CSAP Technical Review #18
Soil Vapour Attenuation Factors for Trench Worker Exposure

Meridian Project No. 121605

Submitted to:

CSAP Society

613 - 744 West Hastings Street
Vancouver, BC V6C 1A5

Submitted by:

Meridian Environmental Inc.
410, 525 - 11th Avenue SW
Calgary, Alberta   T2R 0C9
Tel: 877.597.6368 Fax: 888.546.6368

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EXECUTIVE SUMMARY

Background

The BC Ministry of Environment (MoE) requires that site-specific risk assessments evaluate risks to all receptors likely to be present at a site, including outdoor occupational receptors such as construction and maintenance workers. A particular concern is that workers in trenches may have a higher degree of exposure, particularly to subsurface vapours, than workers at the ground surface. Although MoE allows exposures associated with this scenario to be managed through a health and safety plan, it still requires that the risks be evaluated quantitatively.

Recommended default vapour attenuation factors are available for other vapour exposure scenarios but, to date there has been a lack of guidance on estimating trench vapour concentrations. As a result, there is inconsistency in the way risk assessors are addressing this pathway. On behalf of the Society of Contaminated Sites Approved Professionals, Meridian Environmental Inc. has developed and recommended default attenuation factors for a number of standard trench worker exposure scenarios, which could be used by Approved Professionals and potentially be incorporated into MoE guidance.

There are a number of approaches to estimate vapour concentrations in trenches and excavations. Based on a review of these approaches, a model published by the Virginia Department of Environmental Quality (VDEQ), modified to account for a soil vapour source, was considered suitable for the development of vapour attenuation factors. The model considers diffusion of vapours from the vapour source or point of vapour measurement to the exposed trench base or wall, followed by mixing and dilution within the trench.

A sensitivity analysis was performed using the model to identify key parameters in the determination of vapour attenuation factors. Influential parameters include trench air exchange rate (a function of trench geometry) and depth of vapour source below the trench base (equal to zero if the contaminant source is intersected by the trench). The VDEQ model assigns air exchange rates of 2/h for narrow trenches (width < depth) and 360/h for wide trenches (width > depth). These air exchange rates are based on studies of air flow in urban canyons.

Recommended Default Vapour Attenuation Factors

Four generic scenarios were defined for the determination of default vapour attenuation factors, involving combinations of trench width less than or greater than trench depth (i.e. narrow or wide trench) and vapour source (or location of vapour measurement) either intersected by the trench or a minimum of 30 cm below the trench base (i.e. shallow or deep vapour source). The recommended default vapour attenuation factors are as follows:

Model Scenarios	***Default Vapour Attenuation Factors***	
	Narrow Trench (Width < Depth)	**Wide Trench (Width > Depth)**
Shallow Vapour Source (Source Depth < Trench Depth)	0.09	0.0005
Deep Vapour Source (Source Depth minus Trench Depth > 30 cm)	0.003	0.00002

The default vapour attenuation factor would be selected based on the proposed excavation type and geometry. It is anticipated that utility maintenance and construction would generally be associated with a narrow trench, whereas a building excavation would generally be associated with a wide trench. Contamination under a roadway would be associated in most cases with narrow trench construction.

The attenuation factor would also depend on the depth of the soil vapour source as characterized by vapour measurements from appropriately installed vapour wells. Ideally, vapour wells would be installed within the proposed excavation footprint and screened within the contaminated zone. Sites with relatively deep contamination (e.g. non-detect soil concentrations within the first 2 m) would have deeper wells (screen depths at least 30 cm below the base of the excavation). Vapour well installation and sampling should adhere to applicable guidelines and protocols, including MoE Technical Guidance 4 and methods referenced therein.

Once the appropriate attenuation factors are selected, the measured soil vapour concentrations are multiplied by the attenuation factors to give the estimated vapour concentrations in trench air. These trench air concentrations are then compared to an appropriate toxicological reference value (TRV). Although the default vapour attenuation factors are considered to be conservative, estimated trench air concentrations exceeding the appropriate TRV for a given contaminant may signify the potential for unacceptable risk, and would require risk management measures which may result in conditions being imposed on a site through an appropriate Contaminated Site Regulation (CSR) instrument (eg. the need for a site-specfic health & safety plan for potentially exposed workers). However, a finding of potential unacceptable risk using default vapour attenuation factors would not preclude the use of an alternative approach to the determination of site-specific vapour attenuation factors.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 General

Under the authorization of the Society of Contaminated Sites Approved Professionals (CSAP Society), Meridian Environmental Inc. (Meridian) trench worker exposure. The work was conducted in accordance with a Scope of Work for CSAP Technical Review No. 18, issued in February 2012. The following report presents the findings of our study.

1.2 Background and Objectives

The BC Ministry of Environment (MoE) requires that site-specific risk assessments evaluate risks to all receptors likely to be present at a site, including outdoor occupational receptors such as construction and maintenance workers. A particular concern is that workers in trenches may have a higher degree of exposure, particularly to subsurface vapours, than workers at the ground surface. Although MoE allows exposures associated with this scenario to be managed through a health and safety plan, it still requires that the risks be evaluated quantitatively. The requirement for evaluation of this pathway was formalized in the recent revision of the Ministry's Technical Guidance 7 (MoE, 2012).

While recommended default vapour attenuation factors are available for other vapour exposure scenarios (see Technical Guidance 4, MoE, 2010), there has been, to date, a lack of guidance on estimating trench vapour concentrations. As a result, there is inconsistency in the way risk assessors are addressing this pathway. The objective of the present study is to develop and recommend default vapour attenuation factors for a number of standard trench worker exposure scenarios, which could be utilized by Approved Professionals and potentially be incorporated into MoE guidance.

1.3 Scope of Work

The scope of work involved the following steps:

1. Review of existing guidance and models for estimating soil vapour concentrations in trenches.
2. Identification and definition of standard exposure scenarios, which will include trench configuration, vapour source location, trench air exchange rate and other assumptions.
3. Development of vapour attenuation factors for each of the identified scenarios. Vapour attenuation factors were to be developed for four scenarios, involving combinations of trench width greater than or less than trench depth, and vapour source either a minimum of 0.3 m from the trench base/wall or intersected by the trench.
4. Preparation of a report describing the methodology and recommendations, and preparation of draft guidance.

