Vapour Investigation and Remediation

Introduction

Regulatory context

On January 1, 2009, the Stage 6 amendments to the Contaminated Sites Regulation (the Regulation) under the *Environmental Management Act* came into effect [1]. These amendments included the addition of vapour as a regulated environmental medium and a new schedule: Schedule 11 "Generic Numerical Vapour Standards". The ministry has written this document to clarify its expectations for the assessment of sites in the context of these amendments.

Document organization

This document is divided into sections involving the following four activities (Figure 1):

- identifying site use, areas of potential environmental concern (APECs), and potential contaminants of concern (PCOCs);
- refining the list of vapour PCOCs;
- characterizing vapour contamination; and
- remediating vapour contamination.

Supplementary notes and final comments complete the document. The terms used in this guidance listed in Appendix 1 are defined in the procedure "Definitions and Acronyms for Contaminated Sites."

Identifying site use, APECs, and PCOCs

To begin, identify APECs, PCOCs, and site use as per standard practice for Stage 1 preliminary site investigations (PSIs) [2]. Vapour PCOCs include all substances that are both of the following:

a) associated with activities listed in Schedule 2 of the Regulation (Schedule 2) carried out on or near the site, and

b) listed in Schedule 11 of the Regulation (Schedule 11).

When selecting PCOCs for dry cleaning, waste oil, diesel, or gasoline APECs, the ministry recommends following the guidance "CSAP Soil Vapour Advice and Practical Guidelines" [3] developed by the Contaminated Sites Approved Professional (CSAP) Soil Vapour Advice and Practice Guidelines Development Panel. Site use is determined in accordance with Section 12 (2.2) of the Regulation and footnotes 5, 6, and 7 of Schedule 11.

Note
Regarding footnote 5 of Schedule 11, vapour that passes vertically from water through soil to the breathing zone is deemed to arise from soil. Thus, for example, where vapour arises from groundwater, passes through soil, and enters a commercial building at the surface of a commercial land use site, the site use is commercial and the vapour is deemed to arise from soil, not water.

Refining the list of vapour PCOCs

Gasoline and diesel vapour PCOCs

This refinement step applies only to the gasoline and diesel component substances listed in Table 1. For each APEC, once you have sufficient soil, sediment, and water data, you can remove from the vapour PCOC list those gasoline and diesel substances for which the following are true:

a) substance concentrations are clearly demonstrated to be less than the detection limit[1] in soil, sediment, and water on the site;

b) substance concentrations are clearly demonstrated to be less than the detection limit or likely less than the detection limit in soil, sediment, and water near the site; and

c) there is no other evidence (e.g., odours, staining) suggesting the presence of the substance in soil, sediment, or water.

In other words, for each APEC, you can remove from the vapour PCOC list those gasoline and diesel substances which have no identifiable onsite or offsite source in soil, sediment, or water[2]. The ministry supports this refinement step because gasoline and diesel substances with no identifiable vapour source in soil, sediment, or water pose a negligible vapour risk to human health.

[1] The detection limit is that reported by a Canadian Association for Laboratory Certification (CALA) certified stationary or mobile laboratory using analytical methods specified in a Director's protocol or alternate methods acceptable to Director.

[2] The authority to limit the list of vapour PCOCs to substances associated with a soil, sediment, or water source is found in Section 1 of the Regulation which defines vapour as "gaseous emissions from soil, sediment or water".

Note

The ministry recommends limiting the search for detectable gasoline and diesel substances in soil, sediment, and water to within 30 m lateral of the site boundary except a) where the vapour plume > 30 m away is connected to the site via a preferential pathway; b) where the vapour plume > 30 m away is moving towards the site under pressure; c) where there is continuous, low permeability cover between the vapour source > 30 m away and the site; or d) where the vapour plume > 30 m away from the site is expanding. Refer to Chapter 5 of reference 3 for more information on these conditions.

If, after applying this vapour PCOC refinement step, there are no longer any vapour PCOCs for a given APEC, then the vapour at that APEC is considered not contaminated and characterization of vapour contamination at that APEC is not required.

