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UPDATED REVIEW OF LATERAL VAPOUR ATTENUATION FACTORS FOR POTENTIAL ADOPTION IN BRITISH COLUMBIA REGULATORY FRAMEWORK

Dear Mr. Williams:

Golder Associates Ltd. (Golder) was retained by the Society for Contaminated Sites Approved Professionals to assist in a review of options for derivation of lateral attenuation factors and/or lateral screening distances for the assessment and/or exclusion of receptors for the vapour intrusion pathway. The work scope was developed through discussion with Mr. David Williams, who was retained by CSAP for this project. Lateral attenuation factors and updated screening distances are sought for more efficient site investigations and receptor screening. A draft review was provided on August 18, 2016; this letter provides an update with Section 3.2.1 added.

1.0 BACKGROUND

The problem statement is that soil vapour assessments are based on the application of vertical attenuation factors in BC Ministry of Environment (MoE) Technical Guidance 4 (TG4) to soil vapour concentrations for the estimation of indoor air concentrations. The guidance assumes a building is present above the vapour source. Soil vapour investigations are required to delineate vapour contamination. If there are exceedances of the CSR vapour standard near a site boundary, vapour delineation can be challenging when there are roads or other infrastructure present. Because the outdoor air pathway applies for a road land use, the road itself is likely not of concern, but vapour delineation would be required to assess properties beyond roads, and vapour assessment of buildings within 30 m of detectable concentrations.

The current wording in TG4 is:

"*The ministry considers buildings and outdoor areas which are more than 30 m lateral away from detectable vapour PCOC concentrations in soil, sediment, and water to have a low potential for vapour intrusion. Thus, for the purpose of characterizing vapour contamination, you can assume that current and potential future buildings and outdoor areas that lie more than 30 m laterally from all detectable concentrations of vapour PCOCs in soil, sediment, and water are free of vapour contamination, except where conditions meet those in the following note.*"

Potential modifications to the above framework could consider whether lateral screening distances less than 30 m are supported or whether lateral attenuation factors can be applied to assess buildings that are closer than 30 m to the vapour source. In addition, for application of lateral screening distances, evaluation of less conservative criteria for the boundary of "contamination" or impacts are warranted, which is currently the detection limit.

Conceptually, options for lateral attenuation factors include:

1) Current TG4, Table 2 vapour attenuation factors, but applied laterally.

2) Current TG4, Table 2 factors, but applied laterally with a modifying factor (increase or decrease in the factor).

3) New lateral vapour attenuation factors.

A review of modelling and database studies was conducted to provide a basis for the proposed lateral attenuation factor framework described below.

2.0 REVIEW OF MODELLING AND DATABASE STUDIES

This section provides a review of studies on lateral exclusion distances, lateral attenuation factors, as well as the partitioning between soil and soil vapour concentrations as the basis for the proposed recommendations in Section 3.

2.1 Lateral Exclusion Distances

2.1.1 US EPA (2013)

The US EPA (2013) published a comprehensive evaluation of modelling and database studies that evaluated the attenuation of soil vapour concentrations above petroleum hydrocarbon source zones (either light non aqueous phase liquid (LNAPL) or dissolved phase hydrocarbons). On this basis, vertical exclusion distances for attenuation of petroleum hydrocarbon vapour concentrations in un-impacted soil to below concentrations of potential concern were established consisting of 5 feet (1.5 m) for dissolved sources and 15 feet (4.6 m) for LNAPL sources at underground storage tank (UST) type sites. For larger industrial sites, such as refineries, there were limited data to enable determination of an exclusion distance. The US EPA research provides valuable information on vapour attenuation distances for petroleum hydrocarbon vapours. From this and other similar research, the Interstate Technology and Regulatory Council (ITRC) established a lateral exclusion distance of 30 feet (9.1 m) for aerobically biodegradable petroleum hydrocarbon compounds. Because in theory the vertical exclusion distance is also expected to apply laterally, a lateral distance that is similar to the vertical distance is conceptually supported. However, a larger distance of 30 feet was chosen because of the uncertainty typically associated with the lateral delineation of contamination sources and dissolved plumes.

The adoption of source to building separation distances to screen sites that need further field investigation is becoming a common practice for the evaluation of the vapor intrusion pathway at sites contaminated by petroleum hydrocarbons. Namely, for the source to building vertical distance, the screening criteria for petroleum vapour intrusion have been deeply investigated in the recent literature and fully addressed in the recent guidelines issued by ITRC and U.S.EPA. Conversely, due to the lack of field and modeling studies, the source to building lateral distance received relatively low attention.

Verginelli et al. (2016) present a steady-state vapour intrusion analytical model incorporating a piecewise first-order aerobic biodegradation limited by oxygen availability that accounts for lateral source to building separation. The model can be used to predict lateral screening distances needed to attenuate vapour concentrations to risk-based values. For high benzene source groundwater concentrations representative of a gasoline LNAPL source, the simulation results by this model indicate that, regardless of the depth, 6 m lateral distances from the source is sufficient to attenuate petroleum vapours to below a risk-based benzene concentration of 50 $\mu g/m^3$ value in shallow soil vapour. For low to moderate benzene source concentrations, and deeper sources (greater than 5 m), the lateral distance is essentially zero.

