3.52E-08	12.5	12	74	30
185	4.05E+05	9.31E-02	12.5	12	74	11
186	4.05E+04	6.15E-03	17.5	2	74	1
187	4.09E+04	6.09E-03	17.5	2	74	1
188	8.09E+03	4.93E-05	17.5	2	74	10
189	2.83E+05	2.24E-03	17.5	4	74	1
190	1.21E+05	1.15E-05	17.5	12	74	16
191	8.63E+05	1.25E-03	17.5	12	74	2
192	3.28E+04	1.16E-01	17.5	5	74	1
193	1.21E+04	1.56E-04	22.5	12	76	1
194	4.61E+05	2.19E+00	22.5	12	76	1
195	1.52E+05	-9.99E+02	22.5	12	76	1
196	4.90E+05	1.04E-01	22.5	12	76	1
197	4.05E+05	2.21E-03	22.5	12	76	1
198	2.02E+01	3.45E-02	17.5	1	77	30
199	6.03E+04	4.20E-02	17.5	1	77	11
200	6.07E+04	1.86E-03	17.5	1	77	11
201	3.34E+05	5.63E-03	17.5	1	77	1
202	1.62E+04	2.33E-01	17.5	1	77	1
203	1.34E+05	1.76E+00	17.5	1	77	1
204	4.05E+06	1.40E-03	17.5	1	77	1
205	1.62E+05	1.16E+00	17.5	2	77	1
206	1.94E+05	2.04E-01	17.5	2	77	1
207	6.07E+04	7.75E-02	17.5	4	77	1
208	2.70E+05	9.25E-06	17.5	4	77	16
209	8.09E+05	3.65E-03	17.5	4	77	1
210	2.51E+03	-9.99E+02	22.5	12	78	3
211	1.51E+06	-9.99E+02	22.5	12	78	1
212	1.21E+03	1.57E-02	22.5	12	78	2
213	3.52E+05	-9.99E+02	22.5	10	78	1
214	8.09E+03	-9.99E+02	17.5	1	79	1
215	6.07E+03	3.38E-02	17.5	1	79	9
216	6.75E+05	9.68E-04	17.5	1	79	30
217	5.26E+04	1.18E+00	17.5	1	79	1
218	6.07E+04	6.04E-01	17.5	1	79	1
219	1.62E+04	2.26E-03	17.5	1	79	1
220	4.05E+03	6.71E-03	17.5	1	79	31
221	9.31E+03	6.07E-03	17.5	1	79	7
222	7.42E+03	6.84E-01	17.5	1	79	1
223	6.48E+03	5.82E-02	17.5	1	79	1
224	8.09E+04	6.98E-02	17.5	1	79	1
225	2.02E+05	3.35E-04	17.5	4	79	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
226	1.65E+06	3.56E-03	17.5	4	79	1
227	2.02E+05	1.12E-03	17.5	4	79	1
228	4.61E+05	1.28E-02	17.5	2	80	1
229	2.18E+04	-9.99E+02	17.5	4	80	1
230	4.73E+03	2.71E-02	17.5	4	80	1
231	4.05E+04	1.84E-02	17.5	4	80	1
232	3.24E+02	1.54E-05	22.5	4	81	1
233	5.67E+02	1.76E-04	22.5	4	81	1
234	1.74E+03	1.52E-01	22.5	4	81	1
235	2.43E+04	1.12E-02	22.5	4	81	1
236	5.26E+04	5.01E-01	22.5	4	81	1
237	3.24E+05	1.23E-02	22.5	4	81	1
238	1.34E+05	5.64E-02	22.5	4	81	2
239	1.34E+04	3.74E-07	22.5	4	81	1
240	4.05E+03	9.76E-03	22.5	4	81	1
241	1.62E+04	7.05E-01	22.5	4	81	1
242	1.82E+06	4.59E-03	22.5	4	81	1
243	4.05E+04	3.87E-01	22.5	4	81	2
244	7.28E+05	1.62E-02	22.5	4	81	1
245	2.43E+04	1.54E-02	22.5	4	81	1
246	1.62E+04	1.86E-01	22.5	4	81	1
247	2.43E+04	1.12E-02	22.5	4	81	1
248	9.71E+04	3.89E-03	22.5	4	81	1
249	2.83E+04	7.31E-03	12.5	1	83	1
250	1.62E+04	1.40E-01	7.5	1	84	30
251	1.62E+05	1.12E-03	17.5	12	85	1
252	4.05E+04	1.11E-04	12.5	2	88	30
253	5.67E+03	1.66E-01	12.5	2	88	11
254	2.43E+05	1.21E-01	12.5	2	88	1
255	5.67E+04	4.56E-03	17.5	12	89	1
256	6.88E+05	6.58E-04	17.5	12	89	1
257	4.05E+04	2.09E-02	17.5	12	89	1
258	2.43E+05	7.44E-05	17.5	12	89	2
259	4.05E+02	1.88E-01	17.5	12	89	2
260	2.02E+04	5.10E-03	17.5	12	89	1
261	4.05E+01	2.22E-02	17.5	4	90	30
262	5.26E+04	8.54E-05	17.5	5	90	1
263	2.02E+06	8.95E-04	17.5	5	90	7
264	2.02E+05	5.21E-03	17.5	5	90	30
265	2.02E+04	2.17E-02	17.5	5	90	1
266	6.48E+04	9.07E-01	22.5	12	91	1
267	1.21E+06	6.20E-01	22.5	12	91	1
268	1.54E+05	9.74E-01	22.5	12	91	1
269	3.24E+05	1.01E+00	22.5	12	91	1
270	1.21E+05	1.49E-04	22.5	10	91	1

