Appendix A

VADOSE ZONE MODELING TECHNICAL SUPPORT DOCUMENT

SOIL LEACHING TO GROUNDWATER MODELING

This appendix describes the methods the Montana Department of Environmental Quality (DEQ) used to develop Tier 1 soil leaching to groundwater risk-based screening levels (RBSLs). The soil leaching to groundwater RBSLs were calculated using two computer codes and the EPA soil-water partition equation for organic contaminants (*Soil Screening Guidance Technical Support Document*, EPA, 1996). The EPA partitioning equation was used to relate chemical of concern (COC) concentrations in soil moisture to the total concentration detected in a soil sample, assuming linear partitioning and equilibrium conditions. Dilution/Attenuation Factors (DAFs), representing the ratio of COC concentration in soil leachate at the source area to the COC concentration at the down gradient edge (DGE) were calculated using the VS2DT Solute Transport in Variably Saturated Porous Media code developed by the USGS. The DGE was established as a monitoring well constructed at the downgradient edge of the contaminated source zone, with a well screen extending 1 meter into the water table. The Hydrologic Evaluation of Landfill Performance (HELP) code (U.S. Army Engineer Waterways Experiment Station) was used to generate a generic water budget, including estimates of water infiltration, runoff, evapotranspiration, and soil moisture percolation rates into the contaminated source area. The percolation rates generated by the HELP code were incorporated into the VS2DT modeling.

Physical processes simulated by the DEQ Tier 1 soil leaching to groundwater model include COC adsorption and desorption onto vadose zone soils and the aquifer matrix, advection and hydrodynamic dispersion of COCs in the vadose and saturated zones, and dilution due to mixing of soil leachate and groundwater. The model setup includes a finite contaminant source zone. Biological degradation of the COCs is not considered in the model.

Three scenarios were simulated. In the most conservative scenario, the contaminated source was assumed to be located 0.1 meter above the water table. In the second scenario, the distance between the source and the water table was 3.1 meters. The final scenario incorporated a 6.1-meter layer of unimpacted soil between the source and the water table. DEQ-7 human health standards were used as the groundwater target for individual COCs. Groundwater targets for petroleum fractions were developed based on the toxicity and aesthetics of surrogate chemicals representative of each fraction. In all cases, the soil RBSL represents a COC concentration that, based on the results of the modeling effort, would produce a maximum groundwater concentration equal to the groundwater target at the DGE.

Generic application of the RBSLs to petroleum release sites throughout Montana dictated the use of several conservative assumptions in the soil leaching to groundwater model. Conservative elements included the use of sandy soil as the default soil type, incorporation of an upper end estimate of the water percolation rate, and the assumption that no biodegradation of COCs in the vadose or saturated zones occurs. A description the VS2DT and HELP codes, model input parameters, and results of the modeling efforts are presented below.

Model Description: VS2DT

VS2DT simulates the movement of water in variably saturated porous media under isothermal and isohaline conditions. The governing equation describing the movement and occurrence of water combines the principle of conservation of mass with equations for fluid flux and storage. A thorough discussion of the derivation of VS2D, the USGS code prior to the addition of a solute transport module, is presented in *Documentation of Computer Program VS2D to Solve the Equations of Fluid Flow in Variably Saturated Porous Media*, USGS, 1987. The code uses finite differences to discretize spatial and temporal domains. Non-linear conductance and storage terms and unsaturated hydraulic conductivities are calculated using equations developed by Brooks and Corey, van Genuchten, or Haverkamp.

The code was modified in 1990 to simulate solute transport, using a governing equation accounting for advective transport, hydrodynamic dispersion, and solute sources and sinks. The hydrodynamic dispersion term includes mechanical dispersion and molecular diffusion in water. The code does not simulate volatilization or COC movement in soil vapor. A discussion regarding the addition of the solute transport module is presented in *Simulation of Solute Transport in Variably Saturated Porous Media With Supplemental Information on Modifications to the U.S. Geological Survey's Computer Program VS2D*, USGS, 1990.

Model Description: HELP

The HELP code was written to simulate water movement through landfills. The model accepts weather, soil, and design data and accounts for surface water and snow storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, and unsaturated vertical drainage. The HELP code uses many routines previously developed and used in other hydrologic models, including the WGEN synthetic weather generator (U.S. Department of Agriculture) and Soil Conservation Service (SCS) runoff curves. Snowmelt modeling is based on the National Weather Service River Forecast System Snow Accumulation and Ablation Model, and frozen soils are simulated using a subroutine from the Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) code. Vertical drainage is simulated using Darcy□s law using unsaturated hydraulic conductivity based on the Brooks and Corey relationship. Results are expressed as daily, monthly, and annual water budgets. Documentations of the HELP Model include the *HELP Model User's Guide for Version 3*, EPA, 1994 and the *HELP Model Engineering Documentation for Version 3*, EPA, 1994.

DEQ Soil Leaching Model Setup

The conceptual model for the soil leaching to groundwater pathway was developed as a two-dimensional cross-section consisting of a vadose zone of varying thickness overlying a water table aquifer two meters in thickness. Soil properties were homogeneous and isotropic throughout the model domain. The vertical profile consisted of 1.4 meters of unimpacted soil, overlying 1.5 meters of contaminated soils, overlying a 2-meter saturated zone located 0.1 meter, 3.1 meters, and 6.1 meters below the bottom of the contaminated soils.