2.1.2 California Low Threat Closure Policy

The California Low Threat Closure Policy, which applies to the petroleum UST Cleanup Program, includes a lateral inclusion bioattenuation zone, as shown in Figure 1. The requirements for the bioattenuation zone based on LNAPL and Total Petroleum Hydrocarbon (TPH) concentrations in soil are as follows:

1. "The bioattenuation zone shall be a continuous zone that provides a separation of at least 30 feet b*oth laterally and vertically between the LNAPL in soil and the foundation of existing or potential buildings; and*
2. *Total TPH (TPH-g and TPH-d combined) concentrations that are less than 100 mg/kg throughout the entire lateral and vertical extent of the bioattenuation zone*."

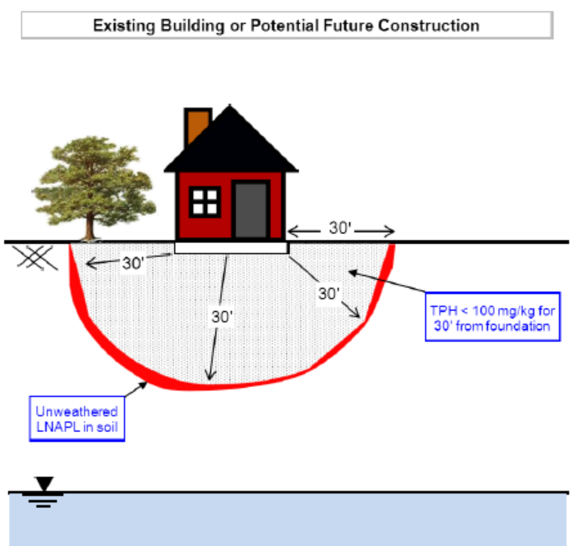

Figure 1: Bioattenuation Zone for California Low Threat Guidance.

2.1.3 CRC Care (2013)

Guidance on petroleum hydrocarbon vapour intrusion prepared by CRC Care (2013) in Australia states that the "*current evidence indicates that petroleum hydrocarbon vapours do not migrate more than one to two metres laterally from the edge of a dissolved phase plume, unless there are preferential pathways*." Preferential pathways include utilities that directly connect zones of significant contamination to buildings.

2.2 Lateral Attenuation Factors

2.2.1 Lowell and Eklund (2004)

Lowell and Eklund (2004) present simulations performed using an analytical model for steady state two-dimensional diffusion within the unsaturated soil zone, without decay (biodegradation) or sorption. The results show that the soil gas concentration and emission flux can be quantified by a decreasing exponential function from the edge of a contaminant plume.

The modelling evaluated the decrease in surface emission flux for increasing distance from the edge of the contamination plume, relative to the diffusive flux that would be estimated at ground surface for a homogeneous unsaturated soil zone above a laterally continuous source of contamination. The flux is calculated as follows:

$$E = [\, D_e C_o / H \,]\ \phi_v\ (\eta)$$

Where $D_e C_o$ / H is the maximum flux that would exist directly above the zone of contamination and $\phi_v(\eta)$, the Dimensionless Flux, is the fraction of the maximum flux at any lateral distance $\eta = x/H$, where x is the lateral distance from the edge of the contamination source and H is the vertical distance between ground surface and contamination. The vapour attenuation factors incorporated in BC MoE TG4 are based on a model that includes diffusion and soil gas advection. While the Lowell and Eklund (2004) model does not include advection, the Dimensionless Flux is considered to provide for a reasonable approximation of the reduction in the vapour attenuation factor that would occur with increasing distance from a source, except for small distances to the building (a few metres) where transport may be advection-dominated.

The predicted Dimensionless Flux is presented in Figure 2 for three vertical distances equal to 2 m, 4 m and 8 m. The results indicate that the flux decreases more rapidly for smaller than larger distances. For a horizontal distance of 10 m from the edge of the contamination source, the Dimensionless Flux ranges from approximately 2E-01 for a vertical distance of 8 m to 1E-03 for a vertical distance of 2 m. Much lower Dimensionless Flux would be expected if aerobic biodegradation were to have been included in the model simulations.

The calculated ratios of the TG4 attenuation factors, for residential land use, based on the lateral distances from edge of contamination to the TG4 attenuation factors for the vertical distances are presented in Figure 3. The calculated TG4 ratios are greater than the Lowell and Eklund (2004) Dimensionless Flux by at least four times and in most cases multiple orders of magnitude. This means applying a lateral attenuation factor based on TG4 is conservative.

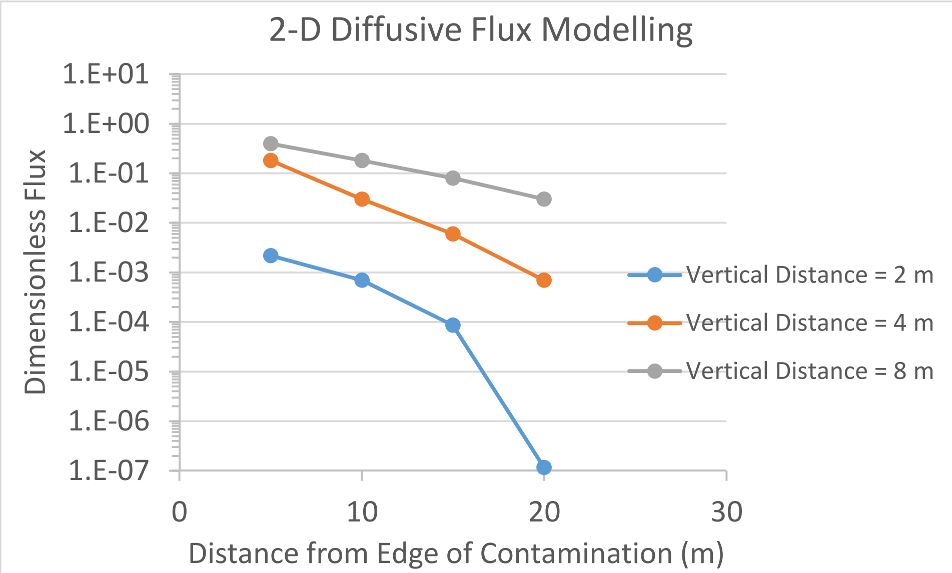

Figure 2: Dimensionless Flux predicted from 2-D analytical model for diffusion based on Lowell and Eklund (2004).

