

APPLICATION OF SUBSURFACE SOIL VAPOUR ASSESSMENT TO MANAGE HEALTH RISKS AND DEVELOP REMEDIATION CRITERIA AT HYDROCARBON IMPACTED SITES

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ABSTRACT

The intrusion of subsurface vapours into buildings is an important pathway to consider when assessing and managing petroleum hydrocarbon impacts beneath service station sites. Subsurface soil vapour assessment is being applied more frequently to evaluate and manage the potential health risks to inhabitants of buildings overlying hydrocarbon impacted soil. This methodology can also be used to derive soil and groundwater remediation criteria for a site to guide remediation and/or risk management activities. This paper outlines the methodology used in conducting subsurface soil vapour assessments and discusses two case studies where this technique is successfully being applied.

The regulatory framework and methodology adopted by SEACOR to apply this technique is based on the approach described by the Canadian Council of Ministers of the Environment (CCME) in the development of the Canada Wide Standards (CWS) for Petroleum Hydrocarbons (PHC) in 2000. This approach involves the estimation of attenuation factors using the vapour transport model developed by Johnson and Ettinger (1991) to derive vapour monitoring objectives that can be used to assess the significance of the measured contaminants of potential concern (COPC), including benzene, toluene, ethyl benzene and xylenes (BTEX) and PHC fractions F1 and F2.

Subsurface hydrocarbon impact underlying an existing commercial building at a former retail service station site was identified during site decommissioning and remediation activities as a potential health risk to future inhabitants of the building. An investigation was conducted to define the nature and extent of hydrocarbon impact beneath the slab-on-grade building. The investigation included drilling, soil and groundwater sampling and analysis, installation of vapour monitoring wells, and collection of subsurface vapour samples for analysis of BTEX, F1 and F2. The subsurface vapour assessment evaluated the significance of the hydrocarbon impacts with respect to the potential health risks to future occupants of the building. The applicable regulatory agency was involved and agreed with our approach and the sale of the building and future commercial development proceeded. The methodology and results of the assessment are discussed.

The use of subsurface vapour assessment is currently being applied to modify generic remediation soil and groundwater criteria at an operating service station site. The approach involves measuring representative soil vapour levels in the vadose zone above soil with the highest measured hydrocarbon concentrations (BTEX, F1 and F2) to establish whether these soil concentrations contribute to subsurface vapour levels that

may result in unacceptable health risks to occupants of a building assumed present above the impacted soil. The applicable regulatory agency is involved and has agreed with our approach. Results of the assessment work to date and how the results will be incorporated into the overall site remediation plan will be discussed.

The vapour assessment methodology and the case studies presented demonstrate that direct measurement of subsurface hydrocarbon soil vapour concentrations in the vicinity of building foundations can be an effective means of assessing the potential risks associated with hydrocarbon impact underlying a site.

INTRODUCTION

The development of revised soil quality guidelines in recent years in several jurisdictions has been based on the science of risk assessment that considers the potential health and environmental risks associated with subsurface petroleum hydrocarbon impacts. These guidelines consider a range of human and ecological exposure pathways that may be applicable at certain sites and provide concentrations of soil and/or groundwater criteria for certain hydrocarbon constituents for each exposure pathway. These generic criteria are typically used to guide remediation and/or risk management activities at a site. Because of the volatile nature of petroleum hydrocarbons, the intrusion of subsurface vapours into buildings is an important pathway to consider when assessing and managing petroleum hydrocarbon impacts beneath service station sites.

The numerical soil criteria provided in the soil quality guidelines developed by Alberta Environment (AENV) and other jurisdictions represent the total mass of the substance that is comprised of three phases: adsorbed to organic carbon in the soil; dissolved in the soil porewater; and, vapour within the air voids. However, most environmental investigations focus only on the measurement of soil and groundwater concentrations. By measuring subsurface vapour concentrations of specific hydrocarbon constituents of concern in close proximity to a building foundation together with the methodology outlined by the CCME in the development of the CWS for PHC in soil, it is possible to better understand the potential health risks associated with hydrocarbon impacts measured in the soil and groundwater beneath a site.

