SUBJECT: SOIL LEACHING TO GROUND WATER EVALUATION FOR TOTAL PETROLEUM HYDROCARBONS (TPH) GUIDANCE

PURPOSE:

The purpose of this position paper is to recommend an approach to evaluate leaching of total petroleum hydrocarbons (TPH) from soil to ground water. This process is designed to address existing contamination only. It is not designed to be used to approve controlled discharges from permitted facilities.

BACKGROUND:

This technical content of this guidance was originally developed by the LAVA (Leaching and Volatilization Assessment) Group of the WMCUPS (Waste Management Cleanup Program Subcommittee). The LAVA group worked in conjunction with the TPH working group authorized by WMCUPS to develop a position paper on leaching from petroleum contaminated soils to ground water. The result of that effort was a guidance for evaluating leaching of TPH chemicals to ground water. That guidance has been revised to form this document. The WMCUPS TPH and LAVA workgroups utilized information published by the Total Petroleum Hydrocarbon Criteria Workgroup (TPHCWG) in the development of their guidances. The TPHCWG was established to encourage consistency between states in addressing TPH contamination. The workgroup was represented by industry, government and academia.

DISCUSSION:

The principal problem in characterizing TPH contamination in soils is that TPH consists of a complex mixture of organics, rather than a single chemical. One approach is to sample for indicator compounds, such as benzene, toluene, ethylbenzene and xylenes (BTEX) and a few polynuclear aromatic hydrocarbons (PAH's), and to ignore the overall TPH level. That theory holds that the health hazard is created chiefly by the indicator chemicals and that so long as the indicators are within acceptable ranges, the other harmful components of TPH will also be within safe levels. However, the BTEX compounds are the most readily degraded components of petroleum products and may disappear well before the rest of the TPH. Secondly, diesel and fuel oils have low BTEX levels, which will not reliably indicate the presence of heavier chemicals in TPH. In addition, for diesel and heating fuels, the components of BTEX are only present at very low percentages which makes them difficult to accurately measure.

SUBJECT: SOIL LEACHING TO GROUND WATER EVALUATION FOR TOTAL PETROLEUM HYDROCARBONS (TPH) GUIDANCE

When evaluating TPH contaminated soils, BTEX, methyl *tertiary* butyl ether (MTBE) and PAHs should be sampled and evaluated separately. The health effects of the remaining TPH content can be safely estimated with the use of surrogates, provided that several conservative simplifying assumptions are made.

The TPHCWG has separated TPH fractions into surrogates based on carbon number and aliphatic versus aromatic nature. Their data tables provide both physico-chemical and toxicity values. Thus, a class of chemicals, such as aromatics with carbon number equivalents between 8 and 10, or 10 and 12 can be simulated using a single set of physico-chemical and toxicity values. Thus leach-based standards for these TPH components can be calculated. Modeling indicates that the C_8 - C_{12} aromatics are the most likely to seriously impact ground water due to their mobility and toxicity. The aliphatics of equivalent carbon number are generally less mobile and less toxic. Heavier weight aromatics also tend to be less mobile. Therefore the C_8 - C_{12} aromatics can be used as the surrogate to calculate TPH standards for the gasoline (GRO) and diesel (DRO) ranges

Data on compositions of petroleum products (in Volumes 2 and 3 of the TPHCWG report) indicate that approximately 15 - 20 percent of most fuels is comprised of high weight aromatics (exclusive of BTEX or PAH). Thus, multiplying the leached-based critical concentration for the C_8 - C_{12} series by approximately 5 or 6 should yield a total TPH number corresponding to a total leach-based standard. This approach is technically sound and defensible and it relies heavily on several conservative assumptions. However, the use of conservative assumptions is a necessary part of the development of sound generic cleanup standards of any kind. If a participant wants to do more detailed site-specific chemical analyses to characterize the exact makeup of the TPH contamination, he/she should be free to do so. If the participant wants generic standards, then he/she should be willing to accept the conservative risk assumptions needed to account for all of the uncertainties of the TPH composition.

The LAVA workgroup utilized the above information, plus the efforts conducted to support LAVA position paper Evaluation of Leaching of Chemicals of Concern in Soils to Ground Water to develop a staged approach in addressing TPH leaching to ground water.