The HELP modeling was performed to simulate water movement through the top 1.5-meter layer of soil and generate a soil moisture flux rate for the top boundary of the VS2DT model domain. The HELP code was selected based on its widespread use, flexibility, and thorough documentation. Necessary soil data included porosity, field capacity, wilting point, saturated hydraulic conductivity, initial moisture storage, and SCS runoff curve number. Design specifications included vegetative cover, soil layer thickness and areal dimensions, surface slope and slope length, and evaporative zone depth. Daily precipitation for six Montana cities (Billings, Great Falls, Havre, Helena, Kalispell, and Miles City) was simulated by the HELP code for a 30-year period based on statistical qualities of 5 years of daily field data recorded in these cities. In the same manner, 30 years of synthetic daily temperature and solar radiation data were generated by the code.

The top of the soil column was modeled as bare ground with a surface slope of 1 percent, with 95 percent of the surface area available for runoff. Default soil properties for a well-graded sand (soil texture #3) were used in the HELP model. This soil series was selected primarily due to its saturated hydraulic conductivity value, which was approximately one-half the value used in the VS2DT simulation. This reduction in conductivity was included to reflect a moderate degree of compaction expected in surface soils and/or the presence of a semi-permeable cover at many sites. HELP model results indicated that percolation through the bottom of the 1.5-meter layer ranged from 8.3 cm/yr (Kalispell) to 3.8 cm/yr (Helena).

VS2DT Boundary Conditions

The VS2DT model domain was 13 meters in the horizontal direction and 5, 8, and 11 meters in the vertical direction, depending on the depth to groundwater. The top horizontal boundary of the VS2DT model domain was set as a constant flux boundary, and a percolation rate of 2.5×10^{-4} meters per day, corresponding to the Kalispell percolation rate, was used. A water saturated zone was established using constant head boundaries extending 2 meters up from the bottom of the model domain, and were set with a total head difference of 0.06 meters from the left side to the right side of the model domain, resulting in a groundwater gradient of 0.005 m/m. The bottom of the model domain was set 2 meters below and parallel to the water table, and the bottom boundary of the domain and side boundaries of the vadose zone were set as no flow boundaries. The source zone dimensions were set to 9 meters wide (parallel to the groundwater flow direction) and 1.5 meters in thickness. The contaminated source was bordered by two meters of unimpacted soils on each side.

VS2DT Initial Conditions

The VS2DT code requires that initial values of total head, moisture content, or pressure heads be specified everywhere in the model domain. For each distance to groundwater scenario, a preliminary model run was performed to compute an equilibrium pressure head profile for all nodes in the domain based on the boundary conditions and soil textural parameters. The equilibrium pressure head matrices generated by the preliminary runs were subsequently used in

the VS2DT simulations for each distance to groundwater scenario. Figure 1 presents the steady-state moisture content profile for the 0.1-meter (most conservative) distance to groundwater scenario.

Unfortunately, the VS2DT code will not accept total COC concentrations in soils as an initial condition. Instead, COC concentrations in soil moisture were set to a constant value (typically 10 g/m^3). An average soil moisture content was calculated for the source zone using the soil moisture profile generated by VS2DT. The total soil concentration in equilibrium with the target soil moisture concentration (back calculated for each COC using the groundwater target multiplied by the DAF) was estimated using the EPA soil-water partitioning equation.

VS2DT Finite Difference Parameters

Rapid changes in pressure heads and moisture content near the capillary fringe dictated relatively fine vertical discretization. Maximum grid spacing in the vertical direction was 0.1 meters in the vadose zone and 0.25 meters in the saturated zone. Minimum grid spacing was 0.01 meters in the vicinity of the water table. Maximum changes in grid spacing ranged from a factor of 1.5 to 2.0. Grid spacing in the horizontal direction was 0.5 meters, and was reduced to 0.25 meters in the vicinity of the compliance monitoring well. Time discretization was set using a maximum time step of 1 day. At the beginning of the simulation, the time step was set to 0.01 day and was subsequently increased by a factor of 1.5 until the 1 day time step was achieved.

Closure criteria for total heads was set to 1.0×10^{-4} meters, and closure criteria for the solute transport equation was set to 1.0×10^{-5} g/m^3 (g/m^3 units convert to mg/L). The strongly implicit procedure (SIP) was used in calculating total head values, and central differencing in space and time was used for the solute transport equation. The arithmetic mean of adjacent cells was used to calculate intercell conductivities.

Physical and Chemical Parameters

Physical parameters for vadose and saturated zone soils, including hydraulic conductivity, specific storage, porosity, residual moisture content, and van Genuchten non-linear parameters were estimated using the *Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model Final Report*, US EPA, 1995. The values selected for these parameters were consistent with a well-sorted sand. Chemical-specific parameters, including the molecular diffusion coefficient in water and the organic carbon-water partitioning coefficient were estimated using the EPA Soil Screening Guidance Technical Support Document. Organic carbon content of vadose and saturated zone soils was estimated as 0.006 g/g and 0.001 g/g, respectively. Longitudinal dispersivity for COCs in the vadose zone was estimated using the equation $D_l = 0.02 + 0.022*L$ where D_l is the longitudinal dispersivity, and L is the vertical distance between the center of the contaminated source area and the top of the water table. For the saturated zone dispersivities, the longitudinal dispersivity was estimated as one tenth the horizontal distance between the center of the contaminated source and the down gradient edge monitoring well, and the transverse dispersivity (in the vertical direction) was estimated as one

tenth of the value of the longitudinal dispersivity. For the vadose zone, the transverse dispersivity was set equal to the longitudinal dispersivity as the flow of soil moisture perpendicular to bedding planes is expected to result in greater transverse spreading of COCs compared to saturated zone flow parallel to bedding planes. Physical and chemical input parameters incorporated in the leaching to groundwater model are presented in Tables 1 and 2.