This methodology can be used to manage potential health risks associated with hydrocarbon impacts at a site as part of ongoing risk management, and/or can also be used to derive soil and/or groundwater remediation criteria at a site to guide remediation and/or risk management activities. This paper summarizes the CCME methodology used to conduct subsurface vapour assessments and discusses two case studies where this technique is successfully being applied.

REGULATORY FRAMEWORK AND METHODOLOGY

The current guidelines in use in Alberta for managing downstream petroleum sites are the Risk Management Guidelines for Petroleum Storage Tank Sites (PST Guidelines, AENV, 2001a), which provide a site management process specifically for soil and groundwater impacts originating from existing or former petroleum storage facilities. As indicated in the PST Guidelines, the numerical criteria presented were developed using a risk-based

approach designed to protect human health, safety and the environment. Central to the development of the generic criteria contained in the PST Guidelines are the Alberta Soil and Water Quality Guidelines for Hydrocarbons at Upstream Oil and Gas Facilities (Upstream Guidelines, AENV, 2001b) which technically use the CCME methodology and development of the CCME CWS for PHC as a starting point, with adaptations to Alberta conditions as appropriate.

The CWS PHC was developed as a three-tiered remedial standard for petroleum hydrocarbon impacted soil and subsoil associated with various land use categories. The standard is based on the CCME Protocol (CCME, 1996), which is founded on the science of risk assessment and risk management, and can be applied at any one of three levels or “Tiers”. Each Tier is intended to provide the same level of protection to human health and the environment but with an increasing amount of site-specific data required. The objective of the standard is to ensure that exposures are kept below levels at which adverse effects are expected (CCME, 2000). The three tiers include: Tier 1 where generic guidelines are developed based on a set of parameters that allow reasonably conservative predictions of risk at most sites; Tier 2 where modified generic guidelines are developed; and, Tier 3 where risk assessment is used to derive site-specific remediation objectives.

Chemicals of concern for the CWS PHC were considered in four broad physico-chemical fractions by the CCME based on the sub-fractions defined by the US Total Petroleum Hydrocarbons Criteria Working Group (TPHCWG, 1997). As indicated in CCME, 2000, the fractions defined in equivalent carbon numbers include: F1 ($C_{>6}$ to C_{10}); F2 ($C_{>10}$ to C_{16}); F3 ($C_{>16}$ to C_{34}); and F4 ($C_{>34}$). These fractions are defined with respect to analytical procedures and correlate with gasoline, diesel, lubricant and heavy lubricant ranges, respectively. Tier 1 levels for each land use were derived by evaluating all pathways of exposure that apply to the receptors of concern identified under the land use (CCME, 2000, and TPHCWG, 1997).

Exposure pathways by which chemicals of concern may reach human and ecological receptors considered in the PST Guidelines and the Upstream Guidelines were adapted from CCME, 2000. These include four human exposure pathways (soil ingestion, inhalation of vapours, dermal contact, and ingestion of surface and/or groundwater); and four ecological pathways (soil contact, soil ingestion by livestock/wildlife, protection of groundwater for aquatic life, and protection of groundwater for livestock and wildlife watering). Of particular interest for conducting subsurface vapour assessments is the inhalation of volatile PHCs following infiltration to the indoor environment. This pathway is discussed in more detail below.

VAPOUR INHALATION PATHWAY

Volatile organic compounds including BTEX and PHC can migrate into buildings via diffusion and barometric pressure differentials between the soil gas beneath the building floor slab and the indoor air. Migration of vapours can occur through cracks and imperfections in building foundations, which can lead to human inhalation exposure. This pathway is assessed in the CWS PHC by the application of the vapour intrusion model developed by Johnson and Ettinger (1991). Details of the model equations and

definitions of input parameters used to calculate the Tier 1 levels contained in the PST Guidelines and the Upstream Guidelines are documented in CCME, 2000 and AENV, 2001b, and are summarized below.

