Report on

Screening Level Risk Assessment

SLRA Level 1 and SLRA Level 2

Submitted by the Science Advisory Board
For Contaminated Sites in British Columbia

To

The Ministry of the Environment
Victoria, BC

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http://www.sabcs.chem.uvic.ca/

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1. INTRODUCTION

During 2002, the British Columbia Ministry of Water, Land and Air Protection (the "Ministry") formed an Advisory Panel on Contaminated Sites to provide recommendations with regard to changes in the regulatory process in British Columbia for investigating, classifying and remediating contaminated sites[1]. In January 2003, the Advisory Panel provided its recommendations, which included the following:

- Establish a new, tiered site assessment and classification process that differentiates sites on the basis of risk to human health and the environment.
- Establish a process that focuses regulatory resources on high-risk sites.
- Establish a Science Advisory Board (SAB) to:
    - Develop a screening level risk assessment methodology that is appropriate and cost-effective;
    - Oversee the review and development of scientifically-defensible numerical screening values, and:
    - Reassess the current detailed risk assessment requirements to determine if appropriate information can be obtained in a more cost-effective manner.

The Ministry adopted the above recommendations and the task of developing a screening level risk assessment procedure was formally delegated to the Science Advisory Board in October 2003. The Board's task was to develop "A simple and streamlined risk assessment procedure to identify sites where substances exist above the numeric standards, but do not represent an unacceptable risk due to the absence of operable pathways of exposure to receptors."

This binder presents the Board's recommended screening level risk assessment methodology in the form of separate procedural modules.

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[1] http://wlapwww.gov.bc.ca/epd/epdpa/contam_sites/ministers_panel/ministerspanel.html

2. APPROACH TO DEVELOPMENT OF SCREENING LEVEL RISK ASSESSMENT PROCEDURE

2.1 FRAMEWORK FOR APPROACH

During discussions with the Board, the Ministry indicated its expectation that the screening level risk assessment methodology will be "a simple, prescriptive, facts-based test that will require a reasonable level of detail site information, but considerably less than would be required to complete a more traditional detailed risk assessment."

To guide the development of the screening level risk assessment protocols, the Science Advisory Board adopted the following four principles:

Principle 1:

The screening level risk assessment (SLRA) will be based upon an assessment of the presence of pathways and receptors at a contaminated site as per the conceptual model shown in Figure 1.

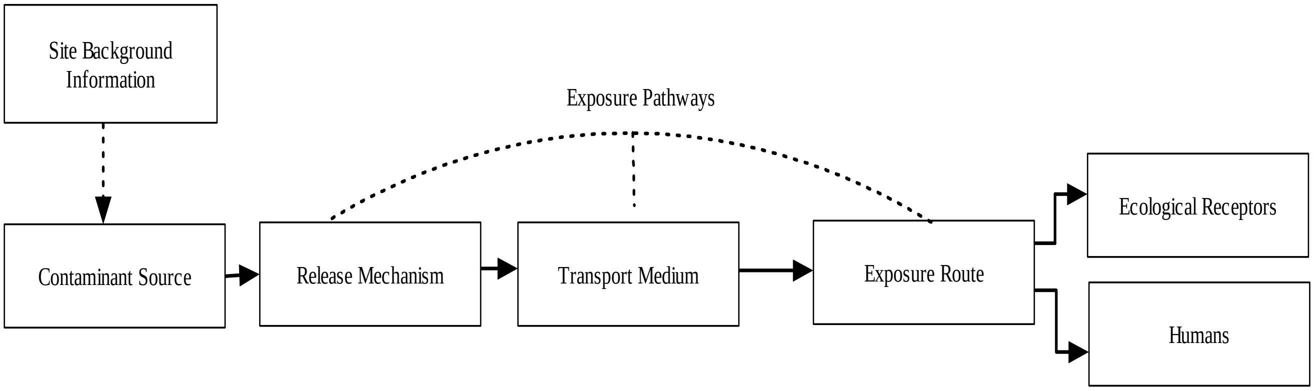


Figure 1: Conceptual model used for development of screening level risk assessment process

If a contaminated site, within its given land-use has no evident pathway of a contaminant to a receptor and/or has no receptor, then the site will be considered as a "no-pathway and/or no receptor" site, i.e., an NPR site.

Principle 2.

The process will consist of two levels of screening.

i) *SLRA Level 1* that consists of simple, highly constrained administrative rules to identify situations where risk is clearly acceptable although a site exceeds numerical standards. Application of professional judgement would be minimal, and it is anticipated the application would be within the abilities of all approved professionals (LEPs). Sites screened by the Level 1 process would have an obvious absence of active pathways and/or critical receptors. An example of such a site would be one where:

- A non-volatile contaminant (metal or organic) is present in soil and located under a cover such as pavement or buildings, hence contact with humans, plants and invertebrates is unlikely; and,
- There is no receptor for groundwater within defined distances.

ii) *SLRA Level 2* enables a further level of screening and, consists of administrative rules and simple constrained models to identify situations where risk is clearly acceptable although a site exceeds numerical standards. The application of professional judgement is limited and a level of specialized training may be required to utilize the procedures. Essentially the Level 2 assessment confirms, by use of conservative models and/or assessments, whether a pathway to a receptor is present. Examples of sites that could undergo further screening by the use of the Level 2 assessment process include sites where:

- A volatile contaminant is present within 30 m of an occupied structure;
- Groundwater contamination by organic substrates is present and a groundwater transport analysis is required to evaluate whether there is the potential for off-site subsurface migration or migration to on-site receptors; or,

  - There is uncertainty with respect to habitat potential (i.e., whether sites would be attractive to terrestrial wildlife).

Principle 3:

Soil contamination in the direct vicinity of an existing beneficial use should not constitute an unacceptable risk, and as such, should be excluded from further concern. Examples include the presence of: PAHs in the direct vicinity of a creosote treated piling; and, zinc at the outfall of galvanized drainage culverts.

Principle 4:

As per proposed Ministry protocols, the SAB understands that the inability of a site to be labelled as an NPR site, would imply the options of:

- Remediation to numeric standards;
- Remediation to risk-based standards;
- Completion of further assessments (for example, detailed risk assessments); or,
- Remediation of a site including measures for risk management for areas that cannot be remediated.

2.2 SAB MECHANISM TO DEVELOP SLRA PROCESS

The SAB, in its attempt to use the best possible current science for development of the SLRA process, used the following sequential approach:

- Sponsorship of an initial workshop with provincial and federal regulators, academic scientists and consultants, to define the scope and objectives of the program and to suggest means of achieving the objectives.
- Contracting to noted experts the preparation of papers to define the state of the science for several topics.

- Solicitation of reviews of the prepared papers by other experts.
- Sponsorship of a detailed workshop with attendance by experts to achieve consensus on the state of the science of the selected topics.
- Preparation of draft reports for the SLRA process with subsequent review by SAB members.
- Review of the resulting reports by the Ministry of Water Land and Air Protection.
- Preparation of a final report of the SAB on the recommended SLRA process.

Section 5 describes the procedures used by the SAB to develop the screening level risk assessment process.

3. USE OF SAB SCREENING PROCEDURES

The application of the Level 1 and 2 modules, provided in this binder, requires the following steps:

Step 1: Site Characterization

The SLRA process suggested by the SAB requires that a Stage I PSI, a Stage II PSI *and* a DSI have been conducted at the site in accordance with Ministry approved procedures and/or best professional practise, such that contamination has been characterized and delineated.

Step 2: Assessment of Site Data

The screening process can be initiated when site characterization has found contaminants in excess of the CSR standards for soil and/or groundwater. A stakeholder would have the option of remediation of the contamination to current CSR standards if the stakeholder does not want to consider the SLRA approach.

Step 3: Development of a Conceptual Model

A conceptual model is a display of the linkages among sources, exposure pathways (release mechanism, transport medium, exposure route), and receptors at and near a site. Complete exposure pathways exist when linkages between sources, pathways and receptors are found to exist. When such linkages do not exist, the exposure pathways are considered to be incomplete and the receptors are not at risk. The presence of complete exposure pathways indicates a potential for exposure and risk that may require further evaluation.

To visualize the “problem” to be assessed and the important receptors and pathways at a site, a conceptual model must be prepared by an assessor. The conceptual model for the site will serve as documentation by the qualified professional that pathways and receptors for the subject site have been assessed and identified. An example of a conceptual model is provided in a working example provided in the Level 1 module.

Step 4: Application of the Screening Level Risk Assessment Process

An overview of the Screening Level Risk Assessment Process is provided in Figure 2. It is anticipated the SLRA level 1 and SLRA Level 2 processes will be applied as follows:

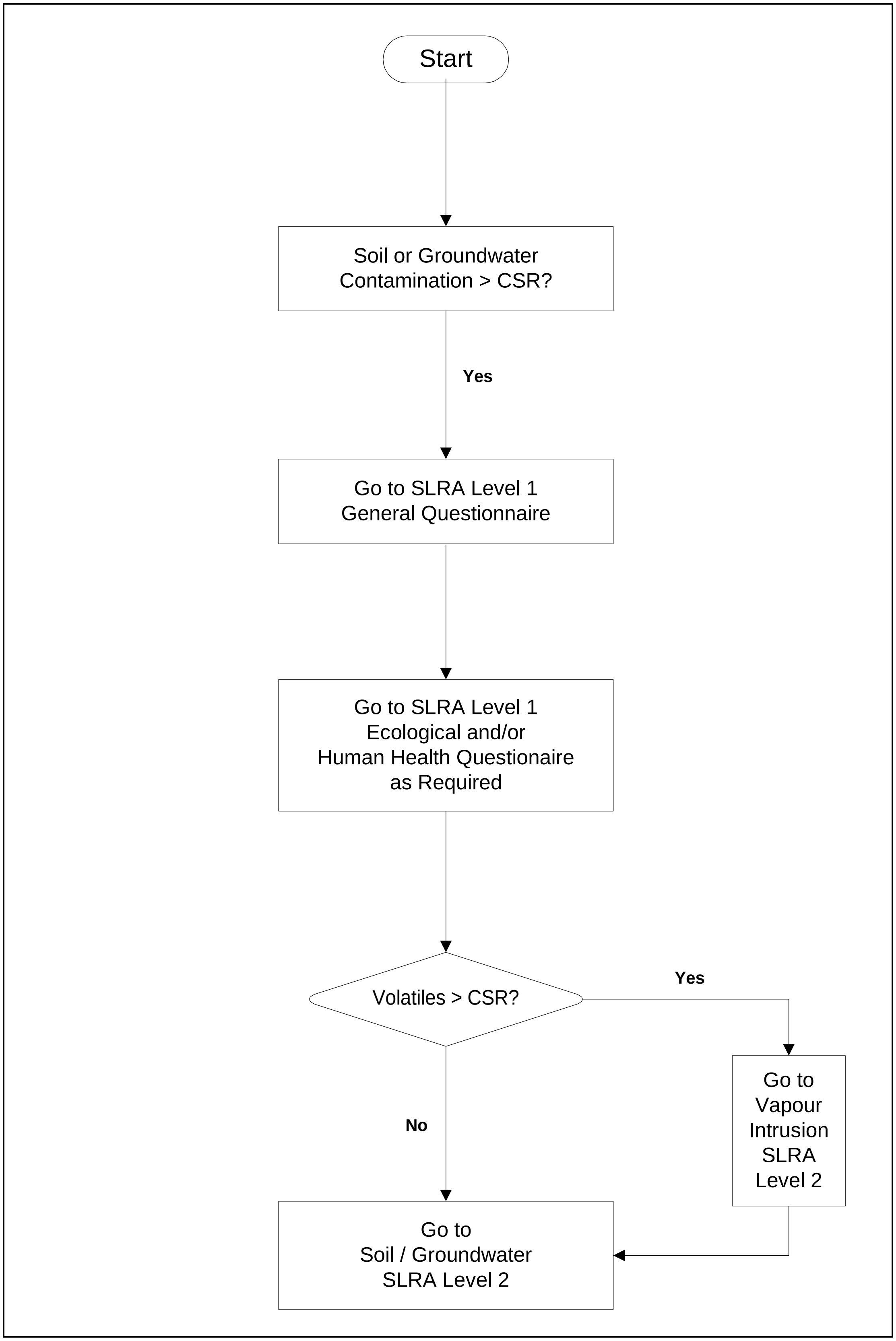
- The screening process would consider only pathways or receptors for which there are exceedences as outlined in Schedules 5 and 6 of the CSR. For example, if a chemical of potential concern (COPC) is found only to be in excess of the Schedule 5 standard for protection of soil invertebrates and plants, but the maximum concentration does not exceed any other standard (i.e., human health or aquatic life protection), then only the components of the SLRAs relevant to protection of soil invertebrates and plants require consideration.

- If a COPC has only a Schedule 4 generic standard (and the COPC concentration is greater than the generic standard), then the entire SLRA evaluation process must be completed for all possible receptors.

- A site determined to have hazardous waste as per Section 13 of the CSR requires Ministry overview and cannot be assessed solely by use of the SLRA process. Relevant portions of the CSR and the Hazardous Waste Regulation are under review by the Ministry, and the approved professional should have up-to-date awareness of regulatory requirements relating to hazardous waste management at contaminated sites.

- In accordance to the Ministry’s proposed process description, it is intended the standards used at the time of the comparison will be crystallized as of the date of provision of the site registry notice by the approved professional. Accordingly, the results of the screening process will be crystallized upon issue of an update of a site registry notice. Any change to the site conditions (e.g., change in use, or removal of a surface cap, etc.) may negate the findings of the initial screening process.

Figure 2: SLRA Screening Procedure



- An approved professional does not require certification as a "risk assessor" in order to apply an SLRA. It is intended that the Level 1 process can be applied by all individuals who are approved professionals. Within the Level 2 process, specific expertise may be required for application of the vapour intrusion module and the soil/groundwater module. A registered professional biologist is required to complete the SLRA Level 2 habitat module.

Step 4.1: Application of Level 1 process:

The key features of the Level 1 process as shown in Figure 2 are as follows:

- Site contamination that is localized and due solely to certain beneficial uses (e.g., presence of installed galvanized culverts or installed pilings preserved with creosote) are not subject to further screening. (Sites where such products are manufactured or stored for distribution are not exempt from further evaluation).

- Sites where volatile compounds are found at distances greater than 30 m from an occupied building can be exempted from further consideration of vapour intrusion (precluding factors listed in the Level 1 process must be considered).

- Contaminated soil covered by barriers (e.g., pavement, buildings, liners) becomes exempt from consideration of risk to human health or terrestrial ecology.

- Sites with undeveloped land less than specified sizes or within specified shapes can be exempt from further habitat assessment.

The details of the application of the Level 1 process are provided in the SLRA Level 1 module of this binder.

Step 4.2: Application of SLRA Level 2

Sites that cannot be removed from further consideration by the Level 1 process can undergo further evaluation by use of a Level 2 procedure. As shown in Figure 2, further screening is enabled when:

- Sites where metals contaminate soil and where groundwater is within CSR standards.
- A site contains organic compounds in soil or groundwater at concentrations in excess of the CSR standards.
- Volatile organic compounds are found within 30 m of occupied buildings.
- Further evaluation is necessary to confirm the significance to terrestrial biota of undeveloped land on a site.

The procedures are outlined in separate SLRA Level 2 modules within this document.

Step 5: Review of results of screening procedures

As per Figures 1 and 2, sites that meet the criteria of the screening procedures (i.e., “pass”) would be considered as NPR sites, i.e., although there is contamination on the site above the CSR standards, the following conditions apply.

- There is no pathway of the contamination to a receptor and/or there is no receptor to the contamination at the given site. As a result, there is no apparent risk due to the contamination found on the site.
- No further action for specified land use is required as long as the conditions at the site remain the same.

Step 6: Documentation of SLRA results

The work of an approved professional is subject to audit. Therefore documentation is required for a screening level risk assessment, and should include the components outlined in Figure 3**.**

Figure 3: Recommended documentation for SLRA evaluations.

1 INTRODUCTION
  1.1 STUDY OBJECTIVE (Including rationale for conducting the SLRA)
  1.2 SCOPE OF WORK

2 BACKGROUND
  2.1 GENERAL SITE DESCRIPTION
    2.1.1 Past and existing site uses
    2.1.2 Future (delete subsections if status quo)
    2.1.3 Adjacent properties

  2.2 SUMMARY OF PREVIOUS ENVIRONMENTAL SITE INVESTIGATIONS
    2.2.1 Phase 1
    2.2.2 PSI
    2.2.3 DSI
    2.2.4 Contaminants of Concern and List of Chemicals Exceeding the Standards
    2.2.5 Overview of Extent of Contamination (with site plans and cross sections) illustrating sample locations, exceedences of applicable standards, and inferred extent of contamination. Ideally one set of figures for each co-occurring group of contaminants of concern. (Such illustrations are normally provided within DSI's).
    2.2.6 Discussion of site sources of COPCs and brief description of fate and effects of COPCs.

  2.3 DESCRIPTION OF POTENTIAL RECEPTORS
    2.3.1 Human Receptors
    2.3.2 Ecological Receptors

  2.4 PRELIMINARY CONCEPTUAL MODEL

3 RESPONSE TO SLRA1 QUESTIONS (INCLUDE RATIONALE EXPLAINING ANSWER TO EACH QUESTION)
  3.1 GENERAL
    3.1.1 G-1- etc.

  3.2 HUMAN HEALTH
    3.2.1 H-1, etc.

  3.3 ECOLOGICAL
    3.3.1 E-1, etc.

4 RESULTS OF SLRA2 EVALUATION (WHEN APPLICABLE)
  4.1 Soil vapour intrusion module
    - Provision of calculations including risk assessment
  4.2 Groundwater/soil module
    - Provision of calculations
  4.3 Habitat module
    - Provision of biologist's assessment

5 FINAL CONCEPTUAL MODEL

6 CONCLUSION

7 PROFESSIONAL STATEMENT

4. BOARD COMMENTS RE: SLRA PROCEDURE

The Science Advisory Board provides the following additional comments with regard to the proposed Screening Level Risk Assessment process:

- It is the opinion of the Science Advisory Board that the screening processes provided within this document provide "best possible science" based on current knowledge.
- Many of the subjects addressed in this screening process are under rapid development, in particular the subjects of soil vapour intrusion and the fate of organic and inorganic substances in groundwater. Updates of the process will be required to reflect advances in knowledge. A review of the process every five years is therefore recommended.
- The initial use of the proposed screening process by approved professionals in B.C. will obviously constitute a "test" of the proposed process. Feedback from users will be critical to evaluate the effectiveness of the process and to evaluate whether changes are necessary. A review of the process should be considered within 18 months after implementation.
- Certain scenarios at sites cannot be assessed by use of either SLRA Level 1 or the Level 2. It is not implied that a higher degree of risk is associated with the sites, but rather the level of knowledge is such that a simplified screening assessment would be inadequate and/or that the situation requires more detailed analysis to enable proper assessment. For example, the modeling and evaluation of subsurface migration of metals is considerably complex and must be evaluated by means more complex than outlined within the Level 1 and Level 2 processes. Another example, is a site where there is potential for human contact with contaminated soil. Site-specific considerations would be required in accordance to proper risk assessment procedures to assess the impact on human health.

The SAB welcomes comments during the course of implementation of the suggested SLRA process and the Board will strive to improve the process, when necessary, to assure appropriate and cost-effective screening level risk assessments.

5. CHRONOLOGY OF SLRA DEVELOPMENT

5.1 DEVELOPMENT OF SLRA LEVEL 1

The Science Advisory Board formed a team to prepare the Level 1, with Board directors, Mr. Will Gaherty and Mr. Marc Cameron, as the project leaders. The development program consisted of several steps:

- Preparation of a draft Level 1 protocol. The draft was prepared by Menzie-Cura Associates Inc. of Winchester, Massachusetts, who had completed a number of similar documents for other jurisdictions. The preparation of the draft occurred during February-March, 2004.
- Review of the draft protocol during a technical workshop attended by invited stakeholders who represented several fields of expertise (March 2004).
- Revision of the draft protocol to reflect comments and conclusions of the workshop.
- Review of the revised draft by the SAB directors and workshop attendees[2], and revision, as necessary.
- Presentation of the draft protocol to the Ministry (May 2004).
- Request for public comments by the Ministry (Comments were due July 31, 2004).
- Review and revision of the draft protocol to address public comments.
- Presentation of a final draft to the Ministry.

Further details of the development program are provided in the Level 1 module of this document.

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[2] A list of workshop attendees is provided within the SLRA Level 1 and SLRA Level 2 modules.

5.2 DEVELOPMENT OF SLRA LEVEL 2

The Level 1 program concluded that for three scenarios, there should be provision for an additional screening process (Level 2) with the understanding that proper assessment tools and proper expertise would be used. The three scenarios are for:

- *Sites where volatile or semi-volatile chemicals are present in groundwater and/or soil, and vapour intrusion is possible;*
- *Sites where groundwater is contaminated in excess of CSR standards and/or where leachable contaminants are present in soil; and,*
- *Sites where the suitability of habitat for terrestrial wildlife is questionable.*

As a first step, draft-screening procedures to address each of the three areas were prepared by teams of SAB members and contractors/support staff as indicated in the following table:

Technical Area	SAB Members	Contractor/Support Staff
Soil vapour intrusion	Mr. Will Gaherty Dr. Jean Cho	Dr. Ian Hers and Ms.Cher Lacoste (Golder Associates)
Groundwater transport	Dr. Jean Cho	Dr. Rina Freed (SAB Research Associate)
Habitat assessment	Dr. Jim Malick	Ms. Lizanne Meloche Ms. Michelle Mahovlich (SAB support)

The draft screening procedures were developed as separate modules, and were distributed for review and discussion by separate working groups[3] at a workshop held on July 16, 2004. The team leaders revised the draft modules on the basis of comments and recommendations provided at the workshop. Those revised drafts were then provided to all workshop attendees and members of the Science Advisory Board for additional review. The finalized versions of the modules are those provided within this document.

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[3] The working groups consisted of noted experts in the respective fields. The experts represented the academic, regulatory and industrial communities, and are listed in appendices within the SLRA Level 2 modules included in this document.

5.3 SLRA INTEGRATION

The B.C. Ministry of the Environment and the Roster Steering Committee both provided significant comments to the draft previous to this document. Under the supervision of Jean Cho, the SLRA documents were integrated and compiled by Rina Freed (Gartner Lee Limited).

Screening Level Risk Assessment (SLRA)
Level 1

Prepared by
Science Advisory Board on Contaminated Sites for British Columbia
http://www.sabcs.chem.uvic.ca/

Prepared for:
B.C. Ministry of Environment
Victoria, BC

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PREFACE

This Screening Level Risk Assessment Guidance Level 1 document provides guidance regarding sites that have no pathway to the receptor (NPR) despite exceedances of generic numerical soil or water standards, or matrix numerical standards. The guidance applies to screening assessment activities that are completed after a Detailed Site Investigation (DSI). The purpose of the document is to evaluate subject sites with contaminant concentrations exceeding generic numerical soil and water standards or matrix numerical standards to determine if the exceedances may necessitate remediation, completion of a Screening Level Risk Assessment (SLRA) or Detailed Risk Assessment. The guidance is designed around a set of prescriptive questions that are used to determine if complete exposure pathways are present. Outcomes of the questionnaire-based evaluation include:

1) there are no complete exposure pathways that require further evaluation and this aspect of the evaluation can be terminated for either human health exposures, ecological exposures or both human and ecological exposures, or
2) complete pathways are clearly insignificant, or
3) there are complete exposure pathways that warrant further evaluation.

To complete SLRA Level 1, a site conceptual model is required. The guidance assumes the availability of a DSI.

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The Screening Level Risk Assessment Level 1 Guidance document provides a prescriptive, qualitative tool for the identification of contaminated sites that lack complete exposure pathways and/or lack potential human and ecological receptors. SLRA Level 1 may be used to determine if further assessment is unnecessary despite exceedances of numerical standards because exposure pathways are incomplete, receptors are not present, or other factors clearly render the exceedances to be acceptable.

Contaminant concentrations in source media may exceed generic numerical soil or water standards, or matrix numerical standards or risk-based standards (CSR, Part 14, 58(1)(B)(iv); SWR; BCMWLAP Technical Guidance 3; BCMWLAP Technical Guidance 6; BCMWLAP Protocol 1) indicating the need for remediation of a site. However, comparisons to generic numerical soil or water standards or matrix numerical standards do not consider whether humans or ecological receptors are actually exposed to contaminants originating at the site. In this guidance document, a series of questions guides the user in judging whether or not potentially complete exposure pathways exist at a site. Completing the questionnaire requires data generally collected during completion of a Site Investigation (CSR). In cases in which a question cannot be answered due to data that has not or cannot be obtained, then additional investigation, or different risk assessment tools may be appropriate.

To complete SLRA Level 1, a site conceptual model is required. Such models provide visual summaries of the linkages from sources through exposure pathways and ultimately to receptors. A site conceptual model is used to help judge whether exposure pathways exist at the site that might warrant further review. Conceptual model development is an iterative process and the preliminary conceptual model developed at the beginning of SLRA Level 1 will likely be modified based on answers to the questions in the questionnaire. The conceptual model may be modified further as additional information or detail becomes available in other assessment stages, as well. The level of detail and form of the conceptual model developed in SLRA Level 1 will vary from site to site. The questions in SLRA Level 1 are linked to the identified exposure pathways in a site conceptual model. Please note that sites having aquatic habitat or Agricultural land use must proceed to SLRA Level 2 or DRA and cannot be dealt with under SLRA Level 1.

1.2 ORGANIZATION OF THE GUIDANCE

The SLRA Level 1 Guidance document is organized by land use categories as defined in the CSR, Part I - Interpretation. Because the decision regarding the need for further assessment is based on the presence or absence of complete exposure pathways and receptors, the conceptual model underlies and supports the SLRA Level 1 assessment process. The screening questions are focused on evaluating the presence or absence of complete exposure pathways and receptors.

To complete the screening questionnaire, an assessor will draw on data and observations made during the DSI. Although the application and overall instructions are the same among land uses, the questions may vary depending on the land use. Finally, a section is provided for each applicable land use including background information, important considerations and the prescriptive screening questionnaire. Agricultural land use are not covered by SLRA Level 1, nor are sites that include aquatic habitat.

2 GENERAL INSTRUCTIONS AND DEFINITIONS

Application of this guidance document involves the completion of a screening questionnaire. The questionnaire is divided into general questions, human exposure questions and ecological exposure questions, except for urban park, which has no ecological-specific questions.

General questions explore the source of the contamination, impacted media, migration of contamination, accessibility of contamination in soil, characteristics of contaminants and concentrations. Although the range of questions is broad, the information required to answer each question should have been collected during the PSI and DSI.

Human pathway questions specifically focus on the presence of humans on the site as well as the potential for human exposure to volatile contaminants migrating to buildings.

The ecological pathway questions focus on the presence of bare or vegetated soil, and separation from habitat offsite.

The questions were selected to evaluate the conditions most likely to determine if an exposure pathway is complete or incomplete. When pathways are complete, a user will choose to:

a) Conduct additional sampling and/or analysis of the data in a case where there is uncertainty about an answer to a question in SLRA Level 1);

b) Conduct SLRA Level 2 or DRA or,

c) Remediate the site.

In addition to these assumptions, numerical and qualitative guidelines are employed in the questionnaire. The values, intended application, and sources for a subset of the guidelines in the questionnaire are summarized in Appendix A-1.

2.1 GENERAL INSTRUCTIONS

The guidance is divided into the four applicable land use categories. Agricultural use is not eligible for SLRA Level 1 screening. Each land use may present specific characteristics that require a unique series of questions. Identify the land use applicable to the subject site and use the applicable questionnaire, which are given in text format in the Appendices 4-7, and in flow chart format in Appendix A-3. The text format questionnaires shall prevail in the event of conflict between them. Specific considerations for each land use are provided in the following subsections:

Section 2.3 – residential
Section 2.4 – urban park
Section 2.5 – commercial
Section 2.6 – industrial

The questionnaires for all but urban park are divided into three series of questions. They include: general questions, human exposure questions and ecological exposure questions. Begin by completing the general questions. Completion of the human and ecological questions will depend on answers to the general questions. Urban park has only two questionnaires because the ecological risks at urban parks are addressed by the general questions. Progression through the questionnaire is guided by the answers to the questions. The answers include, Yes, No or Uncertain. When there is uncertainty in an answer, the questionnaire is designed to be conservative. Although the specific options vary for each question, in general, the answer to each question will direct a user to either:

a. Complete General questionnaire and exit[1] if appropriate;
b. Complete the human and/or the ecological exposure questionnaires;
c. Exit[1] the process for either or both the human and ecological exposure questions;
d. Undertake a more detailed assessment of the site, which may include additional data collection and/or modeling in an SLRA Level 2, DRA; or,
e. Remediate the site.

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[1] The options available to the assessor when directed to 'Exit' the screening process include:
If no complete exposure pathways are present – no further assessment required;
If complete exposure pathways are present – complete a detailed risk assessment using DRA protocols or remediate the site;
If an assessor is unable to determine if complete exposure pathways are present – complete an SLRA Level 2, DRA depending on information required to evaluate exposure pathways, or remediate the site.

The guidance does not direct a user to a specific assessment type because requirements and issues requiring review will vary at each site. If after completing the general questions, further analysis or exiting the process has not been prescribed, then the assessment continues with the human and/or ecological exposure questionnaires. Both must be completed to complete SLRA Level 1 if the general questionnaire directs to them.

Upon completion of each question of the questionnaire, a brief narrative should be presented explaining the rationale for each response, as discussed in the introduction to the SRA tools. Appendix A-2 provides a case study example of the question-specific rationales and the SLRA Level 1 documentation.

A few other general instructions apply to SLRA Level 1:

a) The questions apply only to contaminants/contamination as defined in the CSR, i.e., substances that exceed applicable standards at the site. Only those regulated substances that exceed applicable standards for the receptors at the designated land use should be considered in the questionnaire.

b) Selection of the applicable land use category is completed by the assessor.

c) Agricultural land uses are not assessed in SLRA Level 1 because evaluation of ecological risks at agricultural sites is too complex to address in SLRA Level 1. Proceed to SLRA Level 2, DRA or site remediation for agricultural lands.

d) Current and reasonable potential future conditions and land uses as specified in the CSR, Section 12, Subsection 5 must be considered. If conditions change, then SLRA Level 1 should be re-applied to the new site conditions. Examples of changes that may occur include: the addition or removal of a building, excavation and soil mixing due to utility installation or maintenance, transition from one land use type to another such as agriculture to industrial, gradual weathering of a barrier.

e) Contamination deeper than one metre is assumed to remain below one metre. If construction or utility excavation work occurs, SLRA Level 1 should be revisited based on new site conditions.

f) Barriers over contamination sources or areas where contamination may migrate may prevent exposures. Where a barrier is identified, it must be permanent for current and reasonable potential future use and will be maintained as such. While it is unlikely that barriers would cover entire urban parklands, it is possible that barriers may cover contaminant source areas in this land use. As a result, a question about barriers is included for all land uses.

g) Any requirements related to the Hazardous Waste Regulation and High Risk Ranking are not addressed or met by SLRA Level 1.

h) Critical definitions and notations are provided in Section 2.2.