Characterizing vapour contamination

What is vapour contamination?

Vapour contamination exists if the concentration of any vapour PCOC that is associated with a soil, sediment, or water source exceeds its Schedule 11 standard in the breathing zone.

What is the breathing zone?

The breathing zone is any area where humans can come into direct contact with contaminated vapour. For the purpose of characterizing vapour contamination, this can include indoor and outdoor, onsite and offsite environments that exist at the time of site assessment or that have a reasonable potential to exist after site assessment is complete.

What does it mean to characterize vapour contamination?

Characterizing vapour contamination means determining, for each vapour PCOC, whether there are any Schedule 11 exceedances in the breathing zone, and if so, delineating the entire extent of these Schedule 11 exceedances.

How far should we look for vapour contamination?

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.

Note
Use of the 30 m screening step is not permitted a) where a preferential pathway connects detectable substances in soil, sediment, or water to a building > 30 m away; b) where vapour is moving under pressure; c) where there is continuous, low permeability cover between the detectable substances in soil, sediment, or water and the building > 30 m away; or d) where the vapour plume is potentially expanding. Refer to Chapter 5 of reference 3 for more information on these precluding conditions.

Estimating vapour PCOC concentrations in the breathing zone

To estimate the concentrations of vapour PCOCs in the breathing zone, use one or more of the following approaches:

Approach A
Collect subsurface and/or subslab vapour samples, analyze the samples for vapour PCOCs, and apply appropriate ministry vapour attenuation factors to the analytical results to estimate the concentrations of vapour PCOCs in the breathing zone.

Approach B
Collect indoor, crawlspace, and/or outdoor vapour samples and analyze the samples for vapour PCOCs. Use the analytical results obtained as a direct estimate of the concentrations of vapour PCOCs in the breathing zone.

Approach C
Collect soil and groundwater samples from the site and analyze the samples for vapour PCOCs. Use the partitioning equations in Exhibit 2 of reference 4 to estimate, from the soil and groundwater data, the concentrations of vapour PCOCs in subsurface vapour. Then apply appropriate ministry vapour attenuation factors to the estimated concentrations of vapour PCOCs in subsurface vapour to estimate the concentrations of vapour PCOCs in the breathing zone.

Notes on Approach C

- The option to estimate PCOC concentrations in subsurface vapour from PCOC concentrations in soil and groundwater is intended as a cost-saving characterization approach (a) where soil and water is well characterized, substance concentrations in soil and water are low, and vapour contamination is unlikely, or (b) where the vapour source will be removed from the site regardless of the outcome of the vapour assessment. Use of this modelling approach in other situations is not recommended.
- The estimation of vapour PCOC concentrations in subsurface vapour from measured PCOC concentrations in soil is not recommended as a sole characterization approach for liquids with a specific gravity greater than one because these substances can form dense non-aqueous phase liquids (DNAPLs). DNAPLs are difficult to characterize, so vapour arising from DNAPLs will also be difficult to characterize through modelling alone.
- If you estimate vapour PCOC concentrations in the breathing zone using both vapour data (i.e., Approach A or B) and soil and groundwater data (i.e., Approach C), give preference to the estimates derived using vapour data. Also, if the estimates from vapour data and soil/groundwater data are widely different, provide valid, scientific reasons for the disparity.

Refer to the sections that follow for more information on Approaches A, B, and C.

If, after characterization of vapour contamination, the concentrations of all vapour PCOCs in the breathing zone are clearly less than or equal to applicable Schedule 11 standards, then site vapour is considered to be not contaminated, and no additional vapour characterization is recommended. If, on the other hand, the concentration of any vapour PCOC in the breathing zone exceeds its Schedule 11 standard, then site vapour is considered to be contaminated and must be remediated before a Certificate of Compliance for the site will be issued.

