

APPENDIX A

ATTENUATION FACTOR METHOD

FOR

VOCS

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(February 14, 1996)

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ATTENUATION FACTOR METHOD FOR VOCs

Soil cleanup criteria for volatile organic compounds (VOCs) that are protective of groundwater quality should depend on physical properties of the impacted site and chemical properties of the VOC contaminants. The attenuation factor to be derived as follows is a measure of VOC contaminants that can be retained in the soil above ground water as a function of retention of chemical by the distance and lithology of soils encountered during its transport to ground water. Attenuation factors were calculated using physical and chemical data collected or available in the Los Angeles area.

1. Attenuation Factor (AF)

We have derived an attenuation factor (AF) based on an assumption of attenuation (retention) of chemicals in the vadose zone as illustrated in Figure 1. Considering a vadose zone unit as shown in Figure 2, volatile organic compounds (VOCs) can partition into three phases: sorbed, gaseous, and dissolved (liquid). Jury et al. (1983) suggested that the total soil concentration of a VOC in all three phases can be calculated as:

$$C_T = \rho_b \cdot C_s + (n - \theta_w) \cdot C_g + \theta_w \cdot C_l \quad (1)$$

Where:

- C_T = Total soil concentration (g/ml)
- C_s = Concentration in sorbed phase (g/g)
- C_g = Concentration in gaseous phase (g/ml)
- C_l = Concentration in liquid phase (g/ml)
- ρ_b = Soil bulk density (g/ml)
- θ_w = Soil water content by volume (dimensionless (--))
- n = Soil porosity (dimensionless (--))

Substituting the two partition coefficients between the sorbed and liquid phases $K_d = C_s/C_l = f_{oc} \cdot K_{oc}$, and between the gaseous and liquid phases $K_H = C_g/C_l$, into equation (1), we have:

$$C_T = C_l [\theta_w + \rho_b \cdot f_{oc} \cdot K_{oc} + (n - \theta_w) \cdot K_H] \quad (2)$$

Where:

- f_{oc} = Soil organic carbon content (dimensionless (--))
- K_{oc} = Organic carbon partition coefficient (ml/g)
- K_H = Henry's law constant (dimensionless (--))