2.2 DEFINITIONS AND NOTATIONS

Definitions and Notations are provided roughly in the order they are used in the questionnaires.

IMPORTANT NOTE:

Definitions in SLRA Level 1 are provided for user convenience. Where definitions in this document and legislation are in conflict, the legislation shall prevail. This includes definitions of land use. Where this document is in conflict with definitions in other Ministry of Environment policies, protocols and guidelines, the more recent document shall be considered correct.

Property is legal property under current ownership or control

Site is defined in CSR, s11

Localized (Question G-1) in the context of beneficial uses means within a 0.3m radius

Eligible beneficial uses (Question G-1) are:

(a) zinc localized around galvanized materials (all types of land use),

(b) copper localized around copper pipe or bare wire (all types of land use), or

(c) the applicable wood preservative(s) localized around preserved wood (preserved wood includes all types of preservatives including but not limited to boron, chromium, copper, arsenic, chlorophenols, creosote).

The beneficial use clause is not applicable to sites greater than 0.1 ha[2]. For clarity, beneficial uses may be existing or historical.

Surface water (question G-2) streams, rivers, lakes, estuaries, ocean or other water bodies, as generally defined in Protocol 1.

Aquatic Habitat exists on the site (question G-2): includes any of the following that provides fish habitat:

(a) a watercourse, whether it usually contains water or not;

(b) a pond, lake, river, creek or brook;

(c) a ditch, spring, or wetland that is connected by surface flow to something referred to in paragraph (a) or (b)[3];

Mobile NAPL is suspected to be present (question G-2): Wells exceed triggers considered by MOE to be indicative of mobile NAPL, as defined by SLRA Level 2 Soil and Groundwater Modules and/pr the SAB Hydrologeological Assessment Tools.

Migrating to (question G-4): Potential for upward migration of salts needs to be considered.

SLRA Level 1 Vapour Intrusion Precluding conditions (question H-4) The 30 m horizontal distance criterion is precluded when any of the following four conditions apply or may apply:

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[2] The limit on the site area is intended to exclude sites with large areas of contaminated soil. For example, beneficial use does not apply for PAH-contaminated soils in rail yards originating from railway ties. The site area of 0.1 ha was selected to be consistent with the SLRA Level 1 Ecological Questionnaire.

[3] Riparian Areas Regulation, B.C. Order in Council 837, July 27, 2004, definition of stream.

a) **Significant pathways present:** Potentially significant pathways are present at those sites where:

  (i) subsurface utility conduits directly connect the contaminated area to the enclosed space of the building

  (ii) the media between the contaminants and the surface are characterized by gas permeabilities higher than those generally associated with unconsolidated materials; these materials include fractured bedrock, karst, or soils exhibiting vertical fissuring.

b) **Gas under pressure:** The distance criterion does not account for the movement of gas under pressure, which is often the case at landfills, where methane is produced and trace VOCs may move with the methane carrier gas.

c) **Low permeability cover:** When the ground surface between the contamination and building is covered with a continuous or near continuous low permeability barrier (concrete, pavement, liner, etc.), this barrier may prevent migration of vapours to the atmosphere and result in enhanced vapour migration toward the building.

d) **Expanding contamination zone:** The contaminant plume or source zone (e.g., NAPL) is expanding or migrating toward the buildings under consideration.

Bioaccumulative contaminants (Question E-2) are defined as bioaccumulation factor (BAF) ≥ 5,000 OR bioconcentration factor (BCF) ≥ 5,000 OR Log K_{ow} (octanol-water partition coefficient) ≥ 5.0; BAF, BCF and Log K_{ow} for subject contaminants must be obtained from peer reviewed literature)

Undeveloped land is defined as any bare or vegetated soil, excluding graveled walkways, roadways or parking, soil or vegetation in planters (landscaped soil confined by a container, or on top of a structure), and vegetation growing through a barrier (e.g., cracks in concrete)

Sensitive habitats (Question E-3) are:

a) national (http://www.pc.gc.ca/progs/np-pn/index_e.asp) or provincial parks, (http://wlapwww.gov.bc.ca/bcparks/) and any designated, published, sensitive habitats identified by the environmental authority of the local municipality.

b) wetlands as defined in the Riparian Areas Regulation pursuant to the Fish Protection Act

c) assessment areas as defined in the Riparian Areas Regulation pursuant to the Fish Protection Act, including streams and riparian areas. Users should refer to the Act and Regulations, but in summary, these are:

   (i) within 30m of the high water mark of surface water or

   (ii) within 10m upslope of the top of bank of a ravine (side slope greater than 3:1) wider than 60m containing surface water,

   (iii) within 30m of the top of bank of a ravine (side slope greater than 3:1) if less than 60m wide

High density urban area (Question E-4) is within a municipal boundary but excluding areas that are predominantly characterized by detached single family dwellings or zoned or used for urban park.

Wildlife corridors (Question E-6) are segments of undeveloped land connecting to additional undeveloped lands on- or off-site, and may consist of:

a) hydro rights-of-way, hedges, and vegetated road rights-of-way; or

b) closely spaced (<10m separation) small areas (1m^2 or more) of undeveloped land

2.3 LAND USE CONSIDERATIONS

2.3.1 Residential Land Use

The assessment of a site for residential land use is described below. The CSR s1 defines residential land use as:

> “use of land for the primary purpose of: (a) a residence by persons on a permanent, temporary or seasonal basis, including, without limitation, single family dwellings, cabins, apartments, condominiums or townhouses or (b) institutional facilities, including, without limitation, schools, hospitals, daycare operations, prisons, correctional centers and community centres” (CSR).

A number of considerations regarding residential land uses should be reviewed prior to completing the questionnaire, including:

1. The type of residential activity will impact the potential for exposure. For example, the presence of a school may result in different exposures than the presence of a single family home. Also, a high-rise condominium complex would result in exposures that differ from those of a single family home or a hospital. Understanding the human population inhabiting the residence (e.g. children may be more sensitive than adults, hospital populations may be more sensitive than healthy populations) as well as the type of structure (e.g., size and height may impact exposures) will facilitate completion of the questionnaire.
2. Consideration of zoning may also be important in this screening step. Understanding the limitations or exclusions can provide a better understanding of potential exposures. For example, characterization of a site with a single-family home that is zoned for a school might differ from characterization of a site that is only zoned for single-family homes.
3. In residential areas, the adjacent properties may also be residences. However, this is not always the case and it may be informative to review adjacent land uses and the exposure pathways that may be present in those areas.

Understanding the land use and unique characteristics of the land use will assist in completion of the questionnaire that follows.

2.3.2 Urban Park Land Use

The assessment of a site for urban parkland use is described below. The CSR s1 defines urban parkland use as:

> “the use of urban land for the primary purpose of outdoor recreation including, without limitation, municipal parks, fairgrounds, sports fields, rifle ranges, captive wildlife parks, biking and hiking areas, community beaches and picnic areas, but does not mean wildlands such as ecological reserves, national or provincial parks, protected wetlands or woodlands, native forests, tundra or alpine meadows” (CSR).

A number of considerations regarding urban parkland uses should be reviewed prior to completing the questionnaire, including:

1. Developing an understanding of the range of activities that may occur in an urban parkland will assist in identifying important exposure pathways. For example, some activities, such as walking, may not result in significant exposure, whereas picnicking may result in more direct contact with soil and other media.
2. Urban parklands, although characterized as a park, may contain little unmanaged habitat for wildlife. Some may also reside on tops of buildings, which makes the underlying soil quality irrelevant to terrestrial ecological risk.
3. Buildings on urban parklands may also be important exposure areas. For example, some parklands may include residential caretakers or concessions. Other parks may include indoor recreation facilities.

Understanding the land use and unique characteristics of the land use will assist in completion of the questionnaire that follows. Urban park land use is the one land use that does not have a specific ecological questionnaire. This is because the ecological discriminators that apply to the other land uses cannot be applied to parks.

2.3.3 Commercial Land Use

The assessment of a site for commercial land use is described below. The CSR s1 defines commercial land use as:

> “the use of land for the primary purpose of buying, selling or trading of merchandise or services including, without limitation, shopping malls, office complexes, restaurants, hotels, motels, grocery stores, automobile service stations, petroleum distribution operations, dry cleaning

> operations, municipal yards, warehouses, law courts, museums, churches, golf courses, government offices, air and sea terminals, bus and railway stations, and storage associated with these uses" (CSR).

A number of considerations regarding commercial land uses should be reviewed prior to completing the questionnaire, including:

1. A range of activities, each with a unique set of exposures, may occur on commercial properties. When reviewing the activities it is important to identify potential exposures including exposure media, e.g. are humans drinking water in the facilities, spending time indoors, exposure times, i.e., consider the difference between exposures at a hotel or office building, compared to exposures in a bus station or mall.
2. Commercial properties might be expected to be landscaped, however it is possible that habitat may exist on the site boundaries or on other parts of the site. Impacts on commercial properties may be expected to occur near the activity, but may not extend to the entire site. Also, the range of commercial activities is broad. A golf course may be more likely to contain habitat at the boundaries than a large shopping mall that largely consists of paved parking areas and facility buildings.
3. Barriers to exposure, such as paved parking areas, side walks, cement pads etc. should be identified and considered when completing the screening questionnaire.

Understanding the land use and unique characteristics of the land use will assist in completion of the questionnaire that follows.

2.3.4 Industrial Land Use

The assessment of a site for industrial land use is described below. The CSR s1 defines industrial land use as:

> "the use of land for the primary purpose of conducting industrial manufacturing and assembling processes and their ancillary uses including, without limitation, factories, metal foundries, wood treatment facilities, mines, refineries, hydroelectric dams, metal smelters, automotive assembly

> plants, rail car or locomotive maintenance facilities, rail yards, non-retail breweries and bakeries, roads and highways, wastewater and sewage treatment plants, electrical transformer stations and salvage yards" (CSR).

A number of considerations regarding industrial land uses should be reviewed prior to completing the questionnaire, including:

1. Activities at an industrial site may impact exposures. Developing an understanding of the activity and how the activity impacts media on the site is important in understanding potential migration of contaminants and exposure activities.
2. Industrial activities often involve a complex group of workers. The tasks may be highly variable in terms of potential for exposures. For example, mine workers may spend a workday underground, while factory workers activities may be focused inside a building, or include movement of supplies in a supply yard.

Understanding the land use and unique characteristics of the land use will assist in completion of the questionnaire that follows.

3 REFERENCES

BCMWLAP. 1998. Recommended Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia. Protocol 1. January 1998. Ministry of Environment, Lands and Parks, Environment and Resource Management Department, Pollution Prevention and Remediation Branch, Victoria, British Columbia. http://wlapwww.gov.bc.ca/epd/epdpa/contam_sites/policy_procedure_protocol/protocols/tier_1/index.html

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BCMWLAP.1997. Bill 25 – Fish Protection Act.

Canadian Environmental Protection Act, 1999. Regulation for Persistence and Bioaccumulation, Sections 73-77.

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US EPA. 1996. Laboratory Method 8260B. Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry. http://www.epa.gov/epaoswer/hazwaste/test/pdfs/8260b.pdf

APPENDIX A-1

INFORMATION ON RATIONALE FOR

SLRA Level 1

Table 1. Summary of Numerical and Qualitative Guidelines Applied in Questionnaire

Numeric or Qualitative Guideline	Intended Application	Source
Beneficial Uses: galvanized materials, copper pipe and wire, and treated wood	These uses are implicitly accepted as beneficial. The beneficial use exclusion is explicitly defined based on land use. Generally, it applies to soils containing zinc within 0.3 meters of galvanized materials, OR copper within 0.3m of copper pipe or bare wire, OR soils within 0.3 meters of treated wood products only. Groundwater impacts from beneficial use cannot be addressed by SLRA1.	The uses are implicitly accepted as beneficial since they continue to be permitted. The circumference of impact that is always present when they are used is based on typical observations of the halo of effects in studies by Environment Canada and others. Historical beneficial uses are also encompassed because excluding them would not be logically consistent, and pragmatically because excluding them would create a reverse onus: when a beneficial use ceased, soil remediation would implicitly be necessary.
Contamination migrates onto or off property		MOE policy
Mobile NAPL presence	The effects and considerations related to mobile NAPL are sufficiently complex that they cannot be realistically addressed with a tool such as SLRA1	Professional judgement, MOE policy
Bioaccumulative contaminants defined as contaminants with a BAF≥5,000, BCF≥5,000 OR a LogK_{ow}≥5.0. The BAF, BCF or LogK_{ow} for each chemical must be obtained from a peer reviewed source. (K_{ow} is octanol water partition coefficient)	Bioaccumulative contaminants pose a unique risk because species/humans who may not be directly exposed to the waste, can be exposed through consumption of biota that bioaccumulate contaminants	Canadian Environmental Protection Act, 1999 – Regulation for Persistence and Bioaccumulation, Sections 73-77.
Are humans (e.g., trespassers, recreational users, workers, residents) participating in outdoor activities on the site where generic soil or applicable human health protection "intake of contaminated soil" matrix standards are exceeded or within 10m of it?	10m buffer is to address limitations of site investigation in precisely defining the edge of a site	Spacing between samples typically achieved in a DSI in Areas of Environmental Concern.
Is contamination located in the upper 1m of soil?	This depth is considered accessible surface soil.	Professional Judgment. There is wide agreement that the vast majority of biological activity (soil invertebrates and other fauna, and plants) occurs in this zone, and that if this zone is protected, the majority of ecological exposures are also protected. As well, most utilities and "casual" excavations are shallower than 1m. A 3ft depth is used in a number of US jurisdictions.
30m horizontal setback from buildings for VOC contamination	Low risk of buildings being affected	Extensive empirical observation and modelling.

APPENDIX A-2

CASE STUDY

1. INTRODUCTION

This report presents the findings of a Screening Level Risk Assessment, Level 1 prepared by ABC Environmental at the request of ABC Canned Foods. The subject site is referenced as 123 Big Harbour Road, in the city of Big Harbour, British Columbia (the “Site”). Location and Site plans are included as Figures 1 and 2, respectively.

1.1 STUDY OBJECTIVE

The purpose of the SLRA Level 1 was to provide an evaluation of the potential for adverse effects to human and ecological receptors by assessing the presence/absence of potential exposure pathways from the contaminant source to receptors through the development of a conceptual model. The assessment was then used to determine the need, if any, for further remediation.

1.2 SCOPE OF WORK

The SLRA Level 1 was carried out in accordance with methods described by British Columbia Ministry of Water, Lands, and Parks (BCWLAP) SLRA Level 1 Guidance (2004).

2. BACKGROUND

2.1 GENERAL SITE DESCRIPTION

Existing

The Property is located along the Big Harbour Road on the north side of Four Street. The Property has a total area of approximately 1 hectare. Portions of the Site are covered, grass and trees (0.2 hectare), asphalt (0.5 hectare), and buildings (0.3 hectare) (Figure 1 and Figure 2).

The Property is bordered to the west by Smith Canned Foods and Harvey's, to the east by a parking lot, and to the south by a Jims Furniture Warehouse. It is located in what would be considered a commercial light industrial area of Big Harbour.

The Site is currently used as a warehouse for canned food, prior to delivery to retail food stores. Although trucks are continually coming to and going from the property no maintenance work on the trucks is conducted at the Site, and no trucks are stored at the Site.

A review of Environment Canada climate information for the Big Harbour area revealed the following (EC 1993):

Average daily maximum temperature:	13.9 ^{o}C
Average daily minimum temperature:	5.1 ^{o}C
Average daily mean temperature:	9.5 ^{o}C
Average yearly rainfall:	812.8 mm
Average yearly snowfall:	46.9 cm
Average daily wind speed:	10 km/hr (2.78 m/s)
Most frequent wind direction:	West
Avg. number of days/year with measurable rainfall:	148 days
Avg. number of days/year with measurable snowfall:	11 days
Avg. number of hours of sunshine per year:	2081.9 hours

Future

The owners of the property intend to maintain the current site use into the foreseeable future.

2.2 SUMMARY OF ENVIRONMENTAL SITE INVESTIGATIONS

ABC Environmental was provided with the results of three previous investigations for the Property.

Stage 1 PSI

The Stage 1 PSI for the Site indicated that sandblasting grit and/or foundry sand comprised part of the material that was used to fill the Site in the 1950s. A warehouse was then built, and since the 1950's the site has been used to warehouse various consumer products. Other than the presence of grit and/or foundry sand, no other potential sources of contaminants were indicated for the site. Metals were identified as the potential contaminants of concern. No other environmental issues were identified.

There is one groundwater well within 1.5 km of the Site and the nearest aquatic body to the Site is 2.5 km away.

Stage II PSI Report ABC Environmental 2003

Two boreholes indicated the presence of elevated levels of lead and zinc at the Site that appeared to be associated with sand blast grit. A sample at 2 m was identified as having zinc and lead at concentrations in excess of the applicable regulatory standards for commercial sites.

DSI Report ABC Environmental 2003

Seven boreholes were advanced into the vadose zone as part of the DSI investigation for a total of nine boreholes. Three monitoring wells were also installed as part of the DSI investigation. Lead and zinc were found to be present in soil beneath the asphalt and building (Figure 2) from approximately 1 m to 3 m below ground surface. No chemicals in excess of BC CSR Groundwater Standards were detected in the groundwater. SWEP and TCLP indicate that contamination in soil samples is not leachable.

Contaminants of Concern and List of the Chemicals Exceeding the Standards.

The chemicals listed in the following table exceeded the criteria. The table presents the concentration range the applicable criteria exceeded.

Chemical	Measured Concentration (range)	Media	Standard/Criteria Exceeded	Standard/Criteria Value
Lead	<5 – 2004	Soil	Commercial	Aquatic Life
Zinc	23- 730	Soil	Commercial	Aquatic Life

Chemical Fate and Transport

Although lead and zinc are potentially mobile, contaminant concentrations in groundwater are well below the CSR groundwater standards.

2.3 RECEPTOR IDENTIFICATION

The description of the site surrounding area was used to determine the potential receptors that may be exposed to COPCs at the site

Human receptors

The potential human receptors include:

- Warehouse worker
- Trucker
- Utility Worker

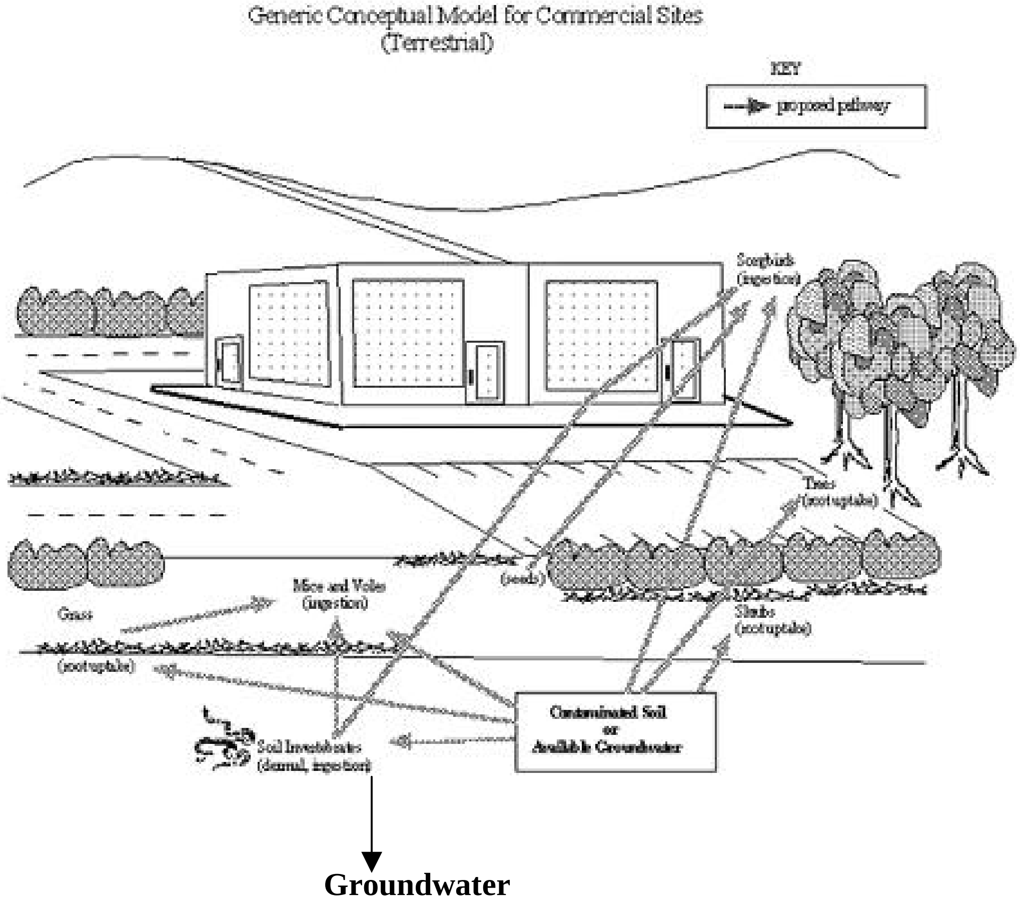
Ecological Receptors

The potential ecological receptors include:

- Small mammals
- Birds
- Plants

2.4 PRELIMINARY CONCEPTUAL MODEL/S

This figure is a preliminary conceptual model for the site.



3. RESPONSE TO SLRA LEVEL 1 QUESTIONS (FOR COMMERCIAL LAND USE)

3.1 GENERAL QUESTIONS

G-1 Is an "eligible beneficial use" the sole source of contamination and is that contamination "localized" around the beneficial use only?

If ***NO*** or ***UNCERTAIN***, then proceed to Question G-2, discounting localized contamination from eligible beneficial uses, if any, in all future questions.

If ***YES***, then requirements for SLRA Level 1 have been met.

Answer: NO, the contamination is not associated with galvanized material or treated wood (see figure 1).

G-2 Are any of the following true:

a) "Surface water" is contaminated
b) Aquatic habitat exists on the site
c) Groundwater is contaminated
d) Mobile NAPL is suspected to be present
e) Contamination has migrated off or onto the property

If ***NO***, then proceed to Question G-3.
If ***YES*** or ***UNCERTAIN,*** proceed to as applicable to SLRA Level 2, DRA or remediate the site.

Answer: ***NO***, there is no surface water on or adjacent to the site (See Figure 1). No contamination of groundwater has been found. No NAPLs are present, and contamination is confined to property soil as shown in Figure 1**.**

G-3 Do soils exceed a generic standard, or applicable matrix water protection standard?

If ***YES*** proceed to SLRA2 (soil/groundwater module), DRA or remediate the site.

If ***NO***, proceed to question G-4.

Answer: ***YES***, there are metals at concentrations in excess of matrix water protection standards for fish.

G-4 Is contamination located in or migrating to the upper 1m of soil?

If ***NO***, then proceed to Question H-2; NPR for ecological risk.

If ***UNCERTAIN*** proceed to SLRA Level 2, DRA or remediate the site.

If ***YES***, proceed to Question G-5.

Answer: ***YES.*** The contamination was found at 1 meter depth.

G-5 Is there a barrier preventing wildlife or human contact with contaminated soil?

If ***NO*** or ***UNCERTAIN***, complete both the human and ecological exposure questionnaires.

If ***YES***, then proceed to the human exposure questionnaire (starting at **Question H-2**). NPR for ecological risk.

Answer: ***YES.*** No bare soil and vegetation is present at the site. The area of contamination is under a building and pavement. The ecological risk is acceptable.

3.2 HUMAN EXPOSURE QUESTIONS

H-1

Are humans (e.g., trespassers, recreational users, workers, residents) participating in outdoor activities on or within 10 m of where generic soil or applicable human health protection "intake of contaminated soil" matrix standards are exceeded?

IF **NO**, then proceed to Question H-2

IF **YES** or **UNCERTAIN**, proceed to SLRA Level 2, DRA1, DRA2 or decide to remediate the site

Answer**: YES**, the Site is used as a warehouse to stored canned food goods and workers are present inside and as needed outside the warehouse building (see Section 2 and Figure 1).

H-2

Are humans living, or working in buildings located on the property or on adjacent properties?

If **NO**, then human health risk is acceptable, exit the Human Exposure Questionnaire.

If **YES** or **UNCERTAIN**, then proceed to Question H-3

Answer: **YES**, workers are working at the building located at the property (see Section 2 and Figure 1).

H-3 Are volatile contaminants present in subsurface media? (Volatile contaminants are defined in Vapour Intrusion Module SLRA Level 2)

If **NO**, then human health risk is acceptable, and exit the Human Exposure questionnaire.

If **YES** then proceed to Question H-4.

Answer: NO, volatile contaminants are not present in media (see Section 2 and 3 and Table 2 and Table 4). Exit human exposure questionnaire.

H-4 Are either of the following true:

a) Current or potential future buildings within 30m horizontally of detectable volatile toxic contaminants in soil or groundwater.
b) “Precluding conditions” apply?

If ***NO***, then human health risk is acceptable, exit the Human Exposure questionnaire

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to SLRA Level 2 (VI module), DRA or decide to remediate the site

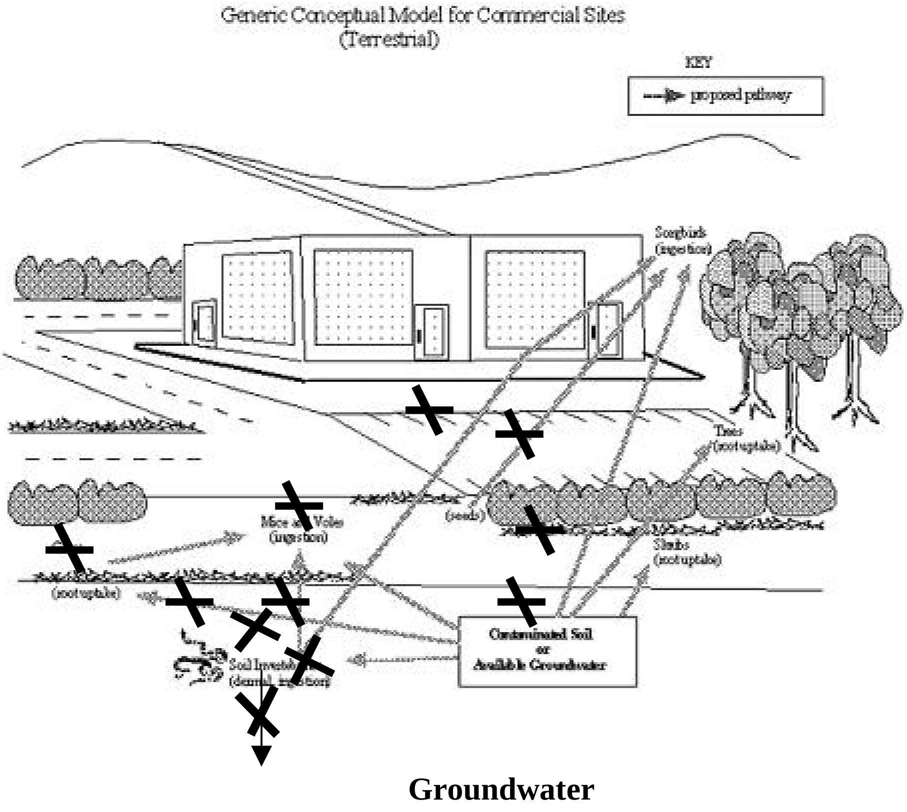
Answer: This question is not applicable to this site.

3.3 ECOLOGICAL EXPOSURE QUESTIONS

The “general questions” i.e., G-6, have excluded the need for any further ecological assessment.

4 FINAL CONCEPTUAL MODEL

The final SLRA Level 1 site conceptual model (SCM) has no operative pathways.



5 CONCLUSION

No complete exposure pathways were determined to be present at the Site. As a result of no complete exposure pathways being present at the Site as assessed in this SLRA Level 1, no further investigation and remediation is warranted at this Site.

