

Tier 2 PCL Equations

Tier 2 Lateral Groundwater Transport PCL Equations

$$\begin{aligned} {}^{GW}LT - {}^{GW}GW_{Ing} &= {}^{GW}GW_{Ing} \cdot DAF \\ {}^{GW}LT - {}^{GW}GW_{Class3} &= {}^{GW}GW_{Class3} \cdot DAF \\ {}^{SW}LT - {}^{SW}GW &= {}^{SW}GW \cdot DAF \\ \text{(for } {}^{GW}GW_{Ing}, {}^{GW}GW_{Class3}, {}^{SW}GW \text{ see Figure: 30 TAC §350.75(b)(1))} \end{aligned}$$

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

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:

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

Steady state:

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

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

Solute Transport with Biodegradation by Electron-Acceptor Superposition Method:

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

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

Tier 2 Lateral Air Transport PCL Equations

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

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

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

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

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

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

Tier 2 Soil-to-Groundwater PCL Equation

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

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

$$K_{sw} \left[\frac{(\text{mg} / \text{L} - \text{H}_2\text{O})}{(\text{mg} / \text{kg} - \text{soil})} \right] = \frac{\rho_b}{\theta_{ws} + K_d \rho_b + H' \theta_{as}}$$

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

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

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) $x' = (b_{gw} \cdot S_d)^2 / \alpha_z$	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)) $K_d = K_{oc} \cdot foc$ $K_d = \text{pH dependent value}$	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 = $1 - (\rho_b / \rho_s)$ (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. <i>Physical and Chemical Hydrogeology</i> , John Wiley & Sons, New York. 824pp. or p. 539, Cherry, J. A., 1979. <i>Groundwater</i> , 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. <i>Physical and Chemical Hydrogeology</i> , John Wiley & Sons, New York. 824pp. or p. 539, Cherry, J. A., 1979. <i>Groundwater</i> , 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, <i>EPA Workbook of Atmospheric Dispersion Estimates</i> ; see Cooper & Alley, 1994, <i>Air Pollution Control</i>)	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, <i>EPA Workbook of Atmospheric Dispersion Estimates</i> ; see Cooper & Alley, 1994, <i>Air Pollution Control</i>)	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) = $\theta_T - \theta_{ws}$	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 x 10 ⁻⁵	No	NA
T	Temperature (°K) = 273 + °C	293	No	NA
LDF	Lateral Dilution Factor 0.5 acre source area 30 acre source area	20 10	Tier 2, 3 Tier 2, 3	§350.75(c) and (d) §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 · i · 36,500 d-cm/yr-m <i>Note:</i> 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 ≤ K _{vs} (3.15 x 10 ⁷ s/yr) •sand •silt •clay	NA	Tier 2, 3 0.0018(P) ² 0.0009(P) ² 0.00018(P) ²	§350.75(c) and (d)
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 · 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/kg-soil)	NA	Tier 2, 3	§350.75(i)(9)