Table D.4 Nationwide Database of Land Application Unit Sites

Site Number	Area (m2)	Depth (m)	Soil/GW Temperature (˚ C)	HG Environment	Nearest Climate Center	Site Weighting
271	2.63E+03	1.72E-02	17.5	4	92	1
272	7.45E+03	5.11E-01	22.5	4	92	1
273	8.09E+03	3.38E-01	22.5	4	92	2
274	2.79E+04	3.87E-02	22.5	4	92	1
275	4.05E+04	2.51E-03	22.5	4	92	1
276	6.07E+05	5.97E-03	22.5	4	92	7
277	5.58E+05	7.97E-04	22.5	4	92	1
278	5.26E+05	2.68E-02	22.5	5	92	1
279	2.83E+04	1.60E-03	17.5	1	93	1
280	2.02E+06	4.47E-03	17.5	1	93	1
281	3.04E+06	1.49E-05	17.5	1	93	1
282	1.05E+04	5.31E-03	17.5	4	93	1
283	5.34E+05	-9.99E+02	17.5	4	93	1
284	4.05E+05	-9.99E+02	17.5	4	93	1
285	4.65E+05	3.84E-02	17.5	4	93	1
286	1.21E+05	3.10E-02	17.5	4	93	1
287	2.02E+04	1.13E-01	17.5	4	93	1
288	8.22E+05	2.40E-04	17.5	4	93	1
289	5.67E+04	1.13E-01	17.5	12	93	1
290	1.62E+05	2.02E-04	17.5	12	93	1
291	3.24E+03	1.54E-06	22.5	12	93	7
292	2.02E+04	3.00E-02	22.5	10	94	1
293	2.02E+04	2.42E-02	17.5	1	95	1
294	9.31E+04	9.47E-01	17.5	1	95	1
295	2.16E+02	9.40E-01	17.5	1	95	1
296	1.21E+05	7.13E-01	17.5	1	95	7
297	1.62E+04	2.01E-02	17.5	1	95	7
298	2.02E+06	1.79E-03	17.5	4	95	1
299	3.64E+05	4.14E-02	17.5	12	95	1
300	4.05E+05	7.46E-05	17.5	12	95	1
301	1.42E+05	1.46E-03	17.5	12	95	1
302	8.09E+03	1.68E-02	22.5	4	96	3
303	2.51E+04	3.30E-02	22.5	4	96	1
304	8.09E+03	9.40E-02	22.5	4	96	1
305	4.05E+03	9.04E-01	22.5	4	96	9
306	1.62E+04	1.85E-05	22.5	4	96	30
307	4.86E+04	-9.99E+02	22.5	4	96	11
308	2.69E+05	8.71E-04	22.5	4	96	1
309	2.89E+05	1.30E-02	22.5	4	96	1
310	1.01E+03	3.58E-02	22.5	4	96	1
311	2.23E+05	1.65E-03	22.5	4	96	1

Table D.5 Hydrogeologic Database for HG Environment 1

Subsurface Environment Description			
Metamorphic and Igneous			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
-999	2.59E+01	-999	1.66E-02
3.15E+00	1.68E+01	1.52E+02	-999
-999	1.52E+01	1.52E+01	-999
-999	6.10E+02	-999	1.00E-04
-999	5.79E+00	9.14E+00	5.00E-02
9.46E+02	4.57E+00	-999	1.40E-02
1.58E+03	3.05E+00	-999	1.40E-02
6.31E+01	4.88E+00	1.22E+01	7.00E-02
3.47E+03	6.10E+00	1.52E+02	3.00E-02
2.84E+01	2.04E+00	9.14E+00	1.00E-02
1.26E+02	6.10E+00	7.32E+00	3.00E-02
1.58E+01	3.81E+00	3.29E+01	9.00E-02
3.15E+02	2.13E+01	3.05E+00	-999
-999	6.10E+00	6.10E+00	7.00E-06
1.10E+04	3.05E+00	1.83E+01	2.00E-02
9.46E+01	1.83E+00	4.27E+00	4.00E-02
-999	1.22E+00	9.14E+00	1.00E-02
7.57E+03	1.52E+00	3.05E+00	7.00E-06
6.31E+00	9.14E-01	6.10E+00	3.80E-02
6.31E+00	1.83E+00	7.62E+00	1.00E-01
3.15E+01	6.10E+00	-999	6.00E-02
3.15E+01	3.05E-01	6.10E+00	5.00E-03
-999	9.14E+00	1.52E+02	8.00E-03

Note: -999 indicates a missing sample value.

Table D.6 Hydrogeologic Statistics for HG Environment 1

	Subsurface Environment Statistics			
	Metamorphic and Igneous			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
	-8.52129	2.81441	3.76962	-3.97399
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
Hydraulic Conductivity ln(cm/s)	6.82319			
Unsaturated Zone Thickness ln(ft)	1.07478	0.8005		
Saturated Zone Thickness ln(ft)	1.80348	0.55257	1.1956	
Regional Hydraulic Gradient ln(ft/ft)	-0.39418	0.4367	0.17788	0.81424