6 PROFESSIONAL STATEMENT

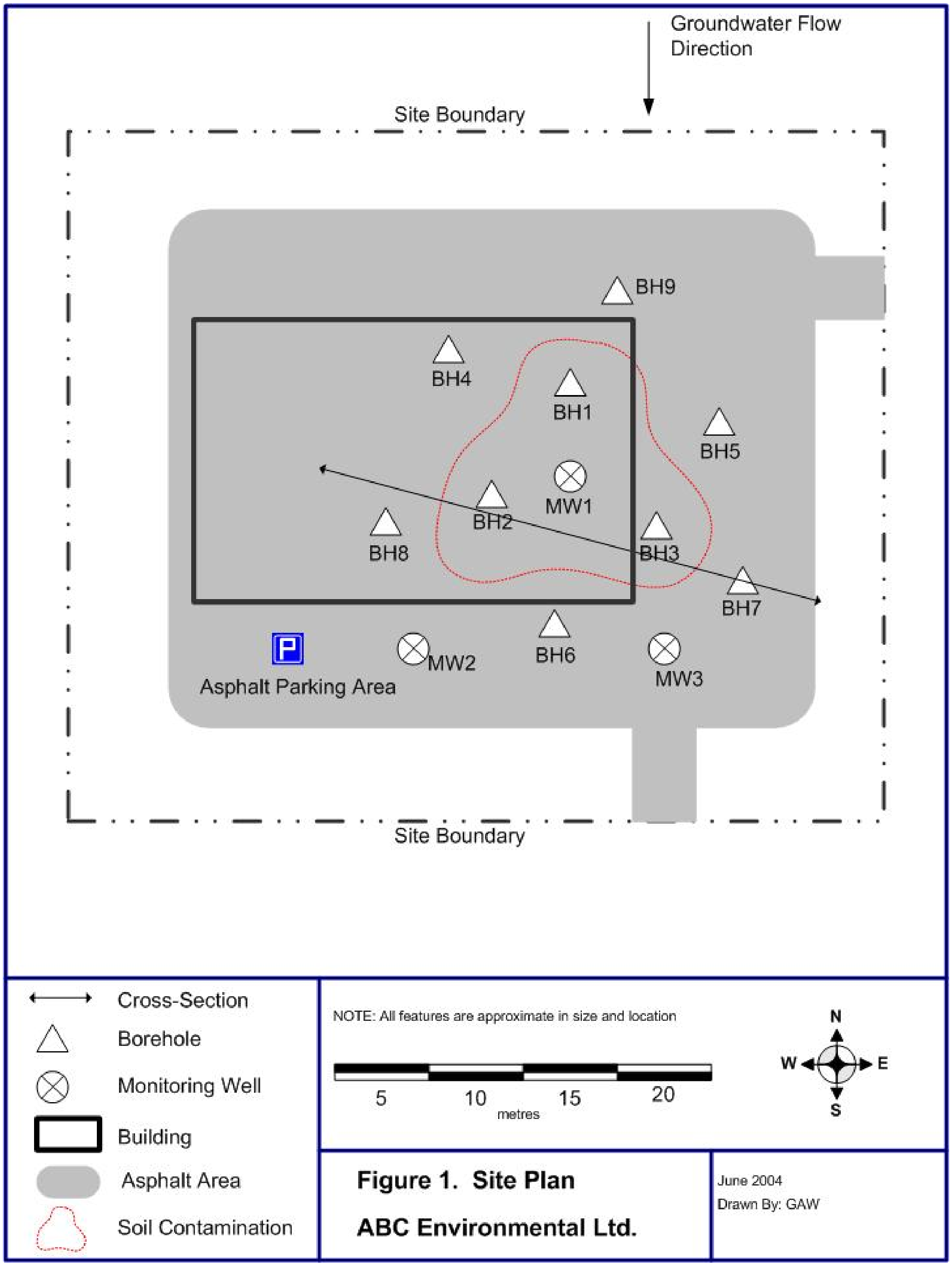


Figure 1. Site Plan

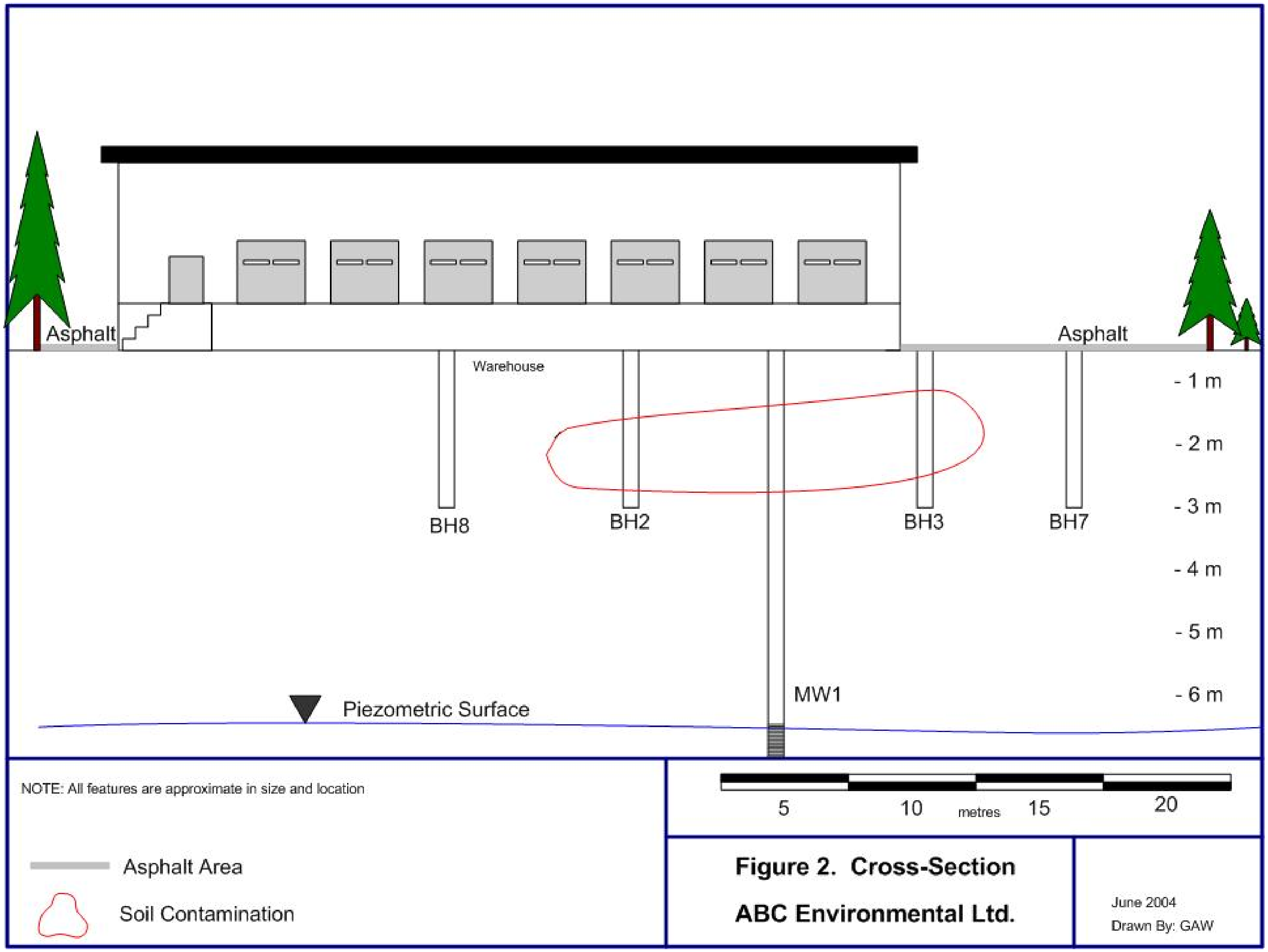


Figure 2. Cross-Section

ABC Environmental Ltd.

APPENDIX A-3

FLOW CHART FOR IMPLEMENTATION OF SLRA Level 1

Figure 1. Flow Chart for Implementation of SLRA Level 1

GENERAL QUESTIONS

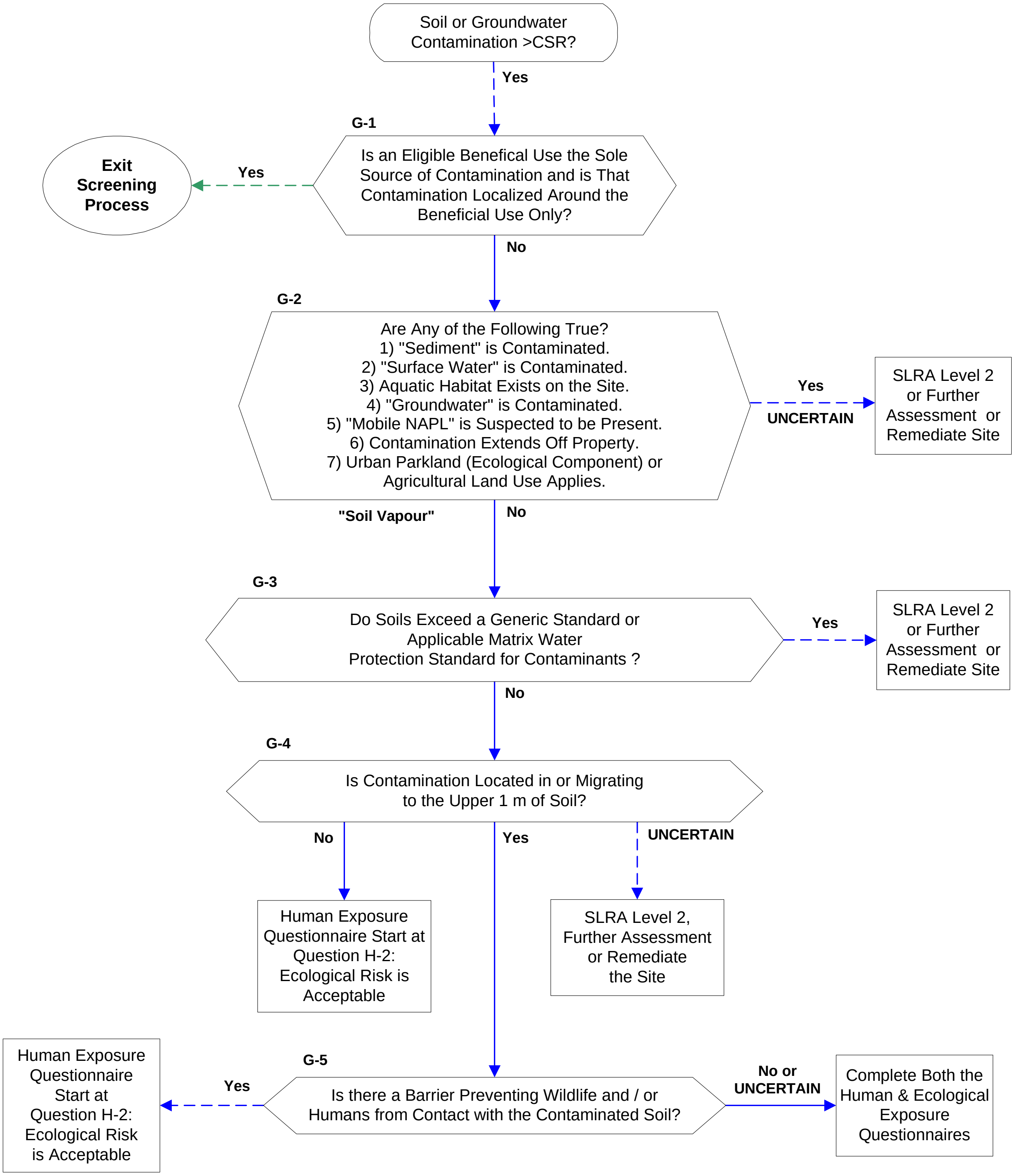


Figure 2. Flow Chart for Implementation of SLRA Level 1

HUMAN EXPOSURE QUESTIONNAIRE

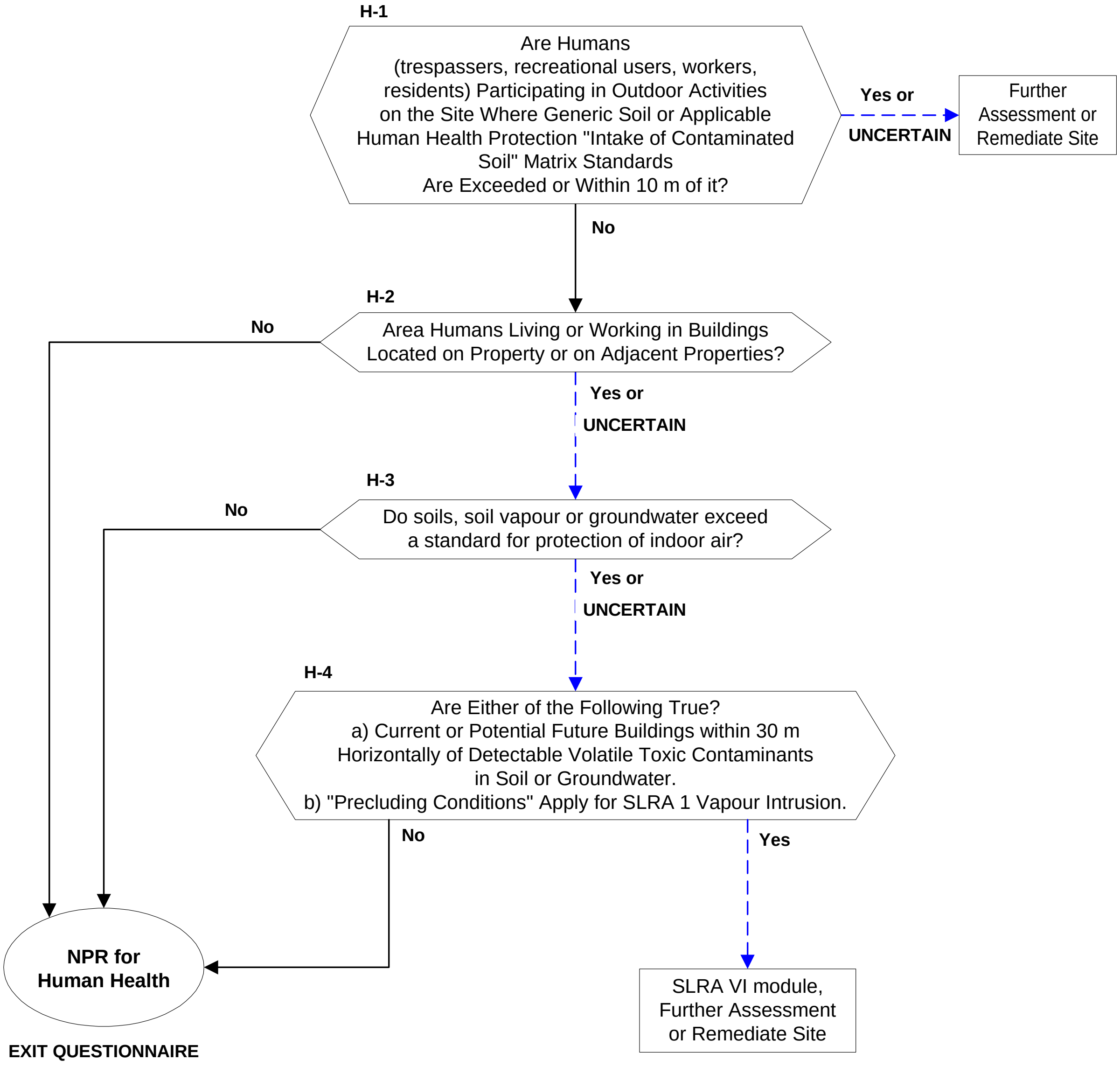
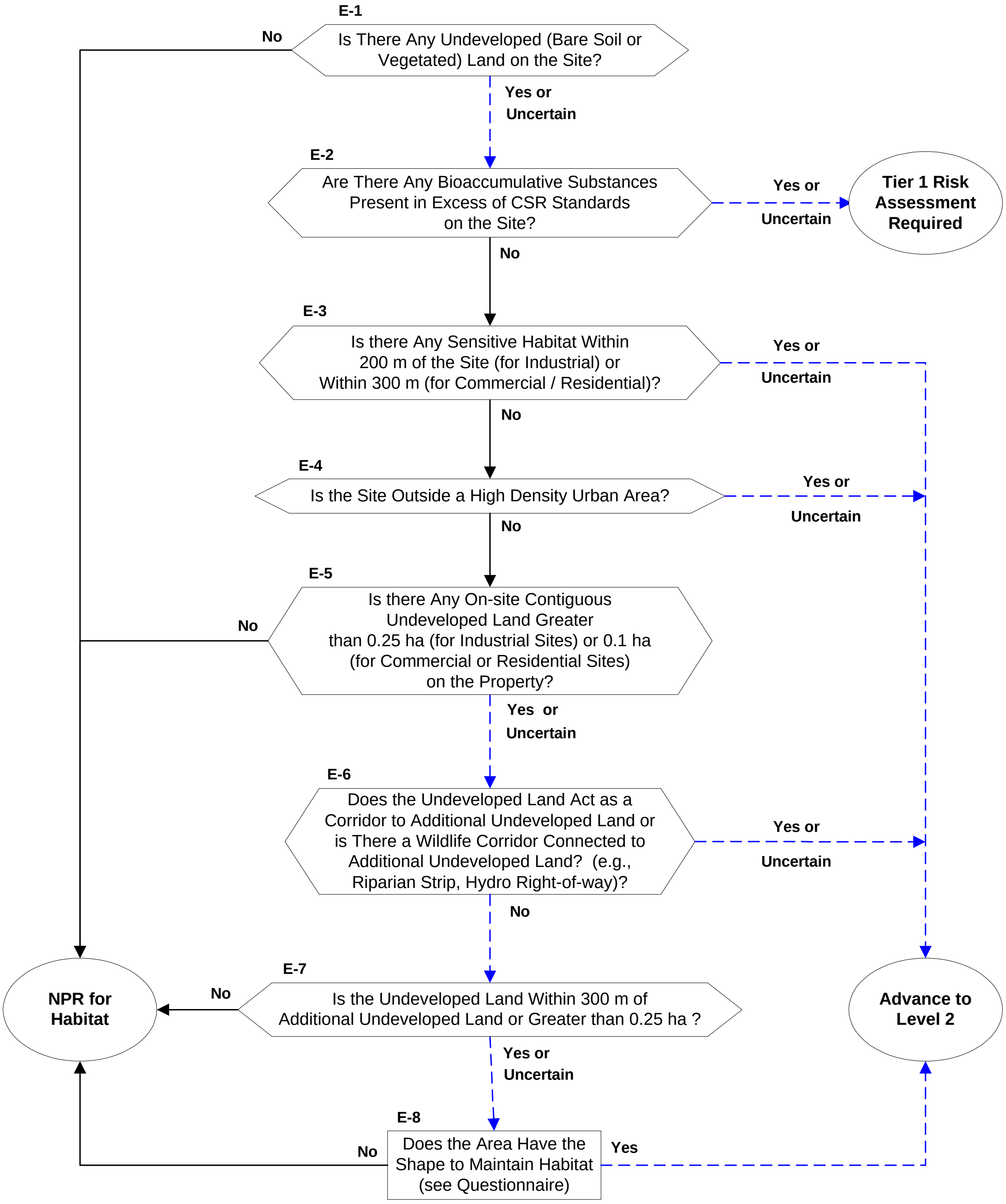


Figure 3. Flow Chart for Implementation of SLRA Level 1

ECOLOGICAL EXPOSURE QUESTIONNAIRE



APPENDIX A-4

RESIDENTIAL QUESTIONNAIRE

GENERAL QUESTIONS – RESIDENTIAL LAND USE

G-1 Is an "eligible beneficial use" the sole source of contamination and is that contamination "localized" around the beneficial use only?

If ***NO*** or ***UNCERTAIN***, then proceed to Question G-2, discounting localized contamination from eligible beneficial uses, if any, in all future questions.

If ***YES***, then requirements for SLRA Level 1 have been met.

G-2 Are any of the following true:

a) "Surface water" is contaminated
b) Aquatic habitat exists on the site
c) Groundwater is contaminated
d) Mobile NAPL is suspected to be present
e) Contamination has migrated off or onto the property

If ***NO***, then proceed to Question G-3.
If ***YES*** or ***UNCERTAIN,*** proceed to as applicable to SLRA Level 2, DRA or remediate the site.

G-3 Do soils exceed a generic standard, or applicable matrix water protection standard?

If ***YES*** proceed to SLRA2 (soil/groundwater module), DRA or remediate the site.

If ***NO***, proceed to question G-4.

G-4 Is contamination located in or migrating to the upper 1m of soil?

If ***NO***, then proceed to Question H-2; NPR for ecological risk.

If ***UNCERTAIN*** proceed to SLRA Level 2, DRA or remediate the site.

If ***YES***, proceed to Question G-5.

G-5 Is there a barrier preventing wildlife or human contact with contaminated soil?

If ***NO*** or ***UNCERTAIN***, complete both the human and ecological exposure questionnaires.

If ***YES***, then proceed to the human exposure questionnaire (starting at **Question H-2**). NPR for ecological risk.

HUMAN EXPOSURE QUESTIONS – RESIDENTIAL LAND USE

Consider only parameters that exceed generic or human exposure matrix standards.

H-1 Are humans (e.g., trespassers, recreational users, workers, residents) participating in outdoor activities on or within 10m of where generic soil or applicable human health protection "intake of contaminated soil" matrix standards are exceeded?

If ***NO***, then proceed to Question H-2.

If ***YES*** or ***UNCERTAIN*** proceed to DRA or decide to remediate the site.

H-2 Are humans living, or working in buildings on the property or on adjacent properties?

If ***NO***, then NPR for human health, exit the human exposure questionnaire.

If ***YES*** or ***UNCERTAIN***, then proceed to question H-3.

H-3 Do soils, soil vapour or groundwater exceed a standard for protection of indoor air?

If ***NO***, then NPR for human health, exit the Human Exposure questionnaire.

If ***YES or uncertain,*** then proceed to Question H-4.

H-4 Are either of the following true:

a) Current or potential future buildings within 30m horizontally of detectable volatile toxic contaminants in soil or groundwater.
b) SLRA Level 1 Vapour Intrusion precluding conditions apply?

If ***NO***, then NPR for human health, exit the Human Exposure questionnaire.

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to SLRA Level 2 (VI module), DRA or decide to remediate the site.

ECOLOGICAL EXPOSURE QUESTIONS – RESIDENTIAL LAND USE

Consider only parameters that exceed generic or non-human exposure matrix standards

E-1 Is there contaminated "undeveloped land" on the site?

If ***NO***, NPR for ecological risk, exit ecological exposure questionnaire

If ***YES*** or ***UNCERTAIN***, then proceed to Question E-2

E-2 Are there any "bioaccumulative substances" present in excess of applicable ecological protection CSR standards in the undeveloped land on the site?

If ***NO***, then proceed to Question E-3

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to DRA[4] or decide to remediate the site

E-3 Is the site within 300m of "sensitive habitat"?

If ***NO,*** proceed to Question E-5

If ***YES*** proceed to Question E-4

E-4 Is the site outside a "high density urban area"?

If ***NO,*** proceed to Question E-5

If ***YES*** or ***UNCERTAIN***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate the site

E-5 Is more than 0.1ha of contiguous area on the property undeveloped land?

If ***NO,*** NPR for ecological risk, exit ecological exposure questionnaire

If ***YES*** or ***UNCERTAIN***, proceed to Question E-6

E-6 Can this undeveloped land onsite act as a "wildlife corridor" to additional undeveloped lands on- or offsite; or, is there a "wildlife corridor" that connects the undeveloped land onsite to additional undeveloped lands on-site or off-site?

IF ***NO,*** proceed to Question E-7

IF ***YES*** or ***UNCERTAIN***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate the site

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[4] The DRA would initiate with the use of the Tier 1 Ecological Risk Assessment Protocols and Checklist.

E-7 Is this undeveloped land within 300m of additional contiguous undeveloped land or larger than 0.25 ha?

IF ***NO,*** NPR for ecological risk, exit ecological exposure questionnaire

IF ***YES*** or ***UNCERTAIN***, proceed to Question E-8.

E-8 Does the area have the shape to maintain habitat, i.e.,

a) Is the on-site contiguous undeveloped land more than 0.1 ha made up of managed lawn that is greater than 10 m width?

b) Is the on-site contiguous undeveloped land more than 0.1 ha made up of managed vegetated landscapes greater than 10 m in average width?, or

c) Is the on site contiguous undeveloped land more than 0.1 ha made up of non-managed vegetation greater than 3 m in average width?

If ***NO***, exit ecological exposure questionnaire.

If ***YES***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate site.

APPENDIX A-5

URBAN PARK QUESTIONNAIRE

GENERAL QUESTIONS – URBAN PARK LAND USE

G-1 Is an "eligible beneficial use" the sole source of contamination and is that contamination "localized" around the beneficial use only?

If ***NO*** or ***UNCERTAIN***, then proceed to Question G-2, discounting localized contamination from eligible beneficial uses, if any, in all future questions.

If ***YES***, then requirements for SLRA Level 1 have been met.

G-2 Are any of the following true:

a) "Surface water" is contaminated
b) Aquatic habitat exists on the site
c) Groundwater is contaminated
d) Mobile NAPL is suspected to be present
e) Contamination has migrated onto or off the property

If ***NO***, then proceed to Question G-3.

If ***YES*** or ***UNCERTAIN,*** proceed to as applicable to SLRA Level 2, DRA or remediate the site.

G-3 Do soils exceed a generic standard, or applicable matrix water protection standard?

If ***YES*** proceed to SLRA Level 2 (soil/groundwater module), DRA or remediate the site.

If ***NO***, proceed to question G-4.

G-4 Is contamination located in or migrating to the upper 1m of soil?

If ***NO***, then proceed to Question H-2; NPR for ecological risk.

If ***UNCERTAIN*** proceed to SLRA2, DRA or remediate the site.

If ***YES***, proceed to Question G-5.

G-5 Is the site or the area where contamination could migrate to covered by a barrier including but not limited to: pavement/cement, buildings, that will prevent wildlife or human contact with the soil?

If ***NO*** or ***UNCERTAIN***,, proceed to SLRA Level 2, DRA or remediate the site.

If ***YES***, then proceed to the human exposure questionnaire. NPR for ecological risk.

HUMAN EXPOSURE QUESTIONS – URBAN PARK LAND USE

Consider only parameters that exceed generic or human exposure matrix standards

H-1 Are humans living, or working in buildings on the property or on adjacent properties?

If ***NO***, then NPR for human health, exit the Human Exposure Questionnaire.

IF ***YES*** or ***UNCERTAIN***, then proceed to Question H-2.

H-2 Are volatile toxic contaminants present in subsurface media? (volatile toxic contaminants are defined in Vapour Intrusion Module SLRA Level 2).

IF ***NO***, then NPR for human health, exit the Human Exposure questionnaire.

IF ***YES,*** then proceed to Question H-3.

H-3 Are either of the following true:

a) Current or potential future buildings within 30m horizontally of detectable volatile toxic contaminants in soil or groundwater.
b) “Precluding conditions” apply?

IF ***NO***, then NPR for human health, exit the Human Exposure questionnaire.

IF ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to SLRA2 (VI module), DRA or decide to remediate the site.

APPENDIX A-6

COMMERCIAL QUESTIONNAIRE

GENERAL QUESTIONS – COMMERCIAL LAND USE

G-1 Is an "eligible beneficial use" the sole source of contamination and is that contamination "localized" around the beneficial use only?

If ***NO*** or ***UNCERTAIN***, then proceed to Question G-2, discounting localized contamination from eligible beneficial uses, if any, in all future questions.

If ***YES***, then requirements for SLRA Level 1 have been met.

G-2 Are any of the following true:

a) "Surface water" is contaminated
b) Aquatic habitat exists on the site
c) Groundwater is contaminated
d) Mobile NAPL is suspected to be present
e) Contamination has migrated onto or off the property

If ***NO***, then proceed to Question G-3.

If ***YES*** or ***UNCERTAIN,*** proceed to as applicable to SLRA Level 2, DRA or remediate the site.

G-3 Do soils exceed a generic standard, or applicable matrix water protection standard?

If ***YES*** proceed to SLRA Level 2 (soil/groundwater module), DRA or remediate the site.

If ***NO***, proceed to question G-4.

G-4 Is contamination located in or migrating to the upper 1m of soil?

If ***NO***, then proceed to Question H-2; NPR for ecological risk.

If ***UNCERTAIN*** proceed to SLRA Level 2, DRA or remediate the site.

If ***YES***, proceed to Question G-5.

G-5 Is the site or the area where contamination could migrate to covered by a barrier including but not limited to: pavement/cement, buildings, that will prevent wildlife or human contact with the soil?

If ***NO*** or ***UNCERTAIN***, complete both the human and ecological exposure questionnaires.

If ***YES***, then proceed to the human exposure questionnaire (starting at **Question H-2**). NPR for ecological risk.

HUMAN EXPOSURE QUESTIONS – COMMERCIAL LAND USE

Consider only parameters that exceed generic or human exposure matrix standards

H-1 Are humans (e.g., trespassers, recreational users, workers, residents) participating in outdoor activities on or within 10m of where generic soil or applicable human health protection "intake of contaminated soil" matrix standards are exceeded?

If ***NO***, then proceed to Question H-2

If ***YES*** or ***UNCERTAIN*** proceed to SLRA Level 2, DRA or decide to remediate the site

H-2 Are humans living, or working in buildings on the property or on adjacent properties?

If ***NO***, then NPR for human health, exit the Human Exposure Questionnaire

If ***YES*** or ***UNCERTAIN***, then proceed to Question H-3

H-3 Are volatile toxic contaminants present in subsurface media? (volatile toxic contaminants are defined in Vapour Intrusion Module SLRA Level 2)

If **NO**, then NPR for human health, exit the Human Exposure questionnaire

If **YES,** then proceed to Question H-4

H-4 Are either of the following true:

c) Current or potential future buildings within 30m horizontally of detectable volatile toxic contaminants in soil or groundwater.
d) "Precluding conditions" apply?

If ***NO***, then NPR for human health, exit the Human Exposure questionnaire

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to SLRA2 (VI module), DRA or decide to remediate the site

ECOLOGICAL EXPOSURE QUESTIONS – COMMERCIAL LAND USE

Consider only parameters THAT *exceed generic or non-human exposure matrix standards*

E-1 Is there contaminated "undeveloped land" on the site?

If ***NO***, NPR for ecological risk, exit ecological exposure questionnaire.

If ***YES*** or ***UNCERTAIN***, then proceed to Question E-2.

E-2 Are there any "bioaccumulative substances" present in excess of applicable ecological protection CSR standards in the undeveloped land on the site?

If ***NO***, then proceed to Question E-3.

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to DRA or decide to remediate the site.

E-3 Is the site within 300m of "sensitive habitat"?

If ***NO,*** proceed to Question E-5.

If ***YES*** proceed to Question E-4.

E-4 Is the site outside a "high density urban area"?

If ***NO,*** proceed to Question E-5

If ***YES*** or ***UNCERTAIN***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate the site

E-5 Is more than 0.1ha of contiguous area on the property undeveloped land?

If ***NO,*** NPR for ecological risk, exit ecological exposure questionnaire.

If ***YES*** or ***UNCERTAIN***, proceed to Question E-6.

E-6 Can this undeveloped land onsite act as a "wildlife corridor" to additional undeveloped lands on- or offsite; or is there a "wildlife corridor" that connects the undeveloped land onsite to additional undeveloped lands on-site or off-site?

If ***NO,*** proceed to Question E-7.

If ***YES*** or ***UNCERTAIN***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate the site.

E-7 Is this undeveloped land within 300m of additional contiguous undeveloped land of larger than 0.25 ha?

IF ***NO,*** NPR for ecological risk, exit ecological exposure questionnaire

IF ***YES*** or ***UNCERTAIN***, proceed to Further Assessment or decide to remediate the site.

E-8 Does the area have the shape to maintain habitat, i.e.,

1. Is the on-site contiguous undeveloped land more than 0.1 ha made up of managed lawn that is greater than 10 m width?
2. Is the on-site contiguous undeveloped land more than 0.1 ha made up of managed vegetated landscapes greater than 10 m in average width?, or
3. Is the on site contiguous undeveloped land more than 0.1 ha made up of non-managed vegetation greater than 3 m in average width?

If ***NO***, exit ecological exposure questionnaire.

If ***YES***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate site.

APPENDIX A-7

INDUSTRIAL QUESTIONNAIRE

GENERAL QUESTIONS – INDUSTRIAL LAND USE

G-1 Is an "eligible beneficial use" the sole source of contamination and is that contamination "localized" around the beneficial use only?

If ***NO*** or ***UNCERTAIN***, then proceed to Question G-2, discounting localized contamination from eligible beneficial uses, if any, in all future questions

If ***YES***, then requirements for SLRA Level 1 have been met.

G-2 Are any of the following true:

a) "Surface water" is contaminated
b) Aquatic habitat exists on the site
c) Groundwater is contaminated
d) Mobile NAPL is suspected to be present
e) Contamination has migrated off or onto the property

If **NO**, then proceed to Question G-3.

If **YES** or **UNCERTAIN,** proceed as applicable to SLRA Level 2, DRA or remediate the site.

G-3 Do soils exceed a generic standard, or applicable matrix water protection standard?

If ***YES*** proceed to SLRA Level 2 (soil/groundwater module), DRA or remediate the site.

If ***NO***, proceed to question G-4.

G-4 Is contamination located in or migrating to the upper 1m of soil?

If ***NO***, then proceed to Question H-2; NPR for ecological risk.

If ***UNCERTAIN*** proceed to SLRA Level 2, DRA or remediate the site.

If ***YES***, proceed to Question G-5.

G-5 Is the site or the area where contamination could migrate to covered by a barrier including but not limited to: pavement/cement, buildings, that will prevent wildlife or human contact with the soil?

If ***NO*** or ***UNCERTAIN***, complete both the human and ecological exposure questionnaires.

If ***YES***, then proceed to the human exposure questionnaire (starting at **Question H-2**). NPR for ecological risk.

HUMAN EXPOSURE QUESTIONS – INDUSTRIAL LAND USE

Consider only parameters that exceed generic or human exposure matrix standards

H-1 Are humans (e.g., trespassers, recreational users, workers, residents) participating in outdoor activities on or within 10m of where generic soil or applicable human health protection "intake of contaminated soil" matrix standards are exceeded?

If ***NO***, then proceed to Question H-2

If ***YES*** or ***UNCERTAIN*** proceed to , DRA or decide to remediate the site

H-2 Are humans living, or working in buildings on the property or on adjacent properties?

