

Total Petroleum Hydrocarbons (TPH) and Light Non-Aqueous Phase Liquid (LNAPL) Characterization, Remediation and Management

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Concurrence



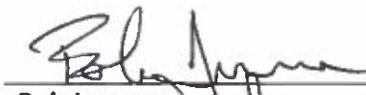
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Acronyms and Abbreviations

AS/SVE	Air Sparge/Soil Vapor Extraction
BER	Bureau of Environmental Remediation
COC	Contaminant of Concern
CSM	Conceptual Site Model
DRO	Diesel Range Organics
EPA	United States Environmental Protection Agency
GRO	Gasoline Range Organics
HRH	High-Range Hydrocarbons for carbon range $\geq C19$ - $\leq C35$
KDHE	Kansas Department of Health and Environment
LNAPL	Light Non-Aqueous Phase Liquid
LRH	Low-Range Hydrocarbons for carbon range $\geq C5$ - $< C9$
MEP	Maximum Extent Practicable
mg/kg	milligram per kilogram
$\mu\text{g/L}$	micrograms per liter
MRH	Mid-Range Hydrocarbons for carbon range $\geq C9$ - $< C19$
NELAP	National Environmental Laboratory Accreditation Program
ORO	Oil Range Organics
RSK	KDHE Risk-based Standards for Kansas RSK Manual, 5 th Edition, and subsequent revisions
TPH	Total Petroleum Hydrocarbons

Glossary

Entity	Kansas Department of Health and Environment Bureau of Environmental Remediation staff, responsible and voluntary parties and their consultants, and other policy users as approved by their respective regulatory program.
EUC	Environmental Use Control measures are an administrative or legal control intended to restrict or prohibit human activities and property use in such a way as to prevent or reduce human exposure to contamination.
LNAPL	A light non-aqueous phase liquid or solution composed of one or more organic compounds having a specific gravity less than one that are immiscible or sparingly soluble in water and encompasses all potential occurrences (i.e., both mobile and immobile/residual fractions).
LNAPL Saturation	Refers to the amount of LNAPL contained in a known volume of subsurface porous media at any given point in time, usually measured as a percent of void space filled.
LNAPL Transmissivity	Represents the volume of LNAPL through a unit width of aquifer per unit time per unit drawdown.
Maximum Extent Practicable	Recovery of all LNAPL with a transmissivity greater than 0.8 ft ² /day that can be recovered in an efficient, cost-effective manner.
Migrating LNAPL	An LNAPL body that is observed to spread or expand laterally or vertically or otherwise result in an increased volume of the LNAPL extent. Migrating LNAPL does not include LNAPL that appears in a well due to a dropping water table. (ITRC, 2009b)
Mobile LNAPL	LNAPL that exceeds residual saturation. Includes migrating LNAPL, but not all mobile LNAPL is migrating LNAPL. (ITRC, 2009b)
Receptor	Human or environmental end receiver impacted by contaminated soils, groundwater or surface water.
Remediation	Process for cleanup of soils, groundwater, and surface water at a contaminated site.
Residual LNAPL	Immobile, non-recoverable LNAPL contained in the fractures or pore space of bedrock or soil.

TPH

For the purposes of this policy, all undifferentiated hydrocarbons for carbon range compounds $\geq C5 - \leq C35$.

1. Introduction

1.1 Introduction

Petroleum and petroleum compounds are commonly used in many industries and applications. Petroleum releases have occurred in Kansas from a multitude of sources including bulk storage, refining operations, retail sales, pipelines, home heating tanks and industrial/manufacturing operations. This policy provides guidance for entities conducting response actions on petroleum contaminated sites, including those with total petroleum hydrocarbons (TPH) and/or light non-aqueous phase liquid (LNAPL). Response actions may include characterization, remediation and management of petroleum releases to the environment.