Vapour sampling and analysis

For guidance on vapour sampling and analysis, use either of the following references, giving preference to the first where they conflict:

- Chapter 7, Chapter 8, and appended checklists of Health Canada's guidance manual for environmental site characterization [5]
- Science Advisory Board guidance on site characterization for vapour intrusion [6]

Both of these references provide extensive direction on and discussion of conceptual site models, study objectives, sampling design, biodegradation assessment, sampling equipment and procedures, sample analysis, quality assurance/quality control procedures, and data interpretation for subsurface, subslab, and above ground vapour sampling. In addition, both references discuss vapour intrusion theory, provide the rationale for sampling procedures, and provide references to sampling literature, all of which can be useful when documenting the rationale for professional judgement decisions made at your site. Environmental consultants carrying out or interpreting the results of vapour investigations should have a detailed understanding of the guidance provided in these references before proceeding with vapour sampling and analysis.

While the above referenced guidance documents from Health Canada and the Science Advisory Board are thorough, they may not be sufficiently comprehensive for your particular site's circumstances. Refer to the following references, listed in order of ministry preference, for supplementary guidance on vapour sampling and analysis:

- CSAP Society Soil Vapour Advice and Practical Guidelines [3]. This document is particularly helpful for sites with shallow vapour sources.
- California EPA vapour intrusion guidance and response to public comments [7, 8]
- ASTM standard practice for vapour assessment [9]
- ITRC vapour intrusion guidance [10]
- Washington State DOE vapour intrusion guidance [11]
- Oregon State DEQ vapour intrusion guidance [12]

Regardless of the vapour sampling and analysis approach taken, characterization of vapour contamination must capture worst-case vapour concentrations expected in the breathing zone over the period of time any Determination of Contaminated Site or Certificate of Compliance for the site is expected to remain valid. Accordingly, please take note of the following when collecting and interpreting vapour data:

- It is up to the environmental consultant to determine how many vapour sampling events are required to capture the worst-case concentrations expected in the breathing zone for a particular site. Vapour data collected from multiple seasons and years is desirable. However, the results of one round

of vapour sampling could be sufficient if accompanied by strong scientific arguments, a well characterized vapour source, and the results of a defensible vapour model which supports the vapour sampling results.

- Environmental consultants must indicate, with supporting documentation, whether or not the substance concentration in vapour is at steady-state or decreasing at the location where the vapour sample was taken. Refer to reference 13 for guidance.
- Indoor, crawlspace, and subslab samples will only be valid for the building from which they were collected unless sufficient documentation is provided to support the case that the results are also valid for other buildings.
- In some situations, subsurface vapour collected from uncovered or partially covered areas of a site will not be representative of vapour concentrations beneath adjacent buildings or beneath a building erected above the sampling site in the future. For details, see page 146, Table 7-1, Table 7-2, and Figure 7-1 of reference 5.

Vapour attenuation factors

Use the following equations to estimate vapour PCOC concentrations in the breathing zone from vapour PCOC concentrations in subsurface or subslab vapour:

$$(1)\ C_{V\text{-}I} = C_{V\text{-}SS} * \alpha$$

$$(2)\ C_{V\text{-}O} = C_{V\text{-}SS} * \alpha$$

Where $C_{V\text{-}I}$ ($\mu g/m^3$) is the estimated PCOC concentration in indoor vapour, $C_{V\text{-}O}$ ($\mu g/m^3$) is the estimated PCOC concentration in outdoor vapour, $C_{V\text{-}SS}$ ($\mu g/m^3$) is the measured or estimated PCOC concentration in subsurface vapour or subslab vapour, and α (unitless) is the vapour attenuation factor.

For vapour characterization purposes, the ministry default vapour attenuation factors shown in Table 2 must be used. The use of alternative vapour attenuation factors is only permitted under risk assessment.

Note the following when applying the default vapour attenuation factors:

- The default vapour attenuation factors do not apply laterally, they only apply to vertical vapour attenuation. Assess lateral attenuation by taking lateral step out samples[3].
- There are a number of precluding conditions to the use of the default vapour attenuation factors—see the footnotes to Table 2 for these precluding conditions.
- The choice of a vapour attenuation factor depends on the current and reasonable potential future configuration of the site (e.g., location and foundation depth of buildings), as per Section 12 (5) of the Regulation.