If ***NO***, then NPR for human health, exit the Human Exposure Questionnaire

If ***YES*** or ***UNCERTAIN***, then proceed to Question H-3

H-3 Are volatile toxic contaminants present in subsurface media? (volatile toxic contaminants are defined in Vapour Intrusion Module SLRA Level 2)

If ***NO***, then NPR for human health, exit the Human Exposure questionnaire

If ***YES,*** then proceed to Question H-4

H-4 Are either of the following true:

a) Current or potential future buildings within 30m horizontally of detectable volatile toxic contaminants in soil or groundwater.
b) "Precluding conditions" apply?

If ***NO***, then NPR for human health, exit the Human Exposure questionnaire

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to SLRA Level 2 (VI module), DRA or decide to remediate the site

ECOLOGICAL EXPOSURE QUESTIONS – INDUSTRIAL LAND USE

Consider only parameters that exceed generic or non-human exposure matrix standards

E-1 Is there contaminated "undeveloped land" on the site?

If ***NO***, NPR for ecological, exit ecological exposure questionnaire.

If ***YES*** or ***UNCERTAIN***, then proceed to Question E-2.

E-2 Are there any "bioaccumulative substances" present in excess of applicable ecological protection CSR standards in the undeveloped land on the site?

If ***NO***, then proceed to Question E-3.

If ***YES*** or ***UNCERTAIN***, then SLRA Level 1 is not appropriate for the site, proceed to DRA or decide to remediate the site.

E-3 Is the site within 200m of "sensitive habitat"?

If ***NO,*** proceed to Question E-5.

If ***YES*** proceed to Question E-4.

E-4 Is the site outside a "high density urban area"?

If ***NO,*** proceed to Question E-5.

If ***YES*** or ***UNCERTAIN***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate the site.

E-5 Is more than 0.25ha of contiguous area on the property undeveloped land?

If ***NO,*** NPR for ecological risk, exit ecological exposure questionnaire.

If ***YES*** or ***UNCERTAIN***, proceed to Question E-6.

E-6 Can this undeveloped land onsite act as a "wildlife corridor" to additional undeveloped lands on- or offsite or is there a "wildlife corridor" that connects the undeveloped land onsite to additional undeveloped lands on-site or off-site?

If ***NO,*** proceed to Question E-7.

If ***YES*** or ***UNCERTAIN***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate the site.

E-7 Is this undeveloped land within 300m of additional contiguous undeveloped land of larger than 0.25 ha?

IF ***NO,*** NPR for ecological risk, exit ecological exposure questionnaire

IF ***YES*** or ***UNCERTAIN***, proceed to Further assessment or decide to remediate the site.

E-8 Does the area have the shape to maintain habitat, i.e.,?

1. Is the on-site contiguous undeveloped land more than 0.1 ha made up of managed lawn that is greater than 10 m width?
2. Is the on-site contiguous undeveloped land more than 0.1 ha made up of managed vegetated landscapes greater than 10 m in average width?, or
3. Is the on site contiguous undeveloped land more than 0.1 ha made up of non-managed vegetation greater than 3 m in average width?

If ***NO***, exit ecological exposure questionnaire.

If ***YES***, proceed to SLRA Level 2 (habitat module), DRA or decide to remediate site.

Screening-Level Risk Assessment Level 2
(SLRA Level 2)

Soil and Groundwater Modules

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List of Acronyms

AW	standards for protection of aquatic life
COPC	contaminant of potential concern
CSR	Contaminated Sites Regulations
DRA	detailed risk assessment
DW	standards for protection of drinking water
IW	standards for protection of groundwater used for irrigation
LW	standards for protection of groundwater used for livestock watering
MWLAP	British Columbia Ministry of Water Land and Air Protection
NAPL	nonaqueous phase liquid
SLRA Level 1	qualitative screening level risk assessment
SLRA Level 2	quantitative screening level risk assessment
USEPA	United States Environmental Protection Agency

List of Symbols

A	factor in dispersivity relationship
C_{gw}	groundwater concentration at the source
C_{gw}'	soil-predicted groundwater concentration at the source
C_L	predicted soil pore water concentration at the source
C_S	measured soil concentration at the source
$C(x_R)$	predicted concentration at the receiving environment
C_{sched_6}	regulatory standard
d	vadose zone-groundwater mixing zone depth
d_a	thickness of aquifer
$d_{\alpha v}$	mixing depth due to vertical dispersivity
d_{Iv}	mixing depth due to downward velocity of the infiltrating water
DF	dilution factor
f_{oc}	fraction of organic carbon
G	exponent in dispersivity relationship
H_{cc}	dimensionless Henry’s Law constant

I	region-specific annual infiltration rate
K_d	soil matrix-to-soil water distribution coefficient
K_{oc}	soil organic carbon-water partition coefficient
L	length of the source parallel to the direction of groundwater flow
n	total porosity
pH	soil pH
R	retardation factor
S_I	dimensionless factor denoting degree of contamination
S_{II}	dimensionless factor denoting attenuation capacity
V	Darcy flux (hydraulic conductivity times gradient)
v	linear groundwater velocity (Darcy flux divided by porosity)
x_R	distance to the receiving environment
α_L	longitudinal dispersivity
λ	first-order decay constant
θ_w	water-filled porosity
θ_a	air-filled porosity
ρ_b	bulk density

1 OVERVIEW

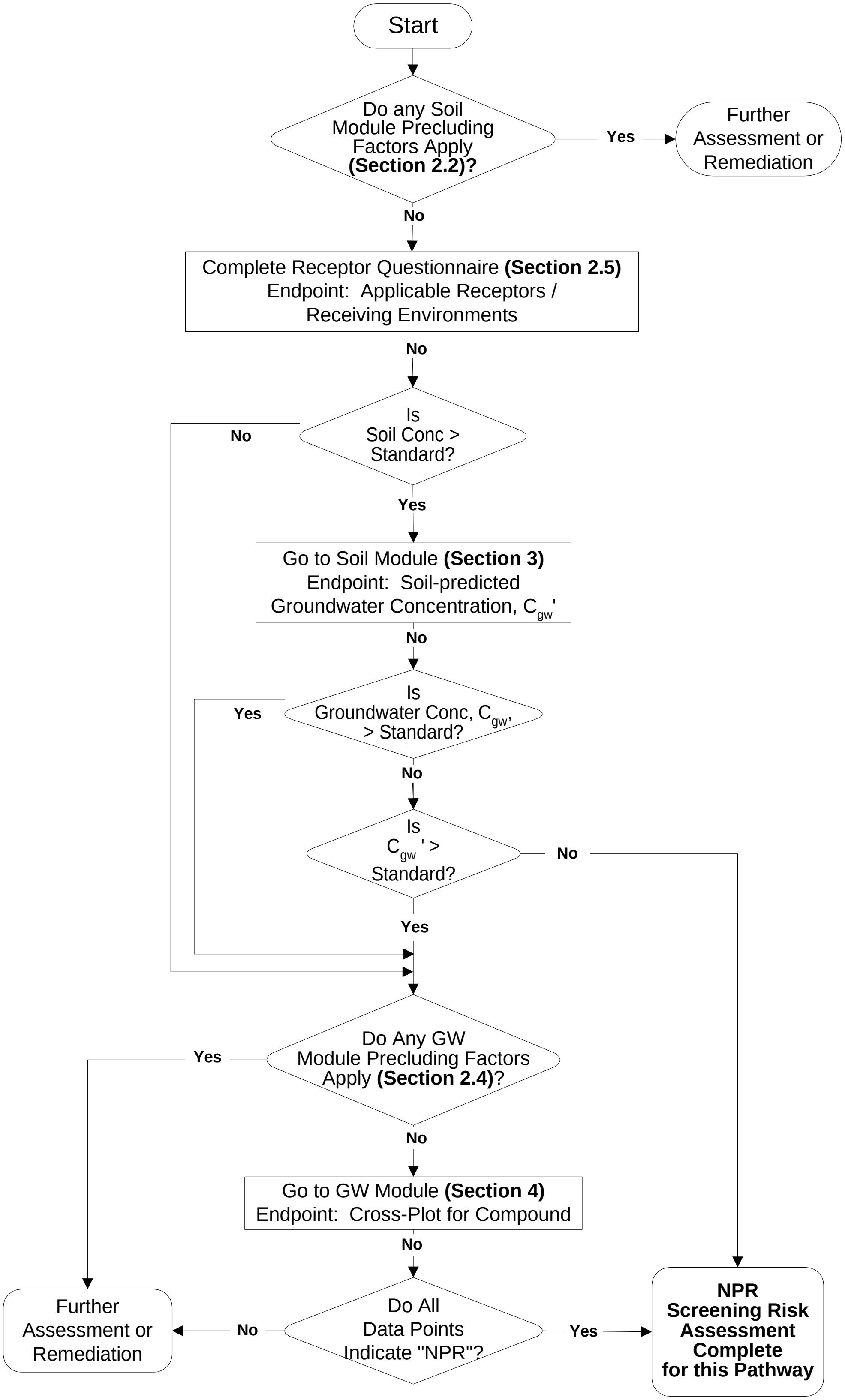
A proposed quantitative screening level risk assessment (SLRA Level 2) protocol for contaminants in soil and groundwater is described in this document. It is assumed that the site under investigation contains soil and/or groundwater concentrations of at least one compound in excess of applicable standards. There are two Modules within this document. The *Soil Module* is designed to evaluate the potential for contaminant migration from soil to groundwater, and the *Groundwater Module* is designed to evaluate the potential for contaminant migration in groundwater to a downgradient receiving environment. A general schematic representation of these two Modules is shown in Figure 1.

SLRA Level 2 is designed to evaluate the soil-to-groundwater and groundwater transport pathways for the purposes of screening sites with no pathway to the receiving environment (NPR). For purposes of this module of SLRA Level 2, NPR is defined to mean that either (1) contaminants in soil are not expected to result in groundwater concentrations in excess of applicable standards, or (2) concentrations of contaminants in groundwater *at the receiving environment* are not expected to exceed applicable standards. Other risk pathways, such as direct ingestion of soil or vapour intrusion into buildings (addressed in the Vapour Intrusion Module), are not evaluated in this document.

Fundamental to SLRA Level 2 is the objective of screening sites out of the regulatory process with no pathway to the receptor or receiving environment while ensuring that no sites with a pathway to the receptor are inadvertently screened. Therefore, the inherent conservatism of the SLRA Level 2 Soil and Groundwater Modules is intentional.

Four sections follow this overview. Section 2 provides a) background information for the development of this document, b) the precluding factors for use of SLRA Level 2, and c) a questionnaire to determine the applicable receptors related to the protection of groundwater. Section 3 of this document describes the soil screening portion of SLRA Level 2 while Section 4 describes groundwater transport. Finally, Section 5 includes techniques for calculating site-specific soil and groundwater cleanup levels.

Figure 1. Summary Soil-Groundwater Module Flowchart



2 BACKGROUND

2.1 PRIMARY SOURCES FOR SLRA LEVEL 2 METHODOLOGY

The proposed Soil and Groundwater Modules of SLRA Level 2 draw on the following soil and groundwater screening documents: United States Environmental Protection Agency (USEPA) Soil Screening Guidance 1996; the British Columbia Ministry of Water Land and Air Protection (MWLAP) Protocol 2 and SSS model[1]; and Washington's State's Model Toxics Control Act (MTCA). In addition, the SLRA Level 2 modules reflect technical comments from the July 16, 2004, SLRA Level 2 workshop held by the Science Advisory Board in Vancouver and further review comments.

2.2 PRECLUDING FACTORS FOR SLRA LEVEL 2 SOIL MODULE

The SLRA Level 2 soil and groundwater modules cannot be applied if any of the following precluding factors exists.

- Soil or groundwater contamination occurs in fractured bedrock
- The measured concentration of metals or other inorganics (e.g., arsenic) in groundwater exceeds applicable Schedule 6 standards.
- The contaminant of potential concern (COPC) is an ionizing organic compound and the soil pH is either less than 4.9 or greater than 8.0.
- Potentially mobile nonaqueous phase liquid (NAPL) exists in soil or groundwater. For the purposes of this document, NAPL is defined by a) physical observations of NAPL in wells, as expressed by the presence of sheens or appreciable product thicknesses[2], and b) exceedance of the NAPL indicator standards of the

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[1] The Site-specific Soil Standards (SSS) Model is a component of Protocol 2 of the Contaminated Sites Regulations under the Environmental Management Act within the British Columbia Ministry of Water Land and Air Protection's. Protocol 2 is to be replaced by this report.

[2] The mobility of NAPL is the key factor with respect to SLRA Level 2. Residual NAPL that is trapped by capillary forces in soil or fine-grained aquifer material does not present a *scientific* challenge to the SLRA Level 2 modules, because trapped residual NAPL will function as a long-term source of aqueous contamination but

MWLAP[3].[4] The SAB's Hydrogeological Assessment Tools can be applied for a more thorough assessment of LNAPL mobility.

If a site has groundwater contamination greater than the applicable standard but no soil contamination greater than the application standard, the SLRA Level 2 Groundwater Module can be used without the Soil Module. Additional precluding factors which are specific to groundwater can be found in Section 2.4.

2.3 BACKGROUND TO DEVELOPMENT OF GROUNDWATER MODULE

2.3.1 Introduction

For organic contaminants, if measured groundwater concentrations or soil-predicted groundwater concentrations exceed the applicable Schedule 6 standard, then the SLRA Level 2 Groundwater Module can be used to assess the risk to receiving environments. This section provides the background and rationale for the approach.

In summary, the groundwater module consists of the following steps:

1. Determine the highest value of the soil-predicted groundwater concentration[5], C_{gw}', and the highest measured groundwater concentrations.

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will not move. Therefore, residual NAPL in soil which is not present in wells does not preclude the applicability of the SLRA Level 2 modules. Note, however, that the minimum groundwater characterization standards in Section 4.2.2 apply with regard to the monitoring well network.

[3] The Ministry's policy is to use NAPL indicator standards or to infer the presence of NAPL where one percent of the effective solubility of a compound is exceeded in groundwater.
The SABCS recognizes that having a single, properly designed well (short screen in the right place, etc) with a groundwater concentration at 1% of the solubility does not automatically imply the presence of mobile NAPL. However, in the absence of minimum performance standards for the delineation of NAPL and the rapidly changing technology for NAPL delineation, the Ministry's conservative policy is adopted in SLRA Level 2.

[4] Note that for purposes of SLRA Level 2, the existence of NAPL per se is not problematic in obtaining a conservative assessment of the pathway analysis. In the Soil Module, use of the three-phase partitioning equation when a soil sample has NAPL will tend to over-estimate the groundwater concentration at the source, thereby resulting in a conservative assessment. The Groundwater Module will only screen out sites at which significant natural attenuation occurs via degradation as opposed to sorption. In such cases, the constant influx of dissolved phase compound due to NAPL dissolution will be balanced by decay in groundwater.

[5] The use of only measured groundwater was discussed at the workshop. The workshop participants concluded that using only measured groundwater concentration would not be appropriate in this context because of data quality and quantity concerns with measured groundwater concentrations.

2. Determine the applicable receiving environment(s) as defined by MWLAP protocol[6].
3. Evaluate the potential for contaminants to migrate to a downgradient receiving environment. If the degree of attenuation exceeds the degree of contamination, then there is no operable soil-to-groundwater pathway at the site and the evaluation of this pathway for this compound is complete.

The Groundwater Module is designed to assess the risk to receiving environments of contaminants in soil or groundwater. As stated in the Overview (Section 1), a fundamental objective of SLRA Level 2 is to screen sites with no pathway to the receiving environment (NPR). A potential outcome of the SLRA Level 2 Groundwater Module is that contaminants which exceed numerical standards will be left in the subsurface in perpetuity without remediation. To promote long-term conservation of British Columbia's groundwater resources, particularly those which may in future be used for water supply, *the Groundwater Module will only screen out sites contaminated with compounds which are naturally degraded in the environment.*

Because of the finality of an SLRA Level 2 screening, one of the objectives of SLRA Level 2 is to be conservative enough that moderate-risk but poorly characterized sites are not inadvertently screened out. Therefore, only conservative groundwater transport and natural attenuation parameters are permitted in SLRA Level 2. It is important to recall in this regard that well-characterized sites that do not require the restrictive assumptions of SLRA Level 2 can be screened out via the SAB's proposed Hydrogeological Assessment Tools or via a detailed risk assessment (DRA).

A final note with regard to SLRA Level 2 is that *if* the soil-predicted groundwater concentration based on the partitioning equations presented here, C_{gw}', is greater than all of the measured groundwater concentrations, then C_{gw}' is generally carried through in the Groundwater Module

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[6] The SLRA soil and groundwater modules were designed with the premise that groundwater use standards (DW,LW,IW) apply if the aquifer in question may be used within the 70 years (the foreseeable future). The SAB has recommended a method to consider the foreseeable future uses of groundwater using the provinces aquifer classification in a letter dated….

computations. For many sites, this will not be necessary. However, at sites with poorly designed well networks or "fresh", not-yet-equilibrated soil sources, the measured groundwater concentration may be increasing at the time of the site assessment. To address this circumstance, the greater of actual groundwater concentrations and C_{gw}' values must be used. If site data demonstrate that the C_{gw}' is high for reasons not associated with poor characterization or non-equilibrated soil-groundwater systems, leaching tests for inorganics as wells as organics have been included in SLRA Level 2. For those sites with non-volatile contaminants, direct pore water measurements can be used in lieu of soil matrix (solid) data in computing the soil-predicted groundwater concentration. Finally, as discussed in section 4.1, at sites with high quality groundwater monitoring data and an acceptable amount of temporal data with which to evaluate trends, measured groundwater data can be used exclusively without consideration of soil data.

2.3.2 Extrapolation

From a contaminant impact perspective, the most problematic implication of natural geological heterogeneity and the consequent non-uniform flow field is the possibility that a pollutant will travel faster than one would predict using field data from only a small portion of the area between a contaminant source and a receiving environment. Groundwater tends to converge in areas of higher relative hydraulic conductivity. Using *site-specific* data from a limited area to extrapolate plume migration over a larger area can be problematic.

To minimize the possibility that geological heterogeneity will lead to plume migration rates that are faster than indicated by site data, a degree of conservatism has been included in the SLRA Level 2 Groundwater Module. First, a minimum groundwater velocity is specified for sites at which the distance between the downgradient-most groundwater sample and the receiving environment exceeds the dimensions of the characterized site.[7] Second, geological heterogeneity is quantified using a relationship between the dispersivity (a measure of plume dilution) and the

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[7] For example, if the dimensions of the area covered by the site assessment is a rectangle with dimensions of 30 m lateral to the flow direction by 80 m parallel to the flow direction, a minimum groundwater velocity of 5 m/yr is specified for receiving environments which are greater than 80 m from the downgradient edge of the downgradient-most sample (i.e., well). If the distance to the receiving environment is less than 80 m, the site groundwater velocity can be used, even if it is less than 5 m/yr.

distance to the receiving environment. Finally, transverse spreading of the contaminants due to dispersion is excluded from the module.

2.3.3 Data Requirements for Groundwater Module

Because the SLRA Level 2 Groundwater Module permits extrapolation up to a distance of 1 km (see Section 4.3) and because of the implicit uncertainties in groundwater transport assessments, the SLRA Level 2 Groundwater Module provides the following minimum performance standards for the site assessment required to undertake an SLRA Level 2.

The following is a list of minimum performance standards. Existing ministry-approved methods and standard practice must also be used to determine applicable performance standards.

1. A detailed conceptual model for the groundwater flow system must be prepared. At a minimum, this conceptual model will make use of geology (stratigraphy) data presented in plan and section view.
2. The monitoring wells from which groundwater samples are collected must have a screen length that is no more than 3 m long. If possible, screens that are 1.5 m or shorter are preferred. The associated sand pack should be no longer than 2 m. The screened elevations should be selected to increase the likelihood that the center of the plume is sampled.
3. The maximum borehole diameter for monitoring wells is 30 cm (12 inches). The maximum monitoring well pipe (i.e., PVC) diameter is 10 cm (4 inches).
4. Hydraulic conductivity tests (e.g., slug tests, pumping tests) in at least three site wells are required for the calculation of the groundwater velocity at the site.
5. A delineation of the plume width, length and vertical thickness is required.
6. A contour map of groundwater concentrations is required. A cross-sectional diagram of soil and groundwater along the groundwater flow path is also required.
7. The uncertainty associated with site-derived parameter estimates must be calculated (Section 4.4).

In regard to Requirement 2, it is recommended that drive point samplers or direct push sampling are used, if practical and feasible (i.e., without layers of coarse gravels, boulders, etc), to delineate the vertical profile of the plume prior to installation of permanent monitoring wells.

2.4 PRECLUDING FACTORS FOR SLRA LEVEL 2 GROUNDWATER MODULE

The SLRA Level 2 Groundwater Module cannot be used if any of the following are true:

- the site assessment does not conform to the minimum standards set out in Section 2.3.3.
- the receiving environment is a water supply aquifer (i.e., DW, IW, LW) *and* the groundwater plume has travelled beyond the property boundary.
- the distance between the contaminated site[8] and a potential receiving environment is less than 30 m.
- the compound in question decays to harmful[9] daughter products that have been detected in groundwater. For example, if trichloroethylene (trichloroethene or TCE) is a contaminant of concern, then groundwater must be analyzed for cis-1,2-dichloroethylene (DCE) or vinyl chloride (VC) concentrations. If daughter products are detected in any well, further assessment or remediation is required, because concentrations of the daughter products may increase with distance from the source.
- the contamination extends to the base of the aquifer. Vertical transport to underlying aquifers can be assessed using the Hydrogeological Assessment Tools.

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[8] As defined by the CSR. The site dimensions will generally *not* be the same as the property size.

[9] Harmful is interpreted as compounds with degradation products that have Schedule 6 groundwater standards.

2.5 INITIAL STEP FOR SLRA LEVEL 2 SOIL AND GROUNDWATER MODULES: DETERMINATION OF APPLICABLE RECEPTORS FOR GROUNDWATER PROTECTION

For both the soil and groundwater modules, the applicable water quality standards must be determined. This section presents a list of criteria to be used to determine the applicable water quality standards for the site. The determination of the applicable receptor(s) is an essential step in screening level risk assessment. In many cases, the determination is done at the site investigation stage or within SLRA Level 1. This section provides a systematic protocol for determining the applicable receptor(s) for groundwater protection. The questionnaire in Section 2.5.2 is not explicitly part of the existing Contaminated Sites Regulations (CSR), but provides a useful format and template to address specific components of the CSR. This method of determining applicable receptors for groundwater use is based on the British Columbia aquifer classification system. When adopting this aquifer classification system, the province did not intend to use the system for purposes of screening contaminated sites. However, it is the SAB's opinion that this classification system is the most comprehensive tabulation of aquifers in the province and hence a reliable starting point for aquifer protection.

2.5.1 Risk to Aquatic Life

The following questions must be answered to determine if standards for the protection of aquatic life (AW) apply to the site.

1a. Does the measured soil concentration exceed the Schedule 4 generic standards (MWLAP, 2004a) or Schedule 5 (MWLAP, 2004b) soil standards for the protection of aquatic life?

1b. Does the measured groundwater concentration exceed the Schedule 6 groundwater standards for protection of aquatic life (MWLAP, 2004c)?

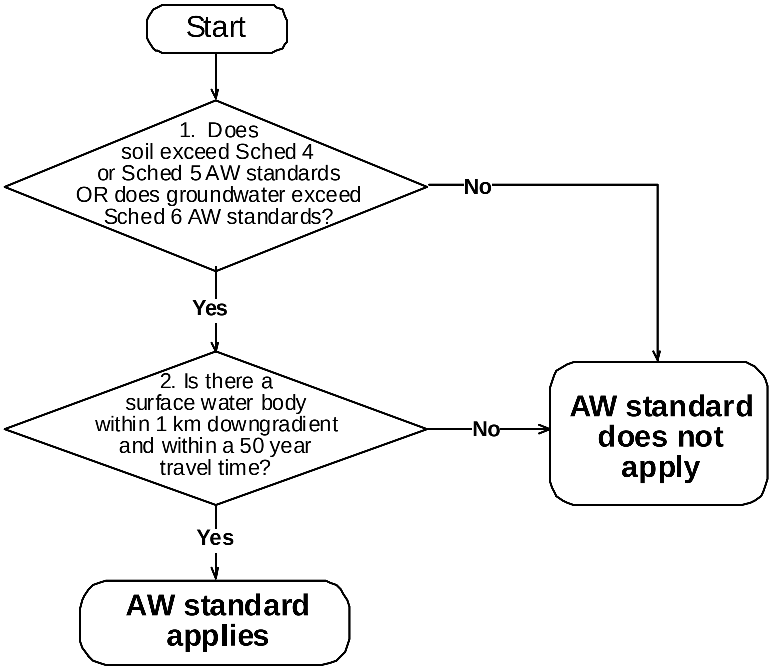
If Yes to either Question 1a or 1b, go to Question 2. Otherwise, the AW standard does not apply to this compound at this site.

2. Is there any surface water within a 1 km distance in the downgradient direction of either the leading edge of the plume or the soil source zone of the contaminated site and is the calculated travel time to a surface water body less than 50 years[10]?

If Yes to Question 2, then an evaluation of the risk to aquatic life receptors is required under SLRA Level 2. If No, aquatic life is not an applicable receptor.

This process is illustrated in Figure 2.

Figure 2. Questionnaire for Determining if AW Standard Applies



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[10] In general this rule is applied only for the semi-circle defined by the 1 km distance. In SLRA Level 2 the distance from the receptor to the source zone is used while MWLAP uses the leading edge of the plume for the 1 km rule.

2.5.2 Risk to Drinking Water, Irrigation Supply or Livestock Watering

The following questions must be answered to determine if standards for the protection of groundwater supply (i.e., DW, IW, LW) apply to the site.

1a. Does measured soil contamination exceed the Schedule 4 or 5 soil standards for protection of groundwater used for DW, IW or LW?

1b. Does measured groundwater contamination exceed the Schedule 6 groundwater standards for groundwater used for DW, IW or LW?

If Yes to either Question 1a or 1b, go to Question 2. Otherwise, the DW, IW and LW standards do not apply to this compound at this site (Exit questionnaire).

2. Is the contaminated site located within or above an aquifer classified by MWLAP[11]? Appendix B-8 includes simplified instructions for use of the MWLAP website: http://maps.gov.bc.ca/apps/wlap_aquifer/

If Yes, go to Question 3. If No, go to Question 6.

3. Is the aquifer vulnerability classified as high (mapped as red, classified as “a”)?

If Yes then DW, IW, LW standards apply (Exit questionnaire). If No, go to Question 4.

4. Is the aquifer vulnerability classified as low (mapped as green, classified as “c”)?

If Yes[12], then DW, IW, LW standards do not apply if there are no wells within 1.5 km. The Hydrogeological Assessment Tools (HAT) to assess vertical transport are required to confirm the integrity of protected aquitards: if the COPC is not likely to migrate through an aquitard to an underlying aquifer, then DW, IW, LW standards do not apply even if a well is within a 1.5 km radius (Exit questionnaire). If No, go to Question 5.

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[11] Consideration could be given to sites located in an aquifer in the process of being mapped or an aquifer identified as needing mapping (due to a large number of wells).

[12] Under the CSR the groundwater travel time to the underlying confined aquifer must be greater than 100 years. The travel time must be assessed on a site-specific basis

5. The aquifer vulnerability is classified as moderate (mapped as yellow, classified as "b"). Is the aquifer demand and aquifer productivity classified as low[13]?

If Yes, then DW, IW, LW standards do not apply if there are no wells within 1.5 km. The HAT Vertical Transport Tools are required to confirm the integrity of protective aquitards: if the COPC is not likely to migrate through the aquitard to an underlying aquifer, then DW, IW, LW standards do not apply even if a well is within a 1.5 km radius (Exit questionnaire). If No, DW, IW, LW standards apply. Exit questionnaire.

For contaminated sites located in areas of the province not yet classified by MOE:

6. Has a municipality declared the aquifer a drinking water source?

If Yes, DW, IW, LW standards apply. If No, go to Question 7.

7. Are there any existing or planned wells within a 1.5 km distance in the downgradient direction from the contaminated site and is the calculated travel time less than 100 years?

If Yes, DW, IW, LW standards apply. If No, facts may be provided that support a claim that usable groundwater is either not vulnerable to the contamination or is unlikely to be used in the foreseeable future, taken to be 100 years[14]. With a supported claim, DW, IW, LW standards do not apply.

This water supply questionnaire is illustrated in Figure 3.

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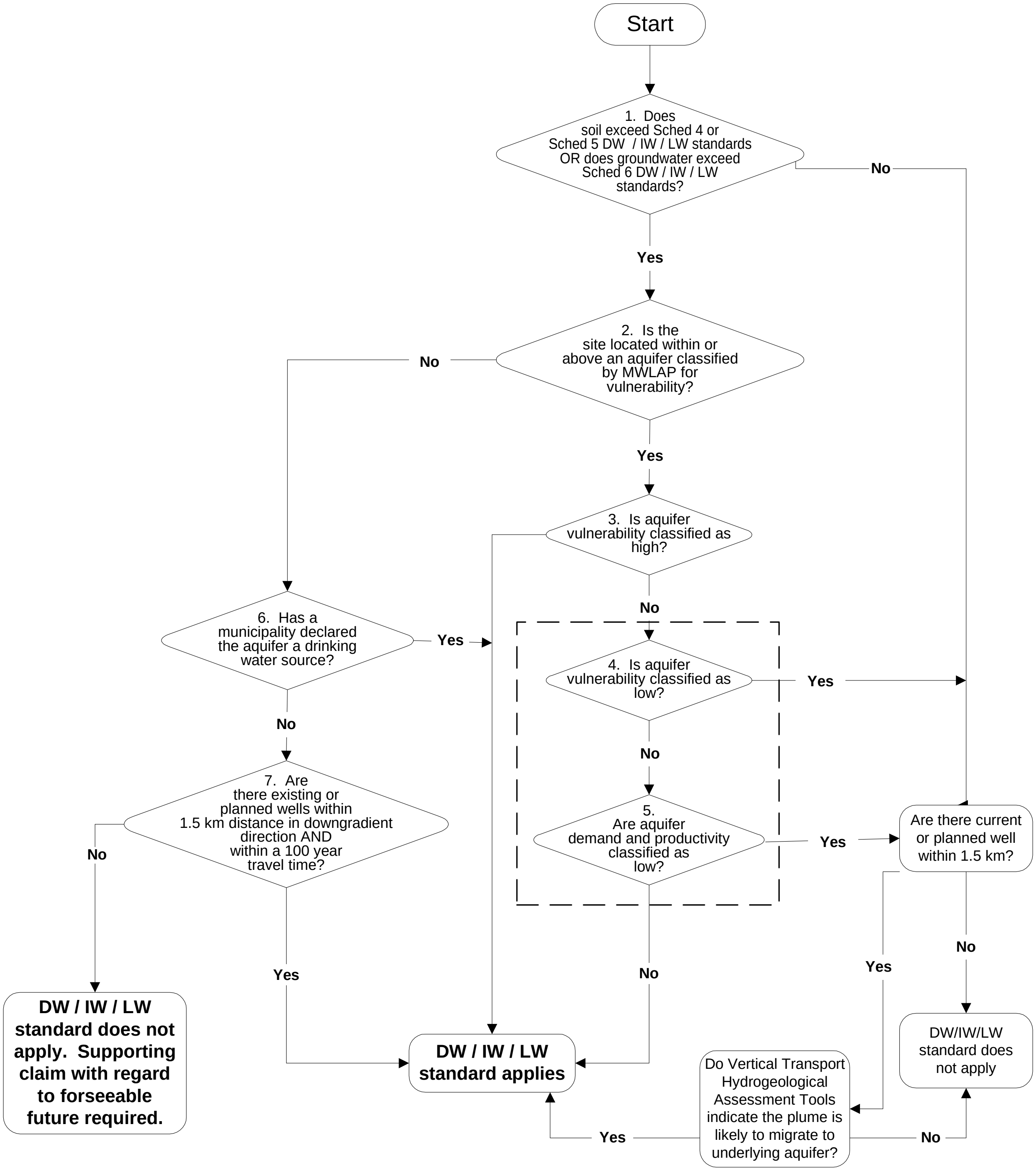
[13] The 1.5 km semi-circle for current wells also applies here.