For the purposes of this policy, “LNAPL” is defined as a non-aqueous phase liquid or solution composed of one or more organic petroleum compounds having a specific gravity less than one that is immiscible or sparingly soluble in water. TPH includes all undifferentiated hydrocarbons for carbon range compounds $\geq C5$ through $\leq C35$, divided into the following fractions:

- Low-Range Hydrocarbons (LRH) for carbon range $\geq C5$ - $< C9$
- Mid-Range Hydrocarbons (MRH) for carbon range $\geq C9$ - $< C19$
- High-Range Hydrocarbons (HRH) for carbon range $\geq C19$ - $\leq C35$

This policy replaces the Kansas Department of Health and Environment (KDHE) Bureau of Environmental Remediation (BER) Policy: *Clean-up Levels for Total Petroleum Hydrocarbons, December 2000, revised December 2005*. This policy was updated in May 2017 to provide additional clarification in Section 1.3 regarding use and the associated analytical methods. Additionally, Appendix A (KDHE Tier 2 Risk-Based Summary Table) of the *KDHE Risk-Based Standards for Kansas Manual – 5th Edition, revised March 2014* (RSK Manual) has been updated to reflect the TPH Tier 2 screening levels identified herein. This policy can also be used for sites outside BER at the discretion of their respective regulatory programs.

Various technical documents and other resources were referenced during the development of this policy. A complete list of references, some of which provide a more thorough discussion of TPH and LNAPL concepts and strategies, is provided at the end of the document.

1.2 Purpose

This policy provides a framework to characterize, manage and mitigate risks to human health and the environment posed by TPH contamination and LNAPL in soil and groundwater. This policy is designed with a tiered approach including KDHE screening levels for a streamlined comparison with the option to progress towards a risk evaluation or risk assessment for more complex sites. Whether making a direct comparison to screening levels under Tier 1 and Tier 2 or performing Tier 3 and Tier 4 assessments, upfront discussions with the KDHE project manager are essential

to ensure the selected approach is appropriate for site-specific circumstances and meets program-specific guidelines.

1.3 How to Use and Limitations of Use

This policy should be used in conjunction with other appropriate guidance documents and program requirements to ensure data collected will be representative of site conditions and sufficient for developing a conceptual site model (CSM) for TPH contamination and LNAPL. The CSM is a dynamic document that evolves as the user progresses through collection and evaluation of site-specific data and information.

The screening levels discussed in Section 2.2 are based only on non-cancer (or “non-carcinogenic”) hazards of TPH as a contaminant group. Thus, potential risk from petroleum product releases must also be assessed by analyzing media for individual constituents, such as benzene, naphthalene, 2-methylnaphthalene, trimethylbenzenes, etc. The intent of this policy is not to replace the necessity for analyzing such individual constituents, which are often the risk drivers guiding corrective action, but rather establish guidance for “other” TPH contaminants that may present a hazard to human health and the environment.

Soil and groundwater samples collected for TPH analysis shall be analyzed in a KDHE certified laboratory for TPH analysis. For the purposes of certification, the laboratory must maintain KS LRH and KS MRH/HRH certifications with appropriate quality control. It is the user’s responsibility to ensure the laboratory analysis is adequate to meet the specified ranges and detection levels consistent with this policy.

KDHE recognizes measurement of LRH, MRH, and HRH may be affected by the presence of naturally occurring polar compounds in the environment. KDHE will consider on a site-specific basis the removal of these polar compounds prior to analysis using an appropriate “cleanup” procedure (e.g., silica gel) described for the analytical method used to analyze the sample.

As discussed above, this policy considers a new approach for evaluating TPH including a division into three carbon ranges (LRH, MRH, and HRH) as opposed to the historical use of two (Gasoline Range Organics (GRO) and Diesel Range Organics (DRO)). For sites currently enrolled in a BER program, this new policy goes into effect as of September 1, 2015, and incorporation into the appropriate phase of the project (e.g., investigation, monitoring, corrective action, etc.) should be coordinated with the KDHE project manager. While it would be problematic for MRH and HRH, KDHE will accept direct comparison of LRH data to historical GRO data on a site-specific basis. KDHE will also accept representative historical TPH fractional data for evaluation of site closure on a site-specific basis if the data was collected under an approved KDHE work plan or

analyzed by a NELAP certified laboratory for TPH analysis. KDHE does not intend to re-open sites that have been closed under the previous guidance.