The work was conducted in consultation with the CSAP Technical Review Committee and Mr. Peter Kickham of the MoE. The following report is organized in accordance with the above steps.

2.0 REVIEW OF EXISTING GUIDANCE AND MODELS

A detailed review and evaluation of approaches for modelling the migration of vapours into trenches and excavations was conducted previously by Meridian on behalf of the Canadian Council of Ministers of the Environment (CCME) in 2010 (Meridian, 2010). The findings of that review are summarized herein.

2.1 General Overview of Approaches

Methods for modelling the migration of vapours into trenches and excavations are generally based on the same underlying physical processes, which include:

- Volatilization or partitioning of contaminants from soil and/or groundwater into the vapour phase;
- Diffusion of vapours into the trench or excavation;
- Mixing of contaminant vapours in the trench or excavation; and
- Removal of vapours from the trench or excavation via exchange with outdoor air.

The available methods vary with respect to the assumed vapour source and its location, characterization of the rate of release of vapours from the soil, and the assumptions regarding trench geometry and rate of air exchange. Methods reviewed by Meridian (2010) include those published or used by Virginia Department of Environmental Quality (VDEQ), United States Environmental Protection Agency (US EPA), American Society for Testing and Materials (ASTM), Ontario Ministry of the Environment, as well as methods based on the original Jury model. These methods are summarized briefly below.

2.2 Virginia DEQ Method

The Virginia Department of Environmental Quality (VDEQ) has published guidance and a spreadsheet model for estimating exposure of workers to vapours in construction and utility trenches (VDEQ, 2010). The approach involves two methods of estimating vapour concentrations originating from groundwater: one where groundwater is pooling in the base of an excavation; the other where vapours are diffusing through the vadose zone to the trench. The model calculates a volatilization factor (VF), defined as the contaminant concentration in trench air divided by the contaminant concentration in the groundwater (equivalent to an attenuation factor). The model determines dilution in the trench based on one of two default air exchange rates: 2/h for a trench whose depth is greater than its width; and 360/h for a trench whose width exceeds its depth. This model can be used, with modification, to estimate vapours from a soil or soil vapour source.

Some advantages of using the Virginia DEQ Method to develop volatilization factors for soil vapour to trench air (VF_{sv}) are that the model is readily adapted to a soil vapour source and that it includes a quasi-theoretical basis for mixing of air in trenches with ambient air that is based upon previous research on urban canyons. There is currently an absence of any empirical studies on air mixing within subsurface excavations.

2.3 Other Approaches

The Jury (1983, 1990) model estimates the diffusive flux of volatile chemicals in soil into a trench where the vapours would accumulate and mix with ambient air to give a trench air concentration. The model is time dependent where the greatest flux of vapour from soil occurs initially, in the first few minutes of excavation, and then declines over time. The Jury model is the basis of several other models used by other jurisdictions to predict vapours originating from a soil source.

The Ontario Ministry of Environment (Ontario MOE) uses an adapted version of the Jury model in their estimation of soil guidelines protective of trench workers. Ontario MOE back-calculates the allowable soil concentrations using the Jury model with the following modifications: excluding high initial release rates; using an air exchange rate of 2/h for a narrow trench (13 m x 1 m x 2 m); assuming the soil source to be in the trench wall. Other approaches reviewed previously (Meridian, 2010) include methods published by US EPA (1996, 1999) and ASTM (2004).

The Johnson and Ettinger (1991) model, which was originally developed for estimating vapours in building air is also occasionally used to estimate vapour concentrations in trench air. The model is modified to reflect a scenario similar to an earthen floored building and typically results in attenuation factors in the range of 10^{-2} to 10^{-3}.

Other approaches used in trench air risk assessments range from a potentially non-conservative use of the BC MOE default outdoor air attenuation factor of (10^{-4}) for open excavations, to the conservative assumption of no attenuation (i.e. a factor of 1) from soil vapour measurements to trench air.

2.4 Model Selection Rationale

The Canadian Council of Ministers of the Environment (CCME) used the Virginia DEQ model in their determination of the management limits for the Petroleum Hydrocarbon (PHC) Canada-wide Standard. CCME subsequently undertook a review of trench air models (Meridian, 2010) and recommended the use of the Ontario implementation of the Jury model for determining management limits for a soil source. However, the Jury model is primarily intended for a soil source, and is not readily modified for a soil vapour source. The Virginia DEQ model is able to be modified for a vapour source without departing from the basic theoretical underpinning of the model.

The science for trench air mixing dynamics is relatively young, and the currently available models still require field validation. While empirical research is still required, the Virginia DEQ model, modified for a soil vapour source, is considered to be a conservative choice, has regulatory precedent in Canada (i.e. CCME) and is therefore proposed herein for the development of trench vapour attenuation factors.

3.0 DEVELOPMENT OF RECOMMENDED ATTENUATION FACTORS

3.1 Model Description

The Virginia DEQ model was modified to account for a soil vapour source from its original consideration of a groundwater source. As noted previously, the term volatilization factor is equivalent to the attenuation factor as referred to in Technical Guidance 4. The model used to estimate the volatilization factors for soil vapour is presented in detail in Appendix A.

In the Virginia DEQ model, the contaminant concentration in soil vapour is estimated by partitioning from the groundwater concentration; the contaminant is then transported by diffusion to the trench base or face (where applicable) and diluted by mixing within the trench. Based on studies on air flow in urban canyons, the Virginia DEQ model uses two different air exchange rates depending upon the relative shape of the trench (Figure 1). Narrow trenches (i.e., trench width is less than trench depth) are hypothesized to have similar air flow to street canyons between tall, closely spaced buildings where the air flow within the lower portion of the trench recirculates (e.g. Oke, 1988) and has little mixing with air above the trench. The Virginia DEQ model uses an air exchange rate of 2/h for a narrow trench, which is similar to an air exchange rate within a building. Wide trenches are assumed to have a greater degree of air exchange with above-grade air than narrow trenches, but have less air exchange than in a fully above-grade scenario. The Virginia DEQ model uses an air exchange rate of 360/h for wide trenches, based on a relatively slow wind speed assumed in an urban setting.