[14] The 100 year timeframe is consistent with the current MWLAP guideline of 100 year travel time or 1.5 km distance for protection of current wells.

Figure 3. Questionnaire for Determining if DW, IW, or LW Standard Applies[15]



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[15] The BC MOE is not in favour of using this aquifer classification system at this level of assessment, however the SAB feels it is important to include aquifer vulnerability and this method is proposed for discussion purposes.

3 PROCEDURE FOR SLRA LEVEL 2 SOIL MODULE

The purpose of the Soil Module of SLRA Level 2 is to evaluate sites where soil contains organic contaminants in excess of CSR standards and screen the sites with no pathway to the receiving environment (NPR). The Module will screen sites based on the likelihood that organic contaminants in soil will adversely affect groundwater. Recall from the overview that the screening *must be conservative enough that sites with potential impacts to the receiving environment are not inadvertently screened as NPR*.

Two processes are modeled in this evaluation: 1) prediction of the concentration of the contaminant in pore water at the contaminant source, and 2) mixing of contaminated pore water with groundwater at the water table. A three-phase partitioning equation with some site-specific parameters is used to predict soil pore water concentrations. After predicting the soil pore water concentration, mixing of unsaturated soil water with saturated groundwater is modeled using either a calculated or empirically-derived dilution factor. Unsaturated transport has not been included in SLRA Level 2. However, unsaturated transport can be addressed with the SAB's Hydrogeological Assessment Tools (HAT).

The end result of the SLRA Level 2 Soil Module are ***soil-predicted groundwater concentrations*** at the source. These are groundwater concentrations predicted based on a combination of the partitioning equation and/or dilution factors. To address the possibility that groundwater impacts from contaminated soil have either not occurred or not been detected in the existing monitoring network, soil-predicted groundwater concentrations must be computed even if all site groundwater samples are within the applicable Schedule 6 standards.[16] Figure 4 illustrates the steps and decision-making process of the Soil Module.

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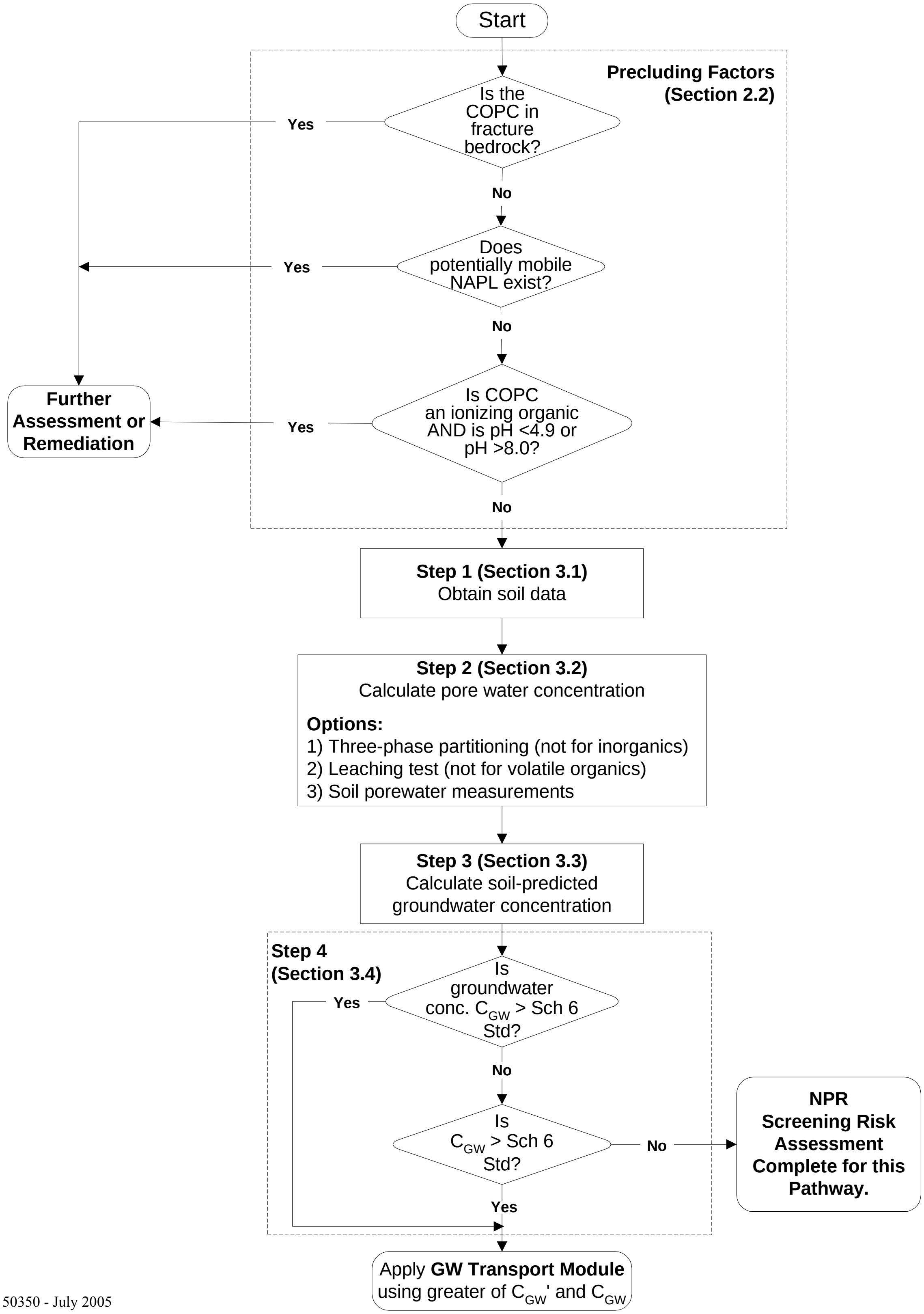
[16] Soil-predicted groundwater concentrations are superseded by measured groundwater concentrations in many, but not all, situations (see Section 4.1)

Figure 4. Soil Module Flowchart



3.1 STEP 1: ATTAIN DATA FOR SLRA LEVEL 2 SOIL MODULE

The first requirement of the soil module is to attain the necessary soil data for the site. As a prerequisite to SLRA Level 2, a detailed site investigation (DSI) must be completed for the site in accordance with Ministry-approved procedures. In some cases, the data required to complete an SLRA Level 2 may be beyond standard methodologies for DSIs; for example, obtaining site-specific data (such as f_{oc}), or determining the presence of mobile NAPL. In these cases, additional investigation may be required.

3.2 STEP 2: CALCULATE SOIL PORE WATER CONCENTRATION AT SOURCE

Methods for predicting soil pore water concentrations are distinct for organic contaminants and metals. For organic contaminants, there are two options available for predicting the soil pore water concentration at the source: (1) three-phase partitioning and (2) leaching tests (with the exception of volatiles). For metals, the only option available for predicting contaminant pore water concentration is leaching tests[17].

3.2.1 Three-phase Partitioning for Organic Contaminants

Equilibrium partitioning among three phases is computed for organic contaminants[18]; these three phases are soil water, soil air and soil matrix (soil solid). The three-phase partitioning equation is shown in Equation 3.1.

$$C_L = \frac{C_S}{K_d + \left(\frac{\theta_w + H_{cc}\theta_a}{\rho_b}\right)} \qquad \text{Equation 3.1}$$

where C_S is the measured soil concentration at the source[19] (mg/kg), C_L is the predicted soil pore water concentration at the source (mg/L), K_d is the soil matrix-to-soil water distribution coefficient (L/kg), H_{cc} is the dimensionless Henry's constant, ρ_b is the bulk density (kg/L), θ_w is the water-filled porosity, and θ_a is the air-filled porosity.

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[17] Justification for this decision is provided in Appendix B-1

[18] Justification for limiting the use of the three-phase model to organics is provided in Appendix A

[19] As determined by Guidance 1 of the MWLAP.

The soil matrix-to-soil water distribution coefficient, K_d, is the product of the soil organic carbon-water partition coefficient, K_{oc}, and the fraction of organic carbon, f_{oc}.

SLRA Level 2 permits the use of a site-specific f_{oc} measured during the site investigation. The f_{oc} value must be determined from a soil sample, collected from outside of the contaminated area that is suitable for the soil-to-groundwater pathway evaluation. For example, if the contaminant of concern is within an unsaturated hydrostratigraphic unit, the soil sample should also be from the appropriate unsaturated soil. If a default value is required, f_{oc} =0.001 g/g is to be used.

For individual non-ionic hydrophobic organic compounds (e.g., benzene and naphthalene), the K_{oc} values in Table B-2-1 (Appendix B-2) are used. For ionizing organic hazardous substances (e.g., pentachlorophenol and benzoic acid), the K_{oc} values in Table B-2-2 (Appendix B-2) are used. Table B-2-2 provides K_{oc} values for three different pHs. To select the appropriate K_{oc} value, the soil pH must be measured. If the soil pH falls between the pH values provided, an appropriate K_{oc} value for chlorinated phenols is calculated using the equations provided in Appendix B-2. In addition, suitable K_{oc} values from the scientific literature are permissible for organic contaminants not listed in Appendix B-2. When selecting a K_{oc} value from the literature, the practitioner is responsible for choosing the most conservative (i.e. minimum) K_{oc} value appropriate for the site. The values for Henry's law constant in Equation 3.1 can be obtained from the scientific literature.

Finally, site data are recommended for soil bulk density, soil volumetric water content, and soil air content. Alternatively, a suitable value based on soil composition and geology may be applied (e.g., values presented hydrogeology textbooks[20]). If a default is required, ρ_b is 1.7 kg/L, θ_w is 0.3, and θ_a is 0.2.

Equation 3.1 may be used to establish soil concentrations for any organic hazardous substance where potentially mobile NAPL is not suspected and may be used to calculate both unsaturated and saturated zone soil pore water concentrations.

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[20] For instance, Fetter, C.W. 2001. *Applied Hydrogeology*. 4th ed. Prentice-Hall. 598pp., Schwartz, W., and H. Zhang. 2002. *Fundamentals of Ground Water*. 1st ed. John Wiley & Sons. 592pp., or Freeze, R. Allen and John A. Cherry, *Groundwater*, Prentice-Hall, 1979.

3.2.2 Leaching Tests

If measured groundwater concentrations for metals are above applicable Schedule 6 standards then further assessment or remediation applies immediately and there is no need to proceed with SLRA Level 2. Furthermore, if the soil pH is less than 5, (e.g., when acid mine drainage is occurring) leaching tests are not permitted under SLRA Level 2, and risk assessment for the site must follow DRA protocols. In addition, leaching tests cannot be used for volatile organics.

If all measured groundwater concentrations are below applicable Schedule 6 standards, then leaching tests may be used to assess the potential for groundwater impacts from soils that exceed the Schedule 4 and 5 standards for inorganics including metals and non-volatile organics. The soil samples for use in the leaching test must come from the source area and must be taken as close as possible to the highest measured soil values. The maximum allowable distance from the highest measured soil value is 2 m if the metals source zone is a definable, relatively uniformly distributed population of contaminants. For the case that the source zone consists of randomly distributed contaminants, which vary across spatial scales of centimetres rather than metres, the number of soil samples to be subjected to leaching tests must be commensurate to the heterogeneity of the soil concentrations.

When using any leaching test, the analytical methods used for analysis of the effluent shall be sufficiently sensitive to quantify hazardous substances at concentrations equal to the applicable Schedule 6 standards.

For a predicted groundwater metals concentration to be considered protective of groundwater, the leaching test solution concentration shall be less than or equal the applicable Schedule 6 standard.

If the site-specific soil pH is greater than 5.5, SLRA Level 2 requires that the USEPA's Method 1312, Synthetic Precipitation Leaching Procedure (SPLP) be applied. The SPLP should be used with a weak acid (Fluid #3, with a pH of 5) as the leaching solution to represent acid rain in the western United States. The application of the SPLP leaching test is region specific and is considered conservative in the context of SLRA Level 2 where there is no exceedance of numeric standards in groundwater, but soil-predicted concentration are higher than standards for groundwater protection.

If the site-specific soil pH is between 5 and 5.5, the USEPA Method 1311, Toxicity Characteristic Leaching Procedure (TCLP) shall be used instead. The TCLP uses Fluid #1 (with a pH of 4.93) to represent organic acids generated by biological degradation processes. This test is intended to represent situations where acidic conditions are present due to biological degradation such as in municipal solid waste landfills.

3.2.3 Pore Water Measurements

Direct measurements of soil pore water are permitted for SLRA Level 2. These measurements should be collected below the suspected zone of soil contamination. This method cannot be used for volatiles if the method used has the potential to result in degassing of the pore water.

3.3 STEP 3: PREDICT GROUNDWATER CONCENTRATION

The final process considered in the Soil Module is the mixing of soil pore water, which has a contaminant concentration C_L, with ambient groundwater. An empirically-derived dilution factor can be applied to predict C_{gw}', the *soil-predicted groundwater concentration:*

$$C_{gw}' = \frac{C_L}{\mathrm{DF}}, \text{ and} \qquad \text{Equation 3.2}$$

where DF is the dilution factor (dimensionless).

For SLRA Level 2, there are two permitted ways of computing the dilution factor.

3.3.1 Default Mixing at the Water Table

A DF of 20 is recommended in the US EPA’s 1996 Soil Screening Guidance for soil contamination in the unsaturated zone for sites less than 0.5 acres (2,000 m^2) in area. Review of the EPA justification for the default dilution factor suggests that DF=20 is appropriate for small sites *except* in the following cases:

1. When the evaluation is for impacts to an aquatic life receiving environment.[21]
2. When soil contamination is located at or below the groundwater table in saturated soils. In these cases, DF=1.
3. When the contaminant concentration upstream of the source is greater than zero[22].

As noted in point 2 above, soils which are below the water table must be evaluated with a DF of one. The elevation of the water table for the purposes of determining the dilution factor is defined as the highest possible elevation in cases where the water table fluctuates seasonally. In order for DF to be greater than one, a minimum buffer zone of 1 m between the water table and the source is required to provide an additional safety factor.[23]

3.3.2 Site Specific Dilution Factor

If the default dilution factor of 20 is not applied, a site specific dilution factor can be determined from the following equation:

$$DF = 1 + \frac{Vd}{IL} \qquad \text{Equation 3.3}$$

where:

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[21] Implicit in the US EPA's default DF is the assumption that the receiving environment is a water supply well with a well screen below the water table. The additional dilution related to flow vertically downward from the water table cannot be assumed for aquatic receiving environments.

[22] In these cases DF could be reduced as a weighted average according to the upstream concentration.

[23] The capillary fringe in fine-grained soils can be as high as 1 m. Within the capillary fringe, the soil water content is equal to the porosity in spite of the fact that the water pressure is less than atmospheric pressure. A seminal source of moisture characteristic data for predicting capillary rises in typical unconsolidated materials is van Genuchten, M. Th., 1980, "A closed-form equation for predicting the hydraulic conductivity of unsaturated soils," *Soil Science Society of America Journal,* 44:892-898.

	Definition	Constraint
V	Darcy flux at the site (m/yr)	site specific measurement
L	length of the source parallel to the direction of groundwater flow (m)	site specific measurement
I	region-specific infiltration (m/yr)	The region specific infiltration value is derived from the precipitation records for representative local climatological stations. A methodology is provided in the SAB's Hydrogeological Assessment Tools. As a default, the infiltration rate may be calculated as the total annual precipitation minus an annual average evapotranspiration of 0.46 m/yr. *However, the accuracy of the assessment will tend to be poor if regional data is not used.* If the computed infiltration rate is less than or equal to zero, DF=1.
d	mixing zone depth (m)	A default mixing zone depth of 0.5 m is permissible for use under SLRA Level 2. Equation 3.4 can be used to derive a site specific value
d_a	aquifer thickness (m) for equation 3.4	site specific estimate based on all available site geological data

The site specific derivation of the mixing zone depth is the sum of the predicted mixing due to vertical dispersivity along the length of the flow path ($d_{\alpha v}$) and the mixing due to the downward velocity of the infiltrating water (d_{Iv}).[24]

$$d = d_{\alpha v} + d_{Iv}$$

$$d = 0.044L^{1.23} + d_a \left\{ 1 - e^{\left(-\frac{LI}{Vd_a} \right)} \right\}$$

Equation 3.4[25]

3.4 STEP 4: EVALUATE RESULTS OF SLRA LEVEL 2 SOIL MODULE APPLICATION

Once a soil-predicted groundwater concentration is calculated, it may be used in two different ways:

- If the potential for soil to contaminate groundwater, as measured by soil-predicted groundwater concentration is sufficiently low, and groundwater is not

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[24] In computing the first term in Equation 3.4, the vertical dispersivity was estimated to be 0.056 times the longitudinal dispersivity (Gelhar and Axness, 1981) and longitudinal dispersivity was estimated by the Neuman (1990) relationship for travel distances less than 100 m.

[25] Derivation of equation 3.4 is provided in Appendix D and in USEPA 1996 section 2.5.5.

contaminated, then the soil to groundwater pathway can be screened out of the regulatory process as NPR by a simple numerical comparison.

- If the site cannot be screened out in this simple manner, the likelihood of contaminants reaching a receiving environment needs to be evaluated more specifically.

The former process involves comparing the soil-predicted groundwater concentration to the applicable numerical standard. If both the soil-predicted groundwater and measured concentrations are less than the applicable standards, then the groundwater pathway can be screened out of the regulatory process for that contaminant of concern for the soil-to-groundwater pathway. Numerical screening can be used for AW, DW, IW and LW receiving environments. Any soil-predicted groundwater concentration, which is greater than numerical standards, must be carried forward to the groundwater module (Section 4).

For non-volatile compounds, the soil-predicted groundwater concentration can be disregarded if all measured groundwater concentrations are below the standard and if soil pore water inferred from leaching tests has concentrations less than the applicable standards. As noted in Section 3.2.3, direct pore water measurements collected in the unsaturated or saturated zone, depending on the location of the contamination[26], may also be used in lieu of soil-predicted groundwater concentrations.

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[26] If pore water samples are collected in the saturated zone, application of the dilution factor is not permitted.

4 PROCEDURE FOR SLRA LEVEL 2 GROUNDWATER MODULE

The SLRA Level 2 screening process for groundwater transport is illustrated in Figure 5. The precluding factors are described in Section 2.4, while the four steps of the SLRA Level 2 assessment are described in this section. As discussed below in Section 4.2.3, there will be situations in which the SLRA Level 2 Groundwater Module must be completed twice for a given compound at a site. In these cases, the assessment will be completed for *both* the aquatic receiving environment and groundwater receiving environment. An example of the use of the Groundwater Module is presented in Appendix B-7.

4.1 STEP 1: SELECTION OF APPROPRIATE CONCENTRATION

In a risk management-based approach to site screening, contaminant levels at the source should be assessed in relation to the attenuation processes that will take place as contaminants migrate toward a receiving environment. NPR sites are those for which $C(x_R)$, the predicted concentration at the receiving environment, is predicted to be lower than a regulatory standard, C_{sched_6}, in one of two ways:

1) If the measured contaminant concentration, C_{gw}, (and/or the soil-predicted groundwater concentration at the source, C_{gw}', if necessary[27]) is less than C_{sched_6}, the site can be screened out of the regulatory process.

2) If the measured contaminant concentration at the source, C_{gw} (and/or the soil-predicted groundwater concentration at the source, C_{gw}', if necessary[28]) is greater than C_{sched_6}, then the site can be screened out of the regulatory process as a low risk site only if the natural attenuation processes are sufficient to reduce $C(x_R)$ below C_{sched_6} at the receiving environment.

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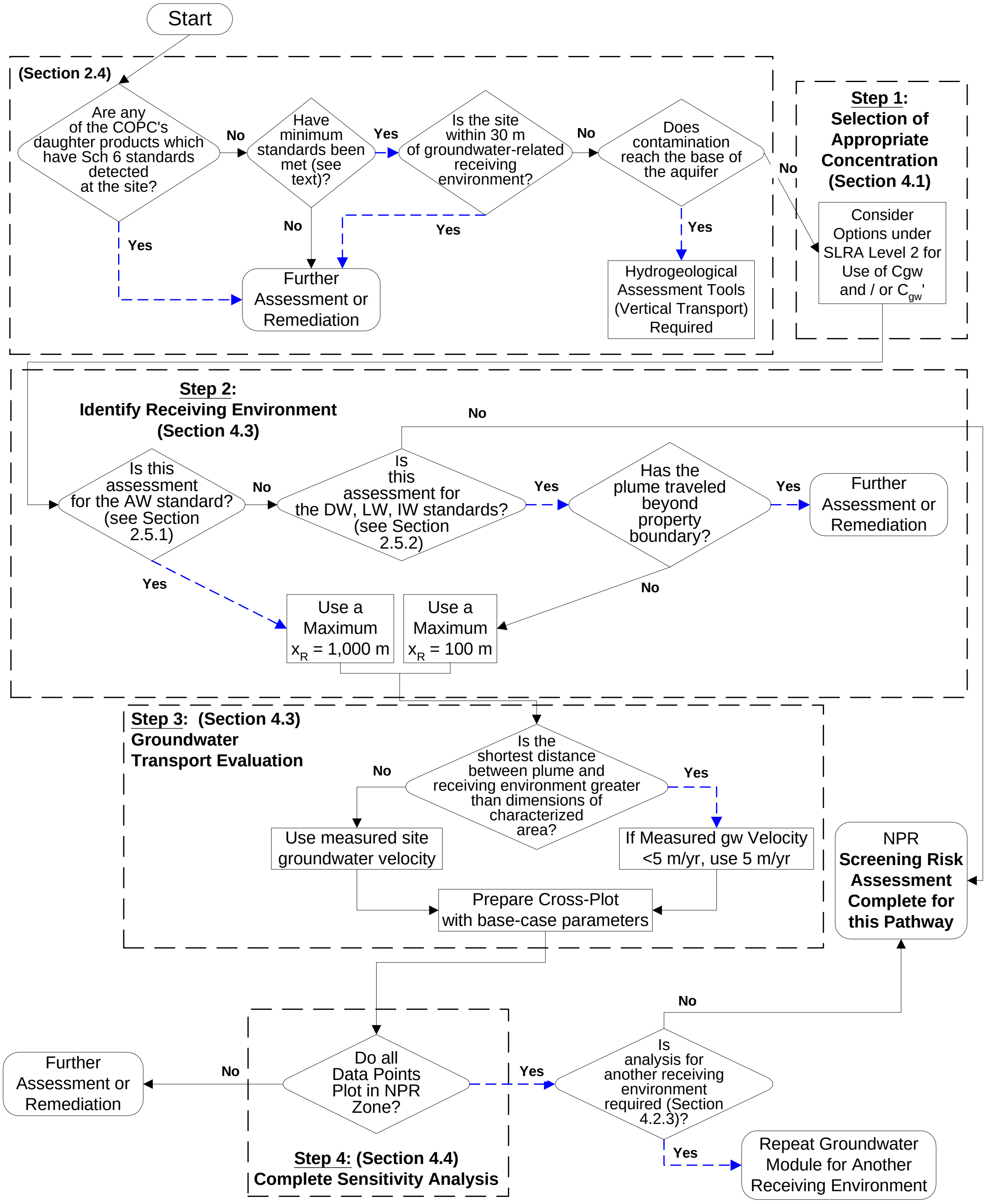
[27] i.e., only if C_{gw}' is greater than all measured groundwater concentrations (or leaching test results or direct pore water concentrations replace soil-predicted groundwater concentrations).

[28] i.e., only if C_{gw}' is greater than all measured groundwater concentrations.

Figure 5. Flow Chart Showing Key Decision Points of Groundwater Module



Two avenues for disregarding conventional soil-predicted groundwater concentrations as input to the groundwater module have already been stated: 1) leaching test, and 2) direct pore water measurements.

A third option is available to allow the use of measured groundwater concentrations without considering soil-predicted concentrations for input to the groundwater module. Requirements for the use of this option include:

- The water table is within 2m of the surface or it can be demonstrated that sufficient time has elapsed to permit unsaturated transport from the source to the water table.

- Groundwater measurements must be available over a period of 2 years on a quarterly basis and the concentrations must be shown to be decreasing or remaining constant with time (within 10%). The Mann-Whitney test is suggested as a method of checking the trend.

- A strong case must be presented that the measured groundwater data is of a high quality.

- Dissolved DNAPL contaminants are excluded from consideration. The restriction still holds if DNAPL has not been detected at concentrations high enough to suggest DNAPL.

4.2 STEP 2: IDENTIFICATION OF USEABLE GROUNDWATER RESOURCES

Current and foreseeable future uses of groundwater are explicitly considered in the SLRA Level 2 Groundwater Module. The procedures for water quality standards designed to protect groundwater supply (i.e., drinking water, livestock watering or irrigation water) and sites which may become subject to one of these water quality designations within the foreseeable future are separate from the transport procedure for sites which are subject to aquatic life protection standards. For the purposes of the SLRA Groundwater Module, foreseeable future use of groundwater supply is defined in Question 7 of Section 2.5.

4.2.1 Sites Subject to Water Quality Standards for Protection of Drinking Water, Livestock and Irrigation

For sites, which are subject to one of the water quality standards defined to protect groundwater supply, the maximum allowable distance-to-receiving environment, x_R, for extrapolation purposes is 100 m. Note that the 100 m distance is in contrast to the 1.5 km distance from a water well that triggers these standards for groundwater at a site. This rule is depicted in Case A of Figure 6. Figure 6 describes the relationship of source, plume and receiving environment, and property boundary for SLRA Level 2. Further explanation of Case B can be found in Section 4.2.1.

The reason for a more limited travel distance (and hence more conservative assessment) is twofold. First, applying the groundwater transport protocol using the ambient groundwater flow velocity does not account for accelerated groundwater velocities in the vicinity of a well. Second, the inclusion of “foreseeable future” in the assessment requires some consideration of supply wells that have not yet been installed.

4.2.2 Sites Subject to Water Quality Standards for Protection of Aquatic Life

For sites that are subject to water quality standards for the protection of aquatic life, the actual distance between the site and the aquatic receiving environment is used in the Groundwater Module.[29] This rule is depicted in Case B of Figure 6 in Section 4.3. Note that, in determining the distance to the receiving environment, the practitioner must use the high water mark.[30]

4.2.3 Final Considerations

The Groundwater Module may have to be applied more than once for a given contaminant of concern at a site. This may arise because of a restricted attenuation distance between the source

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[29] In practice, the maximum distance of 1 km will be permitted, in keeping with MWLAP’s Technical Guidance 6, which states that sites within 1 km of a surface water body are subject to water quality guidelines for protection of aquatic life.

[30] In addition, the practitioner should consider the maximum potential extent of migrating channels to prevent the possibility of a stream washing away the source area.

and the receiving environment (x_R) for those sites that may impact a groundwater supply source, and because of the variety of standards for each type of receiving environment.

4.3 STEP 3: COMPUTE DIMENSIONLESS NUMBERS FOR DATA AND PLOT ON CROSS-PLOT

In this step, two dimensionless factors, S_I and S_{II}, are computed using the maximum source-area groundwater concentration or, if necessary, the soil-predicted groundwater concentration (see Section 4.1). The dimensionless factor S_I describes the level of contamination. If the concentration of a contaminant of concern in a well is equal to the standard, S_I equals zero. If the concentration is one order of magnitude higher than the standard, S_I equals one. If the concentration is two orders of magnitude lower than the standards, S_I equals negative two. The dimensionless factor S_{II} is a measure of the degree of attenuation that may be expected to occur between the source and the receiving environment. The higher the S_{II}, the greater the attenuation that occurs along a groundwater flow path. These two dimensionless factors are defined as:

$$S_I = \log_{10}\left(\frac{\mathrm{C_{gw}}}{\mathrm{C_{sched\_6}}}\right) \qquad \text{and} \qquad S_{II} = \frac{0.22x_R}{\alpha_L}\left[\left(1+\frac{4\lambda\alpha_L R}{v}\right)^{\frac{1}{2}} - 1\right]$$

where x_R is the distance to the receiving environment, $\mathrm{C_{gw}}$ is the highest groundwater concentration at the source[31], α_L is the longitudinal dispersivity, λ is first-order decay constant, R is the retardation factor, and v is the linear groundwater velocity. The retardation factor is defined as $R=1+\rho_b K_{oc} f_{oc}/n$, where ρ_b is the bulk density, K_{oc} is the organic carbon-water partition coefficient, f_{oc} is the fraction organic carbon, and n is the porosity.

The longitudinal dispersion coefficient is defined as

$\alpha_L = Ax_R^H$ For x_R less than 100 m, A is 0.0175 and H is 1.46
For x_R greater than 100 m, A is 0.32 and H is 0.83.

Refer to Table 1 (in Section 4.3) for default and limiting values of f_{oc} and v.