Table D.7 Hydrogeologic Database for HG Environment 2

Subsurface Environment Description			
Bedded Sedimentary Rock			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
6.31E+01	6.10E+00	2.29E+01	8.00E-02
2.84E+01	6.10E+00	7.93E+01	-999
1.89E+03	7.65E+01	-999	8.00E-03
5.99E+03	3.05E+01	1.83E+02	1.00E-03
3.15E+02	6.55E+01	4.57E+01	5.70E-03
3.15E+01	1.52E+01	2.13E+01	1.00E-01
1.58E+03	1.74E+02	3.05E+01	-999
3.15E+02	5.97E+00	3.60E+00	-999
2.21E+01	1.22E+01	1.07E+01	2.80E-02
2.84E+02	1.68E+01	3.05E+00	3.20E-03
9.46E+00	6.10E+00	1.52E+02	3.10E-02
2.21E+02	9.14E+00	-999	8.00E-03
3.15E+00	3.96E+00	4.57E+00	1.00E-02
3.15E+00	4.57E+00	9.14E+01	1.00E-03
2.21E+03	1.52E+01	3.05E+01	3.30E-02

Table D.7 Hydrogeologic Database for HG Environment 2

Subsurface Environment Description			
Bedded Sedimentary Rock			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
1.10E+04	1.83E+01	9.14E+01	-999
1.26E+02	1.34E+01	7.62E+00	4.00E-03
1.33E+03	6.10E+00	2.13E+01	5.00E-03
3.15E+04	1.83E+00	3.05E+00	-999
-999	4.27E+00	8.90E+01	-999
1.89E+03	5.36E+01	6.10E+00	4.30E-02
9.78E+03	1.83E+01	3.05E+01	1.20E-02
6.31E+00	1.22E+01	2.44E+01	1.50E-02
3.15E+00	1.22E+01	1.22E+01	2.50E-02
1.26E+01	3.70E+00	3.00E+01	1.00E-02
2.21E+07	9.14E+00	1.52E+00	1.00E+00
3.47E+04	1.22E+01	4.57E+00	8.00E-03
3.15E+04	1.52E+01	6.10E+00	5.00E-02
3.15E+00	3.66E+00	9.14E+00	4.00E-02
3.15E+02	9.14E+00	2.13E+01	5.00E-03
3.15E+02	8.53E+00	1.90E+01	2.50E-02
-999	4.88E+00	-999	-999
-999	3.05E+00	-999	2.40E-02
6.31E+01	4.57E+00	1.98E+01	4.00E-02
1.89E+02	6.10E+00	6.10E+01	2.30E-02
2.21E+07	4.57E+00	1.83E+00	1.00E+00
-999	1.83E+02	1.22E+01	4.00E-04
2.21E+01	2.74E+00	3.05E+00	-999
1.89E+02	1.52E+01	6.10E+01	1.20E-02
1.10E+04	1.52E+01	2.29E+01	5.00E-04
-999	3.66E+00	1.83E+01	-999
6.31E+01	8.23E+00	5.18E+02	7.00E-03
1.26E+02	4.57E+00	1.07E+02	3.00E-02
-999	1.52E+00	9.14E+01	-999

Note: -999 indicates a missing sample value.

Table D.8 Hydrogeologic Statistics for HG Environment 2

	Subsurface Environment Statistics			
	Bedded Sedimentary Rock			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
	-7.68877	3.4698	4.2618	-4.42479
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
Hydraulic Conductivity ln(cm/s)	12.3279			
Unsaturated Zone Thickness ln(ft)	1.32509	0.54208		
Saturated Zone Thickness ln(ft)	0.47331	-0.01357	1.61831	
Regional Hydraulic Gradient ln(ft/ft)	-1.46902	-0.1757	-0.39626	1.75145

Table D.9 Hydrogeologic Database for HG Environment 3

Subsurface Environment Description			
Bedded Sedimentary Rock			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
2.55E+04	3.66E+00	3.66E+00	9.00E-04
9.46E+02	9.14E+00	5.33E+00	5.00E-03
1.26E+03	1.77E+00	6.10E+00	4.00E-09
2.84E+01	6.10E+00	-999	3.40E-02
3.78E+03	1.68E+01	1.52E+00	4.00E-02
2.68E+03	6.71E+00	2.44E+00	9.00E-03
3.15E+01	9.45E+00	-999	5.00E-02
-999	7.62E+00	-999	1.00E-02
6.31E+01	2.30E+00	4.12E+00	7.00E-03
6.62E+03	3.05E+01	2.13E+01	2.00E-02
1.26E+02	3.06E+00	1.52E+01	1.00E-02
3.15E+01	-999	-999	1.00E-02
8.83E+03	5.33E+00	4.57E+01	5.00E-04
1.58E+02	9.14E-01	4.57E+00	3.00E-03
6.31E+00	1.37E+00	3.66E+00	2.70E-02
9.46E+00	2.56E+00	2.74E+00	4.20E-02

Note: -999 indicates a missing sample value.

Table D.10 Hydrogeologic Statistics for HG Environment 3

	Subsurface Environment Statistics			
	Bedded Sedimentary Rock			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
	-7.81342	2.72776	2.93298	-4.6888
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
Hydraulic Conductivity ln(cm/s)	21.2765			
Unsaturated Zone Thickness ln(ft)	2.78074	1.07038		
Saturated Zone Thickness ln(ft)	0.6463	0.17468	0.96341	
Regional Hydraulic Gradient ln(ft/ft)	-1.30916	0.29718	-0.64536	1.9708

Table D.11 Hydrogeologic Database for HG Environment 4

Subsurface Environment Description			
Sand and Gravel			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
5.08E+04	4.57E+00	9.14E+00	5.00E-03
1.39E+04	-999	3.35E+01	2.80E-02
-999	6.10E+00	-999	-999
-999	1.22E+01	4.57E+00	1.00E-02
1.58E+03	2.13E+00	1.22E+01	1.00E-03
3.15E+00	1.98E+01	2.44E+00	7.00E-03
1.26E+01	4.57E+00	1.07E+01	7.00E-02
-999	9.14E-01	6.10E+00	4.30E-02
2.52E+03	1.52E+00	3.05E+00	2.00E-02
3.15E+03	2.44E+00	-999	2.00E-06
9.46E+00	1.83E+00	6.04E+00	5.50E-02
9.46E+01	6.10E-01	3.96E+00	6.00E-03
-999	6.98E+00	5.33E+01	-999
1.16E+05	1.52E+01	7.62E+01	4.00E-03
1.26E+04	7.62E+00	6.40E+00	4.90E-02