2. Tiered Approach for TPH Criteria

The tiered approach allows for a streamlined comparison to KDHE screening levels with the option to conduct risk evaluations or quantitative risk assessments for more complex sites. At each Tier a determination must be made as to the next course of action, which will include any of the following scenarios:

- No further evaluation required if site concentrations do not exceed the screening levels;
- Adopt the screening levels established under the Tier being evaluated as the cleanup criteria and implement corrective action measures to address impacted media where these criteria are exceeded; or
- Proceed to a subsequent Tier for further evaluation.

It is not necessary to complete each Tier in succession. For example, if an entity knows in advance they will perform a risk assessment, this policy allows advancing straight to Tier 4 without a complete evaluation under Tiers 1 through 3. Appendix B contains a flow chart outlining the overall TPH Evaluation process.

2.1 Tier 1: Comparison to Background

Tier 1 cleanup criteria may be determined for contaminants of concern (COCs) that are naturally present in the environment or contaminants that are endemically enriched in various environments, such as industrial tracts, and are suspected to be higher than the Tier 2 screening levels. To establish Tier 1 cleanup criteria, background concentrations of COCs must be determined at or in the vicinity of the site. If current background environmental concentration data are not available or are not representative of the site, then the collection and analysis of background samples will be required to determine background environmental concentrations. Please refer to the KDHE BER Policy No. 038 *Determining Background Levels for Chemicals of Concern* (2010) for additional information on determining site-specific background concentrations.

2.2 Tier 2: KDHE Risk-Based Screening Levels for TPH

The KDHE Tier 2 screening levels have been calculated to determine whether site TPH concentrations may pose an unacceptable health risk that will require further evaluation or be ruled out as COCs. While derived to assist with evaluating the risk posed for specific carbon ranges of TPH, the KDHE Tier 2 screening levels may also be adopted as cleanup criteria for streamlined cleanups.

Table 1: KDHE Tier 2 Screening Levels for TPH

Contaminant	Soil (mg/kg)		Groundwater (µg/L)		Soil-to-Groundwater (mg/kg)	
	Residential	Non-Residential	Residential	Non-Residential	Residential	Non-Residential
LRH (≥C5 - <C9)	550	950	350	950	50	150
MRH (≥C9 - <C19)	250	350	150	400	50	150
HRH (≥C19 - ≤C35)	6,000	27,500	1,000	2,500	6,000	13,000

The KDHE Tier 2 screening levels presented in Table 1 were calculated using toxicity values developed by the Environmental Protection Agency (EPA), the Massachusetts Department of Environmental Protection, and route-to-route extrapolation. Default exposure factors have been primarily obtained from the *EPA Exposure Factors Handbook: 2011 Edition* (incorporating 2014 updates). Additionally, aliphatic and aromatic compounds within each carbon range were given the following considerations (Alaska, 2000 and TPH Workgroup, 1998):

- Low-Range – calculated based on 100% aliphatic as KDHE RSK Tier 2 screening levels already exist for each specific aromatic compound within this range.
- Mid-Range – calculated based on 60% aliphatic and 40% aromatic.
- High-Range – calculated based on 70% aliphatic and 30% aromatic.

Please refer to Appendix A for complete reference of the equations, toxicities, and exposure factors used.