Stage I assumes direct contact between TPH contaminated soil and the underlying ground water. The TPH components partition between the soil and the water at equilibrium concentrations without dilution in the water. Initially default values for the

various soil properties are used, with the option of substituting site-specific data where available. The approach of this stage represents the most conservative assumptions but also establishes clear threshold soil TPH concentrations below which ground water contamination will not occur.

Stage II allows for some separation between the contaminated soil and the underlying ground water. As the contamination is carried downward by infiltrating precipitation, it will be spread over the previously clean soil reducing its average concentration. This new diluted soil concentration is used to calculate whether acceptable ground water standards will be violated.

Stage III consists of site-specific modeling. In this approach an acceptable quality model is combined with reliable site-specific data to predict whether the existing contamination will, indeed, leach to the underlying aquifer in excess of allowable standards.

These three basic stages are based on a single surrogate TPH chemical range for either DRO or GRO. As an alternative the TPH in the soil can be analyzed for concentrations in several carbon ranges (i.e., C_8 - C_{10}, C_{10} - C_{12}, etc.) and each range evaluated separately. Thus, any of these stages can be conducted using the individual fractions of TPH instead of one surrogate.

Analysis of other parameters

Several constituents in TPH need to be addressed separately because of their known particularly high toxicity and/or mobility. Those components are given in Table 1. The analyses can be limited to those of specific TPH range categories, if the source is known to have resulted from a corresponding product. For example, if a release can be shown to have come from a tank of refined gasoline, then only the specific constituent chemicals listed for GRO need be evaluated. However, for releases from unknown or poorly defined sources, soil must be analyzed for all of the indicator chemicals. The individual leaching effects of all identified chemicals must be considered separately from the total TPH, using the methodologies outlined in the LAVA group's position paper Evaluation of Leaching of Chemicals of Concern in Soils to Ground Water. Individual chemicals may require remediation to achieve their respective ground water potable use standards, even if the total TPH level is acceptable.

TABLE 1. Specific Petroleum Products Requiring Analysis.

TPH Release Type	Indicator Parameters
GRO	BTEX, MTBE
DRO	BTEX, Acenaphthylene, Acenapthene, Anthracene, Benzo (a) pyrene, Benzo (f) fluoranthene, Benzo (g,h,i) perylene, Benzo (k) fluoranthene, Chrysene, Dibenzo (a,h) Anthracene, Fluorene, Fluoranthene, Naphthalene, Phenanthrene, Pyrene
OIL	Acenaphthylene, Acenapthene, Anthracene, Benzo (a) pyrene, Benzo (f) fluoranthene, Benzo (g,h,i) perylene, Benzo (k) fluoranthene, Chrysene, Dibenzo (a,h) Anthracene, Fluorene, Fluoranthene, Naphthalene, Phenanthrene, Pyrene
Unknown	BTEX, MTBE, Acenaphthylene, Acenapthene, Anthracene, Benzo (a) pyrene, Benzo (f) fluoranthene, Benzo (g,h,i) perylene, Benzo (k) fluoranthene, Chrysene, Dibenzo (a,h) Anthracene, Fluorene, Fluoranthene, Naphthalene, Phenanthrene, Pyrene

Applicability/Limitations

Cosolvent Effects: The modeling approach used for these evaluations considered only the chemicals usually contained in refined petroleum products. However, a participant must evaluate co-solvent effects when such effects have a plausible impact on contaminant transport, since, cosolvent contamination may accelerate primary contaminant transport. For example, chlorinated hydrocarbon solvents (i.e., perchloroethylene) or alcohols may facilitate the movement of TPH chemicals to greater depths than would result from transport by infiltrating rain water alone. Thus, the guidelines for leaching factors, given below, can only be reliably applied at sites without

substantial co-contamination by other chemicals that might impact lower mobility compounds.

Secondary Features: The potential for discrete features in the unsaturated zone (both unconsolidated and consolidated deposits) to act as conduits to the water table must be assessed qualitatively. The presence, character, and density of any faults, fractures, joints, subsidence fissures, solution channels, significant sand seams, and other similar features should be evaluated. In the presence of such features, generic methodology may not be applicable.

Soil Stratigraphy: To select the appropriate leaching values, the horizontal and vertical variation in soil properties and stratigraphic units should be evaluated, including the continuous profile of the stratigraphic units beneath the property and the thickness and lateral extent of each unit. The effects of stratification on saturated and unsaturated flow should also be considered, in addition to any anthropogenic influences (e.g. sewer pipes, conduits for utilities, etc.) that may impact the geology/hydrogeology and create preferential pathways for migration.