Adjustment of the default vapour attenuation factors to account for biodegradation

Under certain conditions (see below), the ministry permits a 10-fold adjustment of the Table 2 vapour attenuation factors to account for biodegradation, as per the following equation:

$$(3)\ \alpha_{bio} = \alpha / 10$$

Where α_{bio} (unitless) is the Table 2 vapour attenuation factor adjusted for biodegradation, and α is the Table 2 vapour attenuation factor.

Use of α_{bio} is restricted to the following conditions:

- α_{bio} can be used only for benzene, toluene, ethylbenzene, or xylenes.

[3] Refer to the Technical Guidance 4 Q&As for an exception to this rule: http://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation

- α_{bio} cannot be applied unless the distance between the building foundation (indoor exposure) or ground surface (outdoor exposure) and the vapour source (i.e., all detectable vapour PCOC concentrations in soil and groundwater) exceeds 3 m vertically.
- If α_{bio} is applied to measured vapour data, the vapour data must have been collected near 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.
- O_2, CO_2, and methane concentration gradient data must be collected from the subsurface of the site and must support the assumption that aerobic biodegradation is occurring at the site.

Refer to Chapter 7.6 of reference 4 and Chapter 7.4.4 of reference 5 for more information on the biodegradation adjustment of the Table 2 default vapour attenuation factors.

Offsite migration

Vapour contamination originating onsite and migrating offsite must be fully delineated in accordance with the preceding sections of this document. When characterizing offsite vapour, pay particular attention to the location of any preferential flow pathways—these have the potential to carry vapour contamination far from the site. In addition, base the offsite land use and selection of vapour attenuation factors on the current and reasonable potential future configuration of the offsite area (e.g., location and foundation depth of buildings), as per Section 12 (5) of the Regulation.

Note
If, during a site investigation or independent remediation, one or more substances has migrated (or is likely to have migrated) to a neighbouring property and is causing (or is likely to cause) contamination of that property, the neighbouring property owner and ministry must be notified within 15 days of the responsible person becoming aware of the situation. Go to the following link for a copy of the notification of offsite migration form:
www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation/guidance-resources/forms

Remediating vapour contamination

Under Section 16 of the Regulation, you may remediate a site to either the numerical or risk-based standards. This usually involves the development of a remediation plan and the completion of one or more of the following: source reduction or removal (numerical-based approach), or risk assessment / risk management (risk-based approach). Each of these remedial options is discussed below.

Develop a remediation plan

The first step to vapour remediation is development of a vapour remediation plan, likely as part of a broader remediation plan for the site[4]. Once the remediation plan has been completed, it may be included along with other relevant documents in an application for an Approval in Principle or Certificate of Compliance for the site. Note that characterization of vapour contamination must be completed before an Approval in Principle or Certificate of Compliance will be issued.

Source reduction or removal

Vapour remediation may include source reduction and removal techniques such as soil excavation, groundwater extraction, or biodegradation under monitored natural

[4] See section 1 of the Regulation for the definition of and a listing of some of the components of a "remediation plan".

attenuation. Where source reduction or removal is implemented, the site will be eligible for a Certificate of Compliance with numerical standards when it is demonstrated, through confirmatory sampling and analysis, that the concentration of each vapour contaminant is either less than the applicable Schedule 11 standard in the breathing zone or, for the gasoline and diesel components listed in Table 1, less than their detection limits in soil, sediment, and water.

Risk assessment

Where vapour remediation includes risk assessment, the site will be eligible for a Certificate of Compliance with risk-based standards when it is demonstrated that the risks associated with exposure to vapour contaminants do not exceed the risk-based standards under Section 18 of the Regulation.

See Technical Guidance 7 [14] for general guidance on vapour risk assessment and references 4 and 15 for more detailed guidance on vapour risk assessment. In addition, note that alternative vapour assessment approaches are acceptable under risk assessment provided they are supported by written defensible scientific rationale. Alternative vapour assessment approaches could include the following:

- modelling of PCOC concentrations in vapour from PCOC concentrations in soil and groundwater (see references 16, 17, and 18),
- development of site-specific vapour attenuation factors (see references 4 and 15 for guidance), or
- groundwater mass flux check (refer to Figure 8 and Exhibit 4 of reference 4).

