Establishing Critical Protective Concentration Levels (PCLs) for Lead-Affected Soils

Effective Date: August 2, 2001

Introduction

The purpose of this document is to describe the processes for establishing critical PCLs for lead-affected soils which are protective of human receptors under the Texas Risk Reduction Program (TRRP) and to provide some pre-calculated values.

Tier 1

For lead-affected soils, the TRRP Tier 1 $^{Tot}Soil_{Comb}$ PCL is 500 mg/kg (residential) and 1,600 mg/kg (commercial/industrial), and the Tier 1 $^{GW}Soil_{Ing}$ PCL is 3.0 mg/kg (Class 1 and 2 groundwater) and 300 mg/kg (Class 3 groundwater). Historically, Synthetic Precipitation Leaching Procedure (SPLP) or Toxicity Characteristic Leaching Procedure (TCLP) tests have been used in determining site-specific ^{GW}Soil PCLs for lead in soil. However, the aggressive acidic treatment to which soils are subjected in the TCLP/SPLP extraction procedure do not always provide appropriate results to derive lead soil-water partition coefficients (K_d) and may over predict the amount of leachable lead that is impacting groundwater for many sites.

Background

For sites with Class 1 or 2 groundwater, the Texas-specific median soil lead background concentration of 15 mg/kg, as stated in '350.51(m) or a higher site-specific background concentration replaces the Tier 1 $^{GW}Soil_{Ing}$ PCL for lead. If a site-specific background assessment is planned, samples must be collected from areas unaffected by activities related to waste management activities, in accordance with '350.51(l)(2) and must be representative of the same geologic stratum as the potentially affected stratum with the lead concentrations.

Tier 2

The TRRP Tier 2 $^{GW}Soil_{Ing}$ PCL equation can be used to develop a site-specific level for lead in soil that is protective of groundwater in lieu of the Tier 1 or background approaches. This equation is located at the end of this document. The goal in developing a site-specific lead $^{GW}Soil_{Ing}$ PCL using the Tier 2 equation is to establish a $^{GW}Soil_{Ing}$ PCL which is based on soil and lead-specific properties that affect the migration potential of lead from the soil to groundwater at the site. The following site-specific data may greatly impact the calculated Tier 2 $^{GW}Soil_{Ing}$ PCL for lead at an affected property:

- size of lead source area
- soil type and pH
- thickness of lead-affected soils
- depth to groundwater
- groundwater classification

Even though the Tier 2 equation is used to develop ^{GW}Soil PCLs, default Tier 1 inputs or site-specific data can be used for most of the parameters in the equations. For example, Tier 1 default inputs may be chosen for all the inputs to the K_{sw} equation except for K_d. Since K_d varies based on the soil type and pH of the soil as shown in Figure 30: TAC 350.73(e)(1)(A), the calculation of a site-specific K_d allowed under Tier 2 provides typically higher ^{GW}Soil PCLs than utilizing the default Tier 1. The parameters L_1 and L_2 should be determined on a site-specific basis.

Inputs to the Tier 2 equation are derived from the following affected property data: 1) size of source area; 2) soil type and pH; 3) thickness of affected soil; 4) depth to groundwater; and 5) groundwater classification. A description of how the affected property data can affect the determination of a $^{GW}Soil_{Ing}$ PCL is discussed below.

Size of Source Area

For affected properties with Class 1 or 2 groundwater or where the depth to groundwater is unknown, the lateral extent of affected soil should be determined to 15 mg/kg (Texas-specific median background concentration) or a higher site-specifically established background concentration. Affected properties with Class 3 groundwater should be assessed to the lower of a background concentration or 300 mg/kg (Tier 1 $^{GW}Soil_{Class\ 3}$ PCL). Statistical methods for comparing site-specific background levels to potentially impacted soil are described in '350.79(2)(B). Once the areal extent of lead-affected soil is determined, the data are used to determine the lateral dilution factor (LDF) input to the Tier 2 equation. There are two options for developing the LDF input to the equation. Either the Tier 1 default inputs may be used or a site-specific LDF can be calculated. If a background concentration or a Tier 1 $^{GW}Soil_{Class\ 3}$ PCL was used to establish the source area size, then an LDF of 20 may be used for a source area less than or equal to **2** acre, or an LDF of 10 should be used if the source area is greater than **2** acre but not greater than 30 acres. For source areas greater than 30 acres a site-specific LDF should be determined. The steps necessary to develop a site-specific LDF are not addressed in this document.

Soil Type and pH

Soil type and pH are used to determine the appropriate K_d which is an input into the K_{sw} equation. Soils should be classified using the Unified Soil Classification System ASTM D2488-00 standard or an equivalent classification determined using the U.S. Department of Agriculture classification system of sand, loam or clay within the affected soil horizon.

The soil pH within that soil horizon may be estimated from literature studies such as U.S. Soil Conservation Service (SCS) surveys. If the SCS surveys indicate a pH range which crosses over a pH category, then the geometric mean pH value must be used. If literature information is unavailable, field soil pH should be analyzed throughout the affected soil horizon.

