Ministry of Environment and Climate Change Strategy

PROTOCOL 22
FOR CONTAMINATED SITES

Application of Vapour Attenuation Factors to Characterize Vapour Contamination

Version 1.0

Prepared pursuant to Section 64 of the
Environmental Management Act

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1.0 Definitions

The following words, acronyms and expressions used in this document are defined in the ministry Procedure 8 "Definitions and Acronyms for Contaminated Sites":

Approved Professional
affected parcel
biodegradation
biodegradation attenuation adjustment divisor
breathing zone
biologically active soil
contaminated sites legal instrument
lateral attenuation adjustment divisor
ministry
nonaqueous phase liquid
parkade
parkade attenuation adjustment divisor
preferential flow pathway
Regulation
residential land use
remediation
risk assessment
risk-based standards
site investigation
vapour
vapour attenuation factor

2.0 Introduction

This protocol describes the requirements for determining the presence and extent of vapour contamination at contaminated sites in BC using default vertical vapour attenuation factors (VAFs) for indoor air (α_I) and outdoor air (α_O) listed in Table 1. Vapour contamination exists if the concentration of any substance that is associated with a soil, sediment, or water source exceeds its Contaminated Sites Regulation (the Regulation) Schedule 3.3 numerical vapour standard in the breathing zone.

Guidance for site investigation, characterization, and remediation with respect to vapours is provided in Technical Guidance 4, "Vapour Investigation and Remediation". In Technical Guidance 4, there are three methods for characterizing vapour contamination in the breathing zone:

- Approach A - Estimation based on subsurface and/or sub-slab vapour measurements;
- Approach B - Direct vapour measurement;
- Approach C - Estimation based on soil and/or groundwater measurements.

Approaches A and C may include application of VAFs to measured or estimated subsurface or sub-slab concentrations. If, after characterizing vapour contamination, the concentrations of substances in the breathing zone are less than or equal to applicable Schedule 3.3 standards, the site would not be considered contaminated for vapours. However, if the concentrations of substances in the breathing zone exceed the Schedule 3.3 standards, then the site would be considered contaminated for vapours.

3.0 Vertical vapour attenuation factors

Selection of a vertical VAF must be based on the current and/or reasonable potential future use or configuration of the site (e.g., location and foundation depth of buildings), as per Section 12 (5) of the Regulation.

For the purpose of determining the presence and extent of vapour contamination, the vertical VAFs shown in Table 1 must be used. The Table 1 vertical VAFs may only be applied in the vertical direction, i.e. for a breathing zone (actual or hypothetical) located vertically above the point at which subsurface vapour concentrations have been determined; they do not apply laterally.

> The use of a site-specific vapour attenuation scenario is only permitted under detailed risk assessment. See Health Canada [1] and CCME [2] guidance for information pertaining to the development of site-specific VAFs.

The following equations are used estimate vapour substance concentrations in the breathing zone vertically above vapour concentrations determined in subsurface or sub-slab vapour:

$$C_{V\text{-}I} = C_{V\text{-}SS} * \alpha_I$$
$$C_{V\text{-}O} = C_{V\text{-}SS} * \alpha_O$$

Where $C_{V\text{-}I}$ and $C_{V\text{-}O}$ ($\mu g/m^3$) are the estimated substance concentrations in indoor and outdoor vapour, respectively; $C_{V\text{-}SS}$ ($\mu g/m^3$) is the measured or estimated substance concentration in subsurface or sub-slab vapour; and α_I and α_O (unitless) are the default indoor and outdoor Table 1 vertical VAFs.

> Subsurface or sub-slab vapour concentrations may be measured directly or estimated from soil or groundwater data using appropriate partitioning relationships. See Technical Guidance 4 for more detail.

3.1 Precluding conditions

Use of the Table 1 vertical VAFs for vapour characterization is not permitted if the footnotes of Table 1 preclude the use or if either of the following conditions applies:

a. Groundwater is in contact with the foundation slab at any time of the year, or there is active pumping or drawdown of groundwater at the site, with the exception of parkades built to the equivalent or better: 2012 or later BC Building Codes.

b. Subsurface or sub-slab vapour is under pressure (e.g., as at a landfill).

Regardless of the vapour sampling and analysis approach taken, characterization of vapour contamination must capture worst-case vapour substance concentrations expected in the breathing zone. Furthermore, to support legal instrument applications under the Regulation, vapour contamination must be stable or shrinking.