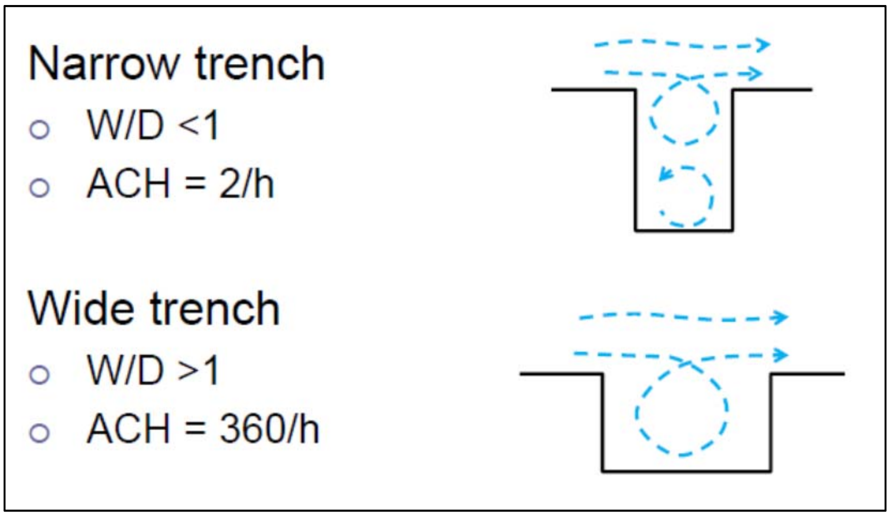

Figure 1: Conceptual Illustration of Air Flow within Narrow and Wide Trenches

3.2 Definition of Default Scenarios and Assumptions

Trench workers are defined in this document as persons who could be present in a subsurface excavation as part of their occupation. Since trench workers are assumed to be employed there is an underlying assumption that their place of employment has existing health and safety protocols in place, such as the worker wearing coveralls and work boots. A trench worker may or may not have training in handling toxic, hazardous or explosive substances. While the term “trench worker” is used throughout this report, it is important to note that this guidance would apply to any worker engaged in subsurface construction work such as the excavation of basements or parking garages, or foundation construction or repair. Trench workers are assumed to be adults, and the public (including children) are assumed to be restricted from entering a construction site with an open excavation.

For the purposes of this study, a trench is considered to be a subsurface excavation that is large enough for an adult to stand in, i.e. a minimum of 2 m in depth. As shown later, however, the absolute depth does not directly affect the modeling. The word ‘trench’ is used in this document as a convenience, but this guidance also applies to larger excavations such as a basement excavation for a building. Two main trench configurations were used in the development of attenuation factors: narrow (where W>D) and wide (where D>W).

The exposure duration is the time period that a trench worker may be exposed to contaminants in an excavation. While this term is not directly used in the attenuation modeling, it is an important assumption in the risk assessment of trench exposures. Exposures of construction workers, particularly trench workers, at a specific site are typically acute to subchronic, meaning that the worker could be present for as little as a few minutes to a period of several months. It is important for the risk assessor to carefully consider the most appropriate toxicity reference value (TRV), given the relatively short exposure duration associated with trench work. However, very few TRVs have been published by regulatory agencies for acute or subchronic exposures, and common practice is to compare exposures to chronic TRVs. Consideration of exposure durations and TRV selection is beyond the scope of this document, but the conservatism associated with present practice in this regard should be kept in mind in the interpretation of vapour measurements and the application of attenuation factors.

The depth to the source of soil vapour is an important variable in the model, particularly since it dictates whether the vapour source is intersected by the trench or is beneath the exposed trench base or wall. In practice, attenuation factors are applied to measured soil vapour concentrations, and thus it is the location of the point of vapour measurement relative to the trench geometry that is important. Soil vapour wells are often installed to a depth of 1.5 m for the purpose of assessing vapour intrusion to buildings. This depth is also appropriate for assessing trench vapours, although vapours measured at a depth of 1.5 m would be assumed to be intersected by the trench whereas vapours measured at a depth of, say, 2.3 m would be 30 cm below the base of a 2 m trench, and would be attenuated by diffusion through the soil. Two default scenarios have been defined, in the context of the depth of vapour measurement or depth to the vapour well screen (more precisely defined as the depth to the bottom of the bentonite seal above the well screen):

1. Vapour source intersected by trench (i.e. depth to the bottom of the seal above the well screen of 2 m or less); and
2. Vapour source a minimum of 30 cm below the base of the trench (i.e. depth to the bottom of the seal above the well screen of 2.3 m or greater).

The air exchange rates for both narrow and wide trenches were fixed values, adopted from VDEQ (2010). A narrow trench was assumed to have an air exchange rate of 2/h, similar to that of a building, and a wide trench was assumed to have an air exchange rate of 360/h based on more complete mixing but with a relatively low ambient wind speed. Both are considered conservative, as is the transition from narrow to wide (discussed later).

3.2.1 Model Scenarios

Based on a preliminary examination of the model, two main parameter values were identified as having a potentially large effect on the volatilization factor for a soil vapour source:

1. Trench width to depth ratio, and
2. Vapour source depth (or depth of vapour well screen) relative to the trench floor.

Soil type (texture) was also included as a variable in the model scenarios using the standard default definitions of fine-grained and coarse-grained soils (CCME, 2006).

The model scenarios evaluated in this report are as follows:

Model Scenarios	**Narrow Trench (Width < Depth)**	**Wide Trench (Width > Depth)**
Shallow Vapour Source (Source Depth < Trench Depth)	Fine & Coarse Soil Narrow Trench Shallow Vapour Source	Fine & Coarse Soil Wide Trench Shallow Vapour Source
Deep Vapour Source (Source Depth minus Trench Depth > 30 cm)	Fine & Coarse Soil Narrow Trench Deep Vapour Source	Fine & Coarse Soil Wide Trench Deep Vapour Source

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3.2.2 Model Sensitivity

Prior to finalizing the parameters corresponding to the above scenarios, the sensitivity of the volatilization factor to variation in key parameters in the modified Virginia DEQ model was evaluated. Model sensitivity analyses are helpful in determining the variables that are most important as well as selecting a final volatilization factor for each scenario. Vapour source depth, trench width, soil texture and diffusivity in air were varied independently in the model while holding all other variables constant.