Soil Contaminant Concentrations Ceilings: For the purpose of using this guidance, soil ceiling concentrations have been developed. These values are summarized in the Stage Sections.

Man-Made Deposits: The modeling approach used to develop this guidance assumed that the incident precipitation infiltrates directly into natural soils. Man-made deposits, such as coal piles, ash or slag heaps, gravel piles or coal tar staining, could potentially alter the chemistry of the infiltrating rain water (e.g., pH, hardness, organic and metallic content), resulting in different rates of leaching than predicted by these models. Thus the presence of any surface feature that allows infiltration through anything other than natural soils could alter the leaching process. If any such features are present, then a site-specific analysis would be necessary to determine their effects on the leaching process. The leaching factors developed in this guidance should be used with great caution at such sites.

Final Ground Water Concentrations The purpose of this guidance is to provide an estimate of the relationship between soil concentrations of TPH components and the resulting contamination levels in the underlying ground water. While the cleanup levels formulated in this guidance are based on the best scientific knowledge currently available, local hydrogeologic conditions and variability in petroleum product

compositions may result in ground water contamination levels above those predicted from the residual soil concentrations. Thus, remediating soil to the predicted TPH levels may not always result in the ground water remedial goals. In those cases, additional remediation would be necessary. Performance goals for remedial actions involving TPH contaminated soil should ultimately be based on the ground water concentrations rather than the soil concentrations.

STAGE I, BASIC EQUILIBRIUM BETWEEN TPH CONTAMINATION AND GROUND WATER

Stage I assumes that TPH contaminated soil is in direct contact and chemical equilibrium with ground water. The basic equilibrium equation is as follow:

(Eq.1)

$$C_{GW} = C_{SOIL} LF_{GW}$$

(Eq.2)

$$LF_{GW} = \frac{\rho}{\left[\theta_w + k_d \rho + H' \theta_a\right]} X \frac{cm^3 \cdot kg}{gm \cdot L}$$

where C_{GW} = the ground water concentration, in mg/l, C_{SOIL} = the soil concentration in mg/kg and LF_{GW} = the leaching factor. That leaching factor is itself a function of the soil parameters:

where:

LF_{gw} = leaching factor (kg/L)
ρ = dry bulk density, (gm/cm^3)
θ_w = fraction of water filled porosity
θ_a = fraction of air filled porosity
K_d = partitioning constant for the soil = Koc X Foc, (cm^3/g)
H' = Henry's Law constant for the COC, (dimensionless)

This equation requires values for the air-filled porosity, water-filled porosity, organic carbon content, and dry soil bulk density, Henry's Law Constant, and partitioning constant. The LF_{GW} would be calculated utilizing site-specific data for water-filled and air-filled porosity, and fraction of organic carbon in the soil. Table 2 provides the values to be used for Henry's Law and K_{oc} and acceptable defaults for other parameters utilized in the equation. Site specific values for these parameters can be substituted wherever reliable data exist. The LF_{GW} values given in this table are based on the surrogates of C_8 - C_{10} for the GRO range, C_{10} - C_{12} for the DRO range and C_{21} - C_{35} for the oil range. Those are the surrogate ranges used by the TPHCWG.

Equation 2 includes all three compartments for chemicals in soil - organic carbon, pore water and vapor phase. For chemicals with low water solubility and low vapor pressures the latter two compartments may be safely ignored and equation 2 will reduce to the following:

(Eq. 3) $$LF_{GW} = 1 / (K_{OC} F_{OC})$$

Alternatively:

(Eq. 4) $$C_{GW} = C_{SOIL} / (Koc \times Foc)$$

Equations 1 and 2 allow the calculation of the ground water TPH concentration that would be in equilibrium with the soil. The critical ground water and soil concentrations for the different TPH fractions are given in Table 3. A detailed discussion of the rationale for these standards appears in the appendix. The standard for oil is based not on leaching to ground water, but on the holding capacity of the soil. That is because the harmful concentration of the oil fraction TPH chemicals exceeds their solubility limit. Instead, the criterion for oil phase TPH concentration is the level at which free phase could flow downward (about 5000 ppm).