Table D.11 Hydrogeologic Database for HG Environment 4

Subsurface Environment Description			
Sand and Gravel			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
4.10E+03	2.13E+00	3.20E+01	3.00E-03
-999	1.07E+01	8.53E+00	6.00E-04
-999	6.10E-01	7.62E+00	1.00E-03
3.15E+03	3.05E-01	9.14E+00	3.00E-03
2.21E+02	1.52E+00	7.62E+00	4.00E-03
-999	4.57E+00	2.74E+01	1.50E-02
3.15E+00	3.05E+00	3.05E+00	2.00E-02
6.31E+02	2.44E+00	7.62E+00	5.00E-03
-999	5.08E+01	1.45E+02	9.20E-02
-999	1.52E+01	6.10E+00	1.00E-07
3.15E+01	3.35E+01	-999	2.30E-02
3.15E+02	9.14E+00	3.05E+00	2.00E-03
4.42E+03	1.52E+00	1.98E+01	2.00E-03
6.31E+02	2.21E+00	3.32E-01	1.00E-03
-999	1.22E+00	-999	-999
-999	9.14E+00	3.05E+00	5.00E-03
7.88E+03	2.29E+01	3.05E+00	2.00E-02
5.36E+03	3.05E+00	6.10E+00	1.00E-03

Note: -999 indicates a missing sample value.

Table D.12 Hydrogeologic Statistics for HG Environment 4

	Subsurface Environment Statistics			
	Sand and Gravel			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
	-6.82634	2.65875	3.3063	-4.9212
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
Hydraulic Conductivity ln(cm/s)	9.60704			
Unsaturated Zone Thickness ln(ft)	0.51036	1.5223		
Saturated Zone Thickness ln(ft)	1.46619	-0.01024	1.28413	
Regional Hydraulic Gradient ln(ft/ft)	-1.4956	0.0939	-0.02391	1.83998

Table D.13 Hydrogeologic Database for HG Environment 5

Subsurface Environment Description			
Alluvial Basins Valleys & Fans			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
5.68E+03	3.05E+00	2.13E+01	2.00E-03
-999	9.14E-01	3.96E+00	-999
9.46E+02	-999	1.52E+01	9.30E-02
-999	3.05E+00	6.10E+00	1.00E-02
1.58E+05	6.10E+00	3.05E+00	1.00E-04
6.31E+04	5.18E+00	1.52E+00	5.00E-03
-999	6.10E+00	3.05E+00	5.00E-03
1.56E+01	3.81E+01	1.52E+00	2.50E-02
1.26E+05	4.57E+00	4.57E+00	1.00E-03
-999	4.57E+00	2.29E+01	3.00E-02
7.57E+03	3.05E+01	-999	-999
-999	1.01E+02	1.52E+01	5.00E-02
1.58E+03	3.35E+01	9.14E+02	1.00E-03
3.15E+04	3.05E+01	2.44E+01	1.00E-03
-999	9.75E+00	1.52E+01	-999
6.31E+00	3.38E+00	7.62E+00	3.00E-03
-999	3.29E+01	4.57E+00	-999

Table D.13 Hydrogeologic Database for HG Environment 5

Subsurface Environment Description			
Alluvial Basins Valleys & Fans			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
2.37E+04	4.27E+01	6.10E+00	3.00E-03
-999	1.07E+01	1.07E+00	-999
1.58E+03	1.98E+01	2.44E+01	5.00E-03
1.26E+03	2.44E+00	-999	-999
3.15E+03	1.22E+01	3.81E+00	-999
1.26E+02	1.52E+01	4.57E+00	2.00E-03
9.46E+02	3.05E+00	3.05E+00	2.00E-03
-999	4.57E+00	-999	-999
-999	2.44E+00	-999	-999
1.39E+03	3.41E+01	9.14E+01	3.00E-03
-999	1.22E+01	8.53E+01	-999
-999	3.66E+00	-999	-999
-999	2.74E+01	-999	6.00E-03
-999	1.59E+01	1.62E+01	4.00E-04
9.46E+01	7.01E+00	9.14E+00	3.00E-04
2.84E+03	4.27E+01	3.05E+01	2.00E-03
1.58E+02	1.30E+01	1.30E+02	1.00E-03
-999	1.83E+01	3.66E+00	1.00E-02
1.26E+03	7.32E+00	1.83E+01	1.00E-04
6.31E+01	8.23E+01	-999	-999
1.58E+04	3.66E+01	-999	1.00E-03
3.47E+03	7.62E+00	1.52E+01	2.00E-02
-999	1.22E+01	1.52E+01	1.00E-03
1.26E+02	1.83E+00	1.10E+01	2.00E-03
2.21E+03	1.52E+01	9.14E+00	-999
3.15E+00	3.66E+00	2.44E+00	5.00E-03
-999	1.22E+01	4.88E+01	1.00E-02
-999	3.66E+01	-999	6.80E-02
6.37E+04	6.10E+01	-999	-999
3.15E+00	6.10E+01	1.52E+01	1.50E-02
-999	7.01E+00	1.83E+01	-999
6.31E+02	1.46E+01	2.44E+01	3.00E-03
3.19E+06	9.14E+00	3.05E-01	2.00E-06
3.15E+03	1.07E+01	3.05E+00	6.00E-03
3.15E+00	4.72E+00	1.83E+01	7.00E-02
9.46E+02	1.37E+01	6.10E+00	8.00E-03
3.15E+03	7.62E+00	7.62E+00	-999
3.15E+02	4.88E+00	9.14E+00	1.70E-02
1.10E+04	2.44E+00	6.10E+00	-999
-999	2.44E+00	5.18E+00	4.00E-02
-999	3.96E+00	1.83E+01	-999
1.26E+01	2.13E+00	6.10E-01	-999