Down Gradient Edge

Conceptually, the down gradient edge (DGE) was set as a monitoring well constructed with a screened interval extending one meter from the top of the water table. As implemented in the VS2DT code, COC concentrations at five adjacent cell nodes in a vertical line, corresponding to the DGE location, were reported for each time step. The uppermost cell was located 10 centimeters below the top of the water table, under the downgradient edge of the vadose zone source. The vertical dimensions of the cells were 0.1, 0.15, 0.25, and 0.25 meters, respectively. In order to generate an average DGE well concentration accounting for the differences in cell dimensions, the concentration in each cell was multiplied the cell vertical dimension, the values for all five cells were totaled, and divided by the total vertical length of the five cells (1 meter). This calculation was performed on the output from each time step, and the highest average of the five nodes was recorded.

RBSL Calculation

Back-calculation of RBSLs incorporated the COC-specific DAF generated by the VS2DT modeling and the EPA soil-water partitioning equation. Table 3 presents the EPA partitioning equation and the parameters required for the calculation of the Tier 1 soil targets. DAFs for the most conservative scenario, with the contaminated source located immediately above the water table (0.1-meter scenario), ranged from 20.4 (MTBE) to 12.6 (Acenaphthalene and Anthracene). The majority of the PAHs have very high soil-water partitioning coefficients and correspondingly high retardation factors, resulting in exceedingly long travel times between the source and the DGE well. As a result, the DAFs for some PAH COCs were estimated using for DAFs computed for Dibenzo(a, h)Anthracene (Table 3).

Mass Balance Results

Use of fine spatial and temporal discretization combined with the steady-state flow of soil moisture and groundwater incorporated in the simulations resulted in low water and COC mass balance errors. Percent mass balance for water was calculated as the ratio between the reported fluid volume balance and the total fluid flux. Similarly, the percent mass balance error for the COCs was the ratio between the reported solute mass balance and the initial starting mass. All simulations assumed linear COC partitioning between soil and water. The VS2DT code calculates an initial mass of COC sorbed to soil as the initial water concentration multiplied by the partitioning coefficient, soil bulk density, and dimensions of the source area.

Sensitivity Analysis Results

Analysis of sensitivity of model output to selected input parameters was performed for the VS2DT and HELP codes. Sensitivity of VS2DT was measured using the benzene/0.1-meter scenario. Sensitivity analysis model runs were performed using expected minimum and maximum values of selected input parameters. Parameter sensitivity was reported as the ratio of predicted DGE concentrations for the minimum and maximum case for each input parameter. Sensitivity results for VS2DT indicated that the benzene/0.1-meter distance to groundwater scenario was most sensitive to the saturated hydraulic conductivity, source width, groundwater gradient, and soil moisture percolation rate. With the exception of the source width, these parameters affect the water balance between percolating soil moisture and the underlying saturated zone. Increasing the saturated zone hydraulic conductivity from 1 meter per day to 15 meters per day resulted in a reduction in the maximum DGE concentration by a factor of 5.3. Sensitivity results for the HELP code indicated that simulation was most sensitive to the soil type, site location, and maximum depth of evapotranspiration.