2.3 Tier 3: Risk Evaluation

Tier 1 and Tier 2 are provided for direct comparison to facilitate streamlined decision making which may involve implementing remedial actions or performing a risk evaluation. Factors such as site characteristics (e.g., soil type, depth to groundwater, complex hydrogeology, etc.), size of source area, composition of TPH, other contaminants, presence of LNAPL, and complete exposure pathways must be considered when performing a risk evaluation. For example, low permeability soils may reduce mobility of certain contaminants whereas sites containing more permeable soils allow contaminants to move more freely. Depth of the water table and type of groundwater aquifer (e.g., unconfined vs confined) may also play a key role when evaluating risk potential. In addition, as noted above the KDHE Tier 2 screening levels incorporate assumptions regarding toxicological properties for each TPH carbon range mixture, and site-specific TPH composition may differ from these assumed values. Other considerations for a Tier 3 evaluation may include current and anticipated future uses of property (e.g., lease road, asphalt parking lot, etc.) and demonstrating incomplete exposure pathways. Coordination with KDHE is highly recommended prior to initiating and throughout the risk evaluation process.

It is imperative in risk-based decision making that an adequate CSM is developed and utilized. When applicable, the CSM should include, but not be limited to site geology and hydrogeology; depth to groundwater; the presence or absence of LNAPL; location of contaminant mass (vadose and saturated zones) including LNAPL, if present; composition and extent of groundwater contaminant plume; any potential or existing vapor plume locations; and the location of all known and potential receptors including a schematic of preferential migration pathways.

A key component during this process is evaluating the presence of LNAPL. For the purposes of this policy, LNAPL will be assumed to be present requiring further evaluation if historical evidence (visual observations documented on boring log and field notes, spill report, etc.) suggests a large release of petroleum has occurred or LNAPL has been observed accumulating in a well.

A detailed description of LNAPL characterization and management is further discussed in Section 3 of this policy.

The CSM document submitted to KDHE for review and approval should consist of text, tables, boring logs, field notes, hydrographs, maps, and cross-sections, as needed, and any other relevant information. A fully developed CSM may then be used to evaluate risk and derive site-specific TPH cleanup criteria for KDHE review and approval. A KDHE-approved Comprehensive Investigation Report, Voluntary Cleanup Investigation Report, or other comparable document may be substituted for or incorporated into the CSM document.

Based on the complexity of the risk evaluation, KDHE may utilize one of its contractors to review the evaluation on behalf of KDHE. The cost associated with a third-party evaluation will be passed on to the responsible or voluntary party as part of KDHE's oversight.

2.4 Tier 4: Quantitative Risk Assessment

If an entity elects to conduct a quantitative risk assessment, a baseline risk assessment work plan including an LNAPL Evaluation as described in the following section must be submitted for KDHE review and approval. Additionally, KDHE will utilize one of its contractors to assist with the review and oversight of the risk assessment process, the cost of which will be passed on to that entity.

3. Light Non-Aqueous Phase Liquid (LNAPL)

This portion of the policy provides entities with a framework/guidance to identify, investigate and effectively manage LNAPL contamination to an endpoint. The endpoint or remedial goal should be one of the first considerations when developing an acceptable strategy for investigating and remediating sites where LNAPL contamination is present.

After a petroleum release, the bulk of the hydrocarbon mass occurs either as mobile, migrating, or residual LNAPL while a relatively small percentage of the petroleum hydrocarbon mass dissolves into the aqueous phase or adsorbs to soil particles. Residual LNAPL is contained in the fractures or pore space of bedrock or soil and does not readily move but can continue to act as a source for groundwater contamination and be a potential cause for concern through soil vapor migration. LNAPL may exist under any of the following scenarios:

- LNAPL is mobile both within the interior portions of an impacted area and along the fringe such that migration is occurring or may occur under certain conditions.
- LNAPL is residual along the fringe, but some mobile and recoverable LNAPL exists within the interior of an impacted area.
- LNAPL is residual (i.e., unrecoverable and not migrating) throughout the site.