Table D.13 Hydrogeologic Database for HG Environment 5

Subsurface Environment Description			
Alluvial Basins Valleys & Fans			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
2.21E+03	9.14E+00	1.52E+00	2.50E-02
-999	3.05E+00	6.10E+00	1.30E-02
2.21E+04	6.10E+00	9.14E+01	1.00E-03

Note: -999 indicates a missing sample value.

Table D.14 Hydrogeologic Statistics for HG Environment 5

	Subsurface Environment Statistics			
	Alluvial Basins Valleys & Fans			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
	-5.61434	3.43835	3.53678	-5.61773
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
Hydraulic Conductivity ln(cm/s)	9.98295			
Unsaturated Zone Thickness ln(ft)	0.28014	0.8396		
Saturated Zone Thickness ln(ft)	0.08839	0.54136	2.05569	
Regional Hydraulic Gradient ln(ft/ft)	2.96927	0.0448	-0.71488	4.17328

Table D.15 Hydrogeologic Database for HG Environment 6

Subsurface Environment Description			
River Valleys and Flood Plains with overbank deposits			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
-999	1.52E+01	1.83E+01	5.00E-03
-999	1.83E+00	9.14E+00	2.00E-03
3.15E+02	4.88E+00	1.52E+01	1.00E-03
6.31E+02	8.53E+00	9.14E+00	1.00E-02
1.07E+05	3.51E+00	7.32E+00	5.00E-03
1.89E+03	2.44E+01	3.66E+01	1.00E-03
3.15E+00	2.74E+00	3.66E+00	3.00E-03
-999	2.13E+01	7.62E+00	1.00E-03
4.10E+03	2.74E+01	3.05E+00	1.00E-03
1.67E+04	2.44E+00	6.40E+00	4.00E-03
1.10E+04	5.49E+00	1.31E+01	2.00E-03
3.15E+02	1.52E+00	3.05E+00	2.00E-03
-999	1.22E+00	1.83E+00	8.00E-03
1.10E+04	5.79E+00	-999	5.00E-04
-999	3.96E+00	4.27E+00	1.70E-02
-999	1.22E+01	1.68E+01	2.00E-03
1.58E+03	4.57E+00	7.62E+00	4.00E-02
3.31E+04	3.05E+01	2.29E+01	1.00E-02
-999	4.57E+00	7.62E+00	1.00E-01
2.52E+02	1.15E+01	-999	5.00E-03
1.42E+04	4.57E+00	1.83E+01	7.00E-04
3.15E+03	1.52E+00	1.52E+00	4.00E-07
5.68E+03	3.05E+00	6.10E+00	1.00E-03
1.89E+03	3.66E+00	6.10E+00	2.00E-03
3.15E+02	3.66E+00	6.10E-01	1.00E-06
3.15E+01	1.52E+00	-999	2.00E-08
3.15E+03	1.19E+00	3.66E+00	-999
1.55E+04	5.18E+00	7.93E+00	6.00E-03
5.52E+03	3.66E+00	5.49E+00	1.00E-02
3.15E+03	3.05E+00	1.68E+01	1.30E-02
1.58E+02	1.52E+00	3.05E+00	1.20E-02
2.21E+01	1.22E+00	1.37E+01	4.00E-03
-999	1.83E+00	9.14E+00	1.10E-02
9.46E+00	9.14E-01	6.10E+00	8.00E-03
-999	1.07E+01	1.52E+01	8.00E-05
-999	1.22E+01	1.22E+01	1.00E-06

Note: -999 indicates a missing sample value.

Table D.16 Hydrogeologic Statistics for HG Environment 6

	Subsurface Environment Statistics			
	River Valleys and Flood Plains with overbank deposits			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
	-6.7624	2.65846	3.15814	-5.6184
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
Hydraulic Conductivity ln(cm/s)	13.8058			
Unsaturated Zone Thickness ln(ft)	1.67704	0.8987		
Saturated Zone Thickness ln(ft)	2.14642	0.34951	0.86919	
Regional Hydraulic Gradient ln(ft/ft)	-0.09303	-0.23716	0.00252	1.23921

Table D.17 Hydrogeologic Database for HG Environment 7

Subsurface Environment Description			
River Valleys and Flood Plains without overbank deposits			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
9.46E+02	2.44E+00	8.23E+00	2.00E-03
1.26E+03	2.13E+00	3.05E+02	3.00E-03
-999	3.54E+01	-999	-999
6.94E+03	-999	2.29E+01	3.00E-03
2.33E+04	1.52E+01	3.66E+01	4.00E-03
4.42E+03	1.83E+00	3.81E+01	7.00E-04
5.61E+04	3.05E+00	1.01E+01	2.00E-03
5.52E+04	3.05E+00	6.10E+01	-999
9.46E+03	5.79E+01	9.14E+00	1.00E-06
-999	9.14E+00	9.14E+00	2.00E-04
-999	1.22E+01	9.14E+00	2.00E-03
9.46E+02	3.05E+00	3.05E+00	8.00E-03
9.78E+03	3.05E+00	3.05E+00	1.30E-02
-999	5.18E+00	1.22E+01	2.00E-03
4.42E+03	3.66E+00	1.52E+01	5.00E-03
4.42E+03	2.44E+01	2.13E+01	1.00E-02