According to the CCME (CCME, 2000), there are three main processes that govern the vapour inhalation exposure pathway. These include partitioning of hydrocarbons adsorbed to the soil to the vapour phase; vapour phase transport from hydrocarbon impacted soil (source) to the soil adjacent to the building foundation; and, infiltration/dilution between the soil and the building air. Measurement of point-of-exposure or intermediate hydrocarbon vapour concentrations at points along the vapour pathway (i.e., between the hydrocarbon impacts and the building foundation) would provide a more representative understanding of hydrocarbons in the vapour phase, reduce the uncertainty in the modeling associated with the first two processes, and improve the accuracy of the exposure estimate. These measurement substitutions can be used in conjunction with simplified modelling of vapour migration into buildings to evaluate the significance of the hydrocarbon vapour concentrations in the soil gas near a building and determine whether these levels may lead to risk levels that exceed those considered acceptable (OAEI/Meridian, 2001).

Development of the generic Tier 1 soil criteria for the vapour inhalation pathway assumed that PHC impacted soil is a minimum of 30 cm ($L_T = 0.3$ m) from the building foundation and that PHC vapours must migrate through this 0.3 m of clean fill before reaching and penetrating the building foundation (CCME, 2000). Soil gas to indoor air dilution factors were derived using the equations described in CCME, 2000 (Table 3.6) as a function of depth/distance from the building foundation to impacted soil (i.e., $L_T > 0.3$ m) for both fine-grained and coarse-grained soils. These dilution factors represent the approximate dilution between hydrocarbon concentrations in the soil gas at various depths beneath a foundation floor slab and the hydrocarbon concentration in the indoor air of the building. This methodology can be used to develop vapour monitoring objectives for the site to assess the significance of measured subsurface vapour concentrations beneath a site.

DERIVATION OF VAPOUR MONITORING OBJECTIVES

In addition to assessing the significance of measured subsurface vapour concentrations, vapour monitoring objectives can be used to assist in determining appropriate Tier 2 soil and groundwater remediation criteria for a site. The vapour monitoring objectives represent maximum acceptable concentrations of BTEX, and PHC fractions F1 and F2 in the subsurface vapour in the vicinity of a building foundation that will not result in potential unacceptable health risks to occupants of the building. The following discussion provides details of the chemicals of concern; assumptions and equations used in the calculations and summarizes the derivation of vapour monitoring objectives.

The chemicals of concern for which vapour monitoring objectives are typically derived for downstream petroleum impacted sites include BTEX and PHC fractions F1 and F2. PHC Fractions F3 and F4 are not considered volatile; therefore, objectives are not derived for these fractions. Appropriate criteria for sites with these non-volatile fractions (F3 and F4) are therefore based on an exposure pathway other than inhalation (i.e. soil contact).

Vapour monitoring objectives for comparison with soil gas beneath a building slab (minimum distance of 30 cm) can be approximated by inserting a dilution factor into Equation 1 below (CCME, 2000). The dilution factor and other supporting calculations are provided in Equations 2 through 7 below (AENV, 2001b).

$$C_{sgs} = \frac{(RfC - C_a)(SAF)(DF_i)}{ET} \quad \text{Eq. 1}$$

where: C_{sgs} = soil gas guideline for BTEX and/or PHC sub-fraction (mg/m^3);
 RfC = reference air concentration or risk specific concentration (mg/m^3);
 C_a = background indoor/outdoor air concentration (mg/m^3);
 SAF = soil allocation factor (unitless);
 DF_i = dilution factor from soil gas to indoor air (unitless), calculated below;
 ET = exposure term (unitless);