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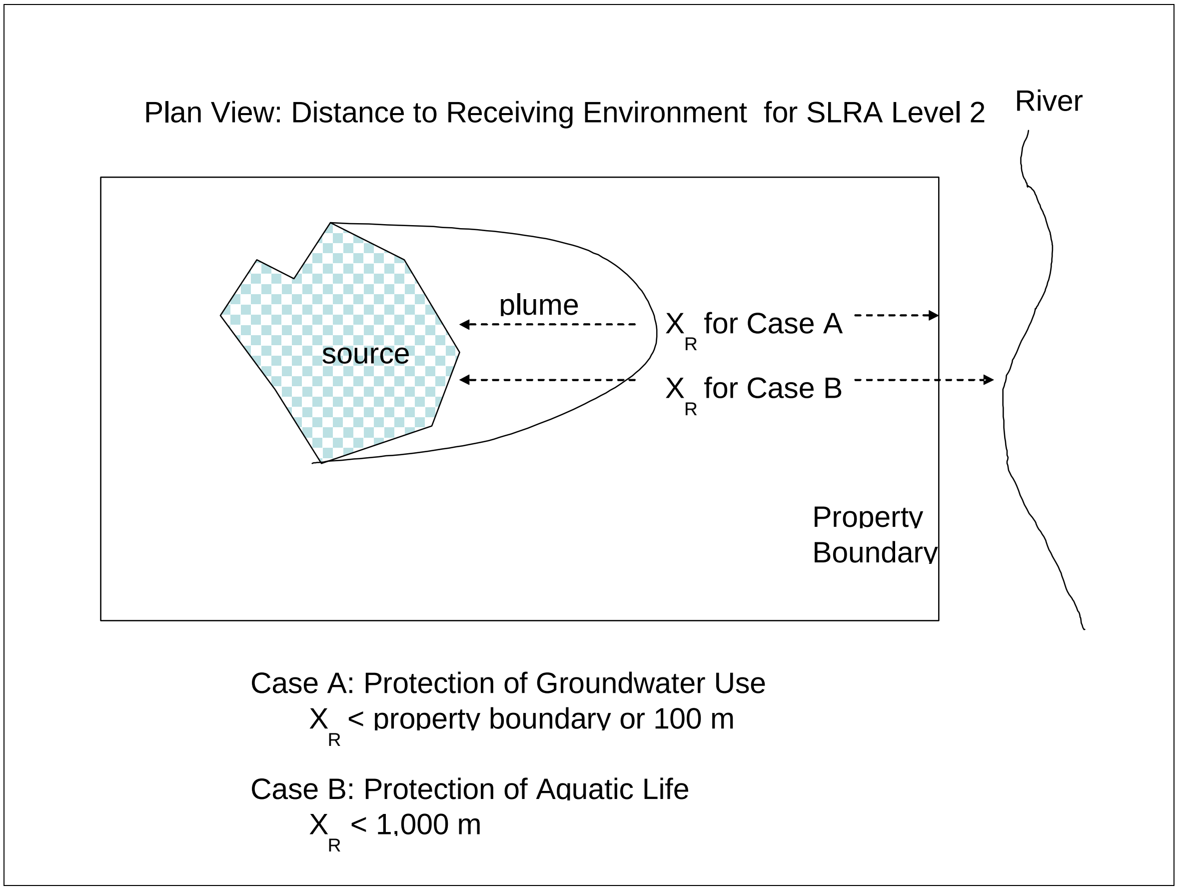
[31] If $\mathrm{C_{gw}}$’ is higher than $\mathrm{C_{gw}}$, $\mathrm{C_{gw}}$’ is used instead of $\mathrm{C_{gw}}$ to predict the risk at the receiving environment.

A discussion of the use of conservative first-order decay constants in the context of SLRA Level 2 is provided in Appendix B-5. First-order decay constants for SLRA Level 2 can be found in Appendix B-6.

A schematic of key parameters for an AW receiving environment is shown in Figure 6.

Figure 6. Schematic Showing the Source, Plume, Receiving Environment and Property Boundary



In the SLRA Level 2 Groundwater Module, the base case S_I and S_{II} are computed using the input values shown in Table 1.

Table 1. Parameters Used to Calculate Base-Case S_I and S_{II} Pair

C_{gw} (C_{gw}')	Highest measured source concentration or soil-predicted groundwater concentration, if higher.
x_R	Distance from source to receiving environment. Use measured value from edge of source area
v	The site-specific linear velocity is calculated at the site investigation stage. If the distance between the downgradient-most groundwater sample and the receiving environment exceeds the longitudinal dimension of the site investigation, the minimum groundwater velocity allowable under SLRA Level 2 is 0.014 m/day or 5 m/yr.
α_L	$\alpha_L = Ax_r^G$ • For x_R less than 100 m, A is 0.0175 and the exponent G is 1.46 • For x_R greater than 100 m, A is 0.32 and the exponent G is 0.83
K_{oc}	From Appendix B-2 or peer-reviewed scientific literature if not listed in Appendix B-2.
f_{oc}	Site-specific f_{oc} is measured outside of the contaminated area in soil suitable for evaluating the groundwater transport pathway. However, if the measured f_{oc} exceeds 0.02 g/g, then a value of 0.02 g/g must be used. If a default value is required, f_{oc} =0.001 g/g will be used.
n	A conservative site-specific value can be used or suitable textbooks can be consulted for a value representative of the geologic medium.
ρ_b	Site specific ρ_b can be used, or the default value of 1.7 g/cm^3
λ	From Appendix B-6
pH	groundwater pH is required only when pH dependence affects contaminant fate or transport (e.g., for ionizing organic compounds).

Pairs of S_I and S_{II}, are plotted on a cross-plot (shown in Figure 7).

1. If any of the data points plot in the "receiving environment impact" zone of Figure 7, then the site cannot be classified as NPR (no risk to receiving environment). Further risk assessment may be conducted using the Detailed Risk Assessment (DRA) protocol, or the site can be remediated.
2. If all of the base-case data points plot in the "NPR" zone of Figure 7, then the sensitivity analysis must be carried out (Step 3).

Sites are considered to have no pathway to the receiving environment if either

- S_I is less than zero (i.e., the site is not contaminated) or
- $S_I < S_{II}$ (i.e., the degree of attenuation between the source and the receiving environment is sufficient to result in a concentration at the receiving environment which is less than the Schedule 6 standard).

Pairs of S_I and S_{II} are plotted on a standardized *cross-plot*. A simplified screening process for a site with $S_I = 4$ and $S_{II} = 5$ can be visualized using the cross-plot representation in Figure 7. In this example, The concentration in groundwater at the source is four orders of magnitude higher than the standard (S_I=4). Nevertheless, between the source and the receiving environment, the concentration of the contaminant of concern is expected to drop by five orders of magnitude (S_{II}=5) due to attenuation processes. Therefore, the site has no pathway to the receiving environment (NPR) in this example.

Figure 7. Example Cross-Plot

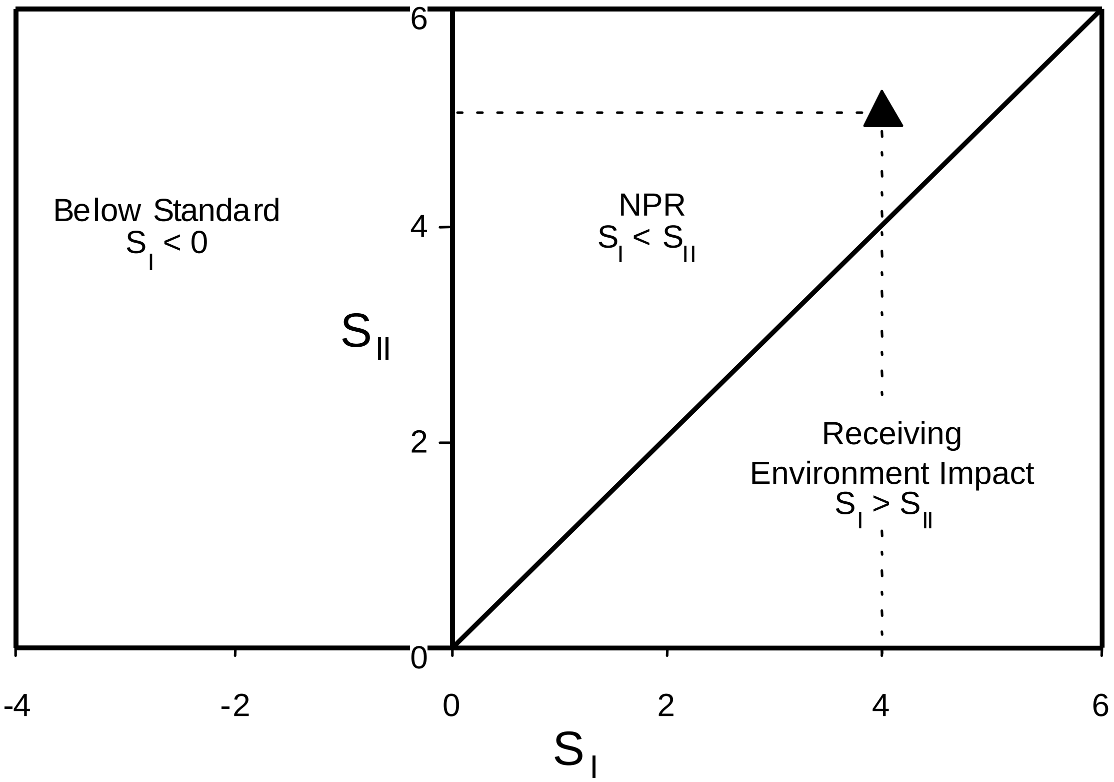


Figure 7 shows that for all S_I values greater than zero, there is no pathway for any corresponding S_{II} that is greater than S_I. Conversely, a source area for which S_I>S_{II} poses a potential risk to the receiving environment.

4.4 STEP 4: COMPLETE SENSITIVITY ANALYSIS

The next step of the SLRA Level 2 Groundwater Module is the sensitivity analysis. In this single-parameter sensitivity analysis, the "worst case" value of a single parameter is substituted for the base case or "best estimate" value, with all the other parameters fixed at the average or base case[32].

The parameters for which a single-parameter sensitivity analysis is required are shown in Table 2. The critical uncertainty range ("worst case") for each site-derived parameter (upper *or* lower bound) is described in the right-most column of Table 2. The uncertainty associated with the distance to the receiving environment and the fraction organic carbon can be estimated either with statistics (as two times the standard deviation of the mean) or as the worst measurement. If the pH and/or groundwater velocity have a normally or log-normal distribution, statistics (for example using probability paper) may also be used.

Table 2. Parameters and Uncertainty Ranges Required for Sensitivity Analysis

Parameter	**"Worst Case" Perturbation**
Distance to receiving environment , x_R	x_R - Δx_R
Velocity, v	$v+\Delta v$
Fraction organic carbon, f_{oc}	f_{oc} -Δf_{oc}
pH	case-specific. The objective is to minimize K_{oc}

For example if the average site groundwater velocity is determined to be 10 m/yr and the upper bound uncertainty associated with this parameter is 5 m/yr, then 10 m/yr would be used for the "base case" and 15 m/yr would be used as the "worst case" in the sensitivity analysis.

In the sensitivity analysis, a minimum of three sets of S_I and S_{II} pairs is computed. For each of these three $S_I - S_{II}$ pairs, one parameter is changed. Following Table 2, the three parameters are:

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[32] A more complex uncertainty analysis may be beyond the scope of SLRA Level 2.

1. Distance to Receiving Environment. S_I and S_{II} must be computed for a distance that corresponds to a minimum distance between the source and the receiving environment.

2. Groundwater Velocity. S_I and S_{II} must be computed for a velocity that corresponds to a maximum groundwater velocity between the source and the receiving environment.

3. Fraction Organic Carbon. S_I and S_{II} must be computed for an f_{oc} that corresponds to a minimum fraction of organic carbon for the site.

In the case of ionizing organics, a sensitivity analysis on the pH must be carried out. SLRA Level 2 only applies for compounds that are more mobile under high pH (i.e., when K_{oc} is relatively low; see Table C-2), so a fourth S_I - S_{II} pair would be computed for a pH equal to pH+Δ pH that corresponds to a maximum pH for the site.

The three (or four) $S_I - S_{II}$ pairs are added to the cross-plot.

4.5 EVALUATE RESULTS OF SLRA LEVEL 2 GROUNDWATER MODULE APPLICATION

If all cross-plot points fall into the "NPR" zone, the groundwater-to-receiving environment pathway does not exist. Screening-level risk assessment is complete for this pathway. If any points fall in the receiving environment impact zone, further assessment of this pathway or remediation is required for this compound.

5 SOIL AND GROUNDWATER CLEAN-UP LEVELS

Under SLRA Level 2 one can calculate site-specific soil and groundwater cleanup targets that are protective of groundwater for drinking water, livestock, irrigation and aquatic life receiving environments.

If a more flexible site-specific soil cleanup target for the protection of groundwater is desired than that provided by SLRA Level 2, the SAB's Hydrogeological Assessment Tools or a detailed risk assessment (DRA) is recommended.

5.1 SITE SOIL CLEAN-UP LEVELS

The methods for evaluating the soil-to-groundwater exposure pathway can be used to calculate protective soil concentrations. The practitioner can work backwards from target groundwater concentrations (either the Schedule 6 groundwater standards or groundwater concentration determined to be protective of all potential receiving environments in the Groundwater Module) to calculate protective soil concentrations.

5.2 SITE GROUNDWATER CLEAN-UP LEVELS

To compute the site-specific groundwater cleanup level, the dimensionless factors are used. The objective is to find the value of S_I (and hence C_{gw}) such that the condition $S_I < S_{II}$ is ensured throughout the site. The cleanup standard is the lesser of the computed $C_{cleanup}$ from Equation 6.1 and the solubility[33] of the compound.

$$C_{\text{cleanup}} = C_{\text{sched\_6}} \times 10^{S_{II}} \qquad \text{Equation 6.1}$$

The base case S_{II} *computed from site data* is used when computing the cleanup standard for remediation.

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[33] The site-specific solubility of the compound must be assessed. SLRA Level 2 does not provide a table of solubilities.

Note that the use of S_{II} when setting site cleanup values is distinct from the use of S_{II} during the screening decision process. In the screening decision process, a sensitivity analysis on the input values to S_{II} is required. Such a requirement would be onerous for setting remediation targets.

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APPENDIX B-1

Justification for Removing Metals K_d Table from SLRA Level 2

Review comments of Section 5.4 of USEPA 1996 part 2 by Dr. Uli Mayer are included below.

SABCS – Comments on approaches for assessing trace metal release and attenuation potential

By Ulrich Mayer, Earth and Ocean Sciences, University of British Columbia, August 12, 2004

Comments on USEPA approach (Section 5.4, USEPA, 1996)

The USEPA has conducted a literature review on K_d values for a number of trace metals determined based on experimental studies (Table 43, USEPA, 1996). From this table and as stated in the EPA report, values for various metals vary significantly from study to study. As stated in the EPA report, it was therefore not possible to derive a set of generally applicable K_d values from experimental data. The large variability of the K_d values makes it clear that attenuation or release potential may be highly variable from site to site and that prediction of trace metal release and attenuation potential based on a *standard parameter set*, will be difficult at best. This is because of the many parameters affecting trace metal mobility, including pH, the presence of clays and oxides, and the presence of ligands (organic acids), redox state, and competition with other ions (USEPA, 1996).

Nevertheless, an attempt was made to derive a standard site- and soil-independent set of K_d-values for metals, which were obtained using MINTEQA2 modeling. This modeling exercise is based on the surface complexation approach, which employs a mechanistic description of trace metal sorption. The results were then parameterized to obtain effective pH-dependent K_d's. As stated in the USEPA-report, this modeling is subject to a number of significant assumptions:

- The modeling was conducted based on the sorption constants available in the database. These constants are only available for amorphous iron oxides, but not for clays, carbonates, Mn-oxides. This implies that the sorption onto these sites was neglected, which is a conservative assumption.
- The simulations were conducted over a pH-range from 4.9 to 8, which covers the pH-range of most natural soils

- The simulations were based on three iron oxide contents of the soils (low, medium, and high, or 0.01, 0.31, and 1.11 wt%). The iron oxide contents were based on 6 (six) soil samples collected throughout the United States. It was assumed that the average value of 0.31 wt % can be used at all sites. This implies that the modeling is not necessarily conducted based on a conservative assumption with respect to iron oxide content.
- Sorption parameters are site- and material-specific. It is impossible to consider this fact in a generic study.

Comparing the K_d values determined based on the modeling study (Table 46 in USEPA, 1996) to measured values (Table 43 in USEPA report), shows in average a fairly good comparison (Section 5.4.4, USEPA, 1996). However, for select trace metals predicted K_d's are much higher than the measured ones from specific studies (USEPA, Section 5.4.4). For example:

- Arsenic (As): predicted K_d is higher than measured K_d by a factor of up to 25,
- Beryllium (Be): predicted K_d is higher than measured K_d by a factor of at least 12,
- Cadmium (Cd): predicted K_d is higher than measured K_d by a factor of up to 160,
- Chromium (Cr): predicted K_d values were higher by orders of magnitude than measured values (which was attributed to a potential experimental error).

In summary, experimental K_d-values reported in Table 43 of the USEPA report indicate that the natural variability of K_d-values is extremely large. Comparing recommended standard values (Table 46 in USEPA, 1996) to the measured values (Table 43 in USEPA, 1996, see also section 5.4.4) suggests that it is very difficult to describe this natural variability with a single standard parameters set, even if pH-dependency is included. This discrepancy suggests that at a certain site, metal release and mobility may be drastically over- or under-predicted, if a standard parameter set is used. In conclusion, it appears to be safer to assess the release of trace metals from specific soils based on leaching tests. This approach would ensure that soil characteristics are taken into account.

Workshop Conclusion

The workshop participants concluded that leaching test were more appropriate that a partition equation for evaluating the soil to groundwater pathway and groundwater transport of metals could be done at a DRA level due to complexity of the processes.

Reference for USEPA, 1996:

United States Environmental Protection Agency, 1996. *Soil Screening Guidance: Technical Background Document,* http://www.epa.gov/superfund/resources/soil/toc.htm

Additional support for the conclusion can be found in the following reference.

Sauve, S., W. Hendershot and H.E. Allen. 2000. Solid-solution partitioning of metals in contaminated soils: dependence on pH, total metal burden and organic matter. Environ. Sci. Technol. 34: 1125-1131.

APPENDIX B-2

Koc Tables for SLRA Level 2

Table B-2-1. Soil Organic Carbon-Water Partitioning Coefficient (K_{oc}) Values: Non-Ionizing Organics.

Hazardous Substance	K_{oc} (ml/g)	Hazardous Substance	K_{oc} (ml/g)
Acenapthene	4,900	Fluoranthene	49,000
Aldrin	49,000	Fluorene	7,700
Anthracene	24,000	Heptachlor	9,500
Benz(a)anthracene	360,000	Hexachlorobenzene	80,000
Benzene	62	α -HCH (-BHC)	1,800
Benzo(a)pyrene	970,000	β-HCH (-BHC)	2,100
Bis(2-chloroethyl)ether	76	γ-HCH (Lindane)	1,400
Bis(2-ethylhexyl)phthalate	110,000	MTBE	11
Bromoform	130	Methoxychlor	80,000
Butyl benzyl phthalate	14,000	Methyl bromide	9
Carbon tetrachloride	150	Methyl chloride	6
Chlordane	51,000	Methylene chloride	10
Chlorobenzene	220	Naphthalene	1,200
Chloroform	53	Nitrobenzene	120
DDD	45,000	PCB-Arochlor 1016	110,000
DDE	86,00	PCB-Arochlor 1260	820,000
DDT	680,000	Pentachlorbenzene	32,000
Dibenzo(a,h)anthracene	1,800,000	Pyrene	68,000
1,2-Dichlorobenzene (o)	380	Styrene	910
1,4-Dichlorobenzene (p)	620	1,1,2,2,-Tetrachloroethane	79
1,1-Dichloroethane	53	Tetrachloroethylene	260
1,2-Dichlororthane	38	Toluene	140
1,1-Dichloroethylene	65	Toxaphene	96,000
Trans-1,2 Dichloroethylene	38	1,2,4-Trichlorobenzene	1,700
1,2-Dichloropropane	47	1,1,1-Trichloroethane	130
1,3-Dichloropropene	27	1,1,2-Trichloroethane	75
Dieldrin	26,000	Trichloroethylene	94
Diethyl phthalate	82	o-Xylene	240
Di-n-butyl phthalate	1,600	m-Xylene	200
EDB	66	p-Xylene	310
Endrin	11,000		
Endosulfan	2,000	VPHw	1,600
Ethyl benzene	200	LEPHw	2,500

Sources for Table B-2-1:

Except as noted below, the source of the K_{oc} values is the 1996 *EPA Soil Screening Guidance: Technical Background Documen*t. The values obtained from this document represent the geometric mean of a survey of values published in the scientific literature. Sample populations ranged from one to 65.

- EDB value from *ATSDR Toxicological Profile* (TP 91/13). http://www.atsdr.cdc.gov/toxpro2.html
- MTBE value from *USGS Final Draft Report on Fuel Oxygenates* (March 1996).
- PCB-Arochlor values from 1994 *EPA Draft Soil Screening Guidanc*e.
- VPHw and LEPHw values from Gustafson, J. B., Tell, J. G. and D. Orem, 1997. *Selection of Representative TPH Fractions Based on Fate and Transport Considerations*. Volume 3 of Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) Series. Amherst, MA: Amherst Scientific Publishers. Available at http://www.aehs.com/publications/catalog/contents/Volume3.pdf.

Table B-2-2. Predicted Soil Organic Carbon-Water Partitioning Coefficient (K_{oc}) as a Function of pH: Ionizing Organics.

Hazardous Substance	**K_{oc} (ml/g)**		
	pH = 4.9	pH = 6.8	pH = 8.0
pH	4.9	6.8	8
Benzoic acid	5.5	0.6	0.5
2-Chlorophenol	400	390	290
2-4-Dichlorophenol	160	150	72
2-Monochlorophenol	80	79	65
3-Monochlorophenol	150	150	140
4-Monochlorophenol	130	120	120
2,3-Dichlorophenol	570	490	160
2,4-Dichlorophenol	460	420	190
2,5-Dichlorophenol	580	480	140
2,6-Dichlorophenol	290	170	22
3,4-Dichlorophenol	580	500	160
3,5-Dichlorophenol	1,000	680	110
2,3,4-Trichlorophenol	1,500	830	110
2,3,5-Trichlorophenol	1,800	1,000	130
2,3,6-Trichlorophenol	2,000	300	22
2,4,5-Trichlorophenol	1,800	1,200	190
2,4,6-Trichlorophenol	1,200	250	19
3,4,5-Trichlorophenol	3,800	3,400	1,300
2,3,4,5-Tetrachlorophenol	5,300	1,100	87
2,3,4,6-Tetrachlorophenol	4,800	270	18
2,3,5,6-Tetrachlorophenol	10,000	440	29
2,3,4,5,6-Pentachlorophenol	9,000	190	12

Source:

- K_{oc} values for the first three compounds are from 1996 *EPA Soil Screening Guidance: Technical Background Documen*t. The predicted K_{oc} values in this table were derived using a relationship from thermodynamic equilibrium considerations to predict the total sorption of an ionizable organic compound from the partitioning of its ionized and neutral forms.

- For the fourth through 22nd compounds, K_{oc} values are derived from the equation:

$$K_{oc} = K_{oc_{non-ionic}} f_n + K_{oc_{ionic}} (1 - f_n)$$

where

$$\log K_{oc_{non-ionic}} = 0.82 \log K_{ow} + 0.14$$

$$K_{oc_{ionic}} = 0$$

$$f_n = \frac{1}{1 + 10^{(pH - pKa)}}$$

The pKa and K_{ow} values used were obtained from Table 8.5.1.1, found on the MWLAP web site at:

http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/chlorophenols/bcchlorophenol-111.htm#P43552_674574

Schwarzenbach et al. (2002)[34] was used to find the Koc (ionic form).

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[34] Schwarzenbach, René, Gschwend, Philip M. and Dieter M. Imboden, 2002. *Environmental Organic Chemistry*, 2nd edition, New York: John Wiley and Sons, 1328 pages.

APPENDIX B-3

Mixing Zone Derivation

The derivation of the mixing zone thickness in USEPA uses the dispersivity relationship of 0.1 of the length of travel along the flow path. To be consistent for source lengths of less than 100 m, the derivation of the mixing zone depth for SLRA Level 2 uses the Neuman 1990 relationship utilized in the groundwater transport section of this report. The derivation of the mixing zone depth only differs slightly from USEPA and this change is included in the derivation below.

From USEPA 1996, section 2.5.5

$$d = d_{\alpha v} + d_{Iv}$$
$$d_{\alpha v} = \left(2\alpha_v L\right)^{0.5}$$
$$\alpha_v = 0.056\alpha_L$$

From Neuman 1990, for travel distances less than 100 m:

$$\alpha_L = 0.0175x^{1.46}$$

Simplifying for the case of $x = L$

$$d_{\alpha v} = 0.044L^{1.23}$$

APPENDIX B-4

Dimensionless Factor (S_I and S_{II}) Derivation

The SLRA Level 2 groundwater transport model uses the one-dimensional Bear (1979) solution to the first-order reactive transport equation. According to Bear (1979), the steady-state concentration of a contaminant at a receiving environment is given by:

$$C(x_R) = C_{gw} \exp\left\{ \frac{x_R}{2\alpha_L} \left[1 - \left(1 + \frac{4\lambda\alpha_L R}{v} \right)^{\frac{1}{2}} \right] \right\} \qquad \text{Equation G.1}$$

where $C(x_R)$ is the concentration at the receiving environment, x_R is the distance to the receiving environment, C_{gw} is the groundwater concentration at the source and/or C_{gw}'[35], α_L is the longitudinal dispersivity, λ is decay constant, R is the retardation factor, and v is the linear groundwater velocity. Equation 4.1 assumes that there is no lateral or vertical dispersive spreading of the plume and decay occurs only in the aqueous phase.

In a risk management-based approach to site screening, contaminant levels at the source should be assessed in relation to the attenuation processes that will take place as contaminants migrate toward a receiving environment. These processes can be characterized using two dimensionless numbers appearing in Equation G.1. These dimensionless numbers are:

$N_D = \frac{x_R}{2\alpha_L}$	This number expresses the relative distance to a receiving environment. If it is large, there is less risk to the receiving environment.
$N_A = \frac{4\lambda\alpha_L R}{v}$	This number characterizes the attenuation of a contaminant due to the combined processes of decay, dispersion, retardation and advection. If it is large, contaminants will be strongly attenuated as they migrate toward a receiving environment.

In terms of these numbers, Equation G.1 can be expressed more concisely as:

$$C(x_R) = C_{gw} \exp\left\{ N_D \left[1 - (1 + N_A)^{\frac{1}{2}} \right] \right\} \qquad \text{Equation G.2}$$

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[35] C_{gw}’ is the soil-predicted groundwater concentration at the down gradient source boundary. If C_{gw}’ is higher than all values of C_{gw}, C_{gw}’ is carried through to predict the risk at the receiving environment.

Sites to be screened out of the regulatory process are those for which $C(x_R)$ is predicted to be lower than a regulatory standard C_{sched_6} in one of two ways:

1. If the measured contaminant concentration, C_{gw}, and/or the soil-predicted groundwater concentration at the source, C_{gw}', is less than C_{sched_6}, the site can be screened immediately.
2. If the measured contaminant concentration at the source, C_{gw} and/or the soil-predicted groundwater concentration at the source, C_{gw}' is greater than C_{sched_6} , then the site can be screened only if the natural attenuation processes characterized by the numbers N_A and N_D are sufficient to reduce $C(x_R)$ below C_{sched_6} at the receiving environment.

If we divide both sides of Equation G.2 by the regulatory standard C_{sched_6}, take their (base 10) logarithms and rearrange terms, the two cases can be expressed mathematically as:

1) Screen site if $S_I = \log\left(\frac{\mathrm{C_{gw}}}{\mathrm{C_{sched\_6}}}\right) < 0$

2) Screen site if $S_I = \log\left(\frac{\mathrm{C_{gw}}}{\mathrm{C_{sched\_6}}}\right) > 0$ and $S_I < S_{II}$

$$\text{where } S_{II} = \frac{N_D\left[(1+N_A)^{\frac{1}{2}} - 1\right]}{\ln 10}$$

APPENDIX B-5

Discussion of Applicability of First-Order Decay Constants

COMMENTS ON FIRST-ORDER DECAY RATES

By Dr. Bruce E. Rittmann[36]

The fundamental questions about using first-order decay rates for modeling the fate of organic contaminants in groundwater are these: "When can they be used to good advantage?" and "When are they likely to be misleading?" These two questions are essentially the "two sides of the same coin." I begin by addressing the "coin," or the foundation for answering each question. Then, I answer each question. Finally, I discuss the role of generic rates for preliminary screening exercises.

General Foundation

The dominant mechanism causing the decay of organic contaminants is biodegradation, which involves oxidation and reduction reactions that are catalyzed by microorganisms. In order to have biodegradation, at least three things must be present together: microorganisms, an electron donor oxidized by the microorganisms, and an electron acceptor reduced by the same microorganisms. The contaminant is either the donor or the acceptor.

This situation can be illustrated simply by a rate expression for a contaminant that is biodegraded by being oxidized, such as toluene:

$$r_D = -k_3 DAX \qquad (1)$$

in which r_D = rate of loss of contaminant (M_D/L^3T), k_3 = mixed third-order rate coefficient (L^6/M_AM_XT), D = donor (and contaminant) concentration (M_D/L^3), A = acceptor concentration (M_A/L^3), and X = biomass concentration (M_X/L^3).

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[36] Dr. Bruce E. Rittmann is the John Evans Professor of Environmental Engineering at Northwestern University. Dr. Rittmann was the chairman of the two National Research Council (NRC) committees that produced *In Situ Bioremediation: When Does It Work? (1993)* and *Natural Attenuation for Groundwater Remediation* (2000). Dr. Rittmann was a member of the Environmental Engineering Committee of the U.S. Environmental Protection Agency's Science Advisory Board in 2002 - 2003 and was elected to the National Academy of Engineering in 2004.

A first-order decay process for the contaminant is represented mathematically by

$$r_D = -k_1 D \qquad (2)$$

in which k_1 is the first-order decay coefficient (1/T). Comparing Eqns. 1 and 2 makes it obvious that

$$k_1 = k_3 AX \qquad (3)$$

For k_1 to be a true constant, the value of AX must be constant. In words, the concentrations of the electron donor and the biomass must not change in time or space for k_1 to be a constant.

Anyone knowledgeable about the subsurface realizes that A and X normally change dramatically in time and space, making AX anything except constant. At the same time, gathering information on how A and X change in time and space is expensive and difficult, whether the gathering occurs by taking field samples or by sophisticated numerical modeling. Herein lies the conflict: We know that assuming a constant first-order decay rate cannot be correct, but the effort to track all donors, acceptors, and biomass seems overwhelming.

If the conflict can be resolved in the right way, first-order rates can bring about real benefit. On the other hand, first-order rates ought to be abandoned when the risk of misuse is too great. This brings me back to the two questions I posed at the beginning.

When Can First-Order Rates Be Used to Good Advantage?

First-order rate coefficients provide value without introducing much risk when they are used on one of two ways. The first way is to compare biodegradation rates among compounds for the same time and place or among times or places for the same compound. For the same time and place, a compound whose k_1 value is 10 times larger than the k_1 value for a second compound definitely is being degraded much faster. Likewise, seeing a tenfold increase in k_1 for the same compound after biostimulation is strong evidence that biostimulation significantly increased the biodegradation rate. Thus, k_1 values provide a convenient scale for comparing rates.

The second way is to estimate unknown concentrations within the regime from which the k_1 value was estimated. This normally is a reliable method to interpolate concentrations between sampling points. The k_1 values also can be appropriate for making modest extrapolations beyond the sampling regime, as long as similar conditions are known to prevail.

When Are First-Order Rates Likely To Be Misleading?

Simple first-order decay rates are likely to be misleading when used to make predictions for settings that are not well characterized. Constant first-order decay rates are especially dangerous when used in a predictive manner, because they cannot take into account factors that determine k_1. For example, the X value in $k_1 = k_3AX$ can span many orders of magnitude, and this means that k_1 can span many orders of magnitude even when good estimates of k_3 and A are available. Furthermore, A and X are likely to change over time and by location.

What about Generic Decay Rates for Preliminary Screening Exercises?

One suggested use for generic first-order decay rates is to do preliminary screening studies. Usually, “conservative” (i.e., small) k_1 values are used with the idea that the results can err only on the “safe side.” The logic is that a model prediction that gives major decay loss with a conservative k_1 is a good sign that biodegradation can be relied up; it is reasonable to explore biodegradation more deeply to confirm that it is effective. On the other hand, minimal decay with a non-conservative k_1 suggests that biodegradation cannot be effective and should be abandoned.