Table D.17 Hydrogeologic Database for HG Environment 7

Subsurface Environment Description			
River Valleys and Flood Plains without overbank deposits			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
1.58E+03	1.52E+00	2.44E+01	1.00E-02
8.20E+04	1.49E+01	8.53E+00	3.00E-03
9.46E+02	1.22E+01	1.83E+01	2.00E-06
1.10E+04	3.05E+00	4.57E+00	-999
-999	4.57E+00	1.37E+01	1.00E-02
6.94E+03	2.13E+00	7.99E+00	4.00E-03
6.31E+03	7.01E+00	5.18E+00	4.90E-02
2.37E+04	4.88E+00	1.83E+01	3.30E-02
1.77E+04	5.79E+00	4.27E+01	2.00E-03
1.89E+03	4.57E+00	1.07E+01	4.00E-06
1.45E+04	1.52E+00	1.83E+01	1.20E-02
1.20E+05	2.20E+01	-999	1.00E-02
2.52E+03	1.52E+00	6.10E+00	1.10E-02
1.26E+01	5.79E+00	4.27E+00	2.10E-02
3.15E+02	6.10E-01	4.57E+00	6.00E-03
3.15E+01	4.57E-01	-999	1.00E-03
-999	4.57E+01	3.05E+00	-999

Note: -999 indicates a missing sample value.

Table D.18 Hydrogeologic Statistics for HG Environment 7

	Subsurface Environment Statistics			
	River Valleys and Flood Plains without overbank deposits			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
	-5.22204	2.81441	3.78819	-5.30668
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
Hydraulic Conductivity ln(cm/s)	13.0649			
Unsaturated Zone Thickness ln(ft)	-1.10808	1.13841		
Saturated Zone Thickness ln(ft)	0.50353	0.0496	1.11517	
Regional Hydraulic Gradient ln(ft/ft)	-0.73884	0.26902	-0.46202	1.11713

Table D.19 Hydrogeologic Database for HG Environment 8

Subsurface Environment Description			
Outwash			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
6.31E+03	7.62E+00	6.10E+01	1.00E-03
2.40E+04	4.88E+00	2.29E+01	2.00E-03
3.00E+04	2.99E+00	1.89E+01	4.00E-03
-999	1.22E+01	6.71E+00	1.00E-03
2.52E+03	3.05E+00	2.13E+01	8.00E-07
1.10E+05	9.14E+00	2.13E+01	4.00E-03
1.33E+04	5.49E+00	1.22E+01	6.00E-03
3.78E+04	4.57E+00	9.14E+00	3.00E-03
1.26E+03	1.07E+01	-999	8.00E-03
2.21E+03	3.05E+00	2.29E+01	9.00E-04
9.78E+03	3.35E+00	1.52E+01	7.00E-04
1.89E+03	4.88E+01	3.20E+01	3.00E-02
3.44E+04	7.62E+00	2.62E+01	6.00E-03
4.42E+04	4.88E+00	1.86E+01	2.00E-03
1.58E+04	2.90E+01	2.44E+01	1.00E-03
7.25E+03	9.14E+00	3.96E+01	6.00E-04

Table D.19 Hydrogeologic Database for HG Environment 8

Subsurface Environment Description			
Outwash			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
1.39E+04	1.22E+01	1.22E+02	2.00E-03
2.90E+04	2.74E+00	1.01E+01	-999
9.97E+04	2.13E+00	7.01E+00	7.00E-04
-999	4.57E+00	6.10E+00	3.00E-03
1.48E+04	1.83E+00	6.10E+01	1.00E-03
7.88E+03	2.44E+00	3.05E+00	3.00E-02
-999	1.52E+01	7.62E+01	9.00E-04
5.68E+03	2.44E+00	6.10E+00	1.00E-03
1.89E+04	4.57E+00	7.62E+00	5.00E-03
3.88E+03	3.66E+00	7.62E+00	4.00E-03
-999	2.20E+01	1.83E+01	6.00E-04
4.73E+02	6.10E+00	4.57E+00	1.70E-02
1.04E+04	7.62E+00	3.05E+01	1.00E-03
2.21E+04	9.14E+00	7.62E+00	5.00E-03
2.78E+04	7.62E+00	2.44E+01	2.00E-03
2.78E+04	7.62E+00	2.44E+01	2.00E-03
-999	6.10E+00	4.57E+00	4.00E-05
1.10E+04	1.22E+01	3.05E+00	7.50E-02
1.92E+04	5.33E+00	1.22E+01	8.00E-03
6.31E+02	9.14E-01	1.07E+01	1.00E-02
1.92E+04	1.83E+01	1.07E+01	1.30E-02
5.05E+03	6.10E-01	1.22E+01	3.00E-03
-999	7.62E+00	3.05E+01	2.00E-03
3.31E+04	1.52E+01	3.05E+01	4.00E-04
-999	4.57E+00	2.29E+01	1.00E-02
2.21E+03	2.13E+00	3.66E+00	2.00E-02
6.09E+04	2.00E+01	3.05E+01	3.00E-03

Note: -999 indicates a missing sample value.