These equations can be modified to calculate a soil cleanup standard based on a target ground water concentration. The following equation gives the soil standard as a function of ground water concentration using all of the soil compartments for contamination:

(Eq. 5)

$$C_{Soil} = \frac{C_{GW}}{\dfrac{\rho}{\left[\theta_W + Kd\rho + H'\theta_a\right]}}$$

When the vapor and dissolved phase concentrations are low compared with the sorbed phase, the equation reduces to the following:

(Eq. 6)

$$C_{SOIL} = C_{GW}\ (Koc\ X\ Foc)$$

TABLE 2. Parameter Inputs and acceptable defaults when developing Leaching Factors.

Parameter	**Acceptable Defaults if Site-Specific Data is unknown**		
bulk density (ρ)	default to 1.6 gm/cm^3 Defaults of 1.6 to 1.8 gm/cm^3 acceptable depending on soil type.		
air-filled porosity (θ_a)	0.26. If site specific total porosity (θ) known, 63 % of Total θ		
water-filled porosity (θ_w)	0.15 If site specific total porosity (θ) known, 37 % of Total θ		
organic carbon content (f_{oc})	Defaults of sand-0.2%, silt 0.25%, clay 0.30%. Site specific data must be made on a adequate number of samples and be based on the entire leaching zone. Depth weighted average is acceptable.		
	GRO	DRO	OIL
Henry's Law constant (dimensionless)	0.48	0.14	6.7E-04

K_{oc} (L/Kg)	1584	2511	1.25E+05
LF_{GW}	0.299	0.195	0.0039

TABLE 3. Leaching Standards for Total TPH based on Concentrations of Various Fractions. (The standards are based on a soil organic carbon fraction of 0.002.)

TPH Group	Leaching Standard mg/Kg
GRO	3.1
DRO	2.7
OIL	5,000 - 40,000

This equilibrium-based calculation assumes no dilution in the underlying aquifer. If dilution were occurring then the allowable soil concentrations could be safely raised. The effects of dilution can be calculated using the Summers equation:

$$C_{GW} = \frac{(Q_R)(C_p) + (Q_{GW}) + (C_a)}{Q_{GW} + Q_R}$$

(Eq. 7)

Where:

C_{gw} = concentration of the contaminant in the saturated zone, µg/ml
Q_R = volumetric flow rate of infiltration (soil water) to the aquifer, cm^3 / d
Q_{gw} = volumetric flow rate of ground water beneath the contaminated area, cm^3 / d
C_a = upgradient concentration of the pollutant in the aquifer (if any), µg/ml
C_p = contaminant concentration in the soil pore water, µg/ml

In this equation the contaminant pore water concentration, C_p is that value which would be in equilibrium with the contaminated soil.

If it is assumed that upgradient ground water does not contain COCs of concern, then C_a is equal to zero and the dilution factor (DF) becomes:

(Eq. 8)
$$DF = \frac{(Q_{GW}) + (Q_R)}{Q_R}$$

An alternative presentation of this equation based on site-specific data is:

(Eq. 9)
$$DF = 1 + \frac{Kmi}{rL}$$

where:

K = aquifer conductivity
m = mixing zone thickness
i = gradient
r = recharge rate
L = length of contaminated zone parallel to ground water flow

The soil contaminant concentrations that were based on equilibrium calculations would be multiplied by the dilution factor to determine the acceptable concentrations over an aquifer with dilution.

STAGE II, EFFECTS OF SMEARING BETWEEN THE CONTAMINATED ZONE AND THE AQUIFER

Stage I considered contaminated soil in direct contact with the aquifer. Very often, there may be some separation between the bottom of the contaminated vadose zone and the water table, as shown in Figure 1.

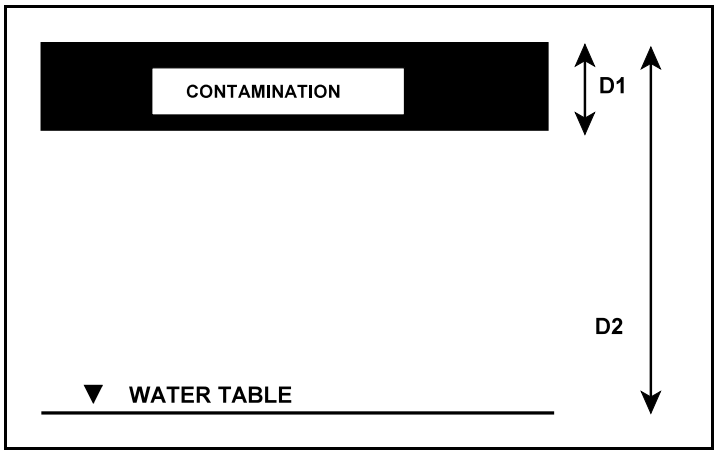

FIGURE 1. CONTAMINATION SEPARATED FROM THE WATER TABLE.