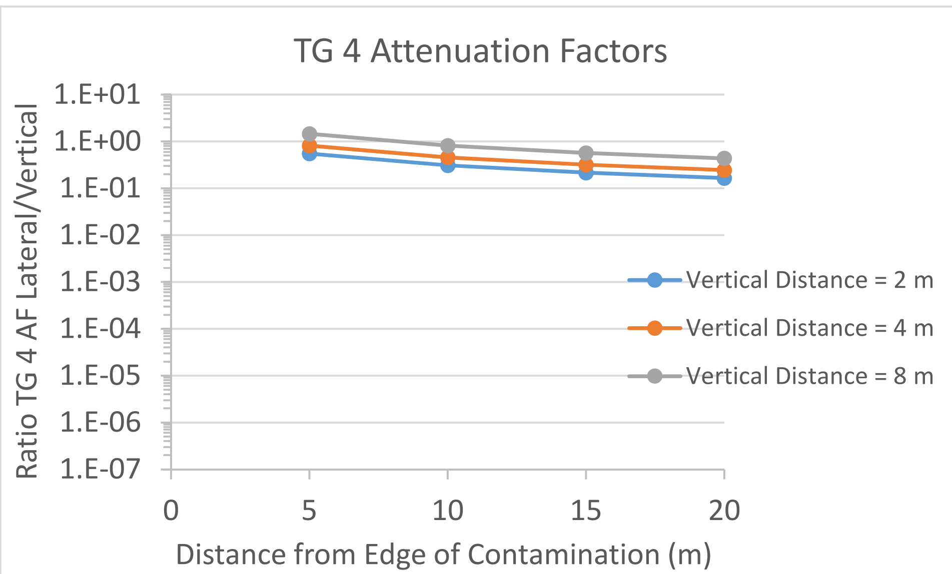

Figure 3: Calculated ratio of the TG4 residential attenuation factors (AF) for lateral distance from edge of contamination to vertical attenuation factors.

2.2.2 Abreu and Johnson (2005)

Abreu and Johnson (2005) present simulation results for a three-dimensional numerical model of the soil vapour-to-indoor air pathway that incorporates diffusive and advective transport, without decay or sorption. Steady-state simulations were conducted to evaluate the influence of lateral separation distance between the edge of a 30 m wide contamination source and building with a basement and slab-at-grade construction. The building is the size of a residential house, the soils are sandy, and soil gas advection was assumed to equal approximately 5 L/min. In general, the input parameters for the modelling were similar to those used to derive the vapour attenuation factors in BC MoE TG4.

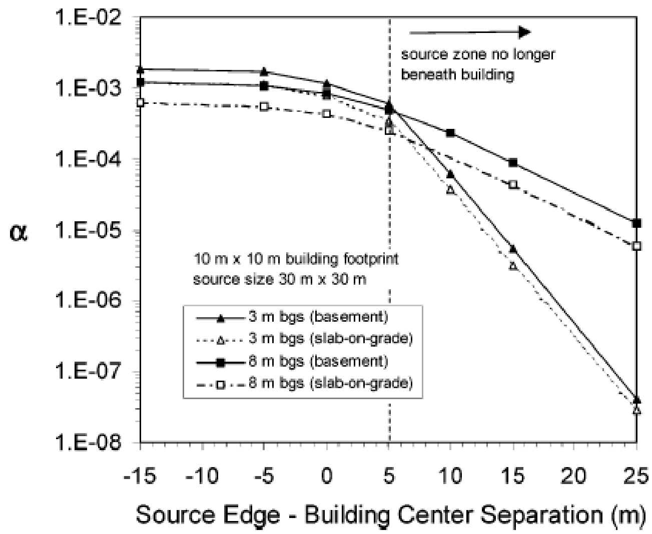

Figure 4: Changes in vapour attenuation coefficient (α) with vapour source-building separation and vapour source depth for basement and slab-on-grade foundation scenarios from Abreu and Johnson (2005).

The predicted vapour attenuation factors for the lateral transport scenario are shown in Figure 4. The distances are to the centre of a 10 m wide building. The rate of decrease in the attenuation factor for increasing lateral separation distances increases for shallow depths to contamination, which is attributed to the effect of oxygen availability on biodegradation. An Additional Lateral Attenuation Factor was calculated from the results of modelling by Abreu and Johnson (2005) and is shown in Figure 5. The Additional Lateral Attenuation Factor was calculated by dividing the attenuation factor at the separation distance of interest by the maximum attenuation factor, which is 1.1×10^{-3} for the basement scenario. The Additional Lateral Attenuation Factor for a horizontal distance of 10 m from the edge of the contamination source, is approximately 5E-03 for a vertical distance of 3 m and 1E-01 for vertical distance of 8 m. The Additional Lateral Attenuation Factor is a smaller number than the Dimensionless Flux predicted using the Lowell and Eklund (2004) model (i.e., the Lowell and Eklund model predicts less attenuation).