Table D.20 Hydrogeologic Statistics for HG Environment 8

	Subsurface Environment Statistics			
	Outwash			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
	-3.59646	2.97372	3.92385	-5.86511
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
Hydraulic Conductivity ln(cm/s)	5.02			
Unsaturated Zone Thickness ln(ft)	0.4862	0.85551		
Saturated Zone Thickness ln(ft)	0.1547	0.26963	0.75329	
Regional Hydraulic Gradient ln(ft/ft)	-0.8019	0.07004	-0.62236	1.62199

Table D.21 Hydrogeological Database for HG Environment 9

Subsurface Environment Description			
Till and Till over outwash			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
9.46E+02	2.10E+00	1.37E+01	5.00E-02
3.15E+02	1.37E+01	1.22E+01	1.00E-03
1.89E+01	3.66E+00	5.49E+00	8.00E-03
2.18E+04	6.10E+00	1.52E+01	4.00E-03
3.47E+03	3.96E+01	5.49E+01	1.70E-02
3.15E+03	2.13E+01	4.57E+00	1.00E-02
1.26E+02	1.00E+00	3.00E+01	-999
3.15E+01	7.62E+00	3.05E+00	9.00E-03
-999	3.05E+00	3.05E+01	5.00E-07
3.15E+01	5.18E+00	1.07E+01	3.00E-02
3.15E+02	3.96E+00	2.29E+01	7.00E-03
6.31E+01	4.57E+00	2.96E+00	2.20E-02
9.15E+02	2.44E+00	1.22E+01	7.00E-04
-999	7.32E+00	1.22E+01	-999
1.89E+03	1.83E+00	9.14E-01	5.00E-03
3.15E+03	7.62E+00	7.62E+00	-999
6.31E+02	3.66E+00	2.13E+00	-999

Table D.21 Hydrogeological Database for HG Environment 9

Subsurface Environment Description			
Till and Till over outwash			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
6.31E+03	2.44E+00	9.14E+00	4.00E-08
-999	2.13E+00	7.62E+00	9.00E-03
4.10E+03	1.52E+00	6.10E+00	1.00E-02
1.26E+02	3.05E+00	4.57E+00	5.00E-02
1.26E+02	3.05E+00	7.62E+00	2.00E-02
-999	6.10E-01	1.83E+00	-999
1.26E+01	1.83E+00	-999	4.00E-02
8.83E+03	1.52E+00	1.83E+01	4.00E-03
3.15E+02	1.52E+00	6.10E+00	-999
2.84E+02	1.74E+00	9.14E+00	1.00E-02
9.46E+00	1.83E+01	2.44E+00	3.00E-03
1.58E+03	3.35E+00	6.10E+00	4.00E-06

Note: -999 indicates a missing sample value.

Table D.22 Hydrogeologic Statistics for HG Environment 9

	Subsurface Environment Statistics			
	Till and Till over outwash			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
	-7.67984	2.48552	3.22796	-4.68545
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
Hydraulic Conductivity ln(cm/s)	11.259			
Unsaturated Zone Thickness ln(ft)	0.17085	0.87319		
Saturated Zone Thickness ln(ft)	0.72472	0.13478	0.81983	
Regional Hydraulic Gradient ln(ft/ft)	-0.72109	-0.12094	-0.0043	1.28625

Table D.23 Hydrogeologic Database for HG Environment 10

Subsurface Environment Description			
Unconsolidated and Semiconsolidated Shallow Aquifers			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
-999	3.35E+00	1.46E+01	3.00E-02
4.42E+03	1.16E+01	5.49E+01	5.00E-03
2.84E+02	4.57E+00	7.62E+00	1.00E-02
1.96E+04	3.96E+01	2.14E+01	3.00E-04
1.58E+02	4.57E+00	3.05E+00	6.00E-04
3.15E+02	1.52E+00	6.10E+00	4.00E-03
-999	6.10E+00	3.66E+00	1.00E-06
1.26E+02	7.62E+00	2.29E+00	5.00E-03
3.15E+02	1.52E+01	1.07E+01	1.00E-02
3.15E+01	2.74E+00	6.86E+00	1.70E-02
1.26E+02	3.05E+00	4.12E+00	3.00E-03
-999	3.81E+00	6.10E+00	1.00E-05
-999	3.66E+00	1.52E+01	1.00E-01
6.31E+02	4.57E+00	9.14E-01	5.00E-03
3.47E+03	3.05E+00	3.05E+00	2.00E-03
2.21E+03	2.59E+01	7.62E+00	1.00E-05
-999	1.52E+00	1.52E+01	2.00E-03
2.84E+03	2.74E+00	4.57E+00	-999
-999	1.83E+00	2.44E+00	8.00E-03
2.21E+03	1.37E+01	7.62E+00	1.00E-02
1.26E+02	1.22E+01	1.22E+01	2.50E-02
-999	3.81E+00	1.68E+01	2.00E-03
-999	3.32E+00	1.83E+00	6.00E-02
3.15E+00	3.66E+00	1.16E+01	1.00E-02
2.52E+01	1.83E+00	4.57E+00	9.50E-03
4.42E+03	1.07E+01	9.14E+00	1.40E-02
-999	6.10E+00	4.27E+01	1.75E-03

Note: -999 indicates a missing sample value.