Risk management

Risk management of vapour contamination—e.g., installation of a system designed to prevent subsurface vapour from entering a building in concentrations that exceed the Regulation's numerical or risk-based standards—is also an acceptable remedial option for contaminated sites. For guidance on the design, installation, monitoring, and maintenance of vapour management systems, refer to the following documents:

- California EPA vapour mitigation advisory [19]
- ASTM guidance for the application of engineering controls [20]

Where vapour management is used, note the following:

- The choice of management system is up to the applicant.
- A site under vapour management is only eligible for an Approval in Principle or a risk-based Certificate of Compliance.
- The following must be submitted before a risk-based Certificate of Compliance can be issued:
  a) a statement of the goals and objectives of the vapour management system;
  b) a detailed description of the selected vapour management system including figures and calculations (this documentation must be signed and stamped by a professional engineer);
  c) a letter of assurance[5] from a professional engineer which 1) confirms that that the system has been installed as designed, and 2) describes the QA/QC tests conducted to confirm that the system operates as designed (e.g., smoke test of the liner system; tests of blowers, gauges,

[5] The ministry is developing a standard template letter of assurance. Until this template is posted, please contact the ministry on a case-by-case basis for more information on the required components of the letter.

alarms; air quality sampling and/or pressure measurements); and

d) a monitoring, maintenance, and contingency plan for the system.

- Until all the above documents are submitted, the site will only be eligible for an Approval in Principle.
- At sites where vapour contamination is risk-managed to meet the Regulation's numerical standards, and where no risk assessment is conducted other than screening level risk assessment in accordance with ministry Protocol 13, a recommendation for a Certificate of Compliance with risk-based standards may be made by a Numerical Standards Approved Professional.

Supplementary notes

Background releases

Currently, the ministry lacks an approved protocol for assessing background concentrations in vapour. As a result, responsible persons seeking a background release for vapour contamination must obtain such a release either as part of a risk assessment for the site or as a site-specific background determination request. If you wish to use the site-specific background determination approach, draft a vapour sampling and analysis plan modelled conceptually on the requirements of Protocol 4 [21] and submit it to the ministry for Director review and approval.

Soil relocation

For general information on the vapour characterization procedures and vapour quality standards applicable to relocated soil, see Administrative Guidance 7 [22], Administrative Guidance 8 [23], and Fact Sheet 41 [24]. In addition, note the following:

- Soil or vapour data can be collected while soil is in the ground or stockpiled *ex-situ* at either the source site or receiving site.
- The ministry lacks technical guidance for assessing vapour in stockpiled soil, so environmental consultants should consult the literature, use professional judgment, and provide defensible scientific rationale if they choose this characterization approach.

Contaminated sites legal instruments

Please note the following for Determinations of Contaminated Site, Certificates of Compliance, and Contaminated Soil Relocation Agreements:

- Site configuration (e.g., building types, foundation depths, and building locations) authorized under a contaminated sites legal instrument is restricted to the range of site configurations considered during the vapour assessment. Changes in site configuration from the range considered in the vapour assessment may invalidate the legal instrument and/or trigger the requirement for additional site investigations.
- An application for a risk-based contaminated sites legal instrument cannot be signed off by a Numerical Standards Approved Professional except as noted in the risk management section above.
- Use of site-specific vapour attenuation factors is only permitted under risk assessment.

Grandfathering

Vapour assessments received by the ministry before February 1, 2011 may be completed in accordance with either this document or the July 2009 version of Draft Technical Guidance 4. Vapour assessments received on or after February 1, 2011 are expected to be completed in accordance with this document.