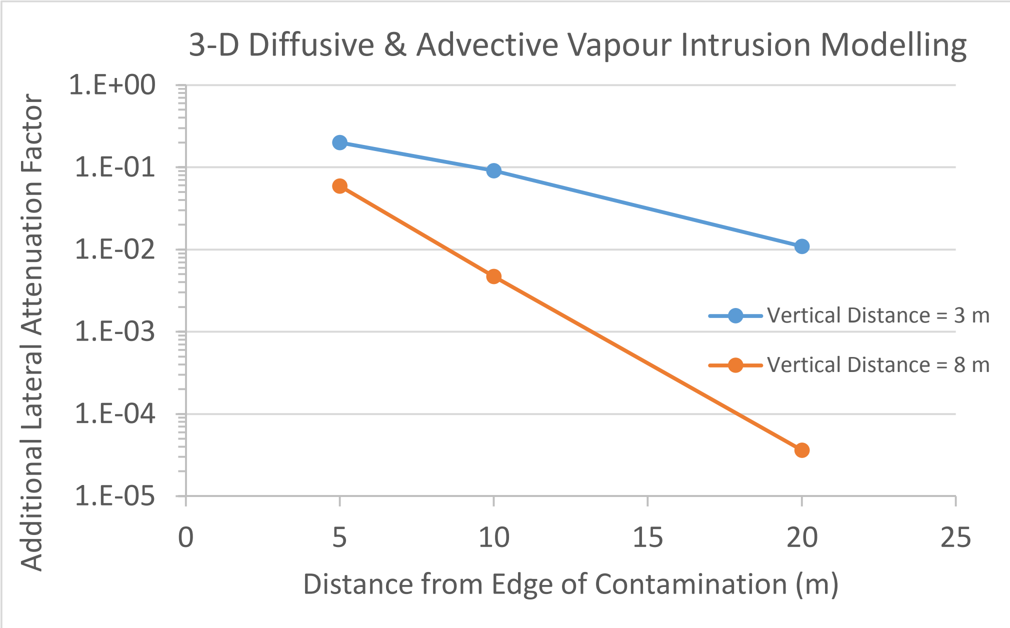

Figure 5: Additional Lateral Attenuation Factor calculated from Abreu and Johnson (2005) modelling in Figure 4 for basement scenario.

2.2.3 Yao et al. (2013)

Yao et al. (2013) present the results of modelling of lateral vapour attenuation using a steady state two-dimensional model for diffusion assuming homogeneous soil. The modelling results are presented as the ratio between the subslab vapour concentration to source vapour concentration (C_k/C_s) as a function of the ratio of the depth to the foundation to the depth to vapour source (d_f/d_s), where the C_k is the subslab vapour concentration, C_s is the source vapour concentration, d_f is the depth to the base of the foundation and d_s is the depth to vapour source (Figures 6 and 7). As shown, the modelling results are presented for varying r values, which is the ratio of the source edge to building distance (d_h) to source depth, d_s (d_h/d_s).

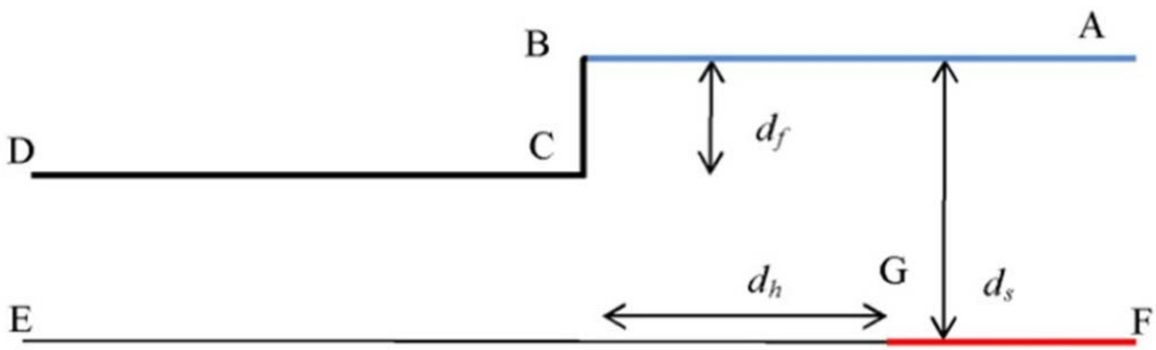

Figure 6: The modelling scenario with lateral source-building separation from Yao et al. (2013).