The logic used for such a screening exercise is reasonable, but the choice of conservative values for k_1 must be scrutinized. Here are some situations in which what appears to be a conservative k_1 value is, in reality, too large and, therefore, anti-conservative.

- Some contaminants cannot be biodegraded at all under certain conditions. A key example is benzene under anaerobic conditions. Although toluene, ethyl benzene, and xylene can be biodegraded under all anaerobic conditions, benzene appears to be recalcitrant in many anaerobic situations. Therefore, the only conservative k_1 value for benzene is zero.

- Some contaminants require a co-substrate for biodegradation. The absence of the co-substrate renders the biodegradation rate zero or very small. One example is the oxidative co-metabolism of trichloroethene (TCE) by bacteria that oxidize methane using a methane mono-oxygenase. TCE co-metabolism requires that the methane-oxidizing bacteria, methane, oxygen and TCE be present together. Missing any ingredient prevents co-metabolism, making the TCE-decay rate zero. A second example is reductive dechlorination of chlorinated solvents, such as TCE and 1,1,1-trichloroethane (TCA). An available electron donor must be present along with the solvent to have significant decay by reductive dechlorination. Without the donor, the rate is zero or very small.
- Many of the anaerobic microorganisms that act in the subsurface are slow growers. This means that it can take weeks, months, or even years to grow enough biomass to have non-zero kinetics. Although the k_1 value may eventually become significant, important periods without decay can occur.

A final risk is that the "preliminary screening" part of a "preliminary screening exercise" is forgotten. Any results often become accepted as authoritative, even when their original purpose was only to gain a rough idea of whether or not biodegradation is within the realm of possibility. Those making decisions based on modeling results usually are not savvy about the under-lying assumptions and limitations. Besides, institutional memories are short. Hence, using generic rates is inherently risky due to scientific and sociological factors.

APPENDIX B-6

Decay Constants for Groundwater Transport

Table B-6-1. Generic Decay Constants Permissible in SLRA Level 2[37]

Substance	Fraction		λ days^{-1}	$T_{1/2sat}$ (days)	Reference
VPHw[1]	Aliphatic	C6-8	9.7×10^{-4}	710	CCME (2000)
	Aliphatic	C8-10	9.7×10^{-4}	710	CCME (2000)
	Aromatic	C8-10	9.7×10^{-4}	710	CCME (2000)
LEPHw[1]	Aliphatic	C10-12	4.0×10^{-4}	1,700	CCME (2000)
	Aliphatic	C12-16	4.0×10^{-4}	1,700	CCME (2000)
	Aromatic	C10-12	4.0×10^{-4}	1,700	CCME (2000)
	Aromatic	C12-16	4.0×10^{-4}	1,700	CCME (2000)
Benzene			0	NA	See Appendix B-5
Ethylbenzene			8.4×10^{-4}	850	Kao and Wang (2000)
Toluene			1.3×10^{-3}	530	Kao and Wang (2000)
Xylenes			7.1×10^{-4}	980	Kao and Wang (2000)
Decay constants for non PHC degradables without harmful daughter products					
Naphthalene			4.5×10^{-5}	15,000	Landmeyer et al. (1998)
Pyrene			1.8×10^{-4}	3,800	Tabak et al. (1981)

Note: [1] In general, specifying generic decay constants for mixtures of hydrocarbons is not recommended. In particular, the decay constants referenced here are from the CCME (2000) report and have no referenced scientific studies to justify them. However, they are included in the interest of consistency with CCME guidelines.

For Compounds Not On Table B-6-1:

The SLRA Level 2 Groundwater Module allows the use of literature values of first-order decay. The value selected must be the highest half-life (lowest decay rate) in the literature for environmental conditions that are applicable to groundwater plumes. For compounds used as a primary substrate by micro-organisms (e.g., petroleum hydrocarbons), the lowest decay rate will generally correspond to anaerobic conditions. For compounds degraded as a secondary substrate (e.g., chlorinated solvents), the lowest decay rate will generally correspond to aerobic conditions. A complete reference must be provided for all values listed. *When selecting a value from the literature, the limitations and cautions presented in Appendix B-5 should be considered.* Furthermore, the precluding factor regarding harmful daughter products as defined in Section 4.3 still applies.

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[37] If there are reasons to suspect that a contaminant may not be degrading at the specific contaminated site in question, the decay constants provided are not appropriate. The groundwater module should not be used in these cases. Conversely, if data exists to demonstrate that biodegradation is occurring at rates in excess of those listed in Table C-1, then DRA should be considered as an alternative to SLRA Level 2.

A more detailed review of decay constants was recommended in the CSST review (2005). Specifically two articles were considered, Newell et al., 2002 and Suarez and Rifai, 1999. In addition, the 25th percentile biodegradation rate was compared to the values in SLRA Level 2. This comparison (shown below) highlights the need for a careful consideration of default, generic decay constants.

Comparison of BTEX Chemical Half-lives for First-Order Biodegradation

	$T_{1/2}$ Benzene (days)	$T_{1/2}$ Toluene (days)	$T_{1/2}$ Ethylbenzene (days)	$T_{1/2}$ m-xylene (days)
CSST	365	105	114	183
SLRA Level 2	N/A	530	850	930
25th Suarez and Rifai (1999)	N/A	600	2,000	690

The SAB's Hydrogeological Assessment Tools for Groundwater Decay Constants can be used to derive site-specific decay constants to supersede the conservative, generic values in Table B-6-1 *for a particular site*.

Appendix B-6 References

Canadian Council of Ministers of Environment (CCME), 2000. Canada-wide Standards for Petroleum Hydrocarbons (pHs) in Soil: Scientific Rationale. http://www.ccme.ca/assets/pdf/phc_scirat_final_e.pdf (note: there are no primary references in this document)

Davis, G. B., Barber C., Power, T. R., Thierrin, J., Patterson, B. M., Rayner, J. L. and Q. Wu, 1999. The variability of intrinsic remediation of a BTEX plume in anaerobic sulphate-rich groundwater, *Journal of Contaminant Hydrology*, 36:265 -290.

Kao, C. M. and C. C. Wang, 2000. Control of BTEX migration by intrinsic bioremediation at a gasoline spill site, *Water Research*, 34(13): 3413-3423.

Landmeyer, J. E., Chapelle, F. H., Petkewich, M. D., and P. M. Bradley, 1998. Assessment of natural attenuation of aromatic hydrocarbons in groundwater near a former manufactured-gas plant, South Caroline, USA, *Environmental Geology*, 34(4): 279 -291.

Newell, C., Rifai, H., Wilson, J., Connor, J., Aziz, J., and Suarez, M., 2002. Calculation and use of first-order rate constants for monitored natural attenuation studies. EPA Groundwater Issue, 27 pages.

Suarez, M. P. and H. S. Rifai, 1999. Biodegradation Rates for Fuel Hydrocarbons and Chlorinated Solvents in Groundwater, Bioremediation J., 3(4):337 - 362, 1999.

Tabak H.H., Quave, S. A., Mashni C. I. and E. F. Barth, 1981, Biodegradability studies with organic priority pollutant compounds, *Journal WPCF*, vol. 53, no. 10, 1503-1517 (1 -258 days, Slurry).

APPENDIX B-7

Example of the Groundwater Module

Example 1 – Drinking Water Receiving Environment

In the following example a hypothetical compound is subject to the drinking water standard. Table H-1 lists the parameters and uncertainty associated with parameters relevant to SLRA Level 2.

Table B-7-1. Input Values for SLRA Level 2 Groundwater Module Example

Site-derived Parameters (determined in PSI or DSI by consultant):	
Slug test derived hydraulic conductivity[38], K (m/s)	8.7×10^{-5} +/- 4.5×10^{-5}
Hydraulic gradient, i	0.0015
Linear velocity and uncertainty, *v* (m/yr)	13.8 +/- 7.1
Distance to receiving environment x_R (m)	200 +/-10
Fraction organic carbon[39], f_{oc} (g./g)	0.0043 +/- 0.0014
Saturated porosity	0.3 +/- 0.1
Internal parameters or defaults:	
K_{oc} (L/kg)	200
$t_{1/2}$ (days)	850
COPC standard in groundwater for DW (ug/L)	2.4
Bulk dry density (default allowed) (g/cm^3)	1.7
Soil Assessment:	
Number of soil boreholes at site	10
Number of soil samples analyzed	40
Highest COPC concentration in soil (ug/g)	4.1
Highest soil-predicted groundwater conc[40] (ug/L)	240
Highest COPC conc. measured in groundwater (ug/L)	240
Groundwater Assessment:	
Number of wells used to assess hydraulic conductivity	5
Number of f_{oc} measurements	7
Number of monitoring wells developed	8
Number of samples analyzed	30
Maximum borehole diameter (cm)	25
Length of well screens (m)	2
Diameter of monitoring pipe (cm)	10

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[38] Uncertainty associated with this value is taken to be the standard deviation associated with the 5 measurements taken.

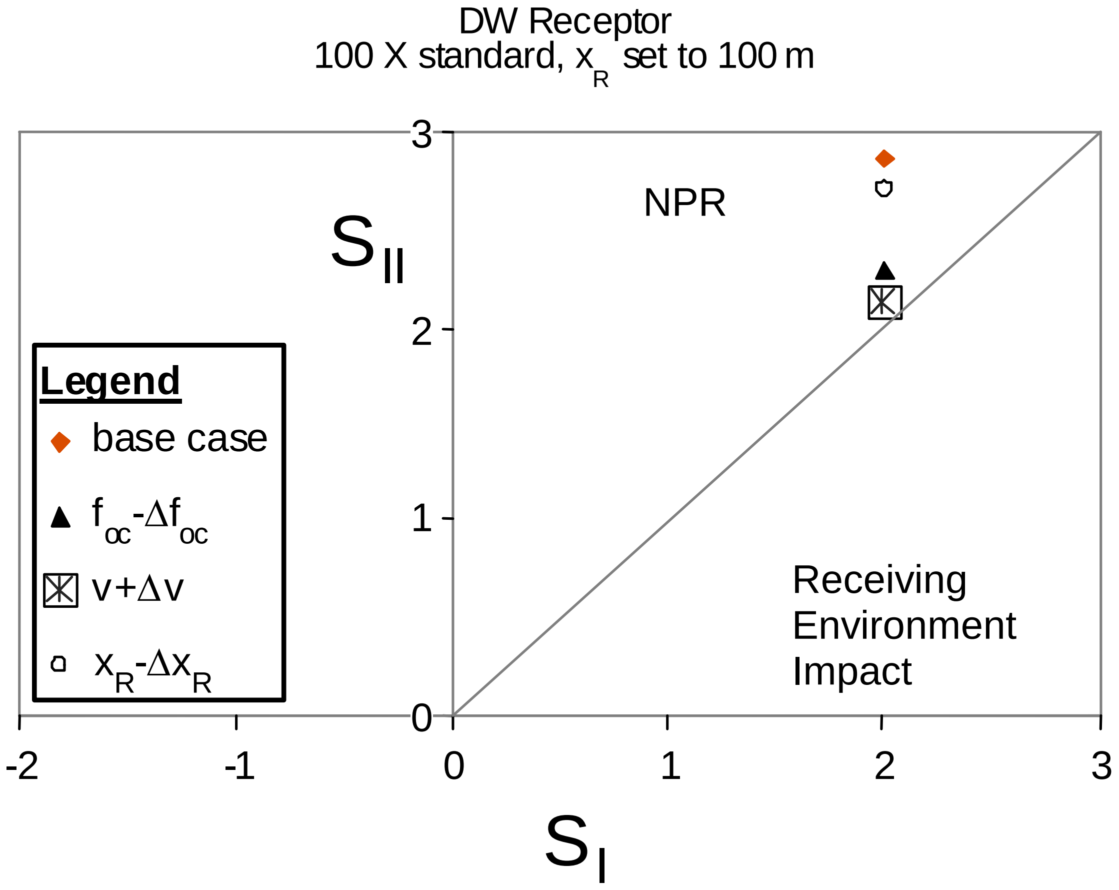
[39] 7 measurements taken.

[40] DF = 20 was applied.

Using the SLRA Level 2 proposed approach, the maximum allowable distance to receiving environment for sites subject to the DW standard is 100 m. Therefore, 100 m, not the measured distance to receiving environment of 200 m is used in the cross-plot shown in Figure B-7-1. In this example, the downgradient property boundary was at 120 m and did not impact the determination of the distance to the receiving environment.

It is clear in Figure B-7-1 that at 100 m, the risk to the receiving environment is acceptable for soil-predicted and measured groundwater concentrations. For this example, the model was most sensitive to uncertainty in the groundwater velocity.

Figure B-7-1. Example Cross-Plot



APPENDIX B-8

Simple Instructions for Using the MWLAP Classification of Aquifers for Contaminated Sites Assessment under SLRA Level 2

From the MWLAP groundwater site, http://wlapwww.gov.bc.ca/wat/gws/index.html

Click on aquifers and from there click on Aquifers and Water wells in BC:

http://maps.gov.bc.ca/apps/wlap_aquifer/

1. View map of province
2. Find Location (blue bar above the map)
3. Place Name (side bar option)
4. Enter place name (for example, Castlegar)
5. Click on "Layers" (blue bar)
6. Under base-auto scaling[41] add water and transportation if these help to identify the location of the site on the map.
7. Under water management click on aquifer vulnerability and if required, demand and productivity.
8. Alternatively, if the site is within or above an aquifer, click on the aquifer in question and all classification information will appear in the side bar.

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[41] It can make the map clearer at small scales if Base-by-Scale is removed. Also changing the scale in the lower left bar to 1:200,000 can help as well

Screening-Level Risk Assessment (SLRA)

Level 2

VAPOUR INTRUSION MODULE

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1 OVERVIEW

Vapour intrusion is the migration of volatile or semi-volatile chemicals from contaminated groundwater and soil into overlying buildings. When releases occur near buildings, volatilization of contaminants from the dissolved or non-aqueous phases in the subsurface can result in the intrusion of vapour-phase contaminants into indoor air. This document provides guidance on screening level risk assessment (SLRA) specific to the vapour intrusion exposure pathway as part of the Screening Level Risk Assessment process in British Columbia. This guidance is relatively simple to implement and is based on data normally obtained during the characterization of contaminated sites.

A flow chart summarizing the SLRA guidance framework for vapour intrusion is provided in Figure 1. The first step in the vapour intrusion assessment protocol is the development of a site conceptual model. Following the development of the conceptual model, the guidance consists of two tiers. The first tier, Preliminary Screening, is a qualitative screening step to categorize sites according to their potential for vapour intrusion and to determine whether further assessment is needed, i.e., whether the assessment should proceed to the second tier. The first tier is part of the SLRA Level 1 protocol and can be found in the SLRA Level 1 report.

The second tier, Secondary Screening, is part of the SLRA Level 2 protocol and consists of a screening-level quantitative risk assessment where representative semi-site specific vapour attenuation factors are used to estimate indoor air concentrations, which, in turn, are used to identify NPR sites[1]. The ***vapour attenuation factors***, defined as the indoor air concentration divided by the soil vapour concentration at some depth, are based on the results of model predictions using the Johnson and Ettinger (J&E) model. If indoor air concentrations predicted by SLRA Level 2 are lower than the indoor air guidelines, then vapour intrusion would not be considered an issue at the subject site. If predicted indoor air concentrations exceed acceptable levels, then it does not necessarily indicate that an unacceptable risk actually exists. However, it

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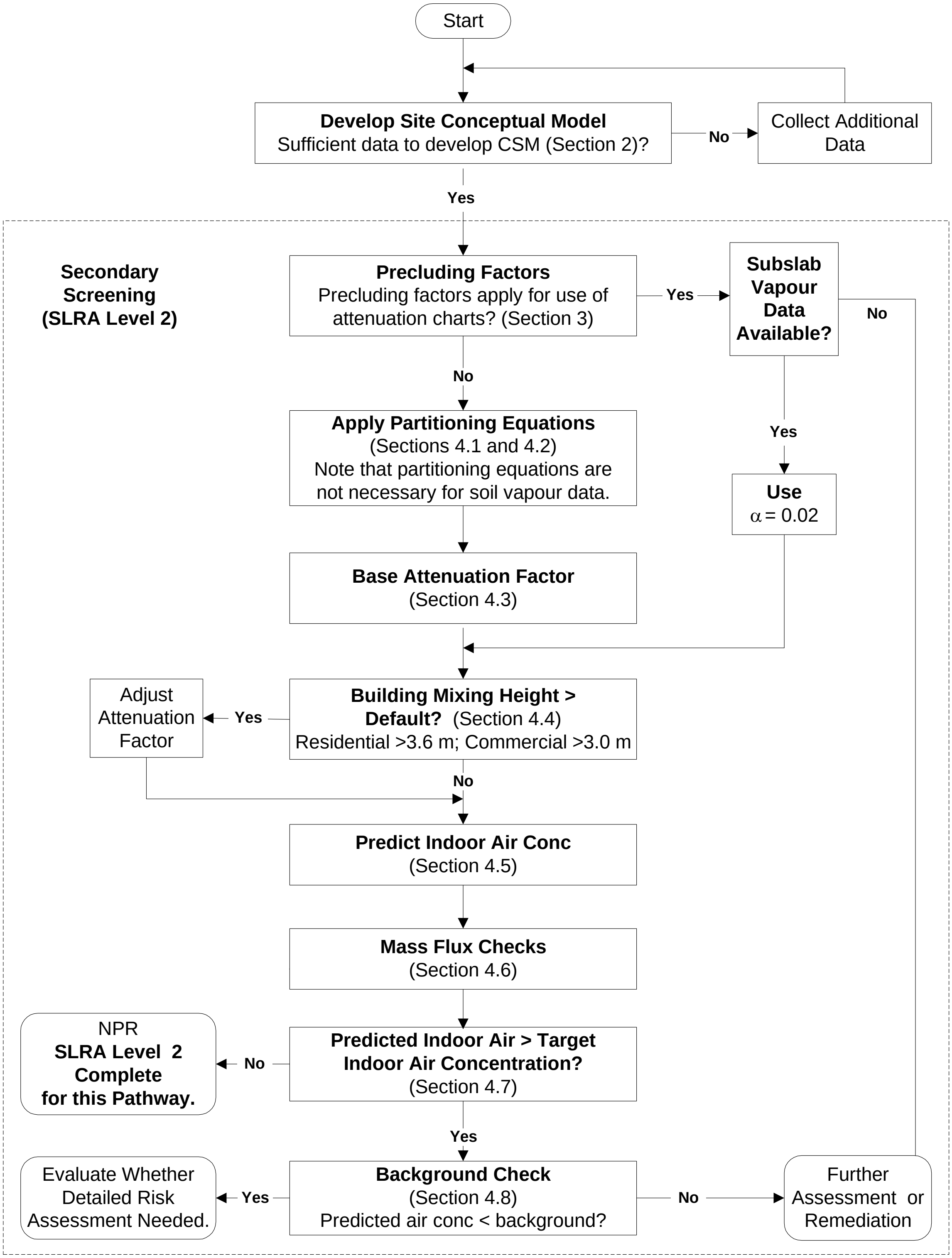
[1] As indicated in the introduction to SLRA, NPR sites are those in which there is either no pathway or no protected receptor.

Figure 1. Flow Chart for SLRA Level 2 Vapour Intrusion Guidance



does indicate that a more detailed and comprehensive risk assessment may be necessary. Alternatively, the stakeholder may elect to undertake the option of remediation (including risk management) without further risk assessment efforts.

The vapour intrusion SLRA does not include guidance on detailed site-specific risk assessment or methods to eliminate potential risk through, for example, exposure controls. Furthermore, the guidance does not provide recommendations on approaches for verification of risk predictions through testing of indoor air, and only limited guidance is provide on subslab vapour testing.

The focus of this guidance is protection of human populations from chronic health risks due to long-term exposure to vapours at low concentrations. The vapour intrusion SLRA is intended for application where there are currently occupied buildings at existing residential and commercial sites, or where there are potentially occupied buildings in a future land use scenario, provided the development parameters are within the range of conditions assumed in the guidance. Separate vapour attenuation factors are provided for representative residential and commercial buildings.

This guidance reflects the current state of knowledge on vapour intrusion.[2] Since vapour intrusion is a developing field of science, it is expected that this guidance will be updated when warranted. It is also important to emphasize that due to uncertainties associated with the vapour intrusion pathway, professional judgment has played a role in the development of the criteria used to screen sites and the models used to derive vapour attenuation factors. The intended users of this guidance are professionals with some experience in vapour intrusion risk assessment.

The main body of this guidance begins with a description of conceptual models for vapour intrusion. Subsequent sections describe the SLRA Level 2 screening process and precluding factors for use of the SLRA Level 2 screening process.

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[2] The approach for the SLRA Level 2 Vapour Intrusion Module is similar to the framework adopted for the Canadian Council for Ministers of Environment (CCME) Canadian Wide Standard (CWS) – Petroleum Hydrocarbon Compound (PHC) framework, with adjusted vapour attenuation factors based on the current scientific knowledge. The vapour attenuation factor is the inverse of the CWS-PHC vapour dilution factor.

Supporting documentation for the SLRA Level 2 vapour intrusion screening process is found in the following appendices:

- Appendix C-1 describes the framework and methodology for the derivation of the indoor air standards and provides an example of how to back calculate acceptable risk based on soil vapour and groundwater criteria.
- Appendix C-2 “*Derivation of Vapour Attenuation Factors*” includes the supporting protocol to this guidance.

2 CONCEPTUAL SITE MODEL

A Conceptual Site Model (CSM) should be developed for the site prior to conducting the Preliminary or Secondary Screening. The conceptual site model should include all relevant available data from the site including:

- Information on concentration, distribution and extent of chemicals of concern (groundwater, soil, soil vapour, non-aqueous phase liquid (NAPL));
- Hydrogeological information (depth to groundwater, groundwater direction and velocity);
- Description of land use and conditions surrounding the building (e.g., paved area, landscaped areas).
- Vadose zone soil properties (including lithology and grain size);
- Approximate size, location and type of building structure; and,
- Location of utility lines.

An example of a CSM is shown on Figure 2.

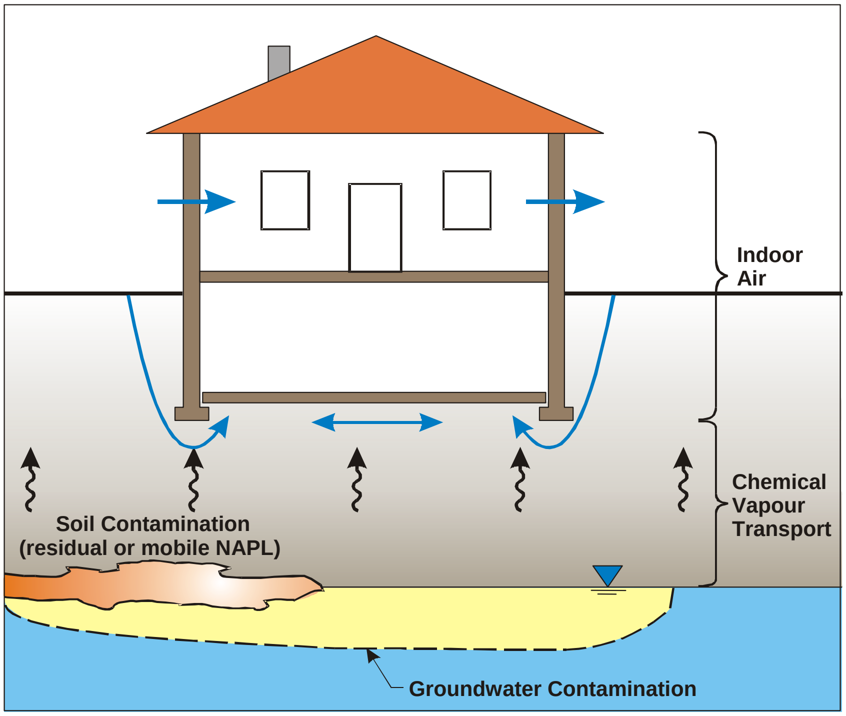
The fate and transport of a chemical from a subsurface source and the ultimate concentration inside a building are controlled by processes that occur in four “compartments” that consist of the saturated zone, vadose zone, building envelope (foundation, walls and nearby utility corridors), and the building. The discussion below focuses on the latter three compartments.

2.1 TRANSPORT AND FATE IN VADOSE ZONE COMPARTMENT

In developing a CSM for the vadose zone, the following factors must be considered:

- Vapour phase diffusive transport of the chemical,
- Vapour phase advective transport of the chemical,
- Biological and abiotic transformation of the chemical,
- Interphase partitioning of the chemical, and
- Overall chemical mass balance.

Figure 2 Conceptual Site Model for Vapour Intrusion – Residential Site



The transport of chemicals in the vadose zone is controlled by chemical diffusion, gas-phase and water-phase advection, and NAPL movement. In most settings, gas-phase diffusion is the dominant transport pathway. The rate of diffusive transport is a function of the concentration gradient and the temperature of the medium through which diffusion is occurring. Soil properties that affect diffusion and gas-phase advection include soil moisture content, porosity, and permeability. Diffusion coefficients in air are about four orders-of-magnitude higher than in water; therefore, diffusive flux tends to be much higher through the air-filled than water-filled soil pores. Advective transport near the building envelope due to pressure coupling between building and soil will be highly dependent on foundation construction and soil permeability. Driving forces for gas-phase advection are pressure gradients due to barometric pressure variation, building underpressurization, water movement, and density gradients due to compositional and temperature variation. Environmental and seasonal factors that affect vadose zone transport processes include precipitation, barometric pressure, wind, water table levels, temperature, snow and frost cover.

The fate of chemicals in the vadose zone is controlled by biological and chemical transformation, and partitioning between the sorbed, soil gas, soil water and NAPL phases (when present). The CSM should identify which of these fate pathways is operable at the site.

Finally, unless there is a constant replenishment of the chemical source, the processes are dynamic and transient since the chemical will be depleted through biodegradation, volatilization (i.e., source depletion), and dissolution through infiltration of surface water.

2.2 SOIL VAPOUR INTRUSION THROUGH BUILDING ENVELOPE COMPARTMENT

Soil vapour intrusion through the building envelope will occur as a result of advective and diffusive soil gas transport through untrapped drains, perimeter cracks at the building wall and floor slab interface, service penetrations, expansion joints and other cracks, if present. The main driving forces for advection are likely building underpressurization and barometric pressure fluctuations. Building underpressurization is controlled by a combination of wind-loading, temperature differences between indoor and outdoor air, and forced-air building ventilation. The subsurface pressure and soil gas flow regime adjacent to, and through the building envelope, will be highly dependent on site specific factors such as building construction, foundation backfill properties, soil permeability and potential preferential pathways such as utility corridors. Diffusive mass flux through the building envelope will be controlled by building construction including the properties of dust-filled cracks, subsurface vapour barrier and type of concrete construction (i.e., poured concrete or concrete block).

Soil vapour intrusion into a building with a crawlspace is largely affected by the degree to which the crawlspace is ventilated by outside air, and whether the crawlspace is connected to the airspace in the rest of the building (e.g., through heating system). In addition to migration through subsurface components of the building envelope, volatile chemicals that have migrated from the subsurface to ambient air could enter a building through windows, doors and other above-ground vents and other openings. Volatilization to outdoor air followed by transport to indoor air is generally not considered to be a significant pathway due to dilution that occurs in ambient air.

2.3 MIXING OF VAPOURS INSIDE THE BUILDING COMPARTMENT

Vapours inside enclosed spaces will diffuse as a result of chemical gradients and disperse through air movement. Mixing between building floors will depend on the heating, ventilation and air conditioning (HVAC) system and possible unintentional air leakage between floors. Most models used for screening-level risk assessment assume uniform and instantaneous mixing of vapour within the enclosed space.

2.4 IDENTIFICATION OF VOLATILE COMPOUNDS OF CONCERN

Appendix C-1 describes the process by which volatile and/or toxic compounds are identified. Appendix C-1 also summarizes the methodology used to define indoor air concentrations that are protective of human health.

3 PRECLUDING FACTORS AND SUBSLAB DATA

3.1 TREATMENT OF INDUSTRIAL SITES

In general, the vapour intrusion SLRA approach should not be applied to industrial sites. In many cases, workers at industrial sites are, with their knowledge, exposed through their occupation to a range of chemicals, which can include those chemicals commonly associated with subsurface vapours. For industrial sites, worker exposure is typically evaluated using permissible exposure limits based on legislation or guidance pertaining to occupational settings, as opposed to the conservative human health toxicity reference values for air adopted for this guidance. However, where subsurface chemicals are different from those used in the workplace, it is recommended that the potential implications of vapour intrusion on worker safety be considered.

3.2 VAPOUR INTRUSION MODULE PRECLUDING FACTORS

When site-specific conditions fall outside of the conceptual site model (CSM) assumed by the J&E model (Johnson and Ettinger, 1991), the Level 2 screening process should not be followed, and instead the assessment should proceed to a detailed risk assessment. This is because the J&E model is based on a simplified representation of physical processes, which causes the J&E model to be less accurate when the site-specific conditions are different from the CSM described by the J&E model. The screening level vapour attenuation factors should not be used when the following *precluding factors* apply:

Expanding Soil Vapour Source: The SLRA Level 2 vapour intrusion assessment protocol assumes that the source of vapour (e.g., groundwater plume, NAPL zone) is not expanding. If further vapour source migration is occurring or likely to occur, SLRA cannot be applied to screen the site.

Shallow Depth to Contamination: Sites with a contaminant source within 1 metre of the building foundation should be precluded from SLRA Level 2. When the contamination source is within 1 metre of the building, the vapour attenuation factors used for this guidance are unreliable as a result of seasonal water table fluctuations, the varying thickness of the tensionsaturated zone (capillary fringe), which depends on soil texture, and the possible presence of sumps in basements.

Crawl Spaces and Earthen Basements: Buildings with unlined crawl spaces or earthen basements should be precluded from SLRA Level 2, unless the depth to the contaminant source is sufficiently deep that transport processes within the soil zone control the vapour flux into the building, as opposed to the building foundation characteristics. The depth where the crawl space or earthen basement property is no longer important will depend on site-specific conditions. A conservative value for this depth is 5 m. Therefore, buildings with unlined crawl spaces or earthen basements where contamination is less than 5 m below the building should be precluded from SLRA Level 2.[3]

Very High Gas Permeability Media: Buildings constructed on vertically or near vertically fractured bedrock, karst, cobbles or other media with unusually high gas permeability should be precluded from the SLRA Level 2 Vapour Intrusion Module. Soil gas advection within the unsaturated zone (i.e., beyond the soil zone immediately around the building), caused by barometric pumping or other environmental factors, can be important in these scenarios and is not part of the CSM described by the J&E model.

Subsurface Utility Conduit Connecting Contamination Source and Building: Common anthropogenic features such as floor drains, sewer lines and utility conduits are present at most sites. The presence of these features is not normally considered a precluding factor. However, if there are utility conduits that directly connect the contaminant source to the enclosed space of the building, then this should be taken as a precluding factor.