In this case a layer of contaminated soil extends to a depth of D1 below the surface while the water table occurs at a depth of D2. Thus, contamination has not yet reached the water table. However, as the contamination is carried downward by water infiltration it will be spread across the currently clean zone below the depth of D1. The resulting safe level of contamination can be calculated by the following equation:

(Eq. 10) $$C_{SOIL} = C_{GW} \,/\, \left(LF_{GW}\left(D1 \,/\, D2\right)\right)$$

where C_{SOIL} = the allowable concentration in the contaminated zone and C_{GW} = the target ground water concentration.

STAGE III, SITE-SPECIFIC MODELING

The third stage consists site-specific modeling of vadose and saturation zone processes to determine allowable soil concentrations for ground water protection. If models are used they must be:

(1) Peer-reviewed.

(2) Model-verified. To be model-verified, the computer code for the model must be shown to produce reliable and mathematically accurate results for all functions of the model;

(3) Field-validated to determine if there exist favorable comparisons between the modeled, or predicted, conditions and observed field conditions for the area being modeled;

(4) Consistent with conditions throughout the modeled area. The assumptions and limitations of the computer code, mathematical solution, technology utilized and computer code structure must be consistent with the conditions throughout the modeled area and the application of the model;

(5) Used consistent with the model's documentation; and

(6) Calibrated to geologic, hydrogeologic, and physical conditions throughout the modeled area.

As with any model, the input data must be determined from site-specific measurements or in the case of defaults, must be reasonably consistent with know site conditions.

SUBJECT: SOIL LEACHING TO GROUND WATER EVALUATION FOR TOTAL PETROLEUM HYDROCARBONS (TPH) GUIDANCE

USE OF SPECIFIC TPH FRACTIONS FOR LEACHING EVALUATION

The three stages of evaluation described above assume that the GRO, DRO and Oil ranges of can be represented by single surrogates. Thus, only the total TPH in each range would need to be measured. As an alternative, concentrations of individual carbon ranges (i.e., C_8 - C_{10}, C_{10} - $C_{12,}$ C_{12} - C_{16}, etc.) could be measured and separately evaluated for cleanup values. The costs of such analyses would be greater than those of lumped TPH ranges (GRO or DRO). At present the recommended analytical procedure would be that of the TPHWCG[1] or some equivalent method. However, the results might indicate that the TPH contamination was mostly in the higher weight, less harmful range (C_{21} - C_{35}), resulting is less stringent cleanup goals. Table 4 gives the relevant chemical properties for the different carbon ranges and the calculated leaching factors (based on 0.002 soil carbon).

TABLE 4. Physical-Chemical Constants for TPH Fractions

Equivalent Carbon Number	**Henry's Law Constant** (dimensionless)	**Koc** (L/Kg)	**LF_{GW}**
C_7-C_8	0.27	251	1.56
C_8-C_{10}	0.48	1580	2.99E-01
C_{10}-C_{12}	0.14	2510	1.95E-01
C_{12}-C_{16}	0.053	5010	9.88E-02
C_{16}-C_{21}	0.013	1.58E+04	3.15E-02
C_{21}-C_{35}	6.7E-04	1.25E+05	3.97E-03

Based on the target water concentrations (see the appendix) residual soil levels can be calculated for these carbon ranges. Table 5 gives those values for a default soil

[1]Weisman, Wade, ed., Analysis of Petroleum Hydrocarbons in Environmental Media. Volume 1 of the TPH Criteria Working Group Series, 1998, Chapter 8.

organic carbon fraction of 0.002.

TABLE 5. Generic Standards for TPH Components

Equivalent Carbon Number	Target Water Concentration, Child Exposure (mg/L) *	Generic Leaching Factor (Kg/L)	Generic Leaching Value (mg/Kg)
Aromatics Ranges			
C_7-C_8	0.49	1.64	0.30
C_8-C_{10}	0.15	3.18E-01	0.47
C_{10}-C_{12}	0.14	2.07E-01	0.68
C_{12}-C_{16}	0.13	1.05E-01	1.24
C_{16}-C_{21}	0.10	3.36E-02	2.98
C_{21}-C_{35}	0.03**	4.30E-03	5,000 - 40,000***

* These target concentrations are based on a hazard quotient of 1.0 for each carbon range. If more that one range is present then the sum total of hazard quotients should not exceed 1.0 for all the ranges combined. Multiple ranges will require adjustment for the additive nature of the health risks for individual ranges.