Table 1. Vertical VAFs

Sample Location	Sample Depth[2,3,4]	Vertical VAF (α_I , α_O)[1]			
		Outdoor Exposure (α_O)	Indoor Exposure (α_I)		
			Agricultural, Urban Park, Residential Use	Commercial, Industrial Use	Parkade Use
Below unlined crawlspace, earthen basement, or wooden[5] basement	0.45 to 5 m	-	1.0×10^{-1}		-
Sub-slab[6]	-	-	2.0×10^{-2}		
In preferential flow pathway[7]	-	1.0×10^{-4}	2.0×10^{-2}		
Subsurface	< 1.0 m[8]	1.0×10^{-4}	2.0×10^{-2}		
	1.0 m	1.5×10^{-6}	2.8×10^{-3}	3.7×10^{-4}	2.8×10^{-3}
	1.5 m	1.2×10^{-6}	2.3×10^{-3}	3.4×10^{-4}	2.3×10^{-3}
	2.0 m	9.2×10^{-7}	2.0×10^{-3}	3.1×10^{-4}	2.0×10^{-3}
	3.0 m	6.1×10^{-7}	1.6×10^{-3}	2.7×10^{-4}	1.6×10^{-3}
	5.0 m	3.7×10^{-7}	1.1×10^{-3}	2.1×10^{-4}	1.1×10^{-3}
	7.0 m	2.6×10^{-7}	8.3×10^{-4}	1.7×10^{-4}	8.3×10^{-4}
	10.0 m	1.8×10^{-7}	6.2×10^{-4}	1.3×10^{-4}	6.2×10^{-4}
	15.0 m	1.2×10^{-7}	4.3×10^{-4}	9.9×10^{-5}	4.3×10^{-4}
	20.0 m	9.2×10^{-8}	3.3×10^{-4}	7.8×10^{-5}	3.3×10^{-4}
	30.0 m	6.1×10^{-8}	2.3×10^{-4}	5.5×10^{-5}	2.3×10^{-4}

[1] Use of these attenuation factors for vapour characterization is not permitted where precluding conditions apply, see Section 3.1.

[2] For subsurface vapour samples taken from probes installed in boreholes (e.g., vapour or ground-water monitoring wells), the sample depth is based on the vertical distance from the bottom of

the bentonite seal to the bottom of the existing or proposed building foundation (indoor exposure) or ground surface (outdoor exposure). For subsurface vapour samples taken from driven probes, the sample depth is based on the vertical distance from the top of the sampling screen to the bottom of the existing or proposed building foundation (indoor exposure) or ground surface (outdoor exposure).

[3] If the sample is collected between two depth increments (e.g., between 2 and 3 m), select the attenuation factor associated with the shallower depth increment (i.e., in this example, 2 m).

[4] If fractured bedrock, karst, cobbles, or other highly-permeable medium lie between the vapour source in soil or groundwater and the building foundation or ground surface, base your choice of attenuation factor on the shorter of (a) the vertical distance between the bottom of the foundation or ground surface and the highest point of the highly-permeable medium, or (b) the vertical distance between the bottom of the foundation slab or ground surface and the bottom of the bentonite seal.

[5] The vapour attenuation factor for samples collected below an unlined crawlspace, earthen basement, or wooden basement applies to data collected from depths more than 1 m below an earthen basement (i.e., more than 1 m below the exposed soil surface) and more than 0.45 m below a surface seal installed on the exposed soil surface. Refer to the CSAP [3] vapour guidance for more information.

[6] The sub-slab vapour attenuation factor (2.0×10^{-2}) applies to vapour data collected from a sub-slab installation at the foundation of a building. Refer to Chapter 7.5.5 of CCME [2] guidance and Chapter 3.3.4 of SAB [4] guidance for more information on sub-slab installations.

[7] If there is a preferential flow pathway through the foundation slab or other direct connection between a utility backfill and indoor breathing zone (such as an unlined inspection or clean-out box), then use of the preferential flow pathway vapour attenuation factor (i.e., 2.0×10^{-2}) is not permitted. Apply the crawlspace vapour attenuation factor (i.e., 1.0×10^{-1}) and sampling restrictions instead. Refer to the CSAP [3] vapour guidance for more information.

[8] Use of this attenuation factor must be consistent with the recommendations for measurement of shallow soil vapours in the CSAP [3] vapour guidance.

4.0 Vapour attenuation adjustment divisors

The Table 1 vertical VAFs may be adjusted to account for additional attenuation using:

1. a biodegradation attenuation adjustment divisor (BAAD);
2. a parkade attenuation adjustment divisor (PAAD); or
3. lateral attenuation adjustment divisors (LAADs).

The application of one or more attenuation adjustment divisors (AAD) can occur as long as the circumstances at the site meet the described conditions for use of that AAD and no precluding conditions for use of a Table 1 VAF apply (see Section 3.1).