The attenuation coefficient (α) is defined as the inverse of the dilution factor. Accordingly, the dilution factor may be calculated as shown in equation (2):

$$DF_i = \frac{1}{\alpha} \quad \text{Eq. 2}$$

where: DF_i = dilution factor (minimum distance of 0.3 m) (dimensionless); and,
 α = attenuation coefficient (dimensionless; calculated as shown below)

The following equation (3) is full Johnson and Ettinger (1991) equation used to calculate the attenuation coefficient for Tier 2 calculations (AENV, 2001b and CCME, 2000).

$$a = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T} \right) \exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right)}{\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T} \right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T} \right) \left[\exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}} \right) - 1 \right]} \quad \text{Eq. 3}$$

where: D_T^{eff} = effective porous media diffusion coefficient (cm^2/s);
 A_B = building area calculated as shown below (cm^2);
 Q_B = building ventilation calculated as shown below (cm^3/s);
 L_T = minimum distance from contaminant source to foundation (m);
 Q_{soil} = volumetric flow rate of soil gas into building; calculated below (cm^3/s);
 L_{crack} = thickness of the foundation (cm);
 D_{crack} = effective vapour pressure diffusion coefficient through the crack (cm^2/s);
 A_{crack} = area of cracks through which contaminant vapours enter building (cm^2).

$$D_T^{eff} \approx D_a \times \left(\frac{\theta_a^{10/3}}{\theta_a^2} \right) \quad \text{Eq. 4}$$

where: D_T^{eff} = overall effective porous media diffusion coefficient (cm^2/s);
 D_a = chemical specific diffusion coefficient in air;
 θ_a = vapour filled porosity; and

θ_t = total soil porosity.

$$Q_B = \frac{L_B \times W_B \times H_B \times ACH}{3,600} \quad \text{Eq. 5}$$

where: Q_B = residential building ventilation rate (cm³/s);
 L_B = residential building length (cm);
 W_B = residential building width (cm);
 H_B = residential building height, including basement (cm);
 ACH = air exchange per hour = 1 h⁻¹; and
 $3,600$ = conversion factor from hours to seconds.

$$Q_{soil} = \frac{2p\Delta P k_v X_{crack}}{\ln[2(Z_{crack})/r_{crack}]} \quad \text{Eq. 6}$$

where: Q_{soil} = volumetric flow rate of soil gas into building (cm³/s);
 ΔP = pressure differential (g/cm s²);
 k_v = soil permeability to vapour flow (cm²);
 X_{crack} = length of idealized cylinder (cm);
 μ = vapour viscosity (g/cm-s);
 Z_{crack} = distance below grade to idealized cylinder (cm);
 r_{crack} = radius of idealized cylinder (cm);

Soil gas vapour monitoring objectives for PHC fractions F1 and F2 were derived for each hydrocarbon sub-fraction according to their mass fraction within the fraction as shown in the algorithm below (CCME, 2000).

$$SQG_{Fraction_i} = \frac{1}{\sum \left(\frac{MF_{sub-fractionj}}{SQG_{sub-fractionj}} \right)} \quad \text{Eq. 7}$$

where: $SQG_{Fraction_i}$ = soil quality guideline for the fraction i (mg/kg)
 $SQG_{sub-fractionj}$ = soil quality guidelines (mg/kg) for each sub-fraction within fraction i for the target Hazard Quotient for fraction i
 $MF_{sub-fractionj}$ = mass fraction of each sub-fraction within the fraction

The following case studies are presented to illustrate how subsurface vapour assessment can be applied to manage potential risks associated with hydrocarbon impacted soil and to derive Tier 2 criteria that can be used for remediation and/or risk management.

CASE STUDY 1

Site Background

The subject site formerly operated as a service station in an urban centre in Western Canada between 1972 and 2002 at which time it was closed. On-site facilities including three underground storage tanks, associated underground piping, two pump islands, a canopy, an underground waste oil tank, an oil fill area, and a parts storage area were removed in August 2003. Current site facilities consist of two commercial buildings,

which formerly operated as a service station carwash and kiosk building, and an office building (former lube shop).