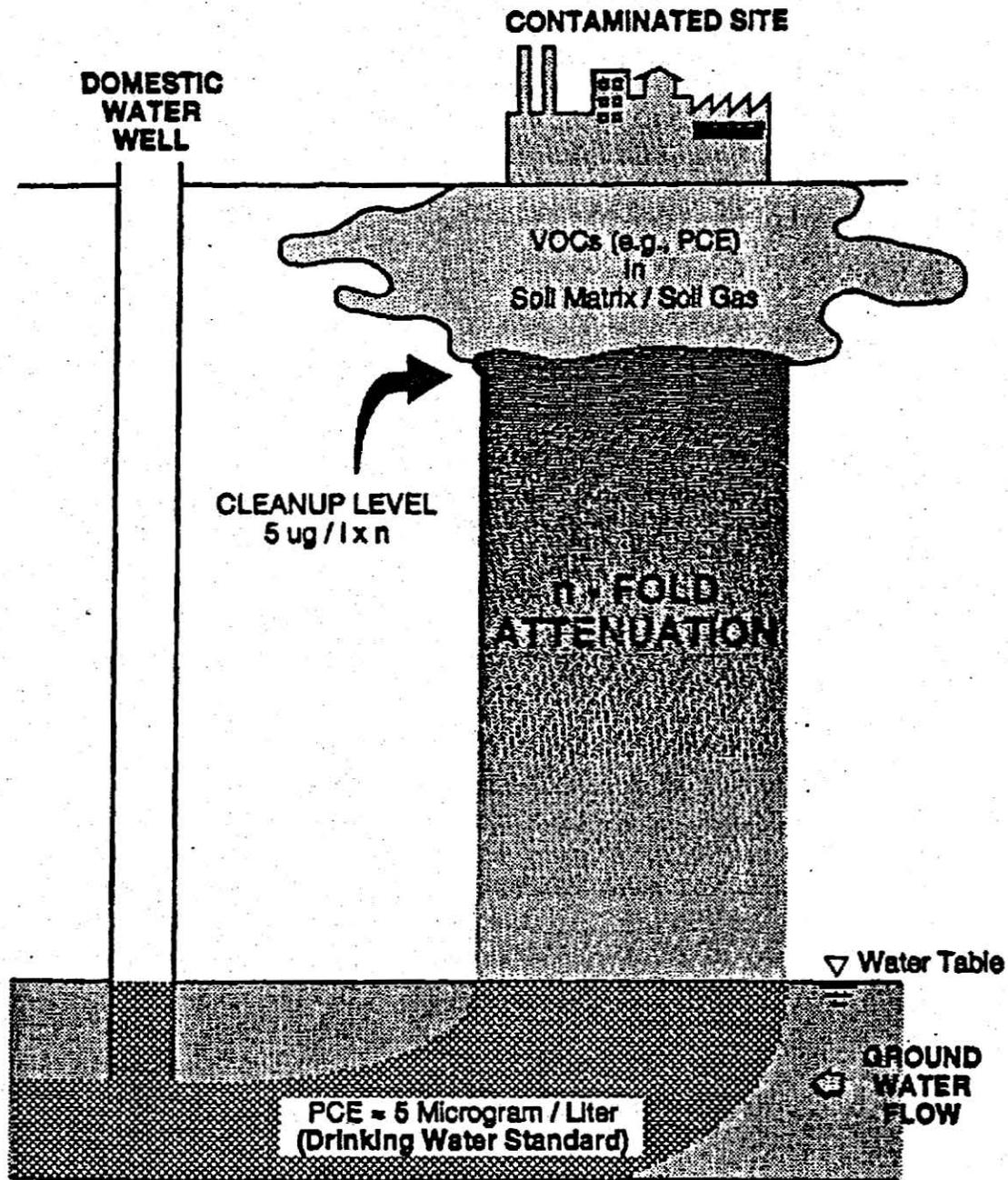


Figure 1: Illustration of Attenuation Effect

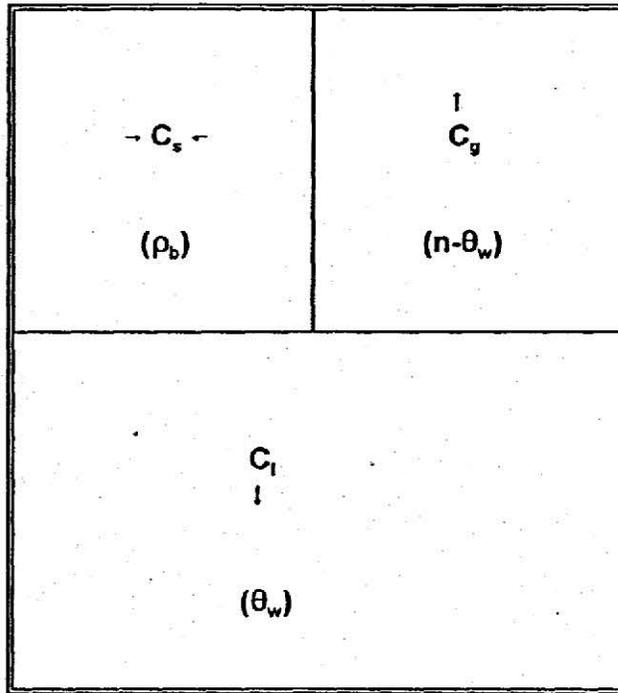


Figure 2: VOC Concentration Partition Distribution in a Conceptual Vadose Zone Unit [All parameters defined in equation (1)]

We also assume that VOC in the liquid phase is the only one moving downward to impact ground water quality and VOC in sorbed and gaseous phases is considered as lost mass in the subsurface for the moment. AF is then defined as the ratio of total soil concentration and the leachate concentration in the soil pores:

$$AF = C_T / (C_l \cdot \theta_w) \quad (3)$$

Hence, substituting (2) into (3), AF becomes:

$$AF = 1 + (\rho_b / \theta_w) \cdot f_{oc} \cdot K_{oc} + (n - \theta_w) \cdot K_H / \theta_w \quad (4)$$

By definition, AF is always greater than or equal to 1, at which there is no attenuation. The larger the AF is, the larger the attenuation effect is, i.e., the larger retention potential of VOC in soils.

Database is established based upon 55 soil samples obtained in the Los Angeles area (38 samples from San Fernando Valley, 6 samples from San Gabriel Valley, and 11 samples from Carson area). The physical parameters required for equation (4) are provided in Table 1 as follows:

Table 1: Statistics of 55 Soil Physical Parameters

	ρ_b (g/ml)	θ_w (—)	f_{oc} (—)	n (—)
Distribution	Normal	Normal	Log-Normal	Normal
Minimum	1.2	0.031	0.0002	0.143
Maximum	2.27	0.4	0.015	0.54
Mean	1.746	0.167	0.00247	0.364
Std Deviation	0.242	0.103	0.00324	0.093
Median			0.00138	

The following values of soil physical property parameters are then selected to produce the maximum attenuation factor, AF_{MAX} :

$$\rho_b = 2.27(\text{g/ml}), \theta_w = 0.031(---), f_{oc} = 0.015(---), n = 0.143(---).$$

Table 2 tabulates the AF_{MAX} for 29 common VOCs, which are calculated using equation (4), along with California MCLs and chemical property parameters K_{oc} and K_H . These 29 VOCs are grouped into four brackets based on the AF_{MAX} values. Rounded average numbers for AF_{MAX} are provided to simplify calculations. To be used under site-specific soil physical conditions, AF_{MAX} should be modified by the following factors to generate soil screening levels for VOC impacted sites.