Vapour source depth was varied over a range of depths that could potentially be encountered at contaminated sites, from 50 cm to 10 m. All other parameters, including the depth of the trench were held constant. As shown in Figure 2, below, vapour source depths even slightly greater than the trench depths have a large effect on the volatilization factor. Additionally, as expected, narrow trenches generate consistently higher volatilization factors than wide trenches.

Trench width was varied from 1 to 10 m, while all other variables were held constant. The results are presented in Figure 3 and clearly demonstrate the influence of the width to depth ratio on the model results as a result of the fixed air exchange rates. It is pointed out that the relationship between trench width and air exchange rate is treated as a discontinuous or discrete function, whereas in reality a transition would be expected. As part of this study, reported air flow patterns under different urban canyon geometries were reviewed qualitatively to obtain some assurance that treating air exchange rates discretely does not over-predict dilution for trench widths slightly greater than the depth. Although empirical data are lacking, it is our opinion that a transition from narrow to wide at a width to depth ratio of one is conservative. Note also that increasing trench volume has no effect on the volatilization factor, indicating that the shape of the trench is more important than the absolute size in this model.

Both Figures 2 and 3 indicate that a fine-grained soil texture resulted in slightly higher volatilization factors than a coarse-grained soil texture, but the difference is marginal overall. Soil texture is therefore not a significant variable in the determination of generic attenuation factors.

Diffusivity in air is the only chemical-specific parameter that affects the model results. Several chemicals which would be commonly encountered at contaminated sites in BC were included in the model sensitivity analysis (Figure 4). In general, diffusivity in air affects the model in a linear fashion with a one order of magnitude difference in volatilization factors over the range of chemicals (232 in total) with available diffusivity values as cited by Health Canada (2009).