Table 1
Leaching Model Physical Parameters

	0.1m simulations	3.1m simulations	6.1m simulations
Model Setup Parameters	**Sand**	**Sand**	**Sand**
Maximum no. of Time Steps	**1,000,000**	**1,000,000**	**1,000,000**
units	meter day gram	meter day gram	meter day gram
Initial Hydraulic Condition	Steady state	Steady state	Steady state
Intercell Relative Hydraulic Conductivity	Arithmetic mean	Arithmetic mean	Arithmetic mean
Hydraulic Characteristic Function	Van Genuchten	Van Genuchten	Van Genuchten
Differencing Scheme for Transport Equation	Centered	Centered	Centered
Adsorption	Linear Isotherm	Linear Isotherm	Linear Isotherm
Relaxation Parameter	0.7	0.7	0.7
Minimum Iterations per Time Step	2	2	2
Maximum Iterations per Time Step	80	80	80
Closure criteria for head [m]	1.00E-04	1.00E-04	1.00E-04
Closure criteria for concentration [g/m^3]	1.00E-05	1.00E-05	1.00E-05
Grid spacing - rows (m)	0.01-0.1	0.01-0.1	0.01-0.1
Grid spacing - columns (m)	0.25-0.5	0.25-0.5	0.25-0.5
Domain width [m]	13	13	13
Domain thickness [m]	5.0	8.0	11.0
Source Area width [m]	9.0	9.0	9.0
Source Area thickness [m]	1.5	1.5	1.5
Vadose zone thickness [m]	3.0	6.0	9.0
Saturated zone thickness [m]	2.0	2.0	2.0
Initial concentration 1.4-2.9m, [g/m^3]	10.0	10.0	10.0
Vadose/Saturated Zone Soil Parameters			
Kz/Kh	1.0	1.0	1.0
Saturated Kh [m/d]	7.0	7.0	7.0
Specific Storage	0	0	0
Porosity	0.4	0.4	0.4
Residual Moisture Content	0.045	0.045	0.045
VG alpha parameter [1/m]	-14.5	-14.5	-14.5
VG beta parameter	2.68	2.68	2.68
Soil density [g/m^3]	1.50E+06	1.50E+06	1.50E+06
Vadose Zone Solute Parameters			
Longitudinal dispersivity [m]	0.05	0.1	0.15
Transverse dispersivity [m]	0.05	0.1	0.15
Decay coefficient [1/d]	0	0	0
Fraction organic carbon (included in Kd value)	0.006	0.006	0.006
Partitioning coefficient, Kd [m^3/g]	EPA values	EPA values	EPA values
Molecular Diffusion Coefficient [m^2/d]	EPA values	EPA values	EPA values
Saturated Zone Soil Parameters			
Kz/Kh	1.0	1.0	1.0
Saturated Kh [m/d]	7.0	7.0	7.0
Porosity	0.4	0.4	0.4
Residual Moisture Content	0.045	0.045	0.045
VG alpha parameter [1/m]	-14.5	-14.5	-14.5
VG beta parameter	2.68	2.68	2.68
Soil density [g/m^3]	1.50E+06	1.50E+06	1.50E+06
Specific Storage	0	0	0
Hydro Parameters			
Number of recharge periods	1	1	1
Recharge period length [d]	varies	varies	varies
Initial Time step [d]	0.01	0.01	0.01
Time step multiplier	1.5	1.5	1.5
Maximum Time step [d]	1	1	1
Minimum Time step [d]	0.01	0.01	0.01
Depth to water [m]	3	6	9
Time step reduction factor	0.1	0.1	0.1
Maximum head change [m]	0.05	0.05	0.05
Steady-state head criterion [m]	0	0	0
Maximum height of ponding [m]	0	0	0
Specified flux boundary [m/d]	2.50E-04	2.50E-04	2.50E-04
Groundwater gradient [m/m]	0.005	0.005	0.005
Specified total head boundary-upgradient [m]	-2.97	-5.97	-8.97
Specified total head boundary-downgradient [m]	-3.03	-6.03	-9.03

HELP Input Parameters	
Parameter	**value**
No. of soil layers	1
Thickness [m]	1.5
Porosity	0.457
Field Capacity	0.083
Wilting Point	0.033
Initial Moisture Content	0.166
Saturated Hydraulic Conductivity [m/d]	2.67
SCS Runoff Curve Number [%]	81.3
Fraction of Area Allowing Runoff	95
Horizontal Area [Hectares]	0.09
Evaporative Zone Depth [m]	0.15

Table 2
VS2DT Chemical Parameters

	Hd	Koc	Di,w	DEQ-7
Constituent		**L/Kg**	**cm^2/s**	**ug/L**
Methyl t-Butyl Ether	2.40E-02	1.2E+01	8.6E-06	30
Benzene	2.28E-01	1.5E+02	1.0E-05	5
Toluene	2.72E-01	2.3E+02	9.2E-06	1000
Ethylbenzene	3.23E-01	4.5E+02	8.5E-06	700
Xylenes	2.76E-01	3.8E+02	8.5E-06	10000
Naphthalene	1.98E-02	1.5E+03	8.4E-06	100
1,2-Dibromoethane	3.04E-02	4.0E+01	1.0E-05	0
1-2-Dichloroethane	4.00E-02	4.0E+01	1.1E-05	4
Acenaphthene	6.36E-03	5.0E+03	8.3E-06	670
Anthracene	2.67E-03	1.6E+04	7.9E-06	2100
Benz(a)Anthracene	1.37E-04	1.8E+05	6.7E-06	0.50
Benzo(a)Pyrene	4.63E-05	5.9E+05	5.6E-06	0.05
Benzo (b)Fluoranthene	4.55E-03	6.0E+05	5.6E-06	0.50
Benzo (k) Fluoranthene	3.40E-05	5.9E+05	5.6E-06	5
Chrysene	3.88E-03	1.8E+05	6.7E-06	50
Dibenzo(a,h) Anthracene	6.03E-07	1.9E+06	5.2E-06	0.05
Fluoranthene	6.60E-04	5.5E+04	7.2E-06	130
Fluorene	2.61E-03	9.2E+03	7.9E-06	1100
Indeno(1,2,3-cd)Pyrene	6.56E-05	2.0E+06	5.2E-06	0.50
Pyrene	4.51E-04	5.43E+04	7.2E-06	830
Methylnaphthalene, 1-	2.1E-02	2.53E+03	7.8E-06	11
Methylnaphthalene, 2-	2.1E-02	2.48E+03	7.8E-06	36