2. Modification Factor Due to Distance above Ground Water (AF_D)

We assume a general linear relationship between AF and vertical distance above ground water. Based upon the definition of AF, the closer the distance to ground water, the smaller the AF should be.

Hydrogeological information in the San Fernando Valley Superfund area, Los Angeles County, indicates that groundwater elevation fluctuation has been ± 20 feet for the last decade or so. Therefore, 40 feet above ground water table is chosen as a "smear zone" where ground water needs more protection and the AF values should be more stringent (i.e., smaller). The average ground water depth in the northwestern portion of the San Fernando Valley Superfund area is about 150 feet above the high concentration plume area. Hence, 150 feet is taken as a depth of concern for the AF modification, which is considered to be reasonable, compared with ground water depth in other areas in the Los Angeles County. We have also assumed no change in AF for distances greater than 150 feet above the ground water table.

A study of VOC downward transport by using an one-dimensional vadose zone transport model, VLEACH (Ravi 1994) indicates that the VOC transport rate can increase an order of magnitude in the "smear zone" immediately above the ground water table. In other words, AF should be reduced to one-tenth of the original value ($AF/10$) at that point.

We then interpolate linearly between the distance from ground water to the vadose zone point of interest to calculate an AF modification factor. Since two zones above ground water table have been distinguished so far: from ground water table to 40 feet above the table and from 40 feet up to 150 feet above the table, we have two segments in the relationship of distance above ground water table and attenuation factor: [150, 40] versus [AF, $AF/10$] and [40, 0] versus [$AF/10$, 1], where the datum point (zero) of the coordinate is at the ground water table and distance is measured up from the water table. Hence, attenuation factor modified by distance above ground water, AF_D , can be determined by the linear interpolation:

$$\begin{aligned} (AF_D - 0.1 \cdot AF) / (AF - 0.1 \cdot AF) &= (D - 40) / (150 - 40) & 40 < D \leq 150 \\ (AF_D - 1) / (0.1 \cdot AF - 1) &= D / 40 & 0 \leq D \leq 40 \end{aligned}$$

TABLE 2: MCL, K_{oc}, K_{ow}, MAXIMUM VALUES OF ATTENUATION FACTOR FOR COMMON VOCs

Compound	MCL(µg/l) ^a	K _{oc} (ml/g) ^b	K _{ow} (-) ^b	AF _{max}
Acetone	610 ^c	2	0.0009	3.2
Methyl Ethyl Ketone (MEK)	1900 ^c	5	0.0011	6.5
Chloroethane		3	0.387	5.7
ROUNDED AVERAGE				6
Benzene	1	65	0.229	73
Chloroform	100	31	0.158	36
Cis-1,2-dichloroethylene (c-1,2-DCE)	6	59	0.274	67
Dichlorodifluoromethane (Freon 12)	390 ^c	58	4.158	80
1,1-Dichloroethane (1,1-DCA)	5	30	0.179	35
1,2-Dichloroethane (1,2-DCA)	0.5	14	0.05	17
Dichloromethane (Methylene Chloride)	5	9	0.11	11
1,1,1,2-Tetrachloroethane	1	54	0.016	60
Trans-1,2-dichloroethylene (t-1,2-DCE)	10	59	0.274	67
1,1,2-Trichloroethane (1,1,2-TCA)	5	56	0.05	63
ROUNDED AVERAGE				50
Carbon Tetrachloride	0.5	110	0.998	125
Chlorobenzene	30	160	0.146	177
1,1-Dichloroethylene (1,1-DCE)	6	65	6.237	95
Ethylbenzene	700	220	0.328	244
1,1,2,2-Tetrachloroethane	1	220	0.021	243
Tetrachloroethylene (PCE)	5	660	0.956	729
Toluene	150	260	0.274	288
1,1,1-Trichloroethane (1,1,1-TCA)	200	150	0.116	166
Trichloroethylene (TCE)	5	130	0.371	145
Trichlorofluoromethane (Freon 11)	150	160	4.03	191
1,1,2-Trichloro-trifluoroethane (Freon 113)	1200	160	2.41	185
Vinyl chloride (VC)	0.5	57	29.1	169
o,m,p - Xylene	1750	240	0.22	265
ROUNDED AVERAGE				200
1,2-Dichlorobenzene	600	1100	0.079	1210
1,3-Dichlorobenzene	600	1200	0.079	1319
1,4-Dichlorobenzene	5	1200	0.066	1319
ROUNDED AVERAGE				1200
OVERALL AVERAGE:				255