** Exceeds solubility limit in water.

*** The residual concentration depends on soil type and corresponds to the Oil category in Table 6 below.

These values are based on the Stage I assumptions of direct contact between ground water and contaminated soil and no dilution in the underlying aquifer. Dilution effects, if present, would be figured for the individual carbon ranges. If there were a separation between the contaminated zone and the water table then the methodology of Stage II would apply for each carbon range. Finally, if site-specific modeling were conducted,

the individual carbon ranges would be treated as separate chemicals in the model.

RESIDUAL TPH HOLDING CAPACITY OF SOILS

The residual contamination standards for TPH in soil are set so that infiltrating precipitation does not carry hazardous levels of chemicals down to the underlying aquifer. In addition, the TPH levels must not be so high that free phase can drip down to the aquifer in that absence of water infiltration. The residual holding capacity of the soil is the measure of how much TPH can be retained without downward flow. Table 6 gives the maximum allowable TPH levels for the different ranges and soil types. As the table shows, the lighter fractions are more mobile and thus have lower limits. Sandy soils also have lower limits than less permeable clayey soils.

TABLE 6. Maximum Allowable Residual TPH Concentrations

Petroleum Fraction	Residual Saturation Concentration, ppm		
	Soil Type I	Soil Type II	Soil Type III
GRO (C_4-C_{12})	1000	5000	8000
DRO (C_{10}-C_{20})	2000	10000	20000
Oil (C_{20}-C_{28})	5000	20000	40000

Where the various soil types are described as follows:

Soil Type I

Vadose zone soil type I is characterized by a K_v ranging from 1×10^{-3} to 1×10^{-4} cm/s, a net recharge rate ranging from approximately eight to fourteen inches per year and a mean annual depth to ground water greater than five feet below grade. This soil type may include vertically continuous well-graded sand and gravel, fine sand, silty coarse sands that are typical of glacial outwash, buried valley aquifers, beach ridges and coarse alluvial deposits. This soil type may also include fill material (e.g., non-native soils).

Soil Type II

Vadose zone soil type II is characterized by a K_v ranging from 1×10^{-4} to 1×10^{-5} cm/s, a net recharge ranging from approximately four to eight inches per year and a mean annual depth to ground water greater than five feet below grade. This soil type may include interbedded sand and gravel lenses with silts and clays, silty/clayey sand and gravel, and poorly-graded sands that can be found in some buried valley aquifers, glacial end moraine deposits and alluvial deposits.

Soil Type III

Vadose zone soil type III is characterized by a K_v less than 1×10^{-5} cm/s, a net recharge of less than approximately four inches per year, and a mean annual depth of ground water greater than five feet below grade. This soil type may include silts, clays, silty clays, and silty clayey gravels that can be found in glacial till, lacustrine sediments, flood plain deposits and thick colluvial deposits.

APPENDIX : RATIONALE FOR TPH STANDARDS

In support of its efforts to establish an approach to evaluate what concentrations of TPH can be left in the soil and still be protective of ground water, the LAVA Workgroup established standards for various fractions of TPH. The chemical surrogates for the various TPH fractions are given in Table A1.

TABLE A1. TPH Fractions and Surrogates

Fraction	Carbon Equivalence Range	Aromatic Surrogate	Assumed Concentration Fraction of Surrogate in TPH
GRO	C_4 - C_{12}	C_8 - C_{10}	0.15
DRO	C_{10} - C_{20}	C_{10} - C_{12}	0.25
Oil	C_{20} - C_{28}	C_{21} - C_{35}	0.20

These concentrations are based on representative analyses of petroleum products as compiled by the TPH Working Group[2]. The bulk of the TPH compounds are assumed to be the less mobile aliphatics and higher weight aromatics. This contrasts with a methodologies for direct contact risk assessment in that the mobility and solubility of specific compounds do not affect direct contact risk while they do control the migration of vadose contaminants to the water table.

The target drinking water concentrations for these fractions were based on the methodology given in the Risk Assessment Guidance for Superfund[3] with reference

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[2] Potter, Thomas L. and Simmons, Kathleen, E., Composition of Petroleum Mixtures, Volume 2 of the TPH Criteria Working Group Series, 1998.