Once the soil type and pH within the affected soil horizon are measured, refer to Figure: 30 TAC 350.73(e)(1)(A) - ASoil-Water Distribution Coefficients (K_d) for Aluminum and Lead@ for identification of the applicable K_d value.

Depth of Affected Soil to Background (L_1) and Depth to Groundwater (L_2)

A ratio of the depth from the top of the affected soil to groundwater (L_2) and the thickness of affected soil (L_1) is calculated to estimate attenuation of contamination in the soil column above groundwater. The vertical extent of affected soil (L_1) should be set as the thickness of the soil that contains chemicals of concern (COCs) in excess of the applicable Tier 1 ^{GW}Soil PCL (either the default or site-specific background concentration will be the Tier 1 PCL as they are at higher concentrations than the default Tier 1 ^{GW}Soil PCL). The vertical extent of affected soil is input as L_1 in the Tier 2 equation. The parameter L_2 should be measured from the top of the affected soil to groundwater. However, if the vertical limit of soil lead concentrations which exceed default or site-specific background has been characterized and no groundwater was encountered, the L_2 should be measured from the top of the affected soil to a depth which results in a concentration at or below the corresponding Tier 2 Lead Groundwater-to-Soil PCL (see example PCLs in the below table).

For example, a commercial affected property with loamy soil has a soil pH in the range of 7, a source area of 0.5 acres and an L_1 thickness of 8 feet (located from 0-8 feet below ground surface) with a highest concentration of 2000 mg/kg. According to the below table, since an L_2/L_1 value of 2 allows a $^{GW}Soil_{Ing}$ PCL of 1098 mg/kg and since this PCL is greater than the 1000 mg/kg sample concentration, the boring completion depth should extend to no less than 16 feet below ground surface (L_2). Since the critical PCL is the lowest PCL for a COC within a source medium determined from all applicable human health exposure pathways, the critical PCL for lead would be 1098 mg/kg ($^{GW}Soil_{Ing}$ PCL) for all soils.

Groundwater Classification

The classification of the groundwater affects the groundwater PCL in the Tier 2 equation. If the groundwater is classified as Class 1 or Class 2, then 0.015 mg/l should be inserted into the equation. If the groundwater is classified as Class 3, then 1.5 mg/L should be inserted into the equation (i.e., 100 x $^{GW}GW_{Ing)}$.

Example Calculations

The following two examples are provided to illustrate calculation of $^{GW}Soil_{Ing}$ PCLs using the Tier 2 equation with modifications to Tier 1 parameter values as noted:

Example 1 - For an affected property with an affected area less than 0.5 acres containing clayey soils and a soil pH between 5 and 9, the K_d is 1,830 (See Figure: 30 TAC ' 350.73(e)(1)(A)) and the LDF is 20, the depth to groundwater is unknown so L_2/L_1 equals one. The resulting lead $^{GW}Soil_{Ing}$ PCL is 549 mg/kg. The calculation is shown below:

$$^{GW}Soil_{Ing} = \frac{(0.015) * 20 * 1}{K_{SW}} \qquad K_{SW} = \frac{1.67}{0.16 + (1830)(1.67) + (0)(0.21)} = 5.46 \text{ X } 10^{-4}$$

$^{Gw}Soil_{Ing}$ = 549 mg/kg

Example 2 - For an affected property with a source area less than 0.5 acres containing 100% clayey soils and a pH between 5 and 9, the K_d is 1,830 (See Figure: 30 TAC §350.73(e)(1)(A)), the LDF is 20. However, in this example the depth of affected soil and the depth from the top of the affected soil to groundwater is known. The total depth from the top of the affected soil horizon to the groundwater table (L_2) is 20 feet and the total thickness of the affected soil (L_1) is 2 feet. Therefore L_2/L_1 equals 10. The lead ^{GW}Soil PCL is 5,490 mg/kg. The calculation is shown below:

$$^{GW}Soil_{Ing} = \frac{(0.015) * 20 * 10}{K_{SW}} \qquad K_{SW} = \frac{1.67}{0.16 + (1830)(1.67) + (0)(0.21)} = 5.46 \text{ X } 10^{-4}$$

$^{Gw}Soil_{Ing}$ = 5490 mg/kg

This example illustrates how incorporating the depth to groundwater into the calculation can significantly change the $^{GW}Soil_{Ing}$ PCL. Examples of precalculated Tier 2 lead $^{GW}Soil_{Ing}$ PCLs for 0.5 and 30 acres source areas with sandy, loamy and clayey soil, pH greater than and less than 5, for ratios of L_2/L_1 ranging from 1 to 8 are depicted in the attached table.