Final comments

Vapour intrusion science is an area of active research and thus the ministry will update this document from time to time to reflect advances in technical knowledge, user feedback, and changes in ministry policy. Given this, please note the following:

- Where vapour assessment guidance is lacking or considered inappropriate, contaminated sites professionals should exercise defensible and documented professional judgement.
- Communication from users of this document to the ministry is important for keeping this document relevant. Please send your questions and suggestions to the following address: site@gov.bc.ca.
- Questions and answers about this document are posted on our website: http://www2.gov.bc.ca/gov/content/environment/air-land-water/site-remediation

For more information, contact the Environmental Management Branch at site@gov.bc.ca

References

1. British Columbia Ministry of Environment (2008). Update on Contaminated Sites: Stage 6 Amendments to the Contaminated Sites Regulation. Victoria, BC. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/updates/csr-stg-6-amend.pdf

2. British Columbia Ministry of Environment (2005). Technical Guidance 10: Checklist for Reviewing a Preliminary Site Investigation. Victoria, BC. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/technical-guidance/tg10.pdf

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. Available at: http://csapsociety.bc.ca/wp/wp-content/uploads/Soil-Vapour-Panel-Stage-1-FINAL-Oct-09.pdf

4. Health Canada (Unpublished). Federal Contaminated Risk Assessment in Canada: Guidance on Human Health Risk Assessment of Soil Vapour Intrusion to the Indoor Environment. Available by request from cs-sc@hc-sc.gc.ca

5. Health Canada (unpublished). Federal Contaminated Site Risk Assessment in Canada: Guidance Manual for Environmental Site Characterisation in Support of Human Health Risk Assessment. Volumes 1-3. Contaminated Sites Division, Safe Environments Directorate, Health Canada, Ottawa. Available by request from cs-sc@hc-sc.gc.ca

6. Science Advisory Board for Contaminated Sites in British Columbia (February 2006). Guidance on Site Characterization for Evaluation of Soil Vapour Intrusion into Buildings. Available at: http://www.sabcs.chem.uvic.ca/guidance%20on%20site%20characterization%20for%20evaluation%20of%20soil%20vapour%20intrusion%20into%20buildings.pdf

7. California Environmental Protection Agency (2005). Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air. Interim Final. Department of

Toxic Substances Control. Available at: http://www.dtsc.ca.gov/AssessingRisk/upload/HERD_POL_Eval_Subsurface_Vapor_Intrusion_interim_final.pdf

8. California Environmental Protection Agency (2008). Response to public comments on 2005 guidance. Department of Toxic Substances Control. Available at: http://www.dtsc.ca.gov/AssessingRisk/upload/DTSC_VIG_RTPCs.pdf

9. ASTM International (2008). Standard Practice for Assessment of Vapor Intrusion into Structures on Property Involved in Real Estate Transactions. American Society for Testing and Materials E2600-08.

10. Interstate Technology & Regulatory Council (ITRC) (2007). Vapor Intrusion Pathway: A Practical Guideline. VI-1. Interstate Technology & Regulatory Council, Vapor Intrusion Team. Washington, D.C. Available at: www.itrcweb.org

11. Washington State Department of Ecology (2009). Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action. Publication no. 09-09-047. Review Draft. Available at: http://www.ecy.wa.gov/programs/tcp/policies/VaporIntrusion/VI%20guid%20rev5%20final%2010-9-09%20.pdf

12. State of Oregon Department of Environmental Quality (2010). Guidance for Assessing and Remediating Vapor Intrusion in Buildings. Available at: http://www.deq.state.or.us/lq/pubs/docs/cu/VaporIntrusionGuidance.pdf

13. Johnson PC, Kemblowski MW, and Johnson RL (1999). Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces: Site-Specific Alternatives to Generic Estimates. Journal of Soil Contamination 8(3): 389–421.