[3] Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part B), EPA/540/R-92/003, December, 1991.

dose data provided by the TPH Criteria Working Group[4] The reference doses and target concentrations are given in Table A2.

Leaching factors were calculated using the default assumptions of the LAVA Group's Position Paper 1. The final soil concentrations for individual fractions were based on the target concentrations, for child exposures, with no dilution factor applied. Those concentrations are given in Table A3. The standards for total DRO and GRO were based on surrogate concentrations of 15 and 25 percent in those fractions. The 5000 - 40,000 ppm value for Oil range hydrocarbons is based on the VAP standard for residual TPH in soil rather than a leaching standard because the hazardous concentration of that range exceeds its solubility limit in water. That high residual number is derived from the holding capacity of the soil rather than an aqueous leaching process. The standard is intended to prevent gravity-driven free phase migration to the water table. The final values for the DRO, GRO and oil ranges are given in Table A4.

The values given in these tables are based on a hazard quotient of 1.0 for each range. If more than one range is present, then the total impact much not exceed a hazard index of 1.0. Thus, the residual cleanup levels must be adjusted for the cumulative nature of the different TPH ranges. In mathematical terms that adjustment is expressed as follows:

$$\sum_{1}^{5} Cn / Cnref = 1.0$$

where C_n = the concentration of TPH in each of the first five series' in Table A3 and C_{nref} = the generic leaching value given for each of those series' in that table.

The GRO and DRO values in Table A4 are considerably less than the value of 400 ppm calculated for JP-4 fuel, by the TPH Criteria Working Group[3]. However, the difference in values derives from the input assumptions. The TPH Criteria Working Group used an organic carbon concentration of 1.0 percent in the soil, as opposed to a default value of 0.3 percent used for these calculations. They also used a dilution factor of approximately 12, while the default value for this calculation was zero. Those two

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[4]Vorhees, D.J., et al, Human Health Risk-Based Evaluation of Petroleum Release Sites: Implementing the Working Group Approach, Volume 5 of the TPH Criteria Working Group Series, 1999.

factors would account for a nearly forty-fold increase in the allowable soil concentration. The process defined in the main body of this position paper allows for site-specific values of organic carbon content and dilution to be substituted for the default values, where the locally obtained data justifies their use. In addition, this calculation uses the target water concentration for a child exposure rather than an adult exposure. As Table A2 shows, that difference introduces another factor of approximately four into the calculation. Thus, the differences in default parameters and the use of the adult exposure scenario, would result in allowable soil TPH concentrations nearly 160 times greater than given in Table A4. With that factor applied, values in Table A4 would increase to approximately 480 ppm, which is nearly the same as calculated by the TPH Criteria Working Group. While the methodology used is the same for both calculations, the site-specific variables are different, as is the assumption of child rather than adult exposure.

TABLE A2. TPH Fractions, Toxicities and Target Water Concentrations

Fraction	Reference Dose, mg/kg/day	Target Water Concentration, ppm	
		Child Exposure	Adult Exposure
C_7 - C_8	0.2	0.49	2.99
C_8 - C_{10}	0.04	0.15	0.72
C_{10} - C_{12}	0.04	0.14	0.64
C_{12} - C_{16}	0.04	0.13	0.51
C_{16} - C_{21}	0.03	0.10	0.29
$C_{21`}$ - C_{35}	0.03	0.03*	0.09*

* Exceeds solubility limit in water.

TABLE A3. Generic Standards for TPH Components

Equivalent Carbon Number	Target Water Concentration, Child Exposure (mg/L)	Generic Leaching Factor (Kg/L)	Generic Leaching Value (mg/Kg)
Aromatics Ranges			
C_7-C_8	0.49	1.64	0.30
C_8-C_{10}	0.15	3.18E-01	0.47
C_{10}-C_{12}	0.14	2.07E-01	0.68
C_{12}-C_{16}	0.13	1.05E-01	1.24
C_{16}-C_{21}	0.10	3.36E-02	2.98
C_{21}-C_{35}	0.03*	4.30E-03	5,000 - 40,000**

* Exceeds solubility limit in water.

**The residual concentration depends on soil type and corresponds to the Oil category in Table 6 of the main text.

TABLE A4. Leaching Standards for Total TPH based on Concentrations of Various Fractions.

TPH Group	Leaching Standard mg/Kg
GRO	3.1
DRO	2.7
OIL	5,000 - 40,000