Reference:

- a = California MCL From CCR Title 22.
- b = USEPA (1994) Region IX Preliminary Remediation Goals (PRGs) Second Half 1994. (August). (except value for chloroethane from Montgomery (1990))
- c = PRG values for tap water (USEPA 1994)

By the assumptions and reorganizing above equations, the linear segment functions of AF_D can be expressed as:

$$\begin{aligned}
 AF_D &= AF & D > 150 & \quad (5) \\
 AF_D &= [0.9 \cdot (D-40)/110 + 0.1] \cdot AF & 40 < D \leq 150 & \quad (6) \\
 AF_D &= D \cdot [0.1 \cdot AF - 1]/40 + 1 & D \leq 40 & \quad (7)
 \end{aligned}$$

Where: AF_D = Attenuation factor modified by distance above ground water (≥ 1 always)
 D = Distance from ground water to point of interest (ft).

If an individual VOC is of interest, the individual AF_{MAX} or rounded average AF_{MAX} from the corresponding bracket in Table 2 can be substituted for AF value in equations (5) through (7). If total VOC concentrations should be concerned, the 29 VOC overall average AF_{MAX} equal to 255 can be used. When $AF = AF_{MAX} = 255$, equations (5), (6), and (7) become:

$$\begin{aligned}
 AF_D &= 255 & D > 150 & \quad (8) \\
 AF_D &= 2.09 \cdot (D-40) + 25.5 & 40 < D \leq 150 & \quad (9) \\
 AF_D &= 0.61 \cdot D + 1 & D \leq 40 & \quad (10)
 \end{aligned}$$

Here AF_D is only a function of D . The function is illustrated in Figure 3.

3. Total Modification Factor Due to Distance above Ground Water and Lithology (AF_T)

Soil types can affect the rate of transport due to infiltration and further retention of VOCs. In general, fine grained soils with relatively slow infiltration have a higher retention ability than coarse materials. Therefore, VOC retention should be different in each lithological layer. Assume AF is different in each lithologic layer and proportional to fractions of each lithologic thickness of gravel, sand, silt, and clay layers within D . Then the relationship can be expressed by the following equation:

$$AF_L = (TGR/D) \cdot AF_{GR} + (TSA/D) \cdot AF_{SA} + (TSI/D) \cdot AF_{SI} + (TCL/D) \cdot AF_{CL} \quad (11)$$

Where: AF_L = Attenuation factor modified by lithology (≥ 1 always)

TGR = Total thickness of gravel layer within D (ft)

TSA = Total thickness of sand layer within D (ft)

TSI = Total thickness of silt layer within D (ft)

TCL = Total thickness of clay layer within D (ft)

AF_{GR} , AF_{SA} , AF_{SI} , AF_{CL} = Attenuation factor for gravel, sand, silt, and clay, respectively.

The data on steady infiltration rate of different soil types in Hillel (1982) indicate that water infiltration rate of gravel/sand materials can be 2 fold greater than sand/silt, 4 fold than silt/clay, and 20 fold than clayey materials. We assume VOC retention rate is inversely proportional to the steady infiltration rate. If only VOC in dissolved phase is of concern as defined in AF, we can determine attenuation factors for gravel, sand, silt, and clay, based upon VOC retention ratio between each lithological class, as shown in Table 3. The ratio between each lithological class in Table 3 is further supported by data in Carsel et al. (1988), which suggest the ratio in Table 3 is more conservative with respect to ground water protection.

Table 3: AF for Different Lithology

Lithology Class	Steady Infiltration Rate (mm/hr)*	AF
Gravel/Sand (GR)	20	$AF_{GR} = (1/20)(AF_D)$
Sand/Silt (SA)	10	$AF_{SA} = (1/10)(AF_D)$
Silt/Clay (SI)	5	$AF_{SI} = (1/5)(AF_D)$
Clay (CL)	1	$AF_{CL} = AF_D$

* = Hillel (1982). AF_D is calculated in (5), (6), or (7).

Substituting values of AF_{GR} , AF_{SA} , AF_{SI} , AF_{CL} in Table 3, equation (11) becomes:

$$AF_T = (AF_D/D) \cdot (TGR/20 + TSA/10 + TSI/5 + TCL) \quad D > 0 \quad (12)$$

Where: AF_T = Attenuation factor with total modification for distance above ground water and lithology
 $AF_D \geq 1$ always.

Hence, AF_T is a function of AF_D , D , and total thickness of each lithological class. Equation (12) represents the overall AF modified for distance above ground water and lithology within D .