14. British Columbia Ministry of Environment (2007). Technical Guidance 7 on Contaminated Sites: Supplemental Guidance for Risk Assessments. Victoria, BC. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/technical-guidance/tg07-v3.pdf

15. Science Advisory Board for Contaminated Sites in British Columbia (August 2005). Report on Screening Level Risk Assessment, SLRA Level 1 and SLRA Level 2. Available at: http://www.sabcs.chem.uvic.ca/SLRAFinal03-06.pdf

16. Health Canada (Unpublished). Federal Contaminated Site Risk Assessment in Canada Part IV: Spreadsheet Tool for Human Health Preliminary Quantitative Risk Assessment (PQRA). Contaminated Sites Division, Safe Environments Directorate, Health Canada, Ottawa. Available by request from cs-sc@hc-sc.gc.ca

17. Johnson PC, Ettinger R (1991). Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapours into Buildings. Environmental Science and Technology 25(8):1445–1452. Available at: http://www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm

18. ASTM (1998). Standard Provisional Guide for Risk-Based Corrective Action. PS 104-98. American Society for Testing and Materials.

Available at: http://www.astm.org/Standards/E2081.htm

19. California Environmental Protection Agency (2009). Vapor Intrusion Mitigation Advisory. Department of Toxic Substances Control. Available at: http://www.dtsc.ca.gov/SiteCleanup/upload/VI_Mitigation_Advisory_Apr09.pdf

20. ASTM International (2005). Standard Guide for Application of Engineering Controls to Facilitate Use or Redevelopment of Chemical-Affected Properties. American Society for Testing and Materials. E 2435-05. Available at: http://www.astm.org/Standards/E2435.htm

21. British Columbia Ministry of Environment (1999). Protocol 4: Determining Background Soil Quality. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/protocols/protocol_4.pdf

22. British Columbia Ministry of Environment (2009). Administrative Guidance 7: Completing and Submitting an Application for a Contaminated Soil Relocation Agreement. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/administrative-guidance/ag07.pdf

23. British Columbia Ministry of Environment (2009). Administrative Guidance 8: Contaminated Soil Relocation Agreement Processing Requirements for Approved Professionals. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/administrative-guidance/ag08.pdf

24. British Columbia Ministry of Environment (2009). Fact Sheet 41: Relocation of Soils from Contaminated Sites. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-remediation/docs/fact-sheets/fs41.pdf