*EPA 2016 RSLs https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016

Conversions	**Koc**	**Koc**	**foc 0.006**	**foc 0.001**	**Di,w**	**Di,w**
Constituent	**L/Kg**	**M^3/g**	**Kd-sand**	**Saturated**	**cm^2/s**	**m^2/d**
Methyl t-Butyl Ether	1.2E+01	1.2E-05	6.94E-08	1.16E-08	8.6E-06	7.42E-05
Benzene	1.5E+02	1.5E-04	8.70E-07	1.50E-07	1.0E-05	8.90E-05
Toluene	2.3E+02	2.3E-04	1.40E-06	2.30E-07	9.2E-06	8.00E-05
Ethylbenzene	4.5E+02	4.5E-04	2.70E-06	4.50E-07	8.5E-06	7.30E-05
Xylenes	3.8E+02	3.8E-04	2.30E-06	3.80E-07	8.5E-06	7.30E-05
Naphthalene	1.5E+03	1.5E-03	9.30E-06	1.50E-06	8.4E-06	7.20E-05
1,2-Dibromoethane	4.0E+01	4.0E-05	2.40E-07	4.00E-08	1.0E-05	9.00E-05
1-2-Dichloroethane	4.0E+01	4.0E-05	2.40E-07	4.00E-08	1.1E-05	9.50E-05
Acenaphthene	5.0E+03	5.0E-03	3.00E-05	5.00E-06	8.3E-06	7.20E-05
Anthracene	1.6E+04	1.6E-02	9.80E-05	1.60E-05	7.9E-06	6.80E-05
Benz(a)Anthracene	1.8E+05	1.8E-01	1.10E-03	1.80E-04	6.7E-06	5.80E-05
Benzo(a)Pyrene	5.9E+05	5.9E-01	3.50E-03	5.90E-04	5.6E-06	4.80E-05
Benzo (b)Fluoranthene	6.0E+05	6.0E-01	3.60E-03	6.00E-04	5.6E-06	4.80E-05
Benzo (k) Fluoranthene	5.9E+05	5.9E-01	3.50E-03	5.90E-04	5.6E-06	4.80E-05
Chrysene	1.8E+05	1.8E-01	1.10E-03	1.80E-04	6.7E-06	5.80E-05
Dibenzo(a,h) Anthracene	1.9E+06	1.9E+00	1.10E-02	1.90E-03	5.2E-06	4.50E-05
Fluoranthene	5.5E+04	5.5E-02	3.30E-04	5.50E-05	7.2E-06	6.20E-05
Fluorene	9.2E+03	9.2E-03	5.50E-05	9.20E-06	7.9E-06	6.80E-05

EPA SSL soil/water partitioning equation
Use the new excel rounding formula
May 2017
Ct = Cw*[(koc*foc)+(Pw+(Pa*Hd))/Pb]

Ct = soil concentration [mg/kg]
Cw = leachate concentration [mg/L]
koc = soil organic carbon-water partition coefficient [L/kg]
foc = fraction organic carbon [kg/kg]
Pw = water-filled soil porosity
Pa = air filled soil porosity
Pb = dry soil bulk density [kg/L]
Hd = dimensionless Henry's Law

Key:

	parameter not modeled; estimated DAF
	2016 entries
na	not applicable
100	DEQ-7/Raw Leaching Soil Target updated