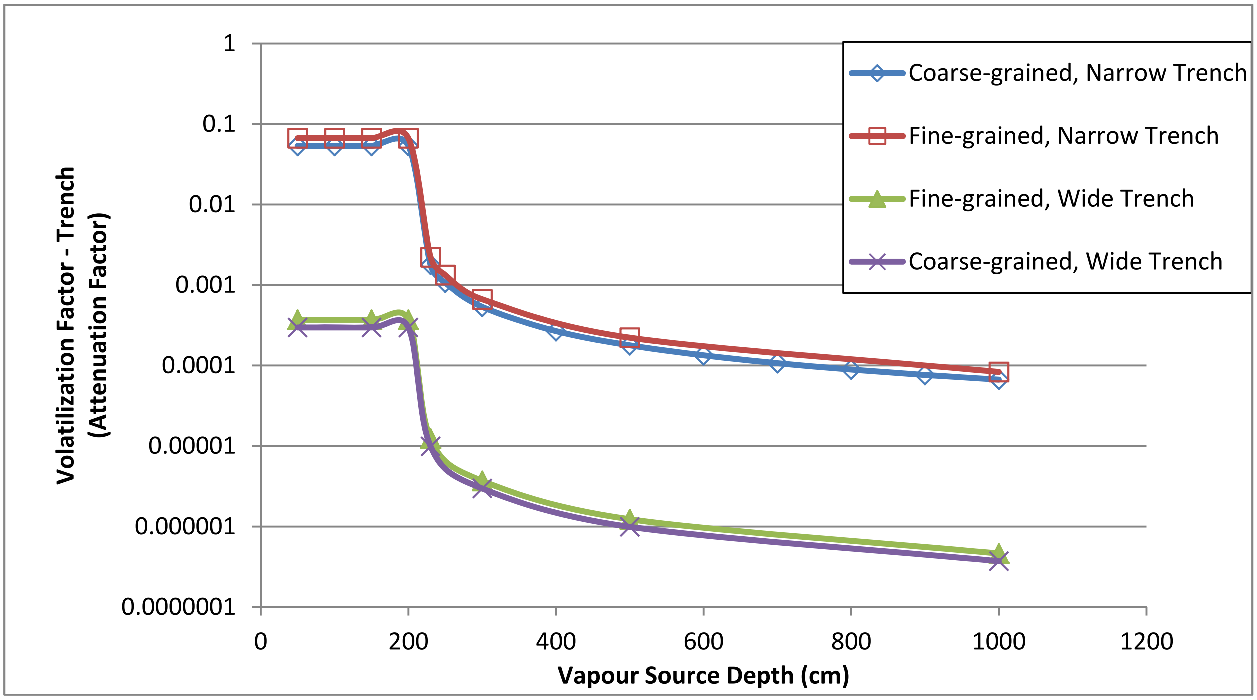

Figure 2: Model Sensitivity Analysis – Vapour Source Depth

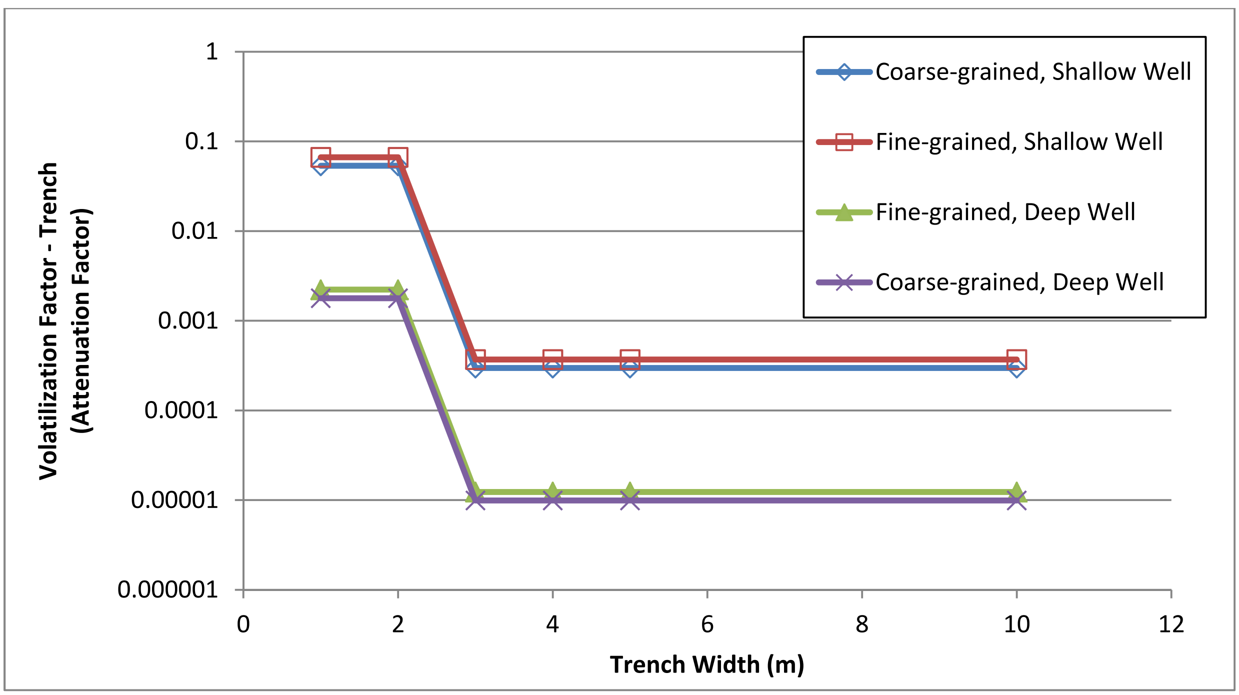

Figure 3: Model Sensitivity Analysis – Trench Width

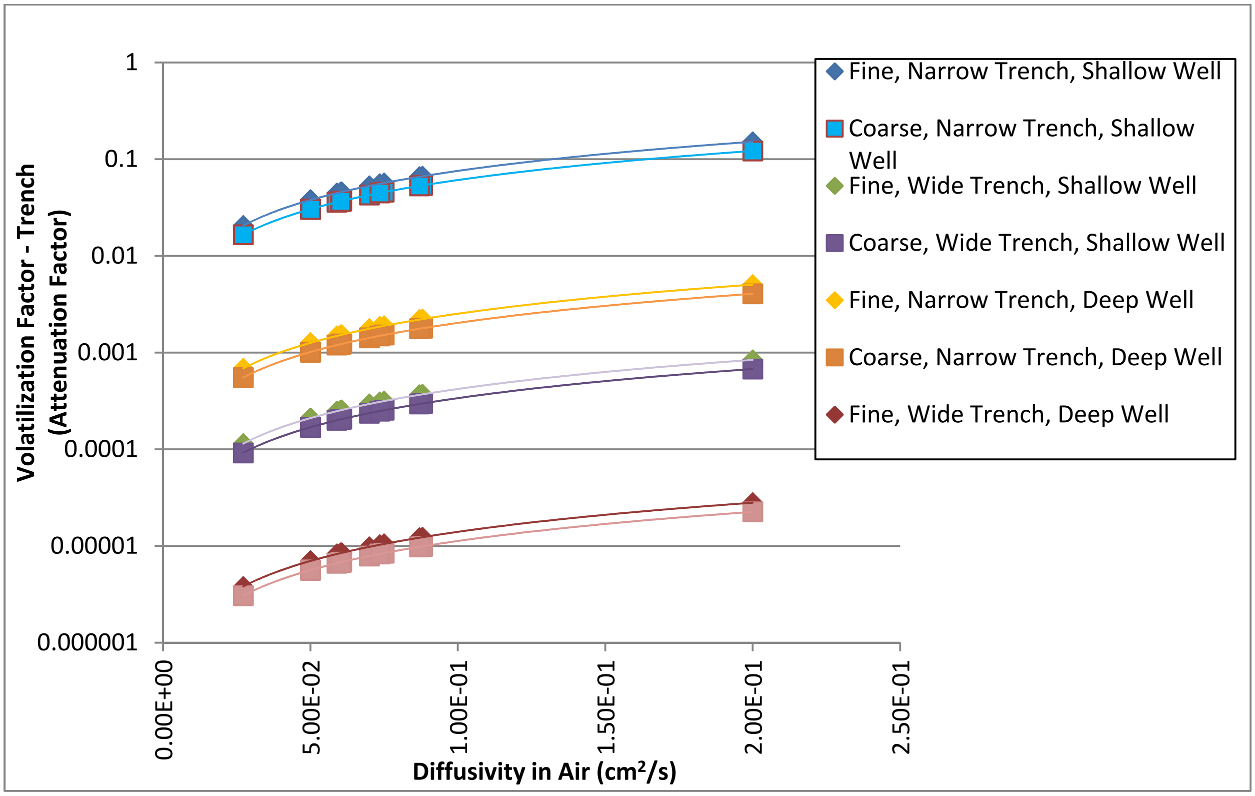

Figure 4: Model Sensitivity Analysis – Diffusivity in Air

3.3 Recommended Default Attenuation Factors

The volatilization factors for trench air from a soil vapour source were selected to be protective of workers for the majority of chemicals of potential concern typically present at contaminated sites in BC, while at the same time accounting for the conservative nature of the model that was used. Since there was little difference between fine- and coarse-grained results, fine-grained values were used in the final model selection. To account for the range of potential air diffusivity values, the 95th percentile value of the range cited by Health Canada was used. The model settings for the final values are presented in detail in Appendix A.

The recommended default attenuation factors are as follows:

Model Scenarios	***Default Vapour Attenuation Factors***	
	Narrow Trench (Width < Depth)	**Wide Trench (Width > Depth)**
Shallow Vapour Source (Source Depth < Trench Depth)	0.09	0.0005
Deep Vapour Source (Source Depth minus Trench Depth > 30 cm)	0.003	0.00002

4.0 APPLICATION OF THE DEFAULT ATTENUATION FACTOR

The default vapour attenuation factor would be selected based on the proposed excavation type and geometry. It is anticipated that utility maintenance and construction would generally be associated with a narrow trench, whereas a building excavation would generally be associated with a wide trench. Contamination under a roadway would be associated in most cases with narrow trench construction.

The attenuation factor would also depend on the depth of the soil vapour source as characterized by vapour measurements from appropriately installed vapour wells. The depth to the vapour source is defined as the depth to the bottom of the bentonite seal above the well screen. Ideally, vapour wells would be installed within the proposed excavation footprint and screened within the contaminated zone. Sites with relatively deep contamination (e.g. non-detect soil concentrations within the first 2 m) would have deeper wells (screen depths at least 30 cm below the base of the excavation). Vapour well installation and sampling should adhere to applicable guidelines and protocols, including MoE Technical Guidance 4 and methods referenced therein.