Determining Critical PCLs for Surface Soils and Subsurface Soils

The calculated $^{GW}Soil_{Ing}$ PCL concentrations stated in this document are critical PCLs for subsurface soils, but may not be critical PCLs for surface soils. The definition for surface and subsurface soils are presented in §350.4(a)(88) and (86), respectively. For example, using the above-stated Tier 2 situation and where the affected property is a commercial/industrial land use, the Tier 1 $^{Tot}Soil_{Comb}$ PCL (1600 mg/kg) is the critical PCL for surface soils (0-5 foot depth) assuming the property has a 0.5 acre source area size and L_2/L_1 of 10 and a pH greater than 5. In this example, the $^{GW}Soil_{Ing}$ PCL (5490 mg/kg) is the critical PCL for soils located below the 5 foot depth (subsurface soils). However, as shown in the example calculations in the attached table, if the soil type was sandy instead of clayey and all other parameters remained the same, the critical PCL for both the surface and subsurface soils would be based upon the $^{GW}Soil_{Ing}$ PCL of 702 mg/kg, since it is less than the $^{Tot}Soil_{Comb}$ PCL of 1600 mg/kg.

Tier 3

If soil concentrations exceed the Tier 2 PCL, one may be able to demonstrate that the soil leachate-to-groundwater exposure pathway is not complete according to §350.75(i)(7)(C); therefore, it may not be necessary to establish a soil leachate-to-groundwater PCL. This section of the TRRP rule provides general criteria where site-specific information gathered through an affected property assessment may be used to demonstrate that contaminated surface soils will not likely leach to groundwater. For example, if lead affected soil overlies several hundred feet of unfractured shale and shallow groundwater is not encountered in the soil horizon, one can deduce the soil-to-groundwater pathway is not complete and that the ^{GW}Soil PCL is not an exposure pathway of concern.

Example Tier 2 Lead Groundwater-to-Soil PCLs for 0.5 and 30 Acre Source Areas with Sandy, Loamy and Clayey Soils for soils with pH <5 and pH >5.

Sandy Soil

0.5 acre source area $^{GW}Soil_{Ing}$ for Lead (mg/kg)								
L_2/L_1	1	2	3	4	5	6	7	8
pH<5 K_d =10	3	6	9	12	15	18	21	24
pH>5 K_d =234	70	140	210	280	350	420	490	560

30 acre source area $^{GW}Soil_{Ing}$ for Lead (mg/kg)								
L_2/L_1	1	2	3	4	5	6	7	8
pH<5 K_d =10	1.5	3	6	9	12	15	18	21
pH>5 K_d =234	35	70	105	140	175	205	240	275

Loamy Soil

0.5 acre source area $^{GW}Soil_{Ing}$ for Lead (mg/kg)								
L_2/L_1	1	2	3	4	5	6	7	8
pH<5 K_d =10	3	6	9	12	15	18	21	24
pH>5 K_d =597	179	358	537	716	895	1074	1253	1432

30 acre source area $^{GW}Soil_{Ing}$ for Lead (mg/kg)								
L_2/L_1	1	2	3	4	5	6	7	8
pH<5 K_d =10	1.5	3	6	9	12	15	18	21
pH>5 K_d =597	90	180	270	360	450	540	630	720

Clayey Soil

0.5 acre source area $^{GW}Soil_{Ing}$ for Lead (mg/kg)								
L_2/L_1	1	2	3	4	5	6	7	8
pH<5 K_d =12	4	8	12	16	20	24	28	32
pH>5 K_d=1830	549	1098	1647	2196	2745	3294	3843	4392

30 acre source area $^{GW}Soil_{Ing}$ for Lead (mg/kg)								
L_2/L_1	1	2	3	4	5	6	7	8
pH<5 K_d =12	2	4	6	8	10	12	14	16
pH>5 K_d=1830	275	549	824	1099	1374	1649	1924	2199

Tier 2 Soil-to-Groundwater PCL Equation
* Critical groundwater PCL as determined in accordance with '350.78.

Term	*COC Chemical/Physical and Affected Property Parameters* *Definition*	*Tier 1 Defaults*	*Change to Tier 1 Default Allowed?*	*Rule Citation*
LDF	Leachate 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 Recommend setting L_1 = to thickness of soil zone containing COCs in excess of Tier 1 ^{GW}Soil	'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)
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)
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)
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)

K_d	Soil-water partition coefficient (cm^3-water/g-soil)
	
	$ for organics
	$ for inorganics
		(Figure 30 TAC '350.73(e))
		
		$K_d = K_{oc}$ @ 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)
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

Term	*COC Chemical/Physical and Affected Property Parameters* *Definition*	*Tier 1 Defaults*	*Change to Tier 1 Default Allowed?*	*Rule Citation*
R	Universal Gas Constant (atm-m^3/gmol-EK)	8.25×10^{-5}	No	NA
T	Temperature (EK) = 273 + EC	293	No	NA
U_{gw}	Groundwater Darcy velocity (cm/yr) U_{gw} = K i x 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: δ_{gw} # b_{gw}	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)
b_{gw}	Aquifer thickness (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)
α_v	Vertical groundwater dispersivity = 0.0056 x W_s (m)	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} (3.15×10^7s/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)