Sand 0.1m scenario **chemical**	**DEQ-7** (mg/L)	**koc**	**koc 2016**	**Hd**	**Predicted attenuation source/POC**	**Predicted attenuation source/POC**	**Target source** (mg/L)	**Target source** (mg/L)	**soil**	**foc**	**Pt**	**Pw**	**Pa**	**Pb**	**Raw Leaching Soil Target**	**Raw Leaching Soil Target** (mg/kg)	**Raw Leaching Soil Target** (mg/kg)	**Raw Leaching Soil Target** (mg/kg)
C5-C8 Aliphatics	7.00E-01	2.27E+03	2.27E+03	5.40E+01	12.6	12.4	8.84E+00	8.68E+00	sand	0.006	0.4	0.079	0.321	1.5	2.23E+02	200	2.19E+02	220
C9-C12 Aliphatics	1.00E+00	1.50E+05	1.50E+05	6.50E+01	12.6	12.3	1.26E+01	1.23E+01							1.15E+04	10,000	1.12E+04	11,000
C9-C10 Aromatics	1.00E+00	1.78E+03	1.78E+03	3.30E-01	12.6	12.5	1.26E+01	1.25E+01							1.36E+02	100	1.35E+02	130
Methyl t-Butyl Ether	3.00E-02	1.20E+01	1.16E+01	2.40E-02	20.1	20.4	6.03E-01	6.12E-01							7.84E-02	0.08	7.78E-02	0.078
Benzene	5.00E-03	6.17E+01	1.46E+02	2.28E-01	16.1	14.3	8.04E-02	7.15E-02							3.79E-02	0.04	6.98E-02	0.070
Toluene	1.00E+00	1.40E+02	2.34E+02	2.72E-01	14.6	13.7	1.46E+01	1.37E+01							1.39E+01	10	2.07E+01	21
Ethylbenzene	7.00E-01	2.04E+02	4.46E+02	3.23E-01	14.1	13.3	9.90E+00	9.31E+00							1.33E+01	10	2.61E+01	26
Xylenes	1.00E+01	2.45E+02	3.83E+02	2.76E-01	13.4	13.4	1.34E+02	1.34E+02							2.12E+02	200	3.23E+02	320
Naphthalene	1.00E-01	1.19E+03	1.54E+03	1.98E-02	12.9	12.7	1.29E+00	1.27E+00							9.32E+00	9	1.18E+01	12
1,2-Dibromoethane	**1.70E-05**	2.50E+01	3.96E+01	3.04E-02	18.03	17.1	3.07E-04	2.91E-04							6.41E-05	0.000064	**8.63E-05**	**0.000086**
1-2-Dichloroethane	4.00E-03	1.74E+01	3.96E+01	4.00E-02	19.23	16.6	7.69E-02	6.64E-02							1.27E-02	0.01	1.98E-02	0.020
C9-C18 Aliphatics	1.00E+00	6.80E+05	6.80E+05	6.90E+01	12.6	13.0	1.26E+01	1.30E+01							5.17E+04	50,000	5.32E+04	53,000
C19-C36 Aliphatics	1.00E+00	immobile	immobile	immobile	immobile	immobile	immobile	immobile							immobile	immobile	immobile	immobile
C11-C22 Aromatics	1.00E+00	5.00E+03	5.00E+03	3.00E-02	12.6	12.3	1.26E+01	1.23E+01							3.80E+02	400	3.70E+02	370
Acenaphthene	**7.00E-02**	4.90E+03	5.0E+03	6.36E-03	12.6	12.6	8.84E-01	8.82E-01							2.60E+01	30	**2.67E+01**	**27**
Anthracene	2.10E+00	2.35E+04	1.6E+04	2.67E-03	12.6	12.6	2.65E+01	2.65E+01							3.74E+03	4,000	2.60E+03	2,600
Benz(a)Anthracene	5.00E-04	3.58E+05	1.8E+05	1.37E-04	12.6	12.8	6.32E-03	6.40E-03							1.36E+01	10	6.79E+00	6.8
Benzo(a)Pyrene	5.00E-05	9.69E+05	5.9E+05	4.63E-05	12.6	13.0	6.32E-04	6.50E-04							3.67E+00	4	2.29E+00	2.3
Benzo (b)Fluoranthene	5.00E-04	1.23E+06	6.0E+05	4.55E-03	12.6	13.0	6.32E-03	6.50E-03							4.66E+01	50	2.34E+01	23
Benzo (k) Fluoranthene	5.00E-03	1.23E+06	5.9E+05	3.40E-05	12.6	13.0	6.32E-02	6.50E-02							4.66E+02	500	2.29E+02	230
Chrysene	5.00E-02	3.98E+05	1.8E+05	3.88E-03	12.6	12.8	6.32E-01	6.40E-01							1.51E+03	2,000	6.93E+02	690
Dibenzo(a,h) Anthracene	5.00E-05	1.79E+06	1.9E+06	6.03E-07	12.6	13.1	6.32E-04	6.55E-04							6.78E+00	7	7.51E+00	7.5
Fluoranthene	**2.00E-02**	4.91E+04	5.5E+04	6.60E-04	12.6	12.7	2.53E-01	2.54E-01							7.44E+01	70	**8.45E+01**	**85**
Fluorene	**5.00E-02**	7.71E+03	9.2E+03	2.61E-03	12.6	12.7	6.32E-01	6.35E-01							2.92E+01	30	**3.49E+01**	**35**
Indeno(1,2,3-cd)Pyrene	5.00E-04	3.47E+06	2.0E+06	6.56E-05	12.6	13.1	6.32E-03	6.55E-03							1.32E+02	100	7.67E+01	77
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	12.9	12.7	1.29E+00	1.27E+00							9.32E+00	9	1.18E+01	12
Pyrene	**2.00E-02**	6.80E+04	5.43E+04	4.51E-04	12.6	12.7	2.53E-01	2.54E-01							1.03E+02	100	**8.28E+01**	**83**
Methylnaphthalene, 1-	1.10E-02	na	2.53E+03	2.1E-02	na	12.8	na	1.41E-01								na	2.14E+00	2.1
Methylnaphthalene, 2-	3.60E-02	na	2.48E+03	2.1E-02	na	12.8	na	4.61E-01								na	6.88E+00	6.9