Table D.24 Hydrogeologic Statistics for HG Environment 10

	Subsurface Environment Statistics			
	Unconsolidated and Semiconsolidated Shallow Aquifers			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
	-6.97635	2.80942	3.15655	-5.57335
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	**Unsaturated Zone Thickness ln(ft)**	**Saturated Zone Thickness ln(ft)**	**Regional Hydraulic Gradient (m/m)**
Hydraulic Conductivity ln(cm/s)	4.99889			
Unsaturated Zone Thickness ln(ft)	1.27993	0.86035		
Saturated Zone Thickness ln(ft)	0.51266	0.40799	0.8467	
Regional Hydraulic Gradient ln(ft/ft)	-1.74813	-0.71454	0.03369	3.61694

Table D.25 Hydrogeologic Database for HG Environment 11

Subsurface Environment Description			
Coastal Beaches			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
9.46E+02	2.13E+00	3.05E+02	1.00E-02
6.31E+01	2.74E+00	3.05E+01	3.00E-02
7.25E+03	9.14E+00	3.66E+01	6.00E-04
2.43E+04	4.57E+00	1.07E+01	6.80E-03
-999	1.52E+00	3.05E+02	1.00E-03
7.57E+03	3.05E+00	4.57E+01	6.00E-03
1.26E+04	9.14E-01	4.57E+00	5.00E-03
6.31E+02	9.14E-01	6.10E+00	1.00E-02
3.15E+03	1.52E+00	6.10E+00	-999
1.26E+03	1.22E+00	1.07E+01	2.00E-03
3.15E+01	9.14E-01	1.52E+01	5.00E-03
1.39E+04	1.52E+00	6.10E+01	2.00E-03
-999	1.68E+00	1.52E+01	2.00E-03
2.52E+03	2.00E+00	2.00E+00	2.00E-03
1.26E+03	1.22E+00	3.05E+00	1.70E-02
-999	9.14E-01	7.62E+00	-999

Table D.25 Hydrogeologic Database for HG Environment 11

Subsurface Environment Description			
Coastal Beaches			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
3.15E+02	1.52E+00	1.52E+00	5.00E-02
1.58E+03	2.74E+00	4.57E+00	2.30E-02
-999	3.35E+00	4.27E+00	1.90E-02
3.15E+02	3.05E+00	2.44E+01	1.00E-03
2.84E+02	1.07E+00	3.05E+01	3.00E-03
9.46E+02	2.13E+00	1.68E+00	2.00E-04
-999	2.74E+00	2.13E+01	3.00E-05
8.17E+03	7.01E+00	6.10E+00	3.30E-03
-999	-999	6.71E+00	-999
-999	3.05E+00	4.27E+01	5.00E-04

Note: -999 indicates a missing sample value.

Table D.26 Hydrogeologic Statistics for HG Environment 11

	Subsurface Environment Statistics			
	Coastal Beaches			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
	-5.38023	1.8991	3.7492	-5.61773
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
Hydraulic Conductivity ln(cm/s)	3.48349			
Unsaturated Zone Thickness ln(ft)	0.52513	0.46903		
Saturated Zone Thickness ln(ft)	-0.00429	0.18069	2.02612	
Regional Hydraulic Gradient ln(ft/ft)	-0.63963	-0.2284	-0.08327	1.97797

Table D.27 Hydrogeologic Database for HG Environment 12

Subsurface Environment Description			
Solution Limestone			
Hydraulic Conductivity (m/yr)	**Unsaturated Zone Thickness (m)**	**Saturated Zone Thickness (m)**	**Regional Hydraulic Gradient (m/m)**
1.58E+05	3.00E+01	3.00E+01	6.00E-03
-999	5.00E+01	1.00E+01	5.00E-03
1.58E+03	5.08E+01	1.44E+02	2.30E-02
-999	1.52E+01	9.14E+01	-999
-999	3.05E+00	-999	1.20E-02
1.58E+03	4.57E+01	-999	-999
1.26E+02	3.05E+00	1.52E+01	5.00E-05
3.15E+02	1.22E+01	6.10E+01	3.30E-02
-999	3.05E+01	-999	2.00E-02
-999	3.20E+02	-999	9.00E-03
-999	5.33E+00	1.52E+01	1.00E-03
1.58E+04	2.93E+01	1.95E+01	-999
-999	1.83E+01	-999	-999
2.21E+02	-999	3.96E+01	2.00E-03
3.15E+02	3.96E+00	3.05E+00	1.80E-02
2.49E+04	1.52E+00	-999	2.00E-03
1.23E+04	3.96E+00	1.83E+01	9.00E-03
-999	3.05E+00	3.05E+02	1.00E-03
9.46E+01	7.62E+00	1.98E+01	1.00E-02
1.26E+03	4.00E+02	1.80E+01	2.00E-06
2.18E+03	1.68E+00	7.32E+00	4.20E-04
6.31E+03	1.22E+00	3.05E+00	-999

Note: -999 indicates a missing sample value.

Table D.28 Hydrogeologic Statistics for HG Environment 12

	Subsurface Environment Statistics			
	Solution Limestone			
	Mean Values			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
	-5.6496	3.47765	4.32063	-5.49537
	Covariance Matrix			
	Hydraulic Conductivity ln(cm/s)	Unsaturated Zone Thickness ln(ft)	Saturated Zone Thickness ln(ft)	Regional Hydraulic Gradient (m/m)
Hydraulic Conductivity ln(cm/s)	12.0503			
Unsaturated Zone Thickness ln(ft)	1.43257	1.25667		
Saturated Zone Thickness ln(ft)	0.53279	0.99541	1.2437	
Regional Hydraulic Gradient ln(ft/ft)	0.79733	1.35511	0.81132	4.45451

Table D.29 Hydrogeologic Database for HG Environment 13

Subsurface Environment Description			
Undefined Hydrogeological Region (Parameters values represent the average of the 12 regions).			
Hydraulic Conductivity (m/yr)	Unsaturated Zone Thickness (m)	Saturated Zone Thickness (m)	Regional Hydraulic Gradient (m/m)
1890	5.18	10.1	5.70E-03