Site cleanup actions should focus first on reducing the mass of LNAPL wherever feasible and practicable to do so. Additionally, in accordance with 40 CFR 280.64, remedial actions will require LNAPL recovery to the “maximum extent practicable” (MEP). For the purposes of this policy, MEP is defined as recovery of all LNAPL with a transmissivity greater than 0.8 ft²/day that can be recovered in an efficient, cost-effective manner. This definition of MEP does not apply to initial spill response actions conducted under the oversight of the KDHE BER Spill Response Program.

It should be recognized that at any site where LNAPL has been discharged the contamination associated with that LNAPL can exist in multiple scenarios simultaneously in the subsurface. Adequate investigation coupled with development of a working CSM will allow appropriate remedial decisions to address complete or potential exposure pathways resulting from an LNAPL discharge.

3.1 Characterization

If LNAPL is assumed to be present, as described in Section 2: Tier 3 Risk Evaluation, KDHE will require further evaluation. Experience has demonstrated that the use of multiple direct and indirect lines of evidence rather than relying on a single indicator is the best investigative approach in determining LNAPL presence and extent. Traditional forms of evidence used as LNAPL indicators include, but are not limited to the following:

- Known LNAPL release
- Visual observations of LNAPL discharge in structures, utilities, excavation areas, water bodies, and/or monitoring wells
- Visible LNAPL in soil cores or subsequent soil and groundwater samples
- Fluorescence response in LNAPL range (visibility under ultraviolet light and Laser Induced Fluorescence)

- TPH concentrations in soil or groundwater indicative of LNAPL presence
- Dissolved-phase plume persistence
- Field screening test positive (e.g. paint filter test, hydrophobic dye test, shake test)
- Membrane Interface Probes response

Another indicator of potential LNAPL presence at a site is hydrocarbon oil saturation in the pore space. The equation identified below offers a simple mechanism to evaluate the potential for LNAPL presence using existing TPH soil data from the saturated zone. For the purposes of this policy, 1% LNAPL saturation is the threshold used for potential LNAPL presence.

Equation (ITRC, 2009b)

$$S_{LNAPL} = \frac{\rho_b * TPH}{\rho_n * n(10^6)}$$

S_{LNAPL} – LNAPL Saturation

ρ_b – Soil Bulk Density (g/cm^3)

ρ_n – LNAPL Density

n – Soil Porosity

TPH – TPH Concentration (mg/kg)*

* - Includes total for all three ranges.

For example, a conservative approach is to assume a gasoline release (LNAPL Density 0.72) in sandy soil (soil bulk density $1.5 g/cm^3$) with a porosity of 0.43. When plugged into the above equation, these default parameters indicate TPH concentrations in excess of 2,000 mg/kg result in a LNAPL saturation of 1% which would require further evaluation. Users of the policy may use 2,000 mg/kg as a threshold value for determining potential LNAPL saturation or if available, incorporate site-specific parameters to modify the equation accordingly.

Using multiple lines of evidence, if LNAPL is determined not to be present at a site, further LNAPL evaluation is not necessary. If LNAPL is determined to be present at a site, complete delineation, horizontal and vertical, of the LNAPL body will be necessary in addition to characterization and delineation of any resulting dissolved phase plume(s). If dissolved phase impacts are well defined and completely understood, it may not be necessary to collect additional samples to determine LNAPL composition.

Recoverability evaluations are another required component of the characterization process, regardless of risks posed at a site. These data will assist in developing acceptable remediation strategies and realistic and practical remedial objectives. Recoverability is estimated through LNAPL transmissivity. LNAPL transmissivity represents the volume of LNAPL through a unit width of aquifer per unit time per unit drawdown and is a directly proportional metric for LNAPL recoverability. Apparent LNAPL thickness gauged in a monitoring well does not provide a

consistent relationship to recoverability. The recoverability for a given gauged LNAPL thickness will vary with different soil types or hydrogeologic conditions. LNAPL transmissivity accounts for those parameters and conditions. Methods for evaluating LNAPL transmissivity include but are not limited to the following:

- LNAPL baildown/slug testing
- Manual LNAPL skimming testing
- LNAPL recovery system performance analysis
- LNAPL fluorescent dye tracer testing

Further guidance for evaluating transmissivity including testing and analysis procedures are outlined in ASTM E2856-13 – *Standard Guide for Estimation of LNAPL Transmissivity*.