Sand 3.1m scenario chemical	DEQ-7 (mg/L)	koc	koc 2016	Hd	Predicted attenuation source/POC	Predicted attenuation source/POC	Target source (mg/L)	Target source (mg/L)	soil	foc	Pt	Pw	Pa	Pb	Raw Leaching Soil Target	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)
C5-C8 Aliphatics	7.00E-01	2.27E+03	2.27E+03	5.40E+01	42.6	43.4	2.98E+01	3.04E+01	sand	0.006	0.4	0.073	0.327	1.5	7.57E+02	800	7.72E+02	770
C9-C12 Aliphatics	1.00E+00	1.50E+05	1.50E+05	6.50E+01	42.6	43.4	4.26E+01	4.34E+01							3.89E+04	40,000	3.97E+04	40,000
C9-C10 Aromatics	1.00E+00	1.78E+03	1.78E+03	3.30E-01	42.6	43.4	4.26E+01	4.34E+01							4.59E+02	500	4.68E+02	470
Methyl t-Butyl Ether	3.00E-02	1.20E+01	1.2E+01	2.40E-02	43.3	43.1	1.30E+00	1.29E+00							1.64E-01	0	1.59E-01	0.16
Benzene	5.00E-03	6.17E+01	1.5E+02	2.28E-01	43.3	43.5	2.17E-01	2.18E-01							1.01E-01	0	2.12E-01	0.21
Toluene	1.00E+00	1.40E+02	2.3E+02	2.72E-01	42.9	43.2	4.29E+01	4.32E+01							4.07E+01	40	6.53E+01	65
Ethylbenzene	7.00E-01	2.04E+02	4.5E+02	3.23E-01	42.7	42.9	2.99E+01	3.00E+01							4.01E+01	40	8.40E+01	84
Xylenes	1.00E+01	2.45E+02	3.8E+02	2.76E-01	43.0	42.9	4.30E+02	4.29E+02							6.79E+02	700	1.03E+03	1,000
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	42.6	42.9	4.26E+00	4.29E+00							3.06E+01	30	4.00E+01	40
1,2-Dibromoethane	**1.70E-05**	2.50E+01	4.0E+01	3.04E-02	44.01	43.5	7.48E-04	7.40E-04							1.54E-04	0	**2.17E-04**	**0.00022**
1-2-Dichloroethane	4.00E-03	1.74E+01	4.0E+01	4.00E-02	43.42	43.7	1.74E-01	1.75E-01							2.81E-02	0	5.16E-02	0.052
C9-C18 Aliphatics	1.00E+00	6.80E+05	6.80E+05	6.90E+01	42.6	42.4	4.26E+01	4.24E+01							1.74E+05	200,000	1.74E+05	170,000
C19-C36 Aliphatics	1.00E+00	immobile	immobile	immobile	immobile	immobile	immobile	immobile							none	immobile	immobile	immobile
C11-C22 Aromatics	1.00E+00	5.00E+03	5.00E+03	3.00E-02	42.6	43.4	4.26E+01	4.34E+01							1.28E+03	1,000	1.30E+03	1,300
Acenaphthene	**7.00E-02**	4.90E+03	5.0E+03	6.36E-03	42.6	42.9	2.98E+00	3.00E+00							8.77E+01	90	**9.07E+01**	**91**
Anthracene	2.10E+00	2.35E+04	1.6E+04	2.67E-03	42.6	42.7	8.94E+01	8.97E+01							1.26E+04	10,000	8.81E+03	8,800
Benz(a)Anthracene	5.00E-04	3.58E+05	1.8E+05	1.37E-04	42.6	42.4	2.13E-02	2.12E-02							4.57E+01	50	2.25E+01	23
Benzo(a)Pyrene	5.00E-05	9.69E+05	5.9E+05	4.63E-05	42.6	42.4	2.13E-03	2.12E-03							1.24E+01	10	7.47E+00	7.5
Benzo (b)Fluoranthene	5.00E-04	1.23E+06	6.0E+05	4.55E-03	42.6	42.4	2.13E-02	2.12E-02							1.57E+02	200	7.62E+01	76
Benzo (k) Fluoranthene	5.00E-03	1.23E+06	5.9E+05	3.40E-05	42.6	42.4	2.13E-01	2.12E-01							1.57E+03	2,000	7.47E+02	750
Chrysene	5.00E-02	3.98E+05	1.8E+05	3.88E-03	42.6	42.4	2.13E+00	2.12E+00							5.08E+03	5,000	2.30E+03	2,300
Dibenzo(a,h) Anthracene	5.00E-05	1.79E+06	1.9E+06	6.03E-07	42.6	42.4	2.13E-03	2.12E-03							2.28E+01	20	2.43E+01	24
Fluoranthene	**2.00E-02**	4.91E+04	5.5E+04	6.60E-04	42.6	42.5	8.51E-01	8.50E-01							2.51E+02	300	**2.83E+02**	**280**
Fluorene	**5.00E-02**	7.71E+03	9.2E+03	2.61E-03	42.6	42.7	2.13E+00	2.14E+00							9.85E+01	100	**1.17E+02**	**120**
Indeno(1,2,3-cd)Pyrene	5.00E-04	3.47E+06	2.0E+06	6.56E-05	42.6	42.4	2.13E-02	2.12E-02							4.43E+02	400	2.48E+02	250
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	42.6	42.9	4.26E+00	4.29E+00							3.06E+01	30	4.00E+01	40
Pyrene	**2.00E-02**	6.80E+04	5.4E+04	4.51E-04	42.6	42.6	8.51E-01	8.52E-01							3.47E+02	300	**2.78E+02**	**280**
Methylnaphthalene, 1-	1.10E-02	na	2.5E+03	2.1E-02	na	42.7	na	4.70E-01								na	7.15E+00	7.1
Methylnaphthalene, 2-	3.60E-02	na	2.5E+03	2.1E-02	na	42.7	na	1.54E+00								na	2.29E+01	23