4. Use of Attenuation Factor for VOC Soil Cleanup Screening Levels

AF as defined in equation (4) incorporates site-specific physical parameters and chemical parameters of VOC mobility. AF_{MAX} , a best case scenario, is then modified by two factors: distance above ground water and lithology. Each modification reduces AF values, which tends toward a conservative estimate. Based on the modified AF_T , the following equation is used to determine VOC soil cleanup screening levels.

$$C = AF_T \times MCL \quad (13)$$

Where: C = Concentration of soil cleanup screening level (ppb)
 AF_T = Attenuation factor modified by distance above ground water and lithology (≥ 1) (dimensionless)
 MCL = Maximum contaminant levels for drinking water (CCR Title 22) if set; or applicable Federal or State water standards if MCLs are not set (ppb)

California MCL values are summarized in Table 2. If soil contaminant is a single VOC, the individual MCL is applied. If total VOCs are of concern, use the lowest MCL among VOCs and their degradation products where they are detected. For example, MCL for 1,1,1-TCA is 200 $\mu\text{g/l}$ (ppb) but its degradation compound could be 1,1-DCA, which has a MCL of 5 $\mu\text{g/l}$ (ppb). In this case, MCL equal to 5 ppb should be used instead of 200 ppb. If soil contamination is a multiple VOCs problem and there is no predominant compound among the multiple VOCs, soil cleanup screening levels may be set for each individual compound based on each respective MCL.

If the aquifer to be protected is a drinking water aquifer, MCL shall be used in equation (13); if the MCLs are not set, applicable Federal or State water quality standards, e.g., tap water criteria of USEPA PRGs shall be considered. If the aquifer is designated as a drinking water aquifer but contaminated at present, the water quality standard shall consider criteria and requirements for water treatment and water usage after remediation, such as well-head treatment, pump and treat, reinjection, etc., which may require less stringent standards than MCLs. If the aquifer is used for non-drinking water, other criteria, such as aquatic life habitat, ecological impact, water beneficial use requirements, etc., may apply (refer to State Water Resources Control Board Resolution 88-63 for criteria to determine a "non-drinking aquifer").

5. Average Attenuation Factor Table

To simplify the calculation, a table for average attenuation factors is prepared. Given the overall average AF_{MAX} for 29 VOCs equal to 255 (Table 2) and using equations (8), (9), (10), and (12), AF_T is calculated for each depth interval and lithological class in Table 4. Distance above ground water (D) in Table 4 is first used to calculate AF_D and then let D in equation (12) equal to TGR, TSA, TSI, and TCL, respectively, to obtain AF_T under each lithological class. Table 4 suggests that AF should be 1 at a primary gravel site with ground water at 40 feet or shallower; and on the other hand, AF should be 255 at a site with all clay and ground water at 150 feet or deeper.

Table 4: Attenuation Factors (AF_T) for Different Distance above Ground Water and Lithology

DISTANCE ABOVE G.W.	LITHOLOGY			
	GRAVEL	SAND	SILT	CLAY
150	13	26	51	255
120	10	19	39	193
100	8	15	30	151
80	5	11	22	109
60	3	7	13	67
40	1	3	5	26
20	1	1	3	13
10	1	1	1	7

Distance (ft) Between Ground Water (G.W.) and the Measured Point;
Lithology (USCS Standard) Between Ground Water and the Measured Point.

For distance greater than 150 feet above ground water, the 150 feet values of AF_T are to be used. AF_T can be interpolated between depth intervals and proportional to fraction of each lithological thickness at the site. For instance, when $D = 70$ feet, $AF_T = 4, 9, 17.5,$ and 88 for gravel, sand, silt, and clay, respectively. If a site lithology consists of 20% gravel, 50% sand, 15% silt, and 15% clay, $AF_T = 0.2 \cdot 4 + 0.5 \cdot 9 + 0.15 \cdot 17.5 + 0.15 \cdot 88 = 21$. Table 4 is designed to provide a quick primary screening benchmark for total VOC soil cleanup levels.

6. Limitations of Attenuation Factor Method

From a perspective of ground water protection, VOC soil cleanup levels should be a function of physical properties of the site and chemical properties of the VOCs. Attenuation factor method formulates such a function, especially emphasizing distance to ground water and site lithology. It lays out a foundation for further quantification of the function as more data become available. However, the limitations of this method must be acknowledged, some of which are discussed as follows.

- a) Non-aqueous phase liquid (NAPL) is not considered in equations (1) and (4). If the cleanup site is a NAPL case, NAPL must be removed or remediated prior to applying attenuation factor method for the NAPL residuals of VOCs.
- b) Attenuation factor method is not a form of vadose zone transport model and cannot predict any change of concentrations over time in the subsurface. Therefore, any estimate of VOC transport with time and depth should be directed to site-specific fate and transport studies.
- c) VOC gaseous phase is assumed as lost mass in the attenuation factor method. If VOC gas transport in the vadose zone is considered to be a major mechanism of threat to ground water quality at a site, more vapor phase fate and transport studies need to be done prior to applying the method.
- d) The attenuation factor method is not a substitute for human health-based risk assessment. Any cleanup screening values derived by this method shall be less than the health risk threshold values, such as USEPA PRGs, above which a formal risk assessment may be required.
- e) The screening numbers calculated by the attenuation factor method should not be used to define the extent of soil contamination in site assessment. The screening numbers should not be applicable until the site is fully characterized.
- f) Ground water historical high level shall be taken into account with attenuation factor calculation in order to protect ground water quality in the long term.