Once the appropriate attenuation factors are selected at the site, the measured soil vapour concentrations would be multiplied by the attenuation factors to give the estimated vapour concentrations in trench air. These trench air concentrations would then be compared to an appropriate TRV. The BC CSR Schedule 11 standards for Industrial Land use would be appropriate in most cases; alternatively a TRV may be selected in accordance with MoE Technical Guidance 7.

The default vapour attenuation factors have been developed for generic use and are therefore considered to be conservative. If the application of default attenuation factors suggest that risks to excavation workers may exceed acceptable levels, risk management measures would be required which may result in conditions being imposed on a site through an appropriate CSR instrument. However, a finding of unacceptable risk using default vapour attenuation factors would not preclude the use of an alternative approach to the determination of site-specific vapour attenuation factors. Such an approach should be based on adequate site characterization and scientifically defensible modeling methods. Consultation with the MoE is recommended if site-specific approaches are used.

5.0 LIMITATIONS AND CLOSURE

This report has been prepared for the exclusive use of the Society of Contaminated Sites Approved Professionals (CSAP Society) and/or the BC Ministry of Environment, in accordance with the agreed scope of work for Technical Review #18.

Quantitative and qualitative human health and environmental risk assessments involve a number of uncertainties and limitations. As a consequence, the use of the results presented herein to develop site management strategies may either be overly protective or may not necessarily provide complete protection of human and environmental receptors or prevent damage of property in all circumstances. The results of any risk assessment calculations or modelling presented herein were determined in accordance with generally accepted protocols and assumed generic site conditions. Given the assumptions used herein, the risk assessment is believed to provide a conservative estimate of exposures and risks. The services performed in the preparation of this report were conducted in a manner consistent with the level of skill and care ordinarily exercised by professional engineers and scientists practising under similar conditions.

We trust that this document is satisfactory for your current needs. Should you have any questions or concerns, please do not hesitate to contact the undersigned.

Respectfully submitted,

MERIDIAN ENVIRONMENTAL INC.

Geneva L. Robins, P.Biol. (Alberta)

David R. Williams, Ph.D., P.Eng.

6.0 REFERENCES

ASTM, 2004. Standard Guide for Risk-Based Corrective Action. ASTM E 2081-00 (Reapproved 2004).

BC CSR (British Columbia Contaminated Sites Regulation). 2010. Schedule 11. Available online: http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/375_96_13

BC MoE (British Columbia Ministry of Environment). 2010. Technical Guidance on Contaminated Sites 4. Vapour Investigation and Remediation. Version 1. Available online: http://env.gov.bc.ca/epd/remediation/guidance/technical/pdf/tg04.pdf

BC MoE. 2012. Technical Guidance on Contaminated Sites 7. Supplemental Guidance for Risk Assessments. Version 2. Available online: http://www.env.gov.bc.ca/epd/remediation/guidance/technical/pdf/tg07-v2.pdf

CCME (Canadian Council of Ministers of the Environment). 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. PN 1332. ISBN-13 978-1-896997-45-2

Health Canada. 2009. Spreadsheet Model for Detailed Quantitative Risk Assessment (version March 16, 2009).

Jury, W.A., W.F. Spencer, and W.J. Farmer. 1983. Behavior assessment model for trace organics in soil: I. Model description. J. Environ. Qual. 12(4):558-564.

Jury, W.A., D. Russo, G. Streile, and H.E. Abd. 1990. Evaluation of volatilization by organic chemicals residing below the soil surface. Water Resources Research 26(1):13-20.

Meridian (Meridian Environmental Inc.). 2010. Review of Approaches for Modelling Vapour Migration into Trenches and Excavations. Submitted to Canadian Council of Ministers of the Environment.

Oke, T.R., 1988. Street design and urban canopy layer climate. Energy and Buildings 11, 103–113.

US EPA (United States Environmental Protection Agency). 2004. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual. Part E, Supplemental Guidance for Dermal Risk Assessment. Final. Office of Superfund Remediation and Technology Innovation. EPA/540/R/99/005. OSWER 9285.7-02EP. PB99-963312. July 2004.

United States Environmental Protection Agency (US EPA) Region 3. 2010. Mid-Atlantic Risk Assessment. Regional Screening Table. Available online: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/pdf/master_sl_table_run_NOVEMBER2010.pdf

US EPA (United States Environmental Protection Agency). 1999. Derivation of a Volatilization Factor to Estimate Upper Bound Exposure point Concentration for Workers in Trenches Flooded with Groundwater Off-gassing Volatile Organic Chemicals. Region 8. 8EPR-PS. Cited in URS. 2008. Vapour Modelling Methodology.

US EPA (United States Environmental Protection Agency). 1996. Soil Screening Guidance: Technical Background Document – Second Edition. Office of Solid Waste and Emergency Response. EPA/540/R95/128, Publication 9355.4-17A.

US EPA. 1988. Superfund Exposure Assessment Manual. Office of Remedial Response, Washington, DC. EPA/540/1-88/001.

VDEQ (Virginia Department of Environmental Quality). 2010. Voluntary Remediation Program Risk Assessment Guidance. Available online: http://www.deq.state.va.us/Programs/LandProtectionRevitalization/RemediationPrograms/VoluntaryRemediationProgram/VRPRiskAssessmentGuidance/Guidance.aspx

APPENDIX A

Virginia DEQ Model

APPENDIX A: VIRGINIA DEQ MODEL AND CALCULATIONS

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

This appendix presents the details of the modelling for the soil vapour volatilization factors. The Virginia Department of Environmental Quality (VDEQ, 2010) trench model is based on vapours arising from a groundwater source and is described below. The VDEQ (2010) model was modified to estimate trench air concentrations arising from a soil vapour source and is presented below in Section 1.2. The volatilization factor calculated by the model is equivalent to an attenuation factor as is commonly referenced in models estimating vapours in a building. A model description and input parameters used to estimate the volatilization factors are presented below.

1.1 Trench Air – Soil Vapour Source

The Virginia Department of Environmental Quality (VDEQ) published a model which predicts exposure of workers to volatile chemicals in construction and utility trenches (VDEQ, 2010). The model includes two different approaches for estimating volatilization of a contaminant from groundwater to a trench – one based on groundwater pooling in the trench, and the other based on contaminant transport through the vadose zone. The soil vapour volatilization factor was based on a modification of the VDEQ model for contaminant transport through the vadose zone. A box model is then used to estimate dilution within the trench.