Use the following equations to modify the Table 1 vertical VAFs with an AAD, as applicable to the site:

$$C_{V\text{-}I} = C_{V\text{-}SS} * \alpha_I / AAD$$
$$C_{V\text{-}O} = C_{V\text{-}SS} * \alpha_O / AAD$$

Where $C_{V\text{-}I}$ and $C_{V\text{-}O}$ ($\mu g/m^3$) are the estimated substance concentrations in indoor and outdoor vapour, respectively; $C_{V\text{-}SS}$ ($\mu g/m^3$) is the measured or estimated substance concentration in subsurface or sub-slab vapour; α_I or α_O (unitless) are the indoor and outdoor Table 1 vertical VAFs, respectively; and AAD is an attenuation adjustment divisor (unitless).

4.1 Biodegradation attenuation adjustment divisor

Since a number of hydrocarbons are readily biodegraded in aerobic environments [1, 2, 5], the ministry permits a 10-fold adjustment of the Table 1 vertical VAFs to account for biodegradation. This 10-fold adjustment divisor is described as the BAAD.

BAAD = 10

Use the BAAD as the AAD term in the equation in Section 4.0.

4.1.1 Conditions for using the BAAD

The BAAD may only be used when "biologically active soil" [6] underlies the entire extent of the breathing zone(s) under evaluation.

Use of the BAAD is restricted to the following conditions:

- If nonaqueous phase liquids are not present in soil or ground water, and $VH_{w6\text{-}10}$ is < 15,000 µg/L and $EPH_{w10\text{-}19}$ is < 5,000 µg/L, then the BAAD can be applied if the building foundation (indoor exposure) or ground surface (outdoor exposure) and the vapour source (i.e., all detectable vapour substance concentrations in soil and groundwater) are separated vertically by 2 m of biologically active soil.
- If nonaqueous phase liquids are present in soil or ground water, or $VH_{w6\text{-}10}$ is > 15,000 µg/L and $EPH_{w10\text{-}19}$ is > 5,000 µg/L, then the BAAD can be applied if the building foundation (indoor exposure) or ground surface (outdoor exposure) and the vapour source (i.e., all detectable vapour substance concentrations in soil and groundwater) are separated vertically by 5 m of biologically active soil.
- If the BAAD is applied to measured soil vapour data, the vapour data must have been collected within 1 m of the vapour source.

- There must be no substantive surface cap at the site. Specifically, paved or other low permeability surfaces cannot represent more than 80% of the area surrounding the building.
- The BAAD can be used only for the aerobically biodegradable substances listed in Table 2 in conjunction with a Table 1 vertical VAF.

Table 2. Substances that are considered to be readily biodegraded in aerobic environments [8].

Substance	Chemical Abstract Service #
benzene	71-43-2
decane, n-	124-18-5
ethylbenzene	100-41-4
hexane, n-	110-54-3
isopropylbenzene	98-82-8
methylcyclohexane	108-87-2
naphthalene	91-20-3
toluene	108-88-3
xylenes, total	1330-20-7
trimethylbenzene, 1,3,5-	108-88-3
trimethylbenzene, 1,2,4-	95-63-6
VPHv	-

4.2 Parkade attenuation adjustment divisor

For buildings with a parkade below the entire footprint[1] of the building, the ministry permits a 50-fold adjustment of the Table 1 vertical VAF [7]. This 50-fold adjustment divisor is described as the PAAD.

PAAD = 50

Use the PAAD as the AAD term in the equation in Section 4.0.

4.2.1 Conditions for using the PAAD

The PAAD may only be applied in conjunction with the sub-slab VAF listed in Table 1 (2.0×10^{-2}).

Use of the PAAD constitutes reliance on an engineered system to increase air exchange within the parkade. Therefore, use of the PAAD constitutes risk management for vapours and only a risk-based contaminated sites legal instrument can be obtained.

[1] "footprint" is defined as the entire area of the foundation of the structure, not including stairs, patios or decks.

Refer to Technical Guidance 4 for more information regarding risk management of vapour contamination.

4.3 Lateral attenuation adjustment divisors

In certain circumstances where the target breathing zone (e.g. current or future building, outdoor receptor location) is offset laterally from the point at which vapours have been characterized, the ministry Table 1 vertical VAFs may be adjusted to account for additional attenuation in the lateral direction [9].

Lateral offset distances are measured horizontally at ground surface from the location of the sampling point to the target breathing zone.

Use the LAADs specified in Table 3 as the AAD term in the equation in Section 4.0.

4.3.1 Conditions for using LAADs

LAADs can only be applied if the following conditions are met:

- Site conditions do not preclude the use of the Table 1 vertical VAFs, including requirements described in Section 3.1;
- The measured or predicted vapour concentration in indoor or outdoor air at the point of measurement is less than or equal to 10 times the vapour standard of the Regulation;
- The point of application of the LAADs (i.e. the point at which subsurface or sub-slab vapours have been characterized) must in all cases be beyond the vapour source in soil or groundwater (i.e., at the boundary of detectable concentrations in soil and groundwater); and
- The contaminant plume must be stable or decreasing in concentration and extent.