An initial environmental investigation was conducted at the site in January 2002 following closure of the service station. A remedial excavation program, completed in September and October 2003, involved excavation of tank bed fill material and hydrocarbon impacted soil in the vicinity of the former USTs and other underground facilities. As a condition of the sale of the property following remediation, the service station buildings were not to be removed from the site. The remedial excavation program removed the majority of soil with residual hydrocarbon concentrations exceeding applicable remediation criteria from the site. However, because of the presence of a former tank bed and the potential presence of hydrocarbon impacts beneath the on-site building, a supplemental environmental investigation was conducted to investigate subsurface conditions beneath the building. The investigation comprised the drilling of six boreholes: four boreholes completed as monitor wells to evaluate soil and groundwater conditions beneath the building; and two shallow vapour monitor wells to evaluate subsurface vapours.

Site Conditions

The stratigraphy at the site consists of a surface layer of asphalt underlain by granular fill extending to a depth of approximately 0.5 m, which was underlain by native clay, which extended to a depth of between 1.2 m and 2.3 m, which in turn was underlain by silt. Clay was encountered underlying the silt and extended to the maximum depth of investigation at the site of 6.1 m. Groundwater was encountered between approximately 1.5 m and 4.5 m below ground surface and the interpreted groundwater flow direction is southwest.

The remedial excavation program was limited by the service station building to the north, and the property line and a City water main to the south; therefore, soil remaining at the extent of excavation near the building had combustible soil vapour concentrations that ranged from 4,070 ppm to >10,000 ppm. In addition, there was a former tank bed located beneath the building that could not be excavated. Laboratory analysis results indicated soil remaining in the north wall of the excavation with a xylenes concentration that exceeded the applicable remedial criterion.

Subsurface Soil Vapour Assessment

In late 2003, two shallow soil vapour wells were installed in two boreholes drilled below the building slab-on-grade foundation: one well was completed in the tank bed sand fill; and the second well was completed in the sand fill near a soil sample with an elevated xylenes concentration. The wells were screened between approximately 0.3 m and 0.6 m below the floor slab and were constructed of 50 mm diameter polyvinyl chloride (PVC) pipe with threaded joints (i.e. see example borehole log provided in Plate 1). The screened portion of the well was comprised of 0.5 mm horizontal slots (0.010 slot). The annulus was backfilled with silica sand from the bottom of the screen to approximately 0.1 m above the top of the screen. A hydrated bentonite chip seal was placed around the annulus of the solid section of pipe to within approximately 0.2 m of the floor surface. A 50 mm diameter slip cap was placed on the bottom of the well and a 50 mm diameter slip

cap fitted with a valve was placed on the top of the well. A drop tube constructed of 9.5 mm internal diameter polyethylene tubing was connected to the valve and extended to the middle of the screened section for shallow soil vapour sampling purposes. The wells were completed with a 200 mm diameter steel protective cover with a bolt down lid set in concrete above the top of the well and finished flush with the floor surface of the building. Soil samples collected during drilling from beneath the building indicated residual BTEX and F1 to F4 fraction concentrations below the applicable criteria. Standpipe combustible vapour concentrations measured in the wells were 25 ppm in BH104 and 155 ppm in BH102.

Soil vapour samples were collected from the two wells in January 2004. Prior to sampling, two well volumes of soil vapour were purged from each well and passed through a tedlar sampling bag. One well volume was approximately equal to one bag volume (1L). Following purging, a sample of soil vapour was collected in the tedlar bag and the bag was sealed. A second tedlar bag sample was collected from each well. A pump and tedlar bags provided by an accredited laboratory were used to complete the purging and sampling (see Plate 2). All four tedlar bag samples (two from each well) were shipped to an accredited laboratory for analysis.