Trench air concentrations based on a groundwater source below the bottom of the trench are estimated by the VDEQ (2010) model as follows:

$$C_{trench} = C_{GW} \times VF \qquad \text{Equation 1}$$

$$VF = \frac{\left(H_i \times D_{air} \times {AC_{vad}}^{3.33} \times A \times F \times 10^{-3} \times 10^{4} \times 3600 \right)}{R \times T \times L_d \times ACH \times V \times {Por_{vad}}^{2}} \qquad \text{Equation 2}$$

where:

C_{trench} = concentration of contaminant in trench (µg/m^3)
C_{GW} = concentration of contaminant in groundwater (µg/L)
VF = volatilization factor (L/m^3)

H_i = Henry's law constant for contaminant (atm-m^3/mol)
D_{air} = diffusion coefficient in air (cm^2/s)
AC_{vad} = volumetric air content in vadose zone (unitless)
A = area of trench (m^2)
F = fraction of floor through which contaminant can enter (unitless)
R = gas constant (8.2 x 10^{-5} atm-m^3/mol-K)
T = average system temperature (K)
L_d = distance between trench bottom and vapour source (cm)
ACH = air changes per hour (h^{-1})
V = volume of trench (m^3)
Por_{vad} = total soil porosity in vadose zone (unitless)
10^{-3} = conversion factor (L/cm^3)
10^{4} = conversion factor (cm^2/m^2)
3600 = conversion factor (s/h)

Combining the above equations gives the following:

$$C_{trench} = C_{GW} \times \frac{H_i \times D_{air} \times AC_{vad}{}^{3.33} \times A \times F \times 10^{-3} \times 10^4 \times 3600}{R \times T \times L_d \times ACH \times V \times Por_{vad}{}^2}$$ Equation 3

Soil vapour concentrations were estimated from groundwater concentrations using the following equation (US EPA, 2004):

$$C_{sv} = H' \times C_{GW}$$ Equation 4

$$H' = \frac{H_i}{R \times T}$$ Equation 5

where:

C_{sv} = Concentration in soil vapour (μg/m^3)
H′ = dimensionless Henry's Law Constant (unitless)

Combining the above equations and solving for the groundwater concentration (C_{GW}) gives the following:

$$C_{GW} = C_{sv} \times \frac{R \times T}{H_i}$$ Equation 6

Substituting the above equation for C_{GW} into the VDEQ (2010) model gives the following:

$$C_{trench} = \left(C_{sv} \times \frac{R \times T}{H_i}\right) \times \frac{H_i \times D_{air} \times AC_{vad}{}^{3.33} \times A \times F \times 10^{-3} \times 10^4 \times 3600}{R \times T \times L_d \times ACH \times V \times Por_{vad}{}^2}$$ Equation 7

The above equation simplifies to the following equations, which were used in Table A3 to estimate trench air concentrations originating from a soil vapour source:

$$C_{trench} = C_{sv} \times \frac{D_{air} \times AC_{vad}{}^{3.33} \times A \times F \times 10^4 \times 3600}{L_d \times ACH \times V \times Por_{vad}{}^2 \times 10^6}$$ Equation 8

$$C_{trench} = C_{sv} \times VF_{sv}$$ Equation 9

$$VF_{sv} = \frac{D_{air} \times AC_{vad}{}^{3.33} \times A \times F \times 10^4 \times 3600}{L_d \times ACH \times V \times Por_{vad}{}^2 \times 10^6}$$ Equation 10

$$L_d = L_{svc} - \mathrm{D_{trench}}$$ Equation 11

where:

VF_{sv} = volatilization factor from a soil vapour source (unitless) – equivalent to attenuation factor
L_d = distance between trench bottom and vapour source (cm; conservatively assumed to equal 1 cm if D_{trench}>L_{svc})
L_{svc} = depth to the bottom of the bentonite seal (above the soil vapour screen) (cm)
D_{trench} = depth of trench (cm)
10^4 = conversion factor (cm^2/m^2)

3600 = conversion factor (s/h)
10^6 = conversion factor (cm^3/m^3)

1.2 Input Parameters

Site characteristics used in the default model scenarios described in the main text are presented in Table A1. Volumetric air content in the vadose zone (AC_{vad}), total porosity in the vadose zone (Por_{vad}), soil dry bulk density (ρ_b), fraction of organic carbon (f_{oc}) were selected from values for default coarse- and fine-grained soil available from CCME (2006).

Trench characteristics used in the model are presented in Table A1. Trench dimensions (depth, width, length, area, volume) were selected based on the results of a sensitivity analysis recently conducted for CCME (Meridian, 2010). The absolute size of the trench has a minor impact on the model results compared to the shape of the trench (i.e., narrow vs. wide and deep vs. shallow). The fraction of the trench floor through which contaminants can enter (F) was conservatively assumed to equal 1, indicating the entire base of the trench is above the contaminated zone and exposed. The number of air exchanges per hour (ACH) was adopted from VDEQ (2010).

Chemical properties for some common chemicals of potential concern (COPC) are presented in Table A2. The diffusion coefficient in air (D_{air}) Health Canada (2009b).

2.0 SAMPLE CALCULATION

Sample calculations for the soil vapour volatilization factor (VF_{sv}) are included for benzene for a narrow, shallow trench in a fine-grained soil.

$$VF_{sv} = \frac{D_{air} \times {AC_{vad}}^{3.33} \times A \times F \times 10^4 \times 3600}{L_d \times ACH \times V \times {Por_{vad}}^2 \times 10^6}$$

$$L_d = 1cm\ (D_{trench} < L_{svc})$$

$$VF_{sv} = \frac{0.088 \frac{cm^2}{s} \times 0.241^{3.33} \times 13m^2 \times 1 \times 10^4 \frac{cm^2}{m^2} \times 3600 \frac{s}{h}}{1cm \times 2h^{-1} \times 26m^3 \times 0.36^2 \times 10^6 \frac{cm^3}{m^3}} = 0.0535$$

3.0 REFERENCES

CCME (Canadian Council of Ministers of the Environment). 2006. A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines. PN 1332. ISBN-13 978-1-896997-45-2

Health Canada. 2009a (draft). Federal Contaminated Sites Risk Assessment in Canada. Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA). Version 2.0. Contaminated Sites Division, Safe Environments Programme.