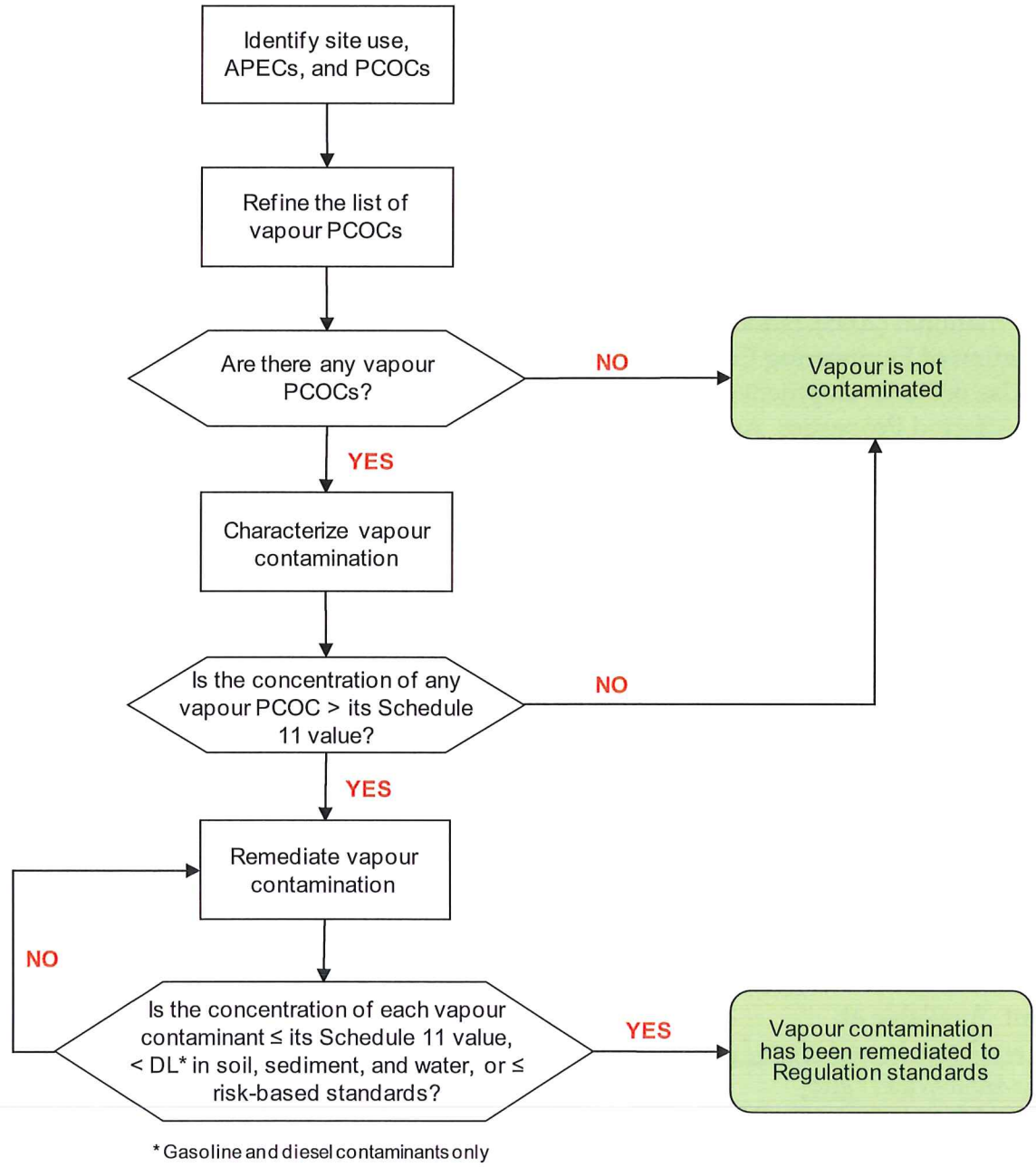

Figure 1. Vapour assessment flowchart

PCOC means potential contaminant of concern
APEC means area of potential environmental concern
DL means detection limit

Table 1. Substances for which vapour PCOC refinement is permitted

Substance:
benzene
ethylbenzene
toluene
xylenes
1,3,5-trimethylbenzene
1,2,4-trimethylbenzene
n-hexane
n-decane
naphthalene
1,3-butadiene
methylcyclohexane
isopropylbenzene (cumene)
VPHv
1,2-dibromoethane
1,2-dichloroethane
MTBE

Table 2. Default vapour attenuation factors

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

[1] Use of these attenuation factors for vapour characterization is not permitted if any of the following conditions apply: (a) the groundwater is in contact with the building at any time of the year; (b) subsurface or subslab vapour is under pressure (e.g., as at a landfill); or (c) there is active pumping or drawdown of groundwater at the site.

[2] For subsurface vapour samples taken from probes installed in boreholes (e.g., vapour or groundwater monitoring wells), the sample depth is based on the 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 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 distance between the bottom of the foundation or ground surface and the highest point of the highly-permeable medium, or (b) the distance between the bottom of the foundation 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 vapour guidance document [3] for more information.

[6] The subslab vapour attenuation factor (2.0×10^{-2}) applies to vapour data collected from a subslab installation at the foundation of a building. Refer to Chapter 7.5.5 of reference 5 and Chapter 3.3.4 of reference 6 for more information on subslab 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 vapour guidance document [3] for more information.

Appendix 1

Terms with Ministry Definitions Used in this Document

The following terms used in this document are defined in the ministry's procedure "Definitions and Acronyms for Contaminated Sites":

Approval in Principle
Approved Professional
background concentration
Certificate of Compliance
commercial land use
contaminated sites legal instrument
contaminated soil relocation agreement
CSAP Society
dense nonaqueous phase liquid
Director
engineering control
environment
environmental media
ministry numerical standards
numerical standards
Numerical Standards Approved Professional
offsite
offsite migration
onsite
owner
potential contaminant of concern
preferential flow pathway
preliminary site investigation
protocol
receiving site
Regulation
release
remediation
remediation plan
responsible person
risk assessment
risk management
screening level risk assessment
sediment
site investigation
soil
soil surface
source site
vapour