Tier 2 Lateral Groundwater Transport PCL Equations

$$^{GW}LT\text{-}GW_{Ing} = {}^{GW}GW_{Ing} \cdot DAF$$

$$^{GW}LT\text{-}GW_{Class3} = {}^{GW}GW_{Class3} \cdot DAF$$

$$^{SW}LT\text{-}GW = {}^{SW}GW \cdot DAF$$

(for $^{GW}GW_{Ing}$, $^{GW}GW_{Class\ 3}$, ^{SW}GW see Figure: 30 TAC §350.75(b)(1))

$$DAF = \frac{C_{si}}{C(x)_i} = \text{inverse of below expression}$$

Solute Transport with First-Order Decay:

Calibrate transient model to site conditions making sure that the condition, $C(x)_i = C_{si}$ at source is satisfied when x=0. Then solve the steady state model to determine DAF using the same parameters used to calibrate the transient model.

Transient:

$$\frac{C(x)_i}{C_{si}}trans = \left(\frac{1}{2}\right)\exp\left(\left(\frac{x}{2\alpha_x}\right)\left[1-\sqrt{1+\frac{4\lambda_i\alpha_x}{v}}\right]\right)erfc\left[\frac{x-vt\sqrt{1+4\lambda_i\alpha_x/v}}{2\sqrt{\alpha_x vt}}\right]erf\left(\frac{S_w}{4\sqrt{\alpha_y x}}\right)erf\left(\frac{Sd}{2\sqrt{\alpha_z(x\text{ or }x')}}\right)$$

Steady state:

$$\frac{C(x)_i}{C_{si}}max = \exp\left(\frac{x}{2\alpha_x}\left[1-\sqrt{1+\frac{4\lambda_i\alpha_x}{v}}\right]\right)erf\left(\frac{S_w}{4\sqrt{\alpha_y x}}\right)erf\left(\frac{S_d}{2\sqrt{\alpha_z(x\text{ or }x')}}\right)$$

Use x′ in vertical dispersivity term when $x \geq x'$, otherwise use x.

Solute Transport with Biodegradation by Electron-Acceptor Superposition Method:

$$C(x)_i = \left[(C_{si} + B\,C_i)\ erf\left(\frac{S_w}{4\sqrt{\alpha_y x}}\right)erf\left(\frac{S_d}{2\sqrt{\alpha_z x}}\right)\right] - BC_i$$

$$\text{where}: \quad BC_i = BC_T \cdot \frac{C_{si}}{\Sigma C_{si}} \quad \text{and} \quad BC_T = \Sigma\frac{C(ea)_n}{UF_n}$$

Tier 2 Lateral Air Transport PCL Equations

$$^{\text{LT-Air}}GW_{\text{Inh-V}} = {}^{\text{Air}}GW_{\text{Inh-V}} \cdot \text{ADF (See Figure : 30TAC §350.75(b)(1))}$$
$$^{\text{LT-Air}}Soil_{\text{Inh-VP}} = {}^{\text{Air}}Soil_{\text{Inh-VP}} \cdot \text{ADF (See Figure : 30TAC §350.75(b)(1))}$$
$$^{\text{LT-Air}}Soil_{\text{Inh-V}} = {}^{\text{Air}}Soil_{\text{Inh-V}} \cdot \text{ADF (See Figure : 30TAC §350.75(b)(1))}$$

$$\text{ADF} = \frac{C_{si}}{C(x)_i} = \text{inverse of below expression}$$

$$\frac{C(x)_i}{C_{si}} = \frac{Q}{2\pi U_{air}\sigma_y\sigma_z} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left(\exp\left(-\frac{(z-\delta_{air})^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+\delta_{air})^2}{2\sigma_z^2}\right)\right)$$

$$\text{where :} \quad Q = \frac{U_{air}(\delta_{air})(A)}{L}$$

Tier 2 Soil-to-Groundwater PCL Equation

$$^{GW}\text{Soil} = \frac{(\text{Groundwater PCL}^{*}) \cdot \text{LDF}}{K_{sw}} \cdot \frac{L_2}{L_1}$$

*Critical groundwater PCL as determined in accordance with §350.78.

$$K_{sw}\left[\frac{(\text{mg / L - } H_2O)}{(\text{mg / kg - soil})}\right] = \frac{\rho_b}{\theta_{ws} + K_d\rho_b + H'\theta_{as}}$$

$$\text{LDF [dimensionless]} = 1 + \frac{U_{gw}\delta_{gw}}{I_f W_s}$$

$$\delta_{gw}\,[\text{m}] = (2\alpha_v W_s)^{0.5} + b_{gw}\left[1 - \exp\left(\frac{-I_f W_s}{U_{gw} b_{gw}}\right)\right]$$