Sand 6.1m scenario chemical	DEQ-7 (mg/L)	koc	koc 2016	Hd	Predicted attenuation source/POC	Predicted attenuation source/POC	Target source (mg/L)	Target source (mg/L)	soil	foc	Pt	Pw	Pa	Pb	Raw Leaching Soil Target	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)
C5-C8 Aliphatics	7.00E-01	2.27E+03	2.27E+03	5.40E+01	65.8	66.9	4.60E+01	4.68E+01	sand	0.006	0.4	0.073	0.327	1.5	1.17E+03	1,000	1.19E+03	1,200
C9-C12 Aliphatics	1.00E+00	1.50E+05	1.50E+05	6.50E+01	65.8	65.5	6.58E+01	6.55E+01							6.01E+04	60,000	5.99E+04	60,000
C9-C10 Aromatics	1.00E+00	1.78E+03	1.78E+03	3.30E-01	65.8	66.9	6.58E+01	6.69E+01							7.10E+02	700	7.22E+02	720
Methyl t-Butyl Ether	3.00E-02	1.20E+01	1.2E+01	2.40E-02	66.7	66.3	2.00E+00	1.99E+00							2.52E-01	0	2.45E-01	0.25
Benzene	5.00E-03	6.17E+01	1.5E+02	2.28E-01	66.8	67.1	3.34E-01	3.36E-01							1.56E-01	0	3.26E-01	0.33
Toluene	1.00E+00	1.40E+02	2.3E+02	2.72E-01	66.3	66.6	6.63E+01	6.66E+01							6.28E+01	60	1.01E+02	100
Ethylbenzene	7.00E-01	2.04E+02	4.5E+02	3.23E-01	65.9	66.3	4.62E+01	4.64E+01							6.20E+01	60	1.30E+02	130
Xylenes	1.00E+01	2.45E+02	3.8E+02	2.76E-01	66.3	66.3	6.63E+02	6.63E+02							1.05E+03	1,000	1.60E+03	1,600
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	65.8	66.2	6.58E+00	6.62E+00							4.74E+01	50	6.17E+01	62
1,2-Dibromoethane	**1.70E-05**	2.50E+01	4.0E+01	3.04E-02	67.7	67.1	1.15E-03	1.14E-03							2.36E-04	0	**3.34E-04**	**0.00033**
1-2-Dichloroethane	4.00E-03	1.74E+01	4.0E+01	4.00E-02	66.9	67.3	2.67E-01	2.69E-01							4.33E-02	0	7.94E-02	0.079
C9-C18 Aliphatics	1.00E+00	6.80E+05	6.80E+05	6.90E+01	65.8	65.5	6.58E+01	6.55E+01							2.69E+05	300,000	2.68E+05	270,000
C19-C36 Aliphatics	1.00E+00	immobile	immobile	immobile	immobile	immobile	immobile	immobile							none	immobile	immobile	immobile
C11-C22 Aromatics	1.00E+00	5.00E+03	5.00E+03	3.00E-02	65.8	66.9	6.58E+01	6.69E+01							1.98E+03	2,000	2.01E+03	2,000
Acenaphthene	**7.00E-02**	4.90E+03	5.0E+03	6.36E-03	65.8	66.2	4.60E+00	4.63E+00							1.36E+02	100	**1.40E+02**	**140**
Anthracene	2.10E+00	2.35E+04	1.6E+04	2.67E-03	65.8	66.0	1.38E+02	1.39E+02							1.95E+04	20,000	1.36E+04	14,000
Benzo(a)Anthracene	5.00E-04	3.58E+05	1.8E+05	1.37E-04	65.8	65.5	3.29E-02	3.28E-02							7.06E+01	70	3.48E+01	35
Benzo(a)Pyrene	5.00E-05	9.69E+05	5.9E+05	4.63E-05	65.8	65.5	3.29E-03	3.28E-03							1.91E+01	20	1.15E+01	12
Benzo (b)Fluoranthene	5.00E-04	1.23E+06	6.0E+05	4.55E-03	65.8	65.5	3.29E-02	3.28E-02							2.43E+02	200	1.18E+02	120
Benzo (k) Fluoranthene	5.00E-03	1.23E+06	5.9E+05	3.40E-05	65.8	65.5	3.29E-01	3.28E-01							2.43E+03	2,000	1.15E+03	1,200
Chrysene	5.00E-02	3.98E+05	1.8E+05	3.88E-03	65.8	65.5	3.29E+00	3.28E+00							7.85E+03	8,000	3.55E+03	3,500
Dibenzo(a,h) Anthracene	5.00E-05	1.79E+06	1.9E+06	6.03E-07	65.8	65.5	3.29E-03	3.28E-03							3.53E+01	40	3.76E+01	38
Fluoranthene	**2.00E-02**	4.91E+04	5.5E+04	6.60E-04	65.8	65.7	1.32E+00	1.31E+00							3.88E+02	400	**4.37E+02**	**440**
Fluorene	**5.00E-02**	7.71E+03	9.2E+03	2.61E-03	65.8	66.0	3.29E+00	3.30E+00							1.52E+02	200	**1.82E+02**	**180**
Indeno(1,2,3-cd)Pyrene	5.00E-04	3.47E+06	2.0E+06	6.56E-05	65.8	65.5	3.29E-02	3.28E-02							6.85E+02	700	3.83E+02	380
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	65.8	66.2	6.58E+00	6.62E+00							4.74E+01	50	6.17E+01	62
Pyrene	**2.00E-02**	6.80E+04	5.4E+04	4.51E-04	65.8	65.8	1.32E+00	1.32E+00							5.37E+02	500	**4.29E+02**	**430**
Methylnaphthalene, 1-	1.10E-02	na	2.5E+03	2.1E-02	na	66.0	na	7.26E-01							na	na	1.11E+01	11
Methylnaphthalene, 2-	3.60E-02	na	2.5E+03	2.1E-02	na	66.0	na	2.38E+00							na	na	3.55E+01	35