Regardless of methods used to conduct the site characterization, once complete, it should be evident where the LNAPL is located, its state (residual, migrating or mobile) and the presence of additional phases (dissolved groundwater plume, vapor phase plume, etc.). Results of LNAPL characterization may be incorporated into the working CSM to evaluate risk and appropriate management of the LNAPL body in addition to any dissolved phase plumes.

3.2 Risk Evaluation and Management

Once completed, the CSM may then be used to evaluate risk, LNAPL recoverability, and to propose appropriate remedial strategies for KDHE review and approval. Additional factors to be considered for developing appropriate remedial actions may include:

- LNAPL composition
- Distances from LNAPL plume to a point of compliance or property boundary
- Presence of receptors
- LNAPL plume and dissolved phase plume stability
- Uncertainties
- Natural Source Zone Depletion (NSZD) Rates

For example, for sites with LNAPL transmissivity greater than 0.8 ft²/day remedial actions will be required and may include LNAPL recovery, containment, and/or appropriate compositional change technique (e.g., AS/SVE, in-situ oxidation, enhanced biodegradation, etc.). For sites with residual LNAPL or with LNAPL transmissivity less than 0.8 ft²/day, the entity may propose appropriate strategies to mitigate risks or demonstrate LNAPL and related dissolved and/or vapor phase plumes do not pose significant risk to human health and the environment.

Any LNAPL site determined to contain migrating LNAPL or residual LNAPL which continues to feed an expanding or unstable dissolved phase plume or create vapor intrusion concerns will likely require containment and/or other appropriate remedial alternatives.

3.4 Threshold for Closure

If LNAPL is present, a site may still be eligible for closure (under the respective BER Program or at the discretion of their respective regulatory programs for sites outside the BER) if it is demonstrated that:

- 1) LNAPL recovery has occurred to the maximum extent practicable;
- 2) The associated dissolved phase plume (including all site related COCs) is stable or decreasing and meets site closure criteria; and
- 3) LNAPL no longer poses risk to human health and the environment through implementation of appropriate measures to address all unacceptable risks. Measures may be program specific and include long-term monitoring, periodic update to the CSM, and institutional controls (e.g., application to the Environmental Use Control Program).

References

- Alaska Department of Environmental Conservation, *Guidance for Cleanup of Petroleum Contaminated Sites*, 2000.
- American Petroleum Institute (API), *Soil and Groundwater Research Bulletin, No.9*, 2000.
- American Petroleum Institute (API), *Evaluating Hydrocarbon Removal from Source Zones and its Effect on Dissolved Plume Longevity and Magnitude*, 2002.
- ASTM International, *Standard Guide for Estimation of LNAPL Transmissivity*, ASTM E2856-13, 2013.
- Interstate Technology & Regulatory Council (ITRC), *Evaluating Natural Source Zone Depletion at Sites with LNAPL. LNAPL-1*, 2009a.
- Interstate Technology & Regulatory Council (ITRC), *Evaluating LNAPL Remedial Technologies for Achieving Project Goals, LNAPL-2*, 2009b.
- Kansas Department of Health and Environment Bureau of Environmental Remediation *Risk-Based Standards for Kansas, RSK Manual*, 2010, 2014.
- Massachusetts Department of Environmental Protection (MADEP), *Updated Petroleum Hydrocarbon Toxicity Values for the VPH/EPH/APH Methodology*, 2004.
- Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 1, Analysis of Petroleum Hydrocarbons in Environmental Media, Appendix II-A*, 1998.
- US Environmental Protection Agency, *Provisional Peer-Reviewed Toxicity Values (PPTRV) for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons*, 2009.
- US Environmental Protection Agency, *Regional Screening Level Tables*, June 2015.
- US Environmental Protection Agency, *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual (Part A through E) Supplemental Guidance "OSWER Directive 9200.1-120*, February 6, 2014.