7. Conversion of Soil Gas Concentrations ($\mu\text{g/L}$) to Total Soil Concentrations ($\mu\text{g/kg}$)

In many soil cleanup cases, a vapor extraction system (VES) is often used to remove VOCs. Therefore, soil gas concentrations are usually obtained for cleanup monitoring. When soil gas data are available, HydroGeoChem (1989) proposes a method to calculate total concentrations in soil from soil gas concentrations, or vice versa.

$$C_T = C_g \cdot [\theta_w + (n - \theta_w) \cdot K_H + \rho_b \cdot f_{oc} \cdot K_{oc}] / (\rho_b \cdot K_H) \quad (14)$$

Where: C_T = Total soil concentration in $\mu\text{g/kg}$
 C_g = Soil gas concentration in $\mu\text{g/L}$
Other parameters defined in equations (1) and (2).

Rosenbloom et al. (1993) indicated that soil gas concentrations were found to be more meaningful than soil matrix data for estimating total soil concentrations at an Arizona Superfund site. Data obtained from San Gabriel Valley and San Fernando Valley Superfund Sites in Los Angeles County also support this assertion.

Let CO be the coefficient between C_T and C_g in equation (14), hence $CO = [\theta_w + (n - \theta_w) \cdot K_H + \rho_b \cdot f_{oc} \cdot K_{oc}] / (\rho_b \cdot K_H)$. Therefore, $C_T = CO \times C_g$. CO values are calculated using equation (14) given soil physical property parameters presented in Table 1 for all 29 VOCs listed in Table 2. Results indicate that in general CO value is relatively small for highly volatile compounds in coarse material soil and CO value tends to be large for less volatile compounds in fine-grained soil. Therefore, in a subsurface investigation where volatile contaminants are in coarse soil such as sand or gravel, soil gas samples could be better choice. When less volatile contaminants are in fine-grained soil such as silt or clay, soil matrix samples should be analyzed. In the former case, soil gas concentration in $\mu\text{g/L}$ can be compared directly with soil cleanup screening levels.

8. Evaluation of Attenuation Factor Method Results

(a) Comparison of Attenuation Factor Method Results with USEPA Preliminary Remediation Goals (PRGs)

To evaluate a worst case scenario for the attenuation factor method, the largest AF value in Table 4, 255, is used to generate results of equation (13) by multiplying each corresponding MCLs listed in Table 2. The preliminary remediation goals (PRGs) for the

category of residential soil designated by the USEPA Region IX (1994) are then used for comparison with these worst case scenario values. As a result, 24 of the 29 VOCs compared show that the attenuation factor method values are much smaller than the corresponding PRG values. Therefore, the soil cleanup screening values calculated by attenuation factor method are generally safe as far as human health risk concerns. In any case, the maximum value used as the soil cleanup screening level should not exceed regulatory threshold values for protection of human health.

(b) Comparison of Attenuation Factor Method Results with Vadose Zone Transport Model (VLEACH)

Attenuation factor method has been compared with a one-dimensional finite difference vadose zone transport model, VLEACH (Version 2.1) (Ravi 1994) at two sites with site-specific soil physical property parameters. Under very conservative assumptions, VLEACH is used to calculate PCE concentrations in dissolved phase at each discrete depth. These concentrations would not result in liquid phase concentrations exceeding MCL for PCE (5 ppb) at historical ground water high level by downward migration.

The comparison is shown in Table 5. Attenuation factor method is within an order of magnitude of VLEACH model. The numerical levels determined by attenuation factor method are a factor of two or three below the VLEACH results. Results from a further uncertainty study by Monte Carlo Simulation based on VLEACH indicate that the 75 percentile concentration can be a factor of three above the resulting median value (Rong 1995). Therefore, this study supports attenuation factor method to be three-fold below VLEACH results. Such a safety factor may be necessary at this time as VOC fate and transport in the vadose zone could not be quantitatively predicted or verified by field data.

Table 5: Comparison Between AF Method and VLEACH

	Depth (ft)	Soil Cleanup Concentration for PCE (ppb)	
		AF	VLEACH
Case 1	30	34	100
	45	19	50
	65	6	25
Groundwater at 95			
Case 2	40	90	275
	50	75	160
Groundwater at 140			

9. Case Study

9.1 Example 1

Ground water depth is 70 feet at a subject site. Use Table 4 to calculate attenuation factor at surface level and 30 feet depth, given lithology of 50 percent gravel and 50 percent sand. Then compare the calculated attenuation factors with the ones under lithology of 60 percent silt and 40 percent clay.