Theoretical Soil Saturation Limit Equation for Liquids

$$C_{sat}\,(\text{mg/kg}) = \left(\frac{S}{\rho_b}\right)[\theta_{ws} + K_d\rho_b + \theta_{as}H']$$

not applicable to mercury

Term	COC Chemical/Physical and Affected Property Parameters Definition	Tier 1 Defaults	Change to Tier 1 Default Allowed?	Rule Citation
C_{si}	Concentration of COC *i* in source zone (mg/L or mg/m^3)	NA	NA	§350.75(c) and (d)
$C(x)_i$	Concentration of COC *i* at distance x downgradient or downwind of source (mg/L or mg/m^3)	NA	NA	§350.75(c) and (d)
x	Distance downgradient or downwind of source (m)	NA	Tier 2, 3	§350.33(f)(4) and §350.37 (b), (e)-(i)
x′	vertical limit over which spreading occurs (m) $x' = (b_{gw}-S_d)^2/\alpha_z$	NA	Tier 2, 3	§350.75(c) and (d)
b_{gw}	Aquifer thickness (m)	NA	Tier 2, 3	§350.75(c) and (d)
S_d	Source depth (m)	NA	Tier 2, 3	§350.75(c) and (d)
α_x	Longitudinal groundwater dispersivity (m)	NA	Tier 2, 3	§350.75(c) and (d)
α_y	Transverse groundwater dispersivity (m)	NA	Tier 2, 3	§350.75(c) and (d)
α_z	Vertical groundwater dispersivity (m)	NA	Tier 2, 3	§350.75(c) and (d)
λ_i	First-order degradation rate (day^{-1}) for COC *i*	NA	Tier 2, 3	§350.75(c) and (d) and §350.75(f)
t	Time since release (days)	NA	Tier 2, 3	--
v	COC velocity (m/day) $v = v_w/R_i$	NA	Tier 2, 3	§350.75(c) and (d)
v_w	Groundwater seepage velocity (m/day) $v_w = K \cdot i/\theta_e$	NA	Tier 2, 3	§350.75(c) and (d)
K	Hydraulic conductivity (m/day)	NA	Tier 2, 3	§350.75(c) and (d)
i	Hydraulic gradient (m/m)	NA	Tier 2, 3	§350.75(c) and (d)
θ_e	Effective soil porosity	NA	Tier 2, 3	§350.75(c) and (d)
R_i	Constituent retardation factor $R_i = 1+K_d \rho_b/\theta_T$	NA	Tier 2, 3	§350.75(c) and (d)
K_d	Soil-water partition coefficient (cm^3-water/g-soil) •for organics • for inorganics	(Figure 30 TAC §350.73(e)) $K_d = K_{oc} \cdot foc$ K_d = pH dependent value	Tier 2, 3	§350.73(e) and (Figures 30 TAC §350.73(e)(1)(A-C)
K_{oc}	Soil organic carbon-water partition coefficient (cm^3-water/g-carbon)	(Figure 30 TAC §350.73(e))	Tier 2, 3	§350.73(e) and (Figures 30 TAC §350.73(e)(1)(A-C)
foc	Fraction of organic carbon in soil (g-carbon/g-soil) (soil-to-groundwater)	0.002 (soil-to-groundwater)	Tier 2, 3	§350.75(c) and (d)
ρ_b	Soil bulk density (g-soil/cm^3-soil)	1.67	Tier 2, 3	§350.75(c) and (d)
θ_T	Total soil porosity = 1 - (ρ_b/ρ_s) (cm^3-pore space/cm^3-soil)	NA	Tier 2, 3	§350.75(c) and (d)
ρ_s	Particle density (g/cm^3)	2.65	Tier 2, 3	§350.75(c) and (d)
erfc	Complimentary error function (see pg 637, Domenico, P.A. and Schwartz, F.W., 1990. *Physical and Chemical Hydrogeology*, John Wiley & Sons, New York. 824pp. or p. 539, Cherry, J. A., 1979. *Groundwater*, Prentice-Hall, New Jersey. 604 pp.)	NA	Tier 2, 3	--