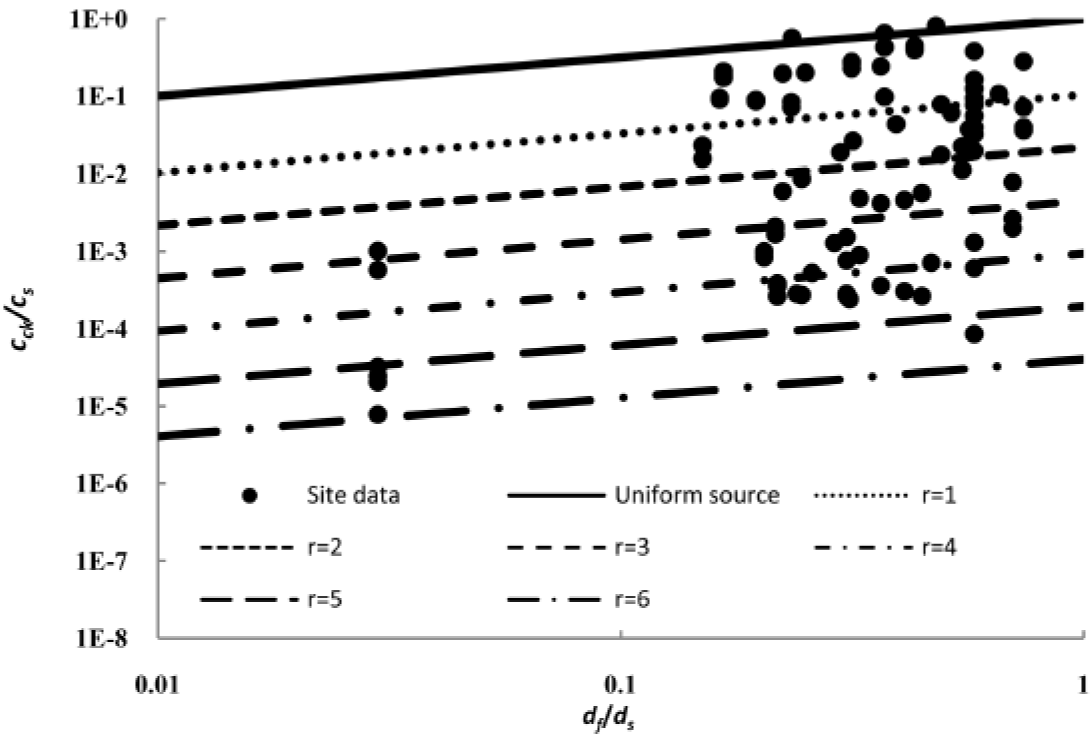

Figure 7: Ratio of measured subslab concentration to measured vapour concentration of a groundwater source as a function of the ratio of foundation depth to source depth for varying r = d_h/d_s values. Included are the US EPA vapour intrusion database values for tetrachloroethylene and trichloroethylene from Yao et al. (2013 indicated as Site data by solid circles).

The ratio of the subslab vapour concentration to the source vapour concentration decreases rapidly to several orders of magnitude as the lateral separation distance increases, as shown in Figure 7. Yao et al. (2013) suggest that the great variation in the attenuation factors predicted by the model may be one reason for the large observed range in the US EPA database of vapour attenuation factors (US EPA, 2012a).

2.2.4 US EPA (2012b)

US EPA (2012b) presents a comprehensive review of conceptual site models for vapour intrusion and results of numerical modelling. Scenarios evaluated include the influence of a capping layer on the lateral vapour attenuation. The following vapour attenuation factors are predicted for a residential house scenario, sandy soil, without biodegradation or sorption, depressurized basement (5 Pa) and vertical distance of 6 m between the vapour source and building:

- Vapour source below building, homogeneous soil: **1.2E-03.**
- Edge of vapour source 20 m from building, homogeneous soil: **1.3E-05** (Additional Lateral Attenuation Factor = **1.2E-2**).
- Edge of vapour source 20 m from building, surface low permeability soil underlain by high permeability soil: **7.6E-05** (Additional Lateral Attenuation Factor = **6.9E-2**) (Figure 8).

The high permeability soil layer has a percent saturation (S) of 20% and soil gas permeability (K_g) of 1E-11 m^2. The 1 m thick low permeability soil layer has a S of 60% and K_g of 1E-13 m^2. These results suggest a soil capping layer would not significantly increase the lateral vapour attenuation factor. Pavement is a relatively permeable material and is not expected to result in order of magnitude higher attenuation factors compared to the low permeability scenario above and should not be considered a precluding condition. A very low permeability cover such as a geomembrane liner would be considered a precluding condition.

The ratio of the TG4 residential attenuation factor for a lateral distance of 20 m to the attenuation factor for a vertical distance of 6 m is 3.6E-01 which is greater than the Additional Lateral Attenuation Factor for the capping scenario (6.9E-02).

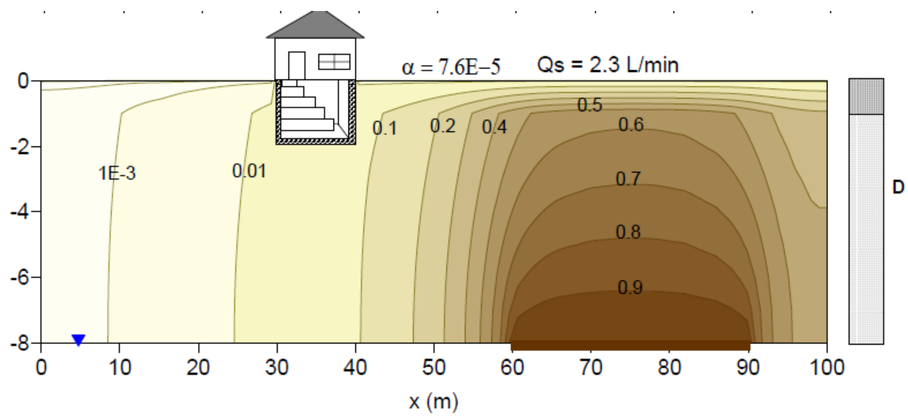

Figure 8: The effect of surface low permeability layer on soil vapour distribution and normalized indoor air concentration (α) for a deep laterally separated vapour source from US EPA (2012b).

2.3 Partitioning Between Soil and Soil Vapour Concentrations

Golder conducted a research project for Health Canada and Canadian Petroleum Products Institute (CPPI), now the Canadian Fuels Association (CFA) (Golder, 2008). For this project, the predicted Canadian Council of Ministers of the Environment (CCME) F1 fraction soil vapour concentrations from soil concentrations were compared to nearby measured soil vapour concentrations for 22 sites. The results, shown in Figure 9, indicate that predicted concentrations from an equilibrium partitioning model over-predicted the measured soil vapour concentrations by at least 10 times, and typically 100 times.