One tedlar bag sample from each well was analyzed for BTEX and hydrocarbon fractions F1 and F2 directly from the tedlar bag. The second tedlar bag sample from each well was absorbed onto a carbotrap tube and analyzed in the laboratory.

Subsurface vapour objectives were derived using the formulas indicated above and the following assumptions:

- Commercial scenario with slab-on-grade foundation;
- Published dilution factors were used for $L_T=30$ cm;
- Input parameters and chemical properties as shown in Tables 1 and 2;
- Vapour concentrations for each PHC fraction were estimated based on the mass fraction of each sub-fraction according to the CCME (Equation 7).

Results

Subsurface hydrocarbon vapour monitoring objectives together with the results of subsurface vapour sampling are presented in Table 3. These objectives represent maximum acceptable concentrations of the identified chemicals of concern in subsurface soil vapours in the vicinity of the on-site building foundation (minimum distance of 30 cm) that according to the CCME methodology described above, will not result in unacceptable health risks to occupants of the building. The results indicated that both sets of soil vapour samples (tedlar bag and tedlar bag/carbotrap tube) collected from the wells had BTEX and hydrocarbon fraction F1 and F2 concentrations below the soil vapour objectives developed for the site. These results indicated that the subsurface hydrocarbon conditions underlying the service station building were not considered to pose unacceptable health risks for future building occupants

Parameter ^a	CCME Term	Fraction 1 (C ₆ - C ₁₀)			Fraction 2 (C ₁₀ - C ₁₆)			
		Aliphatics		Aromatics	Aliphatics		Aromatics	
		C ₆ -C ₈	C ₈ -C ₁₀	C ₈ -C ₁₀	C ₁₀ -C ₁₂	C ₁₂ -C ₁₆	C ₁₀ -C ₁₂	C ₁₂ -C ₁₆
Sub-fraction composition	MF _j	0.55	0.36	0.09	0.36	0.44	0.09	0.11
Reference air concentration (mg/m ³)	RfC	18.4	1	0.2	1	1	0.2	0.2
Background concentration (mg/m ³)	C _a	0.09111	0.03881	0.03745	0	0	0	0
Soil allocation factor (unitless)	SAF	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Organic carbon partitioning coefficient	K _{oc}	3981	31623	1585	251189	5.0E+06	2512	5012
Henry's Law Constant (unitless)	H'	50	80	0.48	120	520	0.14	0.053
Gas constant (atm·m ³ /mol·K)	R	8.2E-05	8.2E-05	8.2E-05	8.2E-05	8.2E-05	8.2E-05	8.2E-05
Diffusivity of Chemical in air (cm ² /s)	D _a	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Diffusion coefficient (cm ² /s) Coarse ^b	D _T ^{eff}	4.54E-03	4.54E-03	4.54E-03	4.54E-03	4.54E-03	4.54E-03	4.54E-03
Diffusion coefficient (cm ² /s) Fine ^b	D _T ^{eff}	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04	6.5E-04
Diffusion coefficient cracks (cm ² /s) ^b	D ^{crack}	4.50E-03	4.50E-03	4.50E-03	4.50E-03	4.50E-03	4.50E-03	4.50E-03

Notes:

- a - Canada-Wide Standards for Petroleum Hydrocarbons in Soil: Scientific Rationale (CCME, 2000) unless otherwise noted.
- b - Calculated based on formulas presented from Scientific Rationale (CCME, 2000).