APPENDIX A

**TABLE 1
EXPOSURE FACTORS and TOXICITY VALUES**

EXPOSURE FACTORS					
		Groundwater		Soil	
ID	Description	Residents*	Non-Residents	Residents	Non-Residents
THI	Target hazard index	1	1	1	1
BW	Body weight (kg)	15	80	15	80
IRw	Daily water ingestion rate (L/day)	0.78	1	NA	NA
INGs	Soil ingestion rate (mg/day)	NA	NA	200	50
VF	Volatilization Factor		(L/m ³)		(m ³ /kg)
	LRH Aliphatic	0.5	0.5	1,090	1,090
	MRH Aromatic	0.5	0.5	87,400	87,400
	MRH Aliphatic	0.5	0.5	1,430	1,430
	HRH Aromatic	NA	NA	NA	NA
	HRH Aliphatic	0.5	0.5	1,510	1,510
CF	Conversion Factor (w - L/cm ³ ; s - mg/kg)	0.001	0.001	0.000001	0.000001
PEF	Particulate Emission Factor (m ³ /kg)	NA	NA	1,180,000,000	1,180,000,000
SA	Skin Surface Area (cm ²)	6,378	20,900	2,690	3,470
Kp	Skin permeability coefficient (cm/hr)				
	LRH Aliphatic	0.2	0.2	NA	NA
	MRH Aromatic	0.069	0.069	NA	NA
	MRH Aliphatic	1.7	1.7	NA	NA
	HRH Aromatic	0.31	0.31	NA	NA
	HRH Aliphatic	2	2	NA	NA
ABS	Absorption Factor (fraction)	NA	NA	0.1	0.1
AF	Adherence Factor (mg/cm ²)	NA	NA	0.2	0.12
ET	Exposure Time (hours/day)	0.54	0.71	NA	NA
EF	Exposure Frequency (days/year)	350	250	350	250
ED	Exposure Duration (years)	6	25	6	25
AT	Averaging Time	6	25	6	25
TOXICITY VALUES					
		Reference Dose, Oral (mg/kg/day)		Reference Concentration (mg/m ³)	
		RfD _o		RfC	
	LRH Aliphatic	0.04 ^a		0.6 ^c	
	MRH Aromatic	0.03 ^a		0.1 ^b	
	MRH Aliphatic	0.1 ^a		0.1 ^c	
	HRH Aromatic	0.04 ^c		0.14 ^{**}	
	HRH Aliphatic	3 ^c		10.5 ^{**}	

Notes:

* - Based on Child Scenario

** - Route-to-route extrapolation

References:

Risk Assessment Guidance for Superfund: Human Health Evaluation Manual (Part A through E) Supplemental Guidance, "OSWER Directive 9200.1-120, February 6, 2014.

a - Massachusetts Department of Environmental Protection (MADEP), Updated Petroleum Hydrocarbon Toxicity Values for the VPH/EPH/APH Methodology, 2004.

b - US Environmental Protection Agency, Provisional Peer-Reviewed Toxicity Values (PPTRV) for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons, 2009.

c - US Environmental Protection Agency, Regional Screening Level Tables, June 2015.

EQUATIONS

Input Parameters for the following equations may be found in Table 1 (groundwater and soil) and Table 2 (soil-to-groundwater).