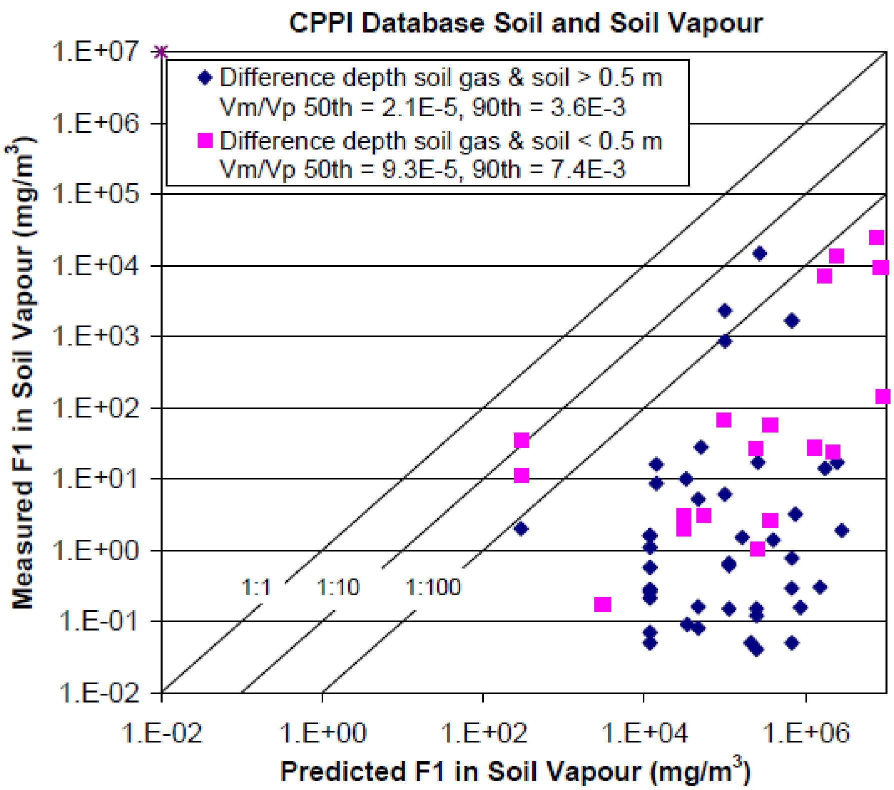

Figure 9: Comparison of measured and predicted CCME F1 soil vapour concentrations from Golder (2008).

3.0 DISCUSSION AND RECOMMENDATION

3.1 Lateral Exclusion Distance

There is a significant body of recent evidence for rapid aerobic biodegradation of petroleum hydrocarbon vapours over short distances in the vadose zone. For this reason, a lateral exclusion distance of 10 m for aerobically biodegradable chemicals (TG 4 Table 1, excluding 1,2-dichloroethane and ethylene dibromide) is proposed. For substances that do not readily biodegrade, the proposed lateral exclusion distance remains as 30 m.

Currently, TG4 indicates this distance is applied to the edge of any detectable concentrations in soil, groundwater and/or soil vapour. It is proposed that this definition be retained, but an optional criteria be included to define the boundary for vapour contamination. The framework for lateral exclusion distances is summarized in Figure 10 and described as follows:

1) NAPL bodies and dissolved plumes are stable or shrinking.

2) No precluding conditions (e.g., preferential pathways).

3) The boundary for vapour contamination is determined from the vertical distance between the vapour source and building and TG4 attenuation factor based on the:

   a) Indoor air concentration predicted from the measured soil vapour concentration that is less than the CSR vapour standard (mandatory).

b) Indoor air concentration predicted from the measured groundwater concentration and Henry's law constant partitioning model that is less than the CSR vapour standard (mandatory).

c) Indoor air concentration predicted from the measured soil concentration and partitioning model with 10X reduction factor applied to the estimated soil vapour concentration to account for the conservative nature of the partitioning equation that is less than the CSR vapour standard (use of soil concentrations is optional, for petroleum hydrocarbon substances only[1]).

d) The boundary for vapour contamination must in all cases be beyond the contamination source (NAPL) zone.

4) Lateral exclusion distance of 10 m for aerobically-biodegradable substances and 30 m for non aerobically-biodegradable substances.

The use of soil data for petroleum hydrocarbon substances is optional because of the uncertainty in the partitioning equations and conservatism associated with predicted soil vapour concentrations from soil concentrations.

An example calculation for groundwater assumes trichloroethylene (TCE) is the substance of potential concern and the Schedule 11 residential vapour standard is 0.5 μg/m^3. If the vertical distance between building and vapour measurement point is 8 m, the vapour attenuation factor is 8E-04 and Henry's Law constant is 0.4 (BC MoE Protocol 13, not temperature corrected), then the back-calculated boundary TCE groundwater concentration for determination of the exclusion distance is 1.6 μg/L. The detection limit is the lower bound for the calculations.

Another example calculation for soil assumes benzene is the substance of potential concern and the Schedule 11 residential vapour standard is 1.5 μg/m^3. If the vertical distance between building and vapour measurement point is 8 m, the vapour attenuation factor is 8E-04, water-filled and total porosity are 0.054 and 0.375, respectively, and Henry's Law constant is 0.227 (BC MoE Protocol 13), then the back-calculated boundary benzene soil concentration for determination of the exclusion distance is 0.047 mg/kg assuming a 10X factor. The detection limit is the lower bound for the calculations.

[1] Soil media is not used for this calculation for chlorinated solvents based on uncertainty in prediction for compounds with density greater than water (i.e., DNAPLs) consistent with TG4.