Term	COC Chemical/Physical and Affected Property Parameters Definition	Tier 1 Defaults	Change to Tier 1 Default Allowed?	Rule Citation
erf	Error function (see pg 637, Domenico, P.A. and Schwartz, F.W., 1990. *Physical and Chemical Hydrogeology*, John Wiley & Sons, New York. 824pp. or p. 539, Cherry, J. A., 1979. *Groundwater*, Prentice-Hall, New Jersey. 604 pp.)	NA	Tier 2, 3	--
S_w	Source width (m)	NA	Tier 2, 3	§350.75(c) and (d)
BC_i	Biodegradation capacity available for COC *i*	NA	Tier 2, 3	§350.75(c) and (d) and §350.75(f)
BC_T	Total biodegradation capacity of all electron acceptors in groundwater	NA	Tier 2, 3	§350.75(c) and (d) and §350.75(f)
$C(ea)_n$	Concentration of electron acceptor *n* in groundwater	NA	Tier 2, 3	§350.75(c) and (d)
UF_n	Utilization factor for electron acceptor *n* (*i.e.*, mass ratio of electron acceptor to hydrocarbon consumed in biodegradation reaction)	NA	Tier 2, 3	§350.75(c) and (d) and §350.75(f)
U_{air}	Windspeed above ground surface in ambient mixing zone (m/s)	2.4	Tier 2, 3	§350.75(c) and (d)
δ_{air}	Ambient air mixing zone height (m)	2	No	NA
A	Cross sectional area of air emissions source (m^2)	NA	Tier 2, 3	§350.75(c) and (d)
L	Length of air emissions source (m) parallel to wind direction	NA	Tier 2, 3	§350.75(c) and (d)
σ_y	Transverse air dispersion coefficient (m) (dispersion estimates based on the Pasquill-Gifford system adopted by U.S. Public Health Service, Turner, 1970, *EPA Workbook of Atmospheric Dispersion Estimates*; see Cooper & Alley, 1994, *Air Pollution Control*)	NA	Tier 2, 3	§350.75(c) and (d)
σ_z	Vertical air dispersion coefficient (m) (dispersion estimates based on the Pasquill-Gifford system adopted by U.S. Public Health Service, Turner, 1970, *EPA Workbook of Atmospheric Dispersion Estimates*; see Cooper & Alley, 1994, *Air Pollution Control*)	NA	Tier 2, 3	§350.75(c) and (d)
Q	Air volumetric flow through mixing zone (m^3/s)	NA	Tier 2, 3	§350.75(c) and (d)
y	Lateral distance from source zone (assumed to be 0) (m)	0	No	NA
z	Height of breathing zone (assumed equal to δ_{air}) (m)	2	No	NA
K_{sw}	Soil-leachate partition factor for COC (mg/L-water/mg/kg-soil)	property-specific	Tier 2, 3	§350.75(e) and §350.75(c) and (d)

Term	COC Chemical/Physical and Affected Property Parameters Definition	Tier 1 Defaults	Change to Tier 1 Default Allowed?	Rule Citation
θ_{ws}	Volumetric water content of vadose zone soils (soil-to-groundwater) (cm^3-water/cm^3-soil)	0.16	Tier 2, 3	§350.75(c) and (d)
θ_{as}	Volumetric air content of vadose zone soils (cm^3-air/cm^3-soil) = θ_T-θ_{ws}	0.21	Tier 2, 3	§350.75(c) and (d)
H'	Henry's Law Constant (dimensionless) H′ = H/RT	(Figure 30 TAC §350.73(e))	No	NA
H	Henry's Law Constant (atm-m^3/mol) H = H′RT	See H′	No	NA
S	Aqueous solubility limit of COC (mg/l)	NA	Tier 2, 3	§350.75(i)(9)
R	Universal Gas Constant (atm-m^3/gmol-°K)	8.25×10^{-5}	No	NA
T	Temperature (°K) = 273 + °C	293	No	NA
LDF	Lateral Dilution Factor			
	0.5 acre source area	20	Tier 2, 3	§350.75(c) and (d)
	30 acre source area	10	Tier 2, 3	§350.75(c) and (d)
L_1	Thickness of affected soil (cm)	NA	Tier 2, 3	§350.75(c) and (d)
L_2	Depth from top of affected soil to groundwater table (cm)	$L_2 = L_1$	Tier 2, 3	§350.75(c) and (d)
U_{gw}	Groundwater Darcy velocity (cm/yr) $U_{gw} = K \cdot i \cdot 36{,}500$ d-cm/yr-m *Note:* U_{gw} must be converted to units of cm/yr	NA	Tier 2, 3	§350.75(c) and (d)
δ_{gw}	Groundwater mixing zone thickness (m) upper bound: $\delta_{gw} \leq b_{gw}$	NA	Tier 2, 3	§350.75(c) and (d)
I_f	Net infiltration rate of water through soil (cm/yr) Upper bound: $I_f \leq K_{vs}$ (3.15×10^7s/yr)	NA	Tier 2, 3	§350.75(c) and (d)
	•sand		$0.0018(P)^2$	
	•silt		$0.0009(P)^2$	
	•clay		$0.00018(P)^2$	
K_{vs}	Saturated hydraulic conductivity of vadose zone soils (cm/s)	NA	Tier 2, 3	§350.75(c) and (d)
P	Mean annual precipitation (cm/yr)	NA	Tier 2, 3	§350.75(c) and (d)
α_v	Vertical groundwater dispersivity = $0.0056 \cdot W_s$ (m)	NA	Tier 2, 3	§350.75(c) and (d)
W_s	Lateral width of affected vadose zone in direction of groundwater flow (m)	NA	Tier 2, 3	§350.75(c) and (d)
C_{sat}	Soil saturation limit (mg_i/kg-soil)	NA	Tier 2, 3	§350.75(i)(9)