Parameter ^a	CCME Term	Benzene	Toluene	Ethyl Benzene	Xylenes
Molecular Weight (g/mol) ^b	MW	78	92	106	106
Reference air concentration (mg/m ³)	RfC	na ^c	3.8	1.0	0.18
Risk Specific Concentration (mg/m ³) ^d	RsC	0.003	na ^c	na ^c	na ^c
Background air concentration (mg/m ³)	C _a	na	0.005	0.0075	0.00182
Soil allocation factor/Hazard Index (unitless)	SAF	0.5	0.5	0.5	0.5
Organic carbon partitioning coefficient (mL/g)	K _{oc}	81.2	234	537	586
Henry's Law Constant (unitless)	H'	0.225	0.274	0.358	0.252
Gas constant (8.2 x 10 ⁻⁵ atm·m ³ /mol·K)	R	8.2E-05	8.2E-05	8.2E-05	8.2E-05
Diffusivity of Chemical in air (cm ² /s)	D _a	0.088	0.087	0.075	0.078
Diffusion coefficient in vapour (cm ² /s) Coarse ^f	D _T ^{eff}	0.0080	0.0079	0.0068	0.0071
Diffusion coefficient in vapour (cm ² /s) Fine ^f	D _T ^{eff}	0.0011	0.0011	0.0010	0.0010
Diffusion coefficient through cracks (cm ² /s)	D ^{crack}	4.54E-03	4.54E-03	4.54E-03	4.54E-03

Notes:

- a - Alberta Upstream Guidelines, (AENV, 2001), and CCME, 2000 unless noted otherwise.
- b - Users' Guide for the Johnson and Ettinger (1991) Model (EQM, 1997).
- c - RfC and RsC as noted in CCME, 2000 and AENV, 2001b
- d - Value based on risk level of 10⁻⁵ (AENV, 2001b).
- e - Calculated as indicated in equations presented from Scientific Rationale (CCME, 2000).
- na - Not available

The results of subsurface soil vapour assessment together with the results of other environmental work completed at the site were submitted to the provincial regulatory agency for review, and were agreed to by the regulators. The property owner was able to complete the sale of the property contingent upon continued commercial use of the building. Follow up subsurface vapour sampling completed in June 2004 has confirmed previous results.

Table 3: CASE STUDY RESULTS - VAPOUR ASSESSMENT							
Sample Name	Date (dd-mm-yy)	Benzene	Toluene	Ethylbenzene	Xylenes	F1	F2
Case Study 1 - Commercial Scenario - Coarse Grained Soils							
BH102	1/1/2004	<3	<3	<4	<4	<30	<30
BH102 Carbotrap	1/1/2004	<0.007	<0.007	<0.007	<0.02	NA	NA
BH104	1/1/2004	<3	<3	<4	<4	<30	<30
BH104 Carbotrap	1/1/2004	<0.008	<0.008	<0.008	<0.02	NA	NA
<i>Soil Vapour Objectives^a</i>		11	306950	78522	11625	452,692	41,880
Case Study 2 - Residential Scenario - Fine Grained Soils							
BH04-1	19-08-04	16.0	<4	<4	<4	440	<30
BH04-2	19-08-04	54.2	<4	9.9	<4	5,600	<30
<i>Soil Vapour Objectives^a</i>		223	282211	75181	13428	84,284	44,870

Notes:

- all concentrations provided in milligrams per cubic metre (mg/m³).
- "<" - less than detection limits indicated.
- F1 - (>C₆ - C₁₀) - BTEX, F2 - (>C₁₀ - C₁₆) - Naphthalene.
- a - derived as documented in the equations and text included in this paper.

CASE STUDY 2

Site Background

The subject site is located in southern Alberta and is currently an operating service station with on-site facilities that consist of three underground storage tanks (USTs), two pump islands with fuel distribution pumps, and a single bay maintenance garage. Several environmental investigations have been conducted at the site since 2001. The investigations have comprised the drilling of a total of eighteen boreholes and the installation of eight monitoring wells, and soil and groundwater sampling and testing. The results indicated concentrations of hydrocarbons in the soil and groundwater beneath the site and adjacent offsite property that did not meet the applicable criteria.

In preparation for planned remediation activities, a Tier 2 approach was recommended for the site to derive soil and groundwater criteria that can be used to guide remediation and/or risk management activities. The approach was documented and agreed to by the applicable regulatory agency.