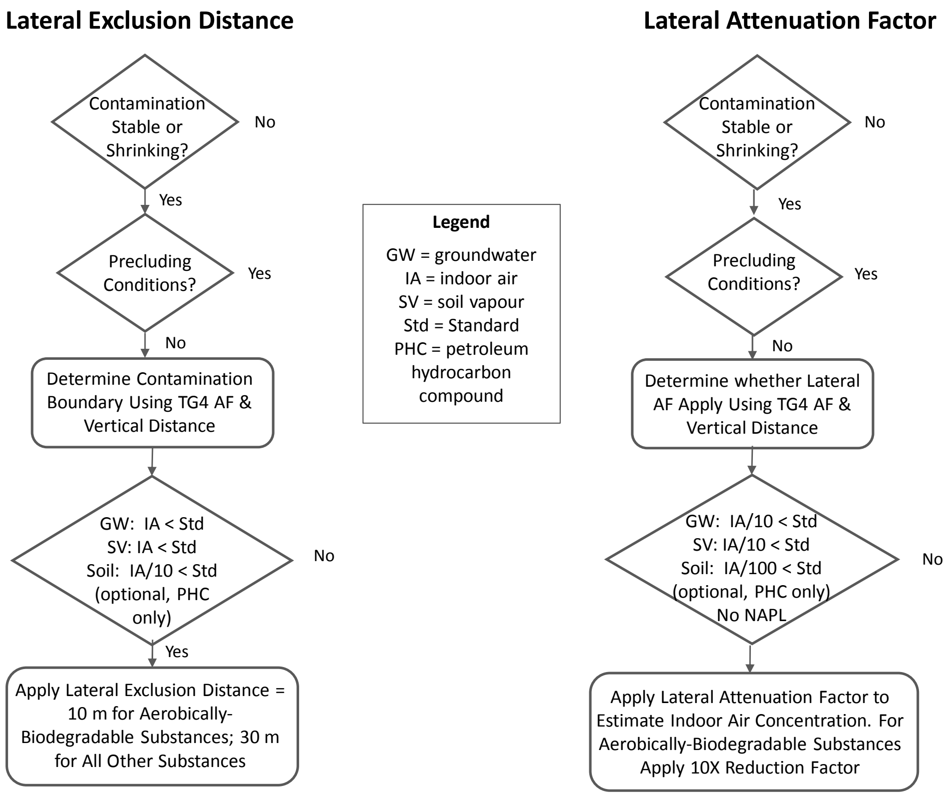

Figure 10: Proposed framework for lateral exclusion distances and attenuation factors.

3.2 Lateral Attenuation Factors

The framework for application of lateral attenuation factors assumes that there is an exceedance of a vapour standard based on the vertical attenuation factors in TG4 but that there are constraints to the lateral delineation of soil vapour and/or need to assess a building within the 30 m lateral exclusion distance. A relatively simple approach that is technically supported based on the data analysis in Section 2.0 is to apply the TG4 attenuation factors in the lateral direction from the vapour measurement point. It is recommended that the use of lateral attenuation factors for this purpose be limited to cases where soil vapour concentrations are less than 10 times the standard based on the attenuation factor for the vertical distance.

The proposed framework consists of two steps. The first step involves determining whether it is protective to apply lateral attenuation factors based on the measured or estimated soil vapour concentrations. Several options were considered including comparison to standards for other pathways (e.g., concentrations less than the drinking water standard) or calculation based on the vapour intrusion pathway. The latter option is proposed because it is directly relevant. An important aspect of this calculation is that groundwater data also be evaluated to increase confidence in the assessment. The conceptual model for the evaluation assumes that the partitioning between groundwater and soil vapour is consistent across the site. The second step involves applying an attenuation factor to the soil vapour concentration based on the site-specific lateral distance to the receptor. The framework is summarized in Figure 10 and described below:

1) NAPL bodies and dissolved plumes must be stable or shrinking.

2) There are no precluding conditions (e.g., preferential pathways).

3) To apply lateral attenuation factors, the following conditions must first be met based on application of TG4 attenuation factors and vertical distance between the source and building:

   a) Indoor air concentration predicted from the measured soil vapour concentration that is less than 10 times the CSR vapour standard (mandatory).

   b) Indoor air concentration predicted from the measured groundwater concentration and Henry's Law constant partitioning model that is less than 10 times the CSR vapour standard (mandatory).

   c) Indoor air concentration predicted from the measured soil concentration and partitioning model that is less than 100 times the CSR vapour standard (use of soil concentrations is optional, for petroleum hydrocarbon compounds only).

   d) The point of application of the lateral attenuation factors must in all cases be beyond the contamination source (NAPL) zone.

4) Estimate the indoor air concentration for the receptor using the measured soil vapour concentration and TG4 attenuation factor based on the lateral distance between the measurement point and building. For aerobically biodegradable compounds, the attenuation factor may be reduced by a factor of 10 times when the separation distance is greater than 3 m, as currently allowed under TG4. No fixed gas data (e.g., oxygen, carbon dioxide) is considered required to support the use of the 10 times adjustment because for a lateral migration scenario the oxygen flux to the subsurface should typically far exceed diffusive hydrocarbon flux, unlike a vertical migration scenario where shallow contamination is directly below a building.