Meridian (Meridian Environmental Inc.). 2010. Review of Approaches for Modelling Vapour Migration into Trenches and Excavations. Submitted to Canadian Council of Ministers of the Environment.

US EPA (United States Environmental Protection Agency). 2004. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual. Part E, Supplemental Guidance for Dermal Risk Assessment. Final. Office of Superfund Remediation and Technology Innovation. EPA/540/R/99/005. OSWER 9285.7-02EP. PB99-963312. July 2004.

APPENDIX A
TABLES

TABLE A1
SOIL AND TRENCH CHARACTERISTICS

Parameter Name	Symbol	Units	Fine-grained Soil, Narrow Trench, Shallow Wells	Coarse-Grained Soil, Narrow Trench, Shallow Wells	Fine-grained Soil, Narrow Trench, Deep Wells	Coarse-grained Soil, Narrow Trench, Deep Wells	Fine-grained Soil, Wide Trench, Shallow Wells	Coarse-Grained Soil, Wide Trench, Shallow Wells	Fine-grained Soil, Wide Trench, Deep Wells	Coarse-grained Soil, Wide Trench, Deep Wells
Depth to Soil Vapour Well Screen	L_{svc}	cm	150	150	230	230	150	150	230	230
Volumetric air content in vadose zone soil	θ_a AC_{vad}	cm^3/cm^3	0.302	0.241	0.302	0.241	0.302	0.241	0.302	0.241
Volumetric water content in vadose zone soil	θ_w	cm^3/cm^3	0.168	0.119	0.168	0.119	0.168	0.119	0.168	0.119
Total soil porosity in vadose zone	n Por_{vad}	cm^3/cm^3	0.47	0.36	0.47	0.36	0.47	0.36	0.47	0.36
Soil dry bulk density	ρ_b	g/cm^3	1.4	1.7	1.4	1.7	1.4	1.7	1.4	1.7
Fraction of organic carbon	f_{oc}	unitless	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Trench depth	d_{trench}	m	2	2	2	2	2	2	2	2
Trench width	w_{trench}	m	1	1	1	1	10	10	10	10
Trench length	l_{trench}	m	13	13	13	13	13	13	13	13
Area of trench	A	m^2	13	13	13	13	130	130	130	130
Volume of trench	V	m^3	26	26	26	26	260	260	260	260
Fraction of floor through which contaminant can enter	F	unitless	1	1	1	1	1	2	3	4
Air changes per hour	ACH	h^{-1}	2	2	2	2	360	360	360	360

TABLE A2
CHEMICAL PROPERTIES

Parameter Name	Diffusion coefficient in Air D_{air} cm^2/s
Benzene	8.80E-02
Toluene	8.70E-02
Ethylbenzene	7.50E-02
Xylenes	7.00E-02
Aliphatic VPH (C_6-C_8)	5.00E-02
Aliphatic VPH (C_8-C_{10})	5.00E-02
Aromatic VPH (C_8-C_{10})	5.00E-02
Aliphatic LEPH (C_{10} - C_{12})	5.00E-02
Aliphatic LEPH (C_{12} - C_{16})	5.00E-02
Aromatic LEPH (C_{10} - C_{12})	5.00E-02
Aromatic LEPH (C_{12} - C_{16})	5.00E-02
n-Hexane	2.00E-01
Methyl-cyclo-hexane	7.35E-02
Naphthalene	5.90E-02
Pyrene	2.72E-02
n-Decane	6.02E-02
1,2,4-Trimethyl-benzene	6.06E-02
1,3,5-Trimethyl-benzene	6.02E-02
Trimethyl-benzene (mixed isomers)	6.02E-02
Trichloroethylene (TCE)	7.90E-02
Tetrachloroethylene (PCE)	7.20E-02
Vinyl Chloride	1.06E-01

TABLE A3
VOLATILIZATION FACTOR CALCULATIONS FOR TRENCH AIR

Parameter Name	Symbol	Units	Benzene	Toluene	Ethylbenzene	Xylenes	Aliphatic VPH (C_6-C_8)	Aliphatic VPH (C_8-C_{10})	Aromatic VPH (C_8-C_{10})	Aliphatic LEPH (C_{10} - C_{12})	Aliphatic LEPH (C_{12} - C_{16})	Aromatic LEPH (C_{10} - C_{12})	Aromatic LEPH (C_{12} - C_{16})	n-Hexane	Methyl-cyclo-hexane	Naphthalene	Pyrene	n-Decane	1,2,4-Trimethyl-benzene	1,3,5-Trimethyl-benzene	Trimethyl-benzene (mixed isomers)	Trichloroethylene (TCE)	Tetrachloroethylene (PCE)	Vinyl Chloride
Chemical Specific Information																								
Diffusion coefficient in air	D_{air}	cm^2/s	8.80E-02	8.70E-02	7.50E-02	7.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	5.00E-02	2.00E-01	7.35E-02	5.90E-02	2.72E-02	6.02E-02	6.06E-02	6.02E-02	6.02E-02	7.90E-02	7.20E-02	1.06E-01
Site Information																								
Depth to Soil Vapour Well Screen	L_{svc}	cm	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Volumetric air content in vadose zone soil	θ_a AC_{vad}	cm^3/cm^3	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302	0.302
Volumetric water content in vadose zone soil	θ_w	cm^3/cm^3	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168
Total soil porosity in vadose zone	n Por_{vad}	cm^3/cm^3	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Trench Dimensions																								
Trench Depth	d_{trench}	m	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Trench Width	w_{trench}	m	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Trench Length	l_{trench}	m	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Area of trench	A	m^2	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Volume of trench	V	m^3	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
Fraction of floor through which contaminant can enter	F	unitless	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Air changes per hour	ACH	h^{-1}	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Estimated Trench Air Concentration - Soil Vapour Source																								
Distance to Soil Vapour Source	L_d	cm	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Volatilization Factor	VF_{sv}	unitless	0.067	0.066	0.057	0.053	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.151	0.056	0.045	0.021	0.046	0.046	0.046	0.046	0.060	0.054	0.080