Table 3. LAADs for three exposure scenarios

A. Outdoor exposure

Sample depth[3] (m)	Outdoor Exposure LAAD[1,2]									
	Lateral offset distance[4,5] (m)									
	1.0	**1.5**	**2.0**	**3.0**	**5.0**	**7.0**	**10.0**	**15.0**	**20.0**	**30.0**
≤ 1.0	1	1	2	2	4	6	8	13	16	25
1.5		1	1	2	3	5	7	10	13	20
2.0			1	2	2	4	5	8	10	15
3.0				1	2	2	3	5	7	10
5.0					1	1	2	3	4	6
7.0						1	1	2	3	4
10.0							1	2	2	3
15.0								1	1	2
20.0									1	2
30.0										1

B. Indoor exposure – Agricultural/urban park/residential and parkade uses

Sample depth[3] (m)	Indoor Exposure – AL/UP/RL LAAD[1,2]									
	Lateral offset distance[4,5] (m)									
	1.0	**1.5**	**2.0**	**3.0**	**5.0**	**7.0**	**10.0**	**15.0**	**20.0**	**30.0**
≤ 1.0	1	1	1	2	3	3	5	7	8	10
1.5		1	1	1	2	3	4	5	7	10
2.0			1	1	2	2	3	5	6	9
3.0				1	1	2	3	4	5	7
5.0					1	1	2	3	3	5
7.0						1	1	2	3	4
10.0							1	1	2	3
15.0								1	1	2
20.0									1	1
30.0										1

C. Indoor exposure – Commercial/industrial uses

Sample depth[3] (m)	Indoor Exposure – CL/IL LAAD[1,2]									
	Lateral offset distance[4,5] (m)									
	1.0	1.5	2.0	3.0	5.0	7.0	10.0	15.0	20.0	30.0
≤ 1.0	1	1	1	1	2	2	3	4	5	7
1.5		1	1	1	2	2	3	3	4	6
2.0			1	1	1	2	2	3	4	6
3.0				1	1	2	2	3	3	5
5.0					1	1	2	2	3	4
7.0						1	1	2	2	3
10.0							1	1	2	2
15.0								1	1	2
20.0									1	1
30.0										1

[1] LAADs are to be used in conjunction with Table 1 vertical VAFs, if no precluding conditions exist.

[2] For blank cells, LAAD = 1, and for distance and depth combinations outside the range of the above table, no adjustment for lateral attenuation may be applied.

[3] The sample depth for selection of the LAAD should be the same as that used to select the Table 1 vertical VAF.

[4] The lateral offset distance is the horizontal distance from the vertical point at which subsurface or sub-slab vapours have been characterized to the breathing zone under investigation (nearest edge of a current or future building or the nearest point of an outdoor exposure area).

[5] If the lateral distance is between two lateral offset increments (e.g., between 10 and 15 m), select the attenuation factor associated with the smaller lateral offset increment (i.e., in this example, 10 m).

5.0 References

1. Health Canada (2010). Federal Contaminated Risk Assessment in Canada: Guidance for Soil Vapour Intrusion Assessment at Contaminated Sites. Available by request from cs-sc@hc-sc.gc.ca

2. Canadian Council of Ministers of the Environment (CCME) (2016). Guidance Manual for Environmental Site Characterisation in Support of Human Health Risk Assessment. Volumes 1-3. PN1551.

3. CSAP Soil Vapour Advice and Practice Guidelines Development Panel (2009). Soil Vapour Advice and Practice Guidelines Development - Stage 1. Contaminated Sites Approved Professionals of British Columbia.

4. Science Advisory Board for Contaminated Sites in British Columbia (SAB) (2011). Guidance on Site Characterization for Evaluation of Soil Vapour Intrusion into Buildings.

5. US Environmental Protection Agency (2013). Evaluation Of Empirical Data To Support Soil Vapor Intrusion Screening Criteria For Petroleum Hydrocarbon Compounds (EPA 510-R-13-001).

6. US Environmental Protection Agency (2015). OSWER Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites. Office of Underground Storage Tanks, EPA-510-R-15-001.

7. Golder Associates and Science Advisory Board for Contaminated Sites in British Columbia (2011). Derivation of High Density Residential Soil Land Vapour Quality Standards for Use under Contaminated Sites Regulation.

8. Interstate Technology & Regulatory Council (ITRC) (2014). Petroleum Vapor Intrusion (PVI) Guidance.

9. Golder Associates (2017). Memorandum to Contaminated Sites Approved Professionals of BC Society "Updated Review of Lateral Attenuation Adjustment Factors For Potential Adoption in British Columbia Regulatory Framework". 17 p.

For more information, please direct inquiries to site@gov.bc.ca.

Revision history

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	November 1, 2017	1.0	Created for CSR Stage 10 amendment