As an example calculation, assume TCE is the substance of potential concern and the Schedule 11 residential vapour standard is 0.5 $\mu g/m^3$. The vertical distance between the building and vapour measurement point is 8 m and vapour attenuation factor is 8E-04 and Henry's Law constant is 0.4 (BC MoE Protocol 13). A soil vapour and groundwater investigation indicates the measured TCE concentrations near to the site boundary are:

- soil vapour equal to 1,000 $\mu g/m^3$ resulting in a predicted indoor air concentration of 0.83 $\mu g/m^3$, which exceeds but is less than 10 times the vapour standard; and
- groundwater equal to 3.2 $\mu g/L$, which results in a predicted indoor TCE concentration of 1 $\mu g/m^3$, which exceeds but is less than 10 times the vapour standard.

The lateral distance between the vapour measurement point and off-site building for this example is assumed to be 20 m. The TG4 attenuation factor for a distance of 20 m is 3.3E-04. The predicted indoor air concentration at the building is 0.33 $\mu g/m^3$ and therefore no further vapour delineation would be required.

For the above example, the predicted indoor air concentration exceeds the standard based on vertical attenuation factor. Therefore, if there was an existing or future building above the vapour measurement point, appropriate actions would need to be taken to address vapour contamination.

3.2.1 Further Refinement to Lateral Attenuation Factor Approach

One option is to apply the attenuation factors in TG4 in the lateral direction as discussed above. Another option would be to develop a set of reduction factors that reduce the TG4 attenuation factors based on a lateral distance off-set distance. The lateral attenuation factor would be estimated as follows:

Lateral attenuation factor = TG4 attenuation factor (vertical distance) / Reduction Factor

Reduction Factor = TG4 attenuation factor (vertical distance) / TG4 attenuation factor (lateral offset)

Where Lateral offset (L) is lateral distance from edge of source to building and vertical distance is the distance between the vapour source and building slab.

The Reduction Factor would only apply when the lateral offset distance > vertical distance.

The Reduction Factors calculated for residential and commercial land use based on TG4 attenuation factors are presented in the Tables 1 and 2. The Reduction Factors for the outdoor air exposure pathway are presented in Table 3.

Table 1. Residential Reduction Factors for Lateral Vapour Attenuation

Distance (m)	Lateral offset (m)	0	1.0	1.5	2.0	3.0	5.0	7.0	10.0	15.0	20.0	30.0
		alpha	2.8E-03	2.3E-03	2.0E-03	1.6E-03	1.1E-03	8.3E-04	6.2E-04	4.3E-04	3.3E-04	2.3E-04
1.0		2.8E-03		1.2	1.4	1.8	2.5	3.4	4.5	6.5	8.5	12.2
1.5		2.3E-03			1.2	1.4	2.1	2.8	3.7	5.3	7.0	10.0
2.0		2.0E-03				1.3	1.8	2.4	3.2	4.7	6.1	8.7
3.0		1.6E-03					1.5	1.9	2.6	3.7	4.8	7.0
5.0		1.1E-03						1.3	1.8	2.6	3.3	4.8
7.0		8.3E-04							1.3	1.9	2.5	3.6
10.0		6.2E-04								1.4	1.9	2.7
15.0		4.3E-04									1.3	1.9
20.0		3.3E-04										1.4
30.0		2.3E-04										

Table 2. Commercial Reduction Factors for Lateral Vapour Attenuation

Depth (m)	Lateral offset (m)	0	1.0	1.5	2.0	3.0	5.0	7.0	10.0	15.0	20.0	30.0
		alpha	3.7E-04	3.4E-04	3.1E-04	2.7E-04	2.1E-04	1.7E-04	1.3E-04	9.9E-05	7.8E-05	5.5E-05
1.0		3.7E-04		1.1	1.2	1.4	1.8	2.2	2.8	3.7	4.7	6.7
1.5		3.4E-04			1.1	1.3	1.6	2.0	2.6	3.4	4.4	6.2
2.0		3.1E-04				1.1	1.5	1.8	2.4	3.1	4.0	5.6
3.0		2.7E-04					1.3	1.6	2.1	2.7	3.5	4.9
5.0		2.1E-04						1.2	1.6	2.1	2.7	3.8
7.0		1.7E-04							1.3	1.7	2.2	3.1
10.0		1.3E-04								1.3	1.7	2.4
15.0		9.9E-05									1.3	1.8
20.0		7.8E-05										1.4
30.0		5.5E-05										

Table 3. Outdoor Reduction Factors for Lateral Vapour Attenuation

Depth (m)	Lateral offset (m)	0	1.0	1.5	2.0	3.0	5.0	7.0	10.0	15.0	20.0	30.0
		alpha	1.5E-06	1.2E-06	9.2E-07	6.1E-07	3.7E-07	2.6E-07	1.8E-07	1.2E-07	9.2E-08	6.1E-08
1.0		1.5E-06		1.3	1.6	2.5	4.1	5.8	8.3	12.5	16.3	24.6
1.5		1.2E-06			1.3	2.0	3.2	4.6	6.7	10.0	13.0	19.7
2.0		9.2E-07				1.5	2.5	3.5	5.1	7.7	10.0	15.1
3.0		6.1E-07					1.6	2.3	3.4	5.1	6.6	10.0
5.0		3.7E-07						1.4	2.1	3.1	4.0	6.1
7.0		2.6E-07							1.4	2.2	2.8	4.3
10.0		1.8E-07								1.5	2.0	3.0
15.0		1.2E-07									1.3	2.0
20.0		9.2E-08										1.5
30.0		6.1E-08										

4.0 CLOSURE

We trust that this letter report provides the information you require. Should you have any questions please do not hesitate to contact the undersigned at 604-298-6623.

Yours very truly,

GOLDER ASSOCIATES LTD.

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