At surface level (i.e., D=70 feet above ground water), from Table 4:

$$\begin{aligned} \text{AF}(\text{gravel, 70 feet}) &= 3+(5-3)/2 = 4, & \text{AF}(\text{sand, 70 feet}) &= 7+(11-7)/2 = 9 \\ \text{AF}(\text{silt, 70 feet}) &= 13+(22-13)/2 = 17.5, & \text{AF}(\text{clay, 70 feet}) &= 67+(109-67)/2 = 88. \end{aligned}$$

At 30 feet depth (i.e., D=70-30=40 feet above ground water), directly from Table 4:

$$\text{AF}(\text{gravel, 40 feet})=1, \text{AF}(\text{sand, 40 feet})=3, \text{AF}(\text{silt, 40 feet})=5, \text{AF}(\text{clay, 40 feet})=26.$$

Scenario 1: Lithology = 50% gravel / 50% sand

$$\begin{aligned} \text{AF}_{70} &= \text{AF}(\text{gravel, 70 feet}) \times 50\% + \text{AF}(\text{sand, 70 feet}) \times 50\% \\ &= 4 \times 50\% + 9 \times 50\% = 6.5 \\ \text{AF}_{40} &= \text{AF}(\text{gravel, 40 feet}) \times 50\% + \text{AF}(\text{sand, 40 feet}) \times 50\% \\ &= 1 \times 50\% + 3 \times 50\% = 2 \end{aligned}$$

Scenario 2: Lithology = 60% silt / 40% clay

$$\begin{aligned} \text{AF}_{70} &= 17.5 \times 60\% + 88 \times 40\% = 45.7 \\ \text{AF}_{40} &= 5 \times 60\% + 26 \times 40\% = 13.4 \end{aligned}$$

Table 6: AF Results under Different Lithology

Distance Above Ground Water (D)(ft)	Depth below Surface (ft)	AF with 50% gravel 50% sand	AF with 60% silt 40% clay
70	0	7	46
40	30	2	13

9.2 Example 2

Ground water at a VOC impacted site is at about 95 feet. Primary soil contaminants are PCE, TCE, and 1,1-DCE. Use Table 2 and equations given in the text to calculate step by step attenuation factors given site-specific lithological information. Then determine soil cleanup screening levels for PCE, TCE, and 1,1-DCE, respectively, and also for total VOCs for this site.

Step 1: to determine AF.

From Table 2, AF_{MAX} for PCE is 729, AF_{MAX} for TCE is 145, and AF_{MAX} for 1,1-DCE is 95. The average AF_{MAX} value for all 29 VOCs is equal to 255 in Table 2.

Step 2: to calculate AF_D , given AF_{MAX} values.

Distance above ground water (D) can be subjectively selected based on site-specific contamination and lithological information, or any point of interest, e.g., around a silt/clay layer or the highest concentration of soil contaminant vertical distribution, etc. Here, we select D=30 feet (65 feet below ground surface (bgs)), D=65 feet (30 feet bgs), and D=90 feet (5 feet bgs), respectively.

a) When D = 30 ft, since $D \leq 40$, use equation (7): $AF_D = D \cdot [0.1 \cdot AF - 1] / 40 + 1$

i.e., $AF_{D=30} = 30 \cdot [0.1 \cdot AF - 1] / 40 + 1$

When AF for PCE = 729, $AF_{D=30}$ (PCE) = $30 \cdot [0.1 \cdot 729 - 1] / 40 + 1 = 55$

Similarly, $AF_{D=30}$ (TCE) = $30 \cdot [0.1 \cdot 145 - 1] / 40 + 1 = 11$
 $AF_{D=30}$ (1,1-DCE) = $30 \cdot [0.1 \cdot 95 - 1] / 40 + 1 = 7.4$
 $AF_{D=30}$ (Total VOCs) = $30 \cdot [0.1 \cdot 255 - 1] / 40 + 1 = 19$

b) When D = 65 ft, since $40 < D < 150$, use equation (6): $AF_D = [0.9 \cdot (D-40) / 110 + 0.1] \cdot AF$

i.e., $AF_{D=65} = [0.9 \cdot (65-40) / 110 + 0.1] \cdot AF = 0.3 \cdot AF$

When AF for PCE = 729, $AF_{D=65}$ (PCE) = $0.3 \cdot 729 = 219$

Similarly, $AF_{D=65}$ (TCE) = $0.3 \cdot 145 = 44$
 $AF_{D=65}$ (1,1-DCE) = $0.3 \cdot 95 = 29$
 $AF_{D=65}$ (Total VOCs) = $0.3 \cdot 255 = 77$