Tier 2 Approach

The Tier 2 approach involved measurement of representative soil vapour levels in the unsaturated zone above soil with the highest measured hydrocarbon concentrations to establish whether these hydrocarbon concentrations contribute to vapour levels that may result in unacceptable health risks to occupants of a nearby residential building. If the results of the soil vapour analysis are considered acceptable, the measured soil concentrations of certain hydrocarbons in this area then become appropriate Tier 2 criteria for the site for the vapour inhalation pathway. .

Site Conditions

The stratigraphy at the site consists of a surface layer of asphalt, approximately 0.1 m thick, underlain by granular fill extending to approximately 0.3 m depth, which in turn overlies clay till to the maximum depth of investigation at the site of 7.6 m. Groundwater

was encountered at a depth of approximately 2.5 m when monitored on several occasions between 2001 and 2004.

On the basis of the results of previous investigations, hydrocarbon impacted soil beneath the site with hydrocarbon concentrations that do not meet the Residential criteria contained in the PST Guidelines is located primarily in the southeast corner of the site and in the area of the pump island. Offsite hydrocarbon impacts above Residential criteria include benzene and F1 in the soil beneath the lane way east of the site and in the soil beneath the adjacent street.

Subsurface Soil Vapour Assessment

In August 2004, two boreholes were advanced to a maximum depth of 2.1 m located near (0.5 m) a previously drilled borehole in the vicinity of the pump islands where a soil sample with elevated hydrocarbons was measured. Soil samples were collected during drilling and field screened for combustible vapour levels. Vapour monitor wells were installed in each borehole as described above with the screened interval located between 1.8 m and 2.1 m below grade (Plate 1). Subsurface vapour samples were collected using the equipment indicated below (Plate 2) and as described above and submitted for laboratory analysis of BTEX, F1 and F2.

Results

The vapour concentrations measured in the two wells were compared with vapour monitoring objectives derived for the site as described above and presented in Table 3, to evaluate the significance of the vapour levels. The results indicated hydrocarbon vapour concentrations that were less than the derived objectives; therefore, the highest soil concentrations of hydrocarbons measured beneath the site do not give rise to unacceptable hydrocarbon vapour concentrations and can be used as Tier 2 criteria for the vapour inhalation pathway.

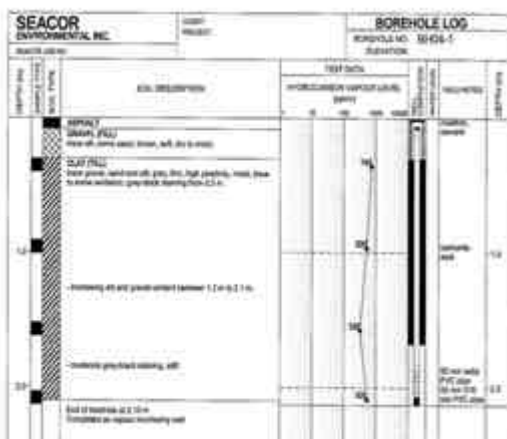


Plate 1: Vapour Monitoring Well

Plate 2: Vapour Sampling Equipment

SUMMARY

The intrusion of subsurface hydrocarbon vapours into buildings is an important pathway that is considered in generic criteria developed by regulatory agencies for assessing and managing petroleum hydrocarbon impacts beneath service station sites. Most environmental investigations focus on the measurement of soil and groundwater concentrations to assess sites. However, measurement of specific hydrocarbon constituents in subsurface vapour near a building foundation can be used to compare with vapour monitoring objectives developed using the CCME methodology to provide a better understand of the potential health risks associated with hydrocarbon impacts measured in soil and groundwater beneath a site.

Two case studies were presented that applied subsurface vapour assessment to determine potential health risks to occupants of a commercial building as part of a land transaction, and to derive Tier 2 criteria for the vapour inhalation pathway that can be used to guide site remediation and/or risk management activities.

REFERENCES

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