Groundwater

$$\text{Ingestion and Dermal Exposure (mg/L)} = \frac{\text{THI} * \text{BW} * \text{AT} * 365 \text{ days/year}}{\text{EF} * \text{ED} * [(\text{IR}_w * 1/\text{RfD}_o) + (\text{ET} * \text{CF} * \text{SA} * \text{Kp} * 1/\text{RfD}_o)]}$$

$$\text{Resident Inhalation Exposure (mg/L)} = \frac{\text{THI} * \text{AT} * 365 \text{ days/year}}{\text{EF} * \text{ED} * \text{VF}_w * 1/\text{RfC}}$$

$$\text{Non-Resident Inhalation Exposure (mg/L)} = \frac{\text{THI} * \text{AT} * 365 \text{ days/year}}{\text{EF} * \text{ED} * (8/24) * \text{VF}_w * 1/\text{RfC}}$$

$$\text{Tier 2 Screening Level (mg/L)} = \frac{1}{\frac{1}{\text{Ingestion and Dermal}} + \frac{1}{\text{Inhalation}}}$$

Notes:

The inhalation exposure for HRH Aromatic was eliminated for the final HRH RSK Tier 2 Screening Level calculation.

The non-resident inhalation exposure equation is based on 8 hours a day; hence "(8/24)" in the equation.

The final RSK Tier 2 Screening Levels were rounded following final calculation as discussed in Section 2 of the policy.

Soil

$$\text{Ingestion and Dermal Exposure (mg/kg)} = \frac{\text{THI} * \text{BW} * \text{AT} * 365 \text{ days/year}}{\text{EF} * \text{ED} * [(\text{ING}_s * \text{CF} * 1/\text{RfD}_o) + (1/\text{RfD}_o * \text{CF} * \text{SA} * \text{AF} * \text{ABS})]}$$

$$\text{Inhalation Exposure (mg/kg)} = \frac{\text{THI} * \text{AT} * 365 \text{ days/year}}{\text{EF} * \text{ED} * 1/\text{RfC} * [(1/\text{VF}_s) + (1/\text{PEF})]}$$

$$\text{Tier 2 Screening Level (mg/L)} = \frac{1}{\frac{1}{\text{Ingestion and Dermal}} + \frac{1}{\text{Inhalation}}}$$

Notes:

The final RSK Tier 2 Screening Levels were rounded following final calculation as discussed in Section 2 of the policy.

The inhalation exposure equation for HRH Aromatic omits the VFs component.

Soil-to-Groundwater

$$\text{Soil-to-Groundwater Protection Pathway (mg/kg)} = C_w * \left((K_{oc} * f_{oc}) + \frac{\theta_w + (\theta_a * H')}{\rho_b} \right)$$

TABLE 2
SOIL TO GROUNDWATER PARAMETERS

ID	Description	Default Values
C _w	Target soil leachate concentration (mg/L)	Groundwater Tier 2 Screening Level * 20
K _{oc}	Soil organic carbon/water partition coefficient (L/kg)	
	LRH Aliphatic	130
	MRH Aromatic	2,000
	MRH Aliphatic	800
	HRH Aromatic	55,000
	HRH Aliphatic	4,800
foc	Fraction organic carbon in soil (g/g)	0.01 ⁺
θ _w	Water-fill soil porosity (L _{water} /L _{soil})	0.3 ⁺
θ _a	Air-filled soil porosity (L _{air} /L _{soil})	0.13 ⁺
ρ _b	Dry soil bulk density (kg/L)	1.5 ⁺
H'	Dimensionless Henry's Law constant	
	LRH Aliphatic	74
	MRH Aromatic	0.02
	MRH Aliphatic	140
	HRH Aromatic	0.00036
	HRH Aliphatic	330

Notes:

+ - Parameter may be modified with property-specific data under a Tier 3 Evaluation.

The final RSK Tier 2 Screening Levels were rounded following final calculation as discussed in Section 2 of the policy.

References:

US Environmental Protection Agency, Regional Screening Level Chemical-specific Parameters Supporting Table, June 2015.

Kansas Department of Health and Environment Bureau of Environmental Remediation Risk-Based Standards for Kansas, RSK Manual, 2010, 2014.

APPENDIX B