c) When D = 90 ft, since $40 < D < 150$, use equation (6): $AF_D = [0.9 \cdot (D-40) / 110 + 0.1] \cdot AF$

i.e., $AF_{D=90} = [0.9 \cdot (90-40) / 110 + 0.1] \cdot AF = 0.5 \cdot AF$

When AF for PCE = 729, $AF_{D=90}$ (PCE) = $0.5 \times 729 = 365$

Similarly, $AF_{D=90}$ (TCE) = $0.5 \times 145 = 73$
 $AF_{D=90}$ (1,1-DCE) = $0.5 \times 95 = 48$
 $AF_{D=90}$ (Total VOCs) = $0.5 \times 255 = 128$

Step 3: to calculate AF_T .

Lithology information can be obtained from site boring logs.

a) Given D = 30 ft and the following lithology:

TGR (Gravel) = 25 ft
TSA (Sand) = 5 ft
TSI (Silt) = 0 ft
TCL (Clay) = 0 ft

Use equation (12): $AF_T = (AF_{D=30}/D) \cdot (TGR/20 + TSA/10 + TSI/5 + TCL)$

AF_T (PCE) = $(55/30) \cdot [(25/20) + (5/10)] = 3$
 AF_T (TCE) = $(11/30) \cdot [(25/20) + (5/10)] = 1$ (by definition)
 AF_T (1,1-DCE) = $(7.4/30) \cdot [(25/20) + (5/10)] = 1$ (by definition)
 AF_T (Total VOCs) = $(19/30) \cdot [(25/20) + (5/10)] = 1.1$

b) Given D = 65 ft and the following lithology:

TGR (Gravel) = 35 ft
TSA (Sand) = 22 ft
TSI (Silt) = 8 ft
TCL (Clay) = 0 ft

Use equation (12): $AF_T = (AF_{D=65}/D) \cdot (TGR/20 + TSA/10 + TSI/5 + TCL)$

AF_T (PCE) = $(219/65) \cdot (35/20 + 22/10 + 8/5) = 19$
 AF_T (TCE) = $(44/65) \cdot (35/20 + 22/10 + 8/5) = 4$
 AF_T (1,1-DCE) = $(29/65) \cdot (35/20 + 22/10 + 8/5) = 2.5$
 AF_T (Total VOCs) = $(77/65) \cdot (35/20 + 22/10 + 8/5) = 7$

c) Given D = 90 ft and the following lithology:

TGR (Gravel) = 35 ft
TSA (Sand) = 31 ft
TSI (Silt) = 24 ft
TCL (Clay) = 0 ft

Use equation (12): $AF_T = (AF_{D=90}/D) \cdot (TGR/20 + TSA/10 + TSI/5 + TCL)$

$$AF_T (\text{PCE}) = (365/90) \cdot (35/20 + 31/10 + 24/5) = 39$$

$$AF_T (\text{TCE}) = (73/90) \cdot (35/20 + 31/10 + 24/5) = 8$$

$$AF_T (1,1\text{-DCE}) = (48/90) \cdot (35/20 + 31/10 + 24/5) = 5$$

$$AF_T (\text{Total VOCs}) = (128/90) \cdot (35/20 + 31/10 + 24/5) = 14$$

Step 4: to determine soil cleanup screening levels.

MCLs for PCE, TCE, and 1,1-DCE are 5 µg/l, 5 µg/l, and 6 µg/l, respectively. Since the lowest MCL among these three compounds detected is 5 µg/l, this value is used in equation (13) to calculate soil cleanup screening levels for total VOCs. The soil cleanup screening levels at different depths for different compounds are summarized in Table 7.

Table 7: Soil Cleanup Screening Levels for Different Compounds

Distance above Ground Water (D)(ft)	Depth below Surface (ft)	PCE (MCL=5ppb)			TCE (MCL=5ppb)			11DCE (MCL=6ppb)			Total VOCs (use MCL=5ppb)		
		AF _D	AF _T	C	AF _D	AF _T	C	AF _D	AF _T	C	AF _D	AF _T	C
90	5	365	39	195	73	8	40	48	5	30	128	14	70
65	30	219	19	95	44	4	20	29	2.5	15	77	7	35
30	65	55	3.2	16	11	1	5	7.4	1	6	19	1.1	6

C=Soil Cleanup Concentration (ppb)

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ACKNOWLEDGEMENTS

In addition to the Technical Review Committee members, the authors would like to thank Wayne Chiou, Hubert Kang, Kevin Mayer, John Menatti, Wayne Praskins, and Ruen Fang Wang for their comments during the development of the attenuation factor method. Constructive comments from the public during the interim period are also greatly appreciated.