Poorly Characterized NAPL: The presence or suspected presence of non-aqueous phase liquid (NAPL) below or near to the building is not considered to be a precluding factor for Secondary Screening provided that soil vapour samples are obtained from slightly above the NAPL zone. However, as discussed below in Section 4, the vapour intrusion pathway can be evaluated at sites with less-dense-than water NAPL using soil vapour data but ***not*** using groundwater data.

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[3] Additional evaluation of whether the 5 m criteria can be supported scientifically is on-going

If one of these precluding factors applies to the site, then the SLRA Level 2 Vapour Intrusion Module can only be used if subslab vapour measurements are available and consistent with ministry guidance. Subslab vapour measurements if used for screening purposes should be representative and not subject to precluding factors described above (e.g., preferential pathways). For cases where subslab vapour measurements are available select a base attenuation factor of 0.02 (justification presented in Table 9 of Appendix C-2) and go to Section 4.4.

For the majority of sites where one of these precluding factors apply, the assessment should proceed to detailed risk assessment. Detailed risk assessment, while beyond the scope of this document, will typically comprise site-specific modeling often in conjunction with subslab and indoor air measurements.

4 PROCEDURE FOR SLRA LEVEL 2 VAPOUR INTRUSION MODULE

4.1 STEP 1: ATTAIN DATA FOR SLRA LEVEL 2 SCREENING

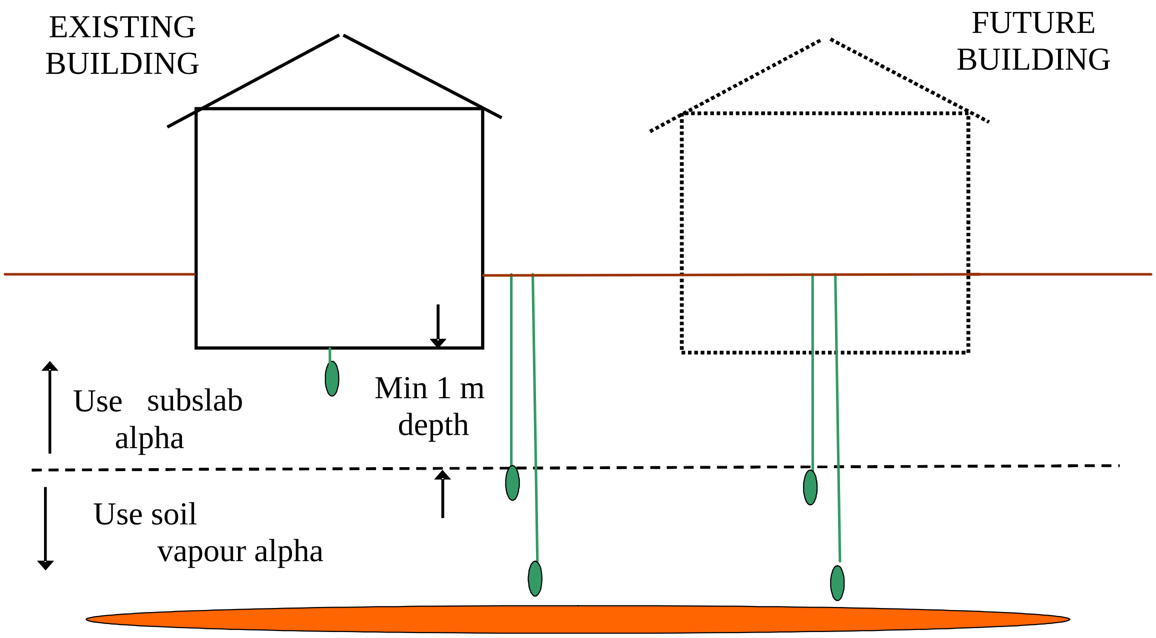
As per Figure 1, the first step is the determination of soil vapour concentrations. The preference of this guidance is the analysis of soil vapour and groundwater. For sites with less-dense-than-water NAPL (e.g., petroleum hydrocarbons) in either continuous or residual form, soil vapour data is to be used in the assessment. For sites where the source of volatile compounds is groundwater (e.g., downgradient of a denser-than-water NAPL release), groundwater data can be used instead of or as a supplement to the soil vapour data. The use of soil (matrix) data in this screening process will likely result in large uncertainties and is not recommended.

4.1.1 Soil Vapour Data

Soil vapour characterization, while subject to some uncertainty and data quality issues, is nevertheless considered to provide a more direct characterization of source vapour concentrations and potential risk through vapour intrusion than soil (matrix) characterization since the partitioning calculations are by-passed. Furthermore, soil vapour data is the most reliable source of information for vapour intrusion from a light nonaqueous phase liquid source. Soil vapour characterization programs can include both measurement of soil vapour concentrations directly above the contamination or higher up in the unsaturated zone, providing the measurement point is at least 1 m below the building (Figure 3).

For situations where the source of volatile compounds is groundwater, multiple lines of evidence should be used as a cross check to assess if the field collected data is consistent with the results from modelling. For example if soil vapour data is only available for one location and the results are below the detection limit, it is possible that either the vapour sample was not collected properly (i.e., not collected under a vacuum) or there were other factors mitigating the vapour

Figure 3. Conceptual Model for Use of Soil Vapour Measurements



Vapour Contamination Source

source or generating a false negative. If, however, the partitioning equations (see Section 4.2) indicate that there could be vapours at an unacceptable concentration, additional sampling might be warranted. The assessor should be aware of widely diverging results (e.g., soil vapour concentration less than the detection limit, while the partitioning calculations indicate an unacceptable soil vapour concentration) and should use the partitioning equations as a cross check with field data.

It is important that appropriate protocols are followed for sampling and analysis of soil vapour. The design of soil vapour characterization programs, particularly at sites with deep vadose zones and multiple depth samples, should consider possible temporal changes in vapour concentrations due to transient vapour migration. Sorption and biodegradation can delay the development of steady-state vapour concentration profiles. Measurement of fixed gases such as oxygen and carbon dioxide can also be helpful in interpretation of vadose biogeochemical processes. Nomographs that enable estimation of the approximate time for vapour concentrations to reach steady state conditions are provided in Johnson et al. (1998) and API (2004).

When using soil vapour concentrations to determine the risk of vapour intrusion to buildings, partitioning calculations are not required and the user should proceed to Section 4.3 of the guidance.

4.1.2 Groundwater Data

Groundwater characterization studies should provide information on concentrations in groundwater near to the water table. This is because cross-media transfer from groundwater to soil vapour occurs when chemicals in pore-water volatilize into soil gas. Therefore, groundwater data can be used to characterize the horizontal distribution of soil vapour.

When evaluating the soil vapour intrusion pathway using groundwater data, relatively short monitoring well screens situated across the water table are recommended. However, since hydrogeologic systems can undergo changes, due to natural seasonal fluctuations of the water table elevation and/or through human activities, contaminants at depth within groundwater systems could pose future vapour intrusion potential. Consequently, it is recommended that groundwater characterization programs also include investigation of vertical concentration variability either through the use of nested wells (at different elevations) or vertical profiling using a Geoprobe or similar groundwater sampling technique. As warranted, groundwater characterization for evaluation of soil vapour intrusion should take into consideration concentration gradients and the possible effect of future water table fluctuations.

When groundwater concentrations are used for soil vapour assessment, partitioning calculations are required to estimate soil vapour concentrations. The practitioner should proceed to Section 4.2 of the guidance.

4.1.3 Soil Matrix Data

The preference of this guidance is for risk characterization based on analysis of groundwater and soil vapour samples. There are a number of uncertainties associated with the use of soil (solid or matrix) data. Depending on the contaminant type and geologic conditions, there may be significant spatial variation in soil concentrations, which may be difficult to detect based on conventional sampling programs. Finally, there are uncertainties associated with soil partitioning calculations and predicted vapour concentrations are sensitive to the partitioning coefficient between water and organic carbon, and the fraction organic content in soil, a parameter that can be difficult to accurately determine. If soil analysis results are to be used for the vapour pathway, it is recommended that that the soil samples be field preserved (e.g., using methanol), where possible. *The practitioner is advised that the accuracy of the assessment will tend to be poor when soil matrix data is used.*

When soil matrix concentrations are used for soil vapour assessment, partitioning calculations are required to estimate soil vapour concentrations. The practitioner should proceed to Section 4.2 of the guidance.

4.2 STEP 2: APPLICATION OF PARTITIONING EQUATIONS

In the absence of soil vapour data, partitioning equations are used to predict soil vapour concentrations on the basis of groundwater or soil data. The means to use the partitioning relationships are provided in Exhibits 1 and 2 . Chemical-specific data required for the equations are found in Tables 1 and 2 of Appendix C-1. Derivations of the partitioning relationships can be found in Appendix C-2, Section 1.3. If at this early stage, the predicted vapour concentration does not exceed the indoor air guideline *and* the measured vapour concentrations also do not exceed the limit, the vapour intrusion pathway will not be of concern for that particular chemical. The screening process can then cease at this point.

4.2.1 Groundwater-to-Soil Vapour Partitioning Calculations

When the groundwater concentration is below the solubility limit, the soil vapour concentration is computed using Henry’s Law. The equilibrium partitioning of a chemical between the gas and water phases is governed by Henry’s Law, which is a linear relationship. Henry’s Law is applicable for most organic contaminants that are sparingly soluble (the mole fraction of that contaminant in water is less than 0.001).

When the groundwater concentration is at the solubility limit, the NAPL to vapour partitioning relationship is used.

4.2.2 Soil-to-Soil Vapour Partitioning Calculations

A *three-phase* model describing partitioning between the sorbed, soil-water and soil-air phases is assumed when no non-aqueous phase liquid (NAPL) is present. Henry's Law describes partitioning between the gas and water phases. For partitioning between the sorbed and aqueous phases, a linear absorption model based on the soil organic matter content is typically used to predict the sorbed concentration under equilibrium conditions.

For a single chemical, NAPL will not be present at concentrations below the soil saturation limit[4] (USEPA, 1996; ASTM E1739). When NAPL is present, a *two-phase* partitioning model is used where partitioning between NAPL and air phases is proportional to the vapour pressure of the compound. When multi-component mixtures are present, partitioning based on Raoult's Law is typically used to quantify the effective solubility of an individual chemical in the mixture under equilibrium conditions, and is also used to predict the vapour concentration when NAPL is present.

The three-phase model predicts that the vapour concentration directly above the source of soil contamination cannot be greater than that associated with the soil saturation concentration; for groundwater contamination, the vapour concentration cannot be greater than that associated with the solubility limit. When a soil concentration is greater than C_{sat} and groundwater concentration is greater than the solubility limit, the NAPL to vapour partitioning relationship is used, and vapour concentrations are constant regardless of concentration. If the vapour concentration predicted based on the NAPL to vapour relationship does not exceed the health-based limit in indoor air, the vapour intrusion pathway will not be of concern for that particular chemical. There may, however, be other potential exposure pathways of concern when NAPL is present at a site.

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[4] See Appendix C-2, Equations 10 and 11 for a definition of the soil saturation limit.

EXHIBIT 1
PARTITIONING EQUATIONS

1. Groundwater Contamination Source (*Preferred*)

If $C_{w,i} < X_i * S_i$ then $C_{a,i} = UCF_2 * C_{w,i} * H'$

If $C_{w,i} >= X_i * S_i$ then $C_{a,i} = \max [UCF_2 * X_i * S_i * H', UCF_1 * MW_i * P_i / RT]$

2. Soil Contamination Source (*Not Recommended*)

If $C_{soil,i} < C_{sat,soil,i}$ then $C_{a,i} = UCF_2 * C_{soil,i} * H' * \rho_b / (\theta_w + K_{oc}*f_{oc}* \rho_b + H'*\theta_a)$

If $C_{soil,i} >= C_{sat,soil,i}$ then $C_{a,i} = \max [UCF_2 * C_{soil,i} * H' * \rho_b / (\theta_w + K_{oc}*f_{oc}* \rho_b + H'*\theta_a), UCF_1 * MW_i * X_i* P_i / RT]$

Parameter	Default
$C_{w,i}$ = Soil-water concentration (mg/L)	Measured site specific
X_i = Mole fraction (unitless)	Estimated from chemical data
S_i = Pure-chemical solubility (mg/L)	Chemical specific
$C_{a,i}$ = Soil-air concentration (mg/m^3)	Calculated
H' = Dimensionless Henry's Law Constant	Chemical specific
UCF_1 = Unit conversion factor	1,000 mg/g
UCF_2 = Unit conversion factor	1,000 L/m^3
MW_i = Molecular weight (g/mole)	Chemical specific
P = Pure chemical vapour pressure (atm)	Chemical specific
R = Gas constant (m^3-atm/K-mole)	8.21E-05
T = Absolute temperature (K, 273^{o}C + T(^{o}C))	Estimated, site specific
$C_{soil,i}$ = Total soil concentration (mg/kg)	Measured site specific
$C_{sat,soil,i}$ = Soil saturation concentration (mg/kg)	Calculated
ρ_b = Dry bulk density (kg/L)	1.7
θ = Total porosity (dimensionless)	0.375 (coarse-grained soil)
	0.399 (fine-grained soil)
θ_w = Water-filled porosity (dimensionless)	0.054 (coarse-grained soil)
	0.148 (fine-grained soil)
K_{oc} = Organic carbon-water partitioning coefficient (mg/kg-OC per mg/L-water)	Chemical specific
f_{oc} = Fraction organic carbon (dimensionless)	0.006 (recommend site-specific measurement)
θ_a = Air-filled porosity (dimensionless)	$\theta - \theta_w$

Note: For chemicals that are solids at room temperature the subcooled liquid solubility should be used in place of the solid solubility. Calculations for temperature corrected vapour pressure and Henry's constant are shown in Exhibit 2

EXHIBIT 2
TEMPERATURE CORRECTED VAPOUR PRESSURE AND HENRY’S CONSTANT

1. Temperature Corrected Vapour Pressure

$P' = P \exp (\Delta H_1/R_1 * (1/T_r-1/T_s))$

2. Temperature Corrected Henry’s Law

$H'' = \exp(-\Delta Hts/R_2 * (1/T_s-1/T_r)) * H/(T_s * R_3)$

$\Delta H_{ts} = \Delta H_2 [(1-T_s/T_c)/ (1-T_b/T_c)]^{\eta}$

if $T_b/T_c < 0.57$ then $\eta = 0.3$

if $T_b/T_c = 0.57$ to 0.71 then $\eta = 0.74 (T_b/T_c) – 0.116$

if $T_b/T_c > 0.71$ then $\eta = 0.41$

Parameter	**Default**
P = Pure chemical vapour pressure (atm)	Chemical specific
P’= Temperature corrected pure chemical vapour pressure (atm)	Chemical specific
ΔH_1 = Enthalpy of vaporization at normal boiling point (j/mol)	Chemical specific
ΔH_2 = enthalpy of vaporization at normal boiling point (cal/mol)	Chemical specific
ΔHt_1s = Enthalpy of vaporization at average soil temp (cal/mol)	Chemical specific
H = Henry’s Law Constant (atm-m^3/mol)	Chemical specific
H” = Temperature corrected dimensionless Henry’s Law Constant	Chemical specific
R_1 = Gas constant (j/mol-°K)	8.3145
R_2 = Gas constant (cal/°k-mol)	1.9872
R_3 = gas constant (m^3-atm/k-mol)	8.21×10^{-5}
T_r = Reference temperature (°K)	Specific to the temperature used for the derivation of the Henry’s Constant
T_s = Average soil temperature (°K)	Site specific
T_c = critical temperature (°K)	Chemical specific
T_b = normal boiling point (°K)	Chemical specific

4.3 STEP 3: SELECTION OF BASE VAPOUR ATTENUATION FACTORS

Soil vapour at a contaminant source would be subject to diffusion and advection (attenuation) within the soil-vapour-to- indoor pathway. The vapour attenuation factor is the ratio of vapour concentration in the indoor space to the vapour concentration at the contamination source.

4.3.1 Introduction to Attenuation Factor Charts

The attenuation factor charts are provided in Figures 4 to 7. The charts were derived using the J&E model (Johnson and Ettinger, 1991), as described in detail in Appendix C-2. The following assumptions were made during the preparation of the charts:

- The contaminants are homogeneously distributed at their source, are present below the entire building, and source concentrations remain constant over time.
- For the residential scenario, the attenuation factors assume a single family residence with a basement. A slab-on-grade scenario was also considered as part of the development process, and was found to yield similar factors compared to a basement, therefore, only a basement scenario was included. For the commercial scenario, a slab-on-grade scenario was assumed.
- The attenuation factor charts are based on physico-chemical properties for benzene, but are applied to all chemicals with the assumption that their properties are sufficiently similar to benzene for screening purposes. This is a reasonable assumption since the free-air diffusion coefficient, which is the main physical-chemical parameter affecting the attenuation factor, varies by about a factor of two for most volatile chemicals.
- Two different types of contaminant sources are assumed:
    1. A contaminant source in groundwater, such that chemical transport occurs through both the capillary transition zone and unsaturated zone, and
    2. A contaminant source in soil with accompanying vapour-phase transport through the unsaturated zone.

As part of the attenuation factor derivation process, the model-predicted attenuation factors were found to be reasonably protective, in that the measured attenuation factors were, in almost all cases, less than those predicted using the J&E model (see Appendix C-2, Section C-2-5). The vapour attenuation factor charts developed for this guidance assume no biodegradation of hydrocarbons such as benzene, toluene, ethylbenzene and xylenes (BTEX).

4.3.2 Guide to Use of Attenuation Factor Charts

The following factors must be considered when using the attenuation factor charts:

4.3.2.1 Soil Type

The vapour attenuation factors are derived for two soil types; fine grained and coarse grained. Fine grained soils are defined as having a median grain size of less than 75 μm and coarse grained soils are those with a median grain size of greater than 75 μm (CCME, 2000). The soil-dependent properties for the coarse- and fine-grained soil fractions were derived using a water retention model and sand and loam as the representative coarse- and fine-grained soil types. Test data according to the US Soil Conservation Service (SCS) system of soil texture classification as published by the USEPA (2002a) was used to obtain the soil properties for sand and loam shown in Exhibit 1.

When there is limited information on grain size or where site soils comprise a mixture of fine and coarse grained media, the attenuation factor for coarse soil type should be used.

4.3.2.2 Land Use

The two choices for land use for the SLRA Level 2 Vapour Intrusion Module are a residential scenario and a commercial scenario.

Residential: A residential scenario should be selected if the site has a single family or multi-family (townhouse or apartment) residential dwelling that is occupied for some or all of the time. A residential scenario would also apply to institutional land use (e.g., school, daycare) or operations where food is grown.

Commercial: A commercial land use should be selected for sites other that are not residential and do not include operations where food is grown.

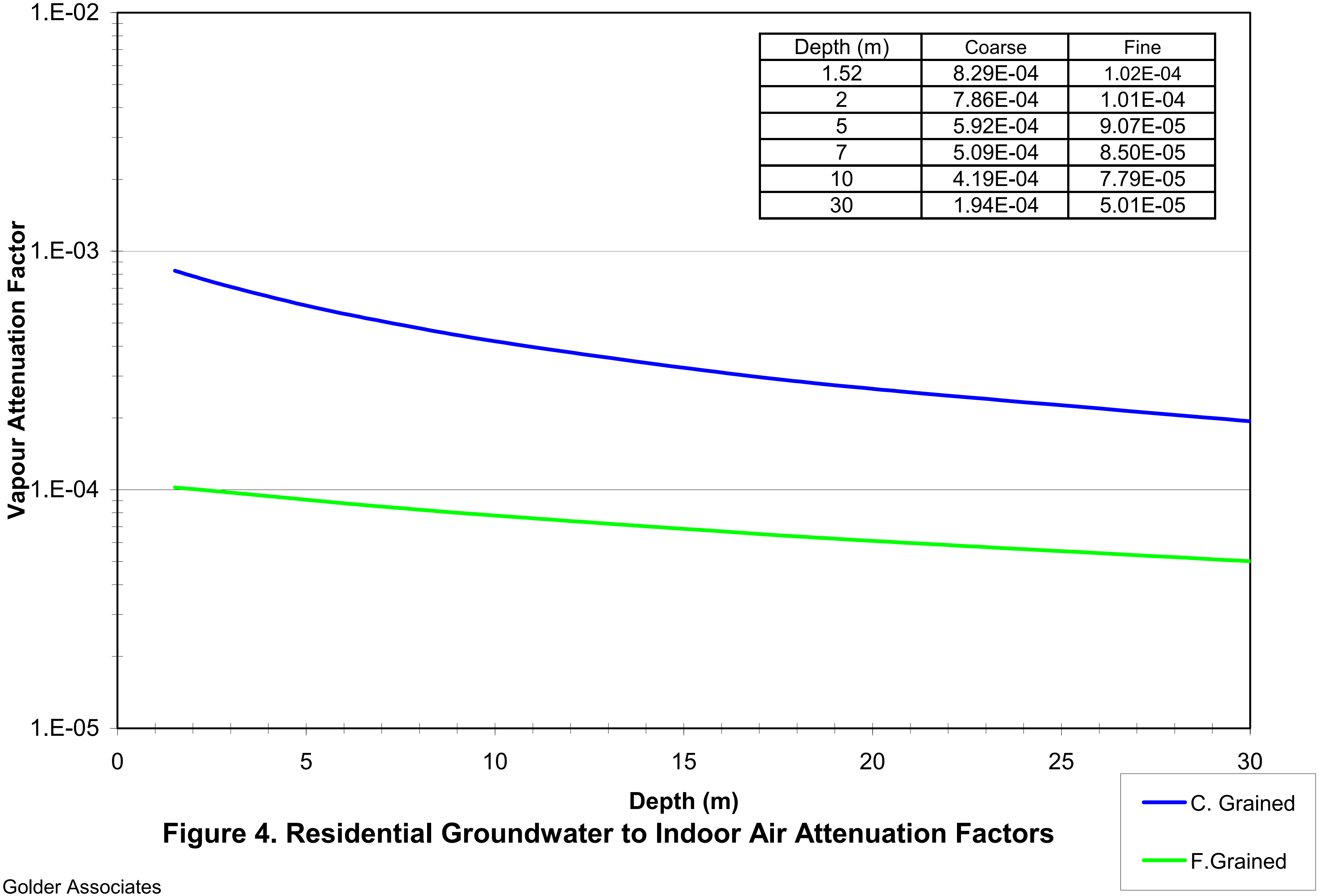
4.3.2.3 Depth to Vapour Contamination Source

The depth to vapour contamination source is the distance between the underside of the building foundation and vapour contamination source.

- The vapour contamination source is the water table when contamination originates as dissolved constituents in groundwater. When estimating this distance, allowance for water table fluctuations should be made by selecting the minimum depth below the slab.
- When the vapour source is vadose zone soil, the distance is to the top of the contaminated soil zone.

4.3.3 Select Vapour Attenuation Factor

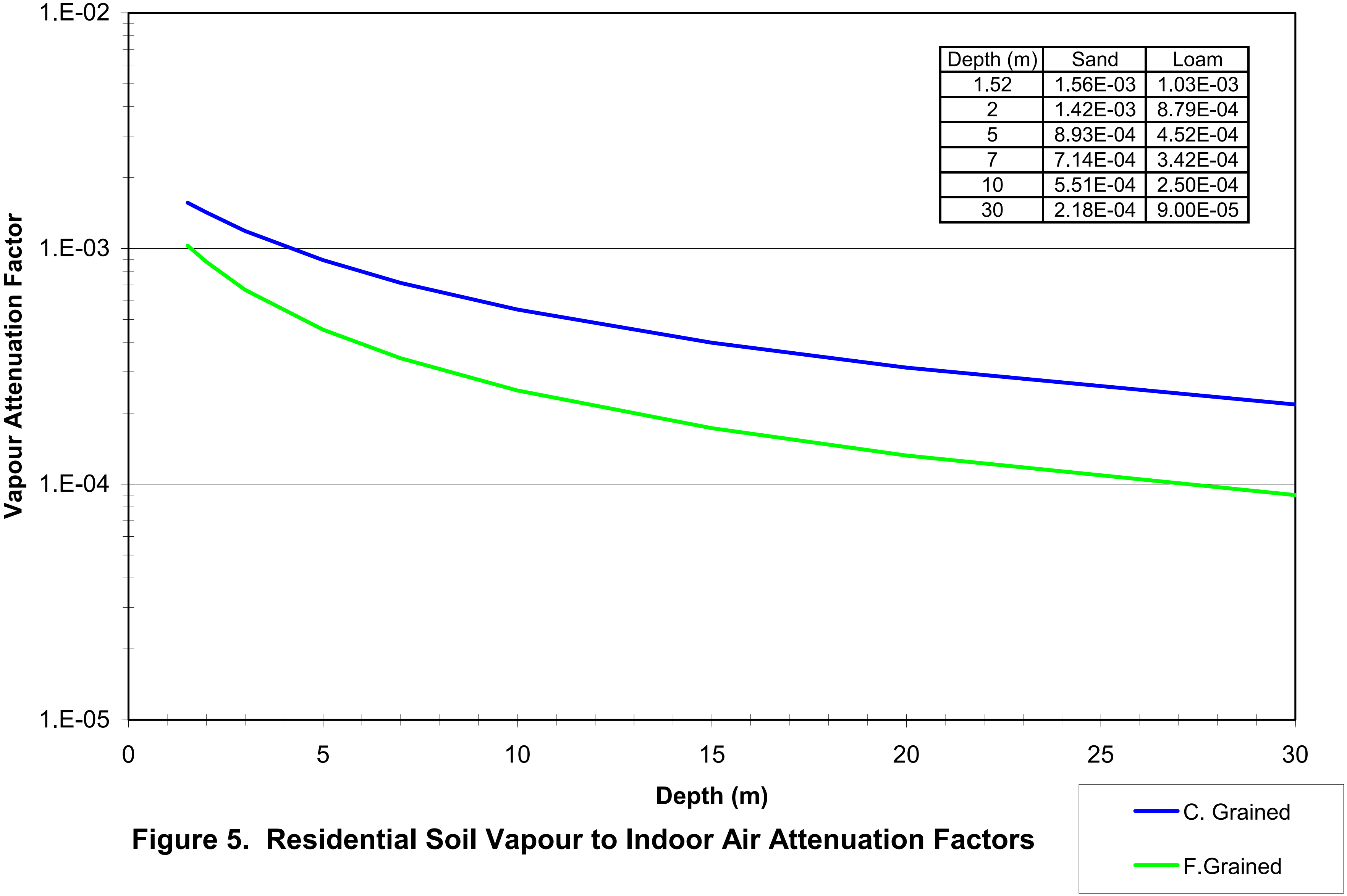
Based on the inputs described above, a vapour attenuation factor is selected for the site. Where contamination is limited to dissolved constituents in groundwater (saturated zone), the groundwater-to-indoor air pathway charts are used (Figures 4 and 6). Where there is a soil contamination source above the water table, the soil vapour-to-indoor pathway charts are used (Figures 6 and 7).



Depth (m)	Coarse	Fine
1.52	8.29E-04	1.02E-04
2	7.86E-04	1.01E-04
5	5.92E-04	9.07E-05
7	5.09E-04	8.50E-05
10	4.19E-04	7.79E-05
30	1.94E-04	5.01E-05

Figure 4. Residential Groundwater to Indoor Air Attenuation Factors

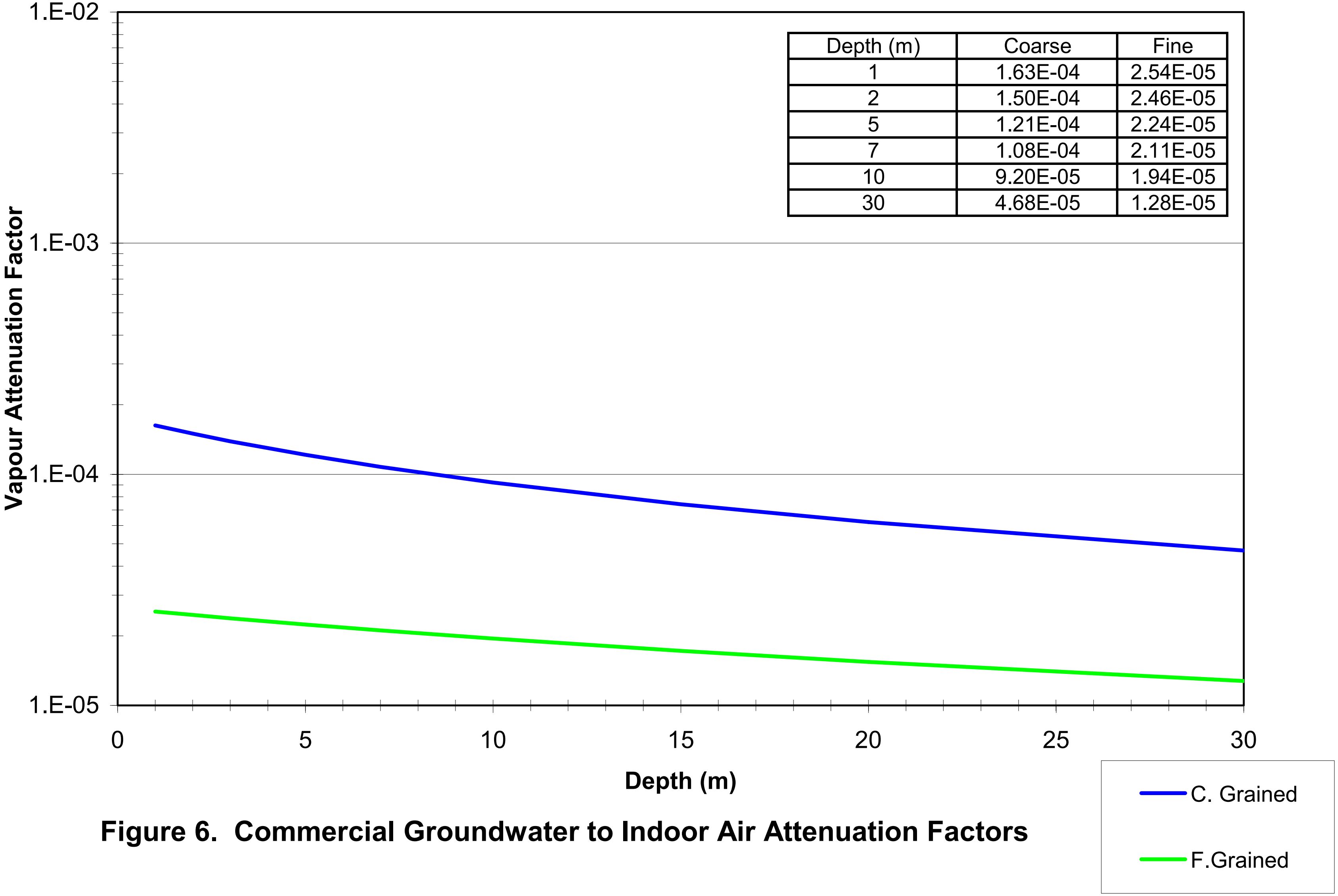
Golder Associates



Depth (m)	Sand	Loam
1.52	1.56E-03	1.03E-03
2	1.42E-03	8.79E-04
5	8.93E-04	4.52E-04
7	7.14E-04	3.42E-04
10	5.51E-04	2.50E-04
30	2.18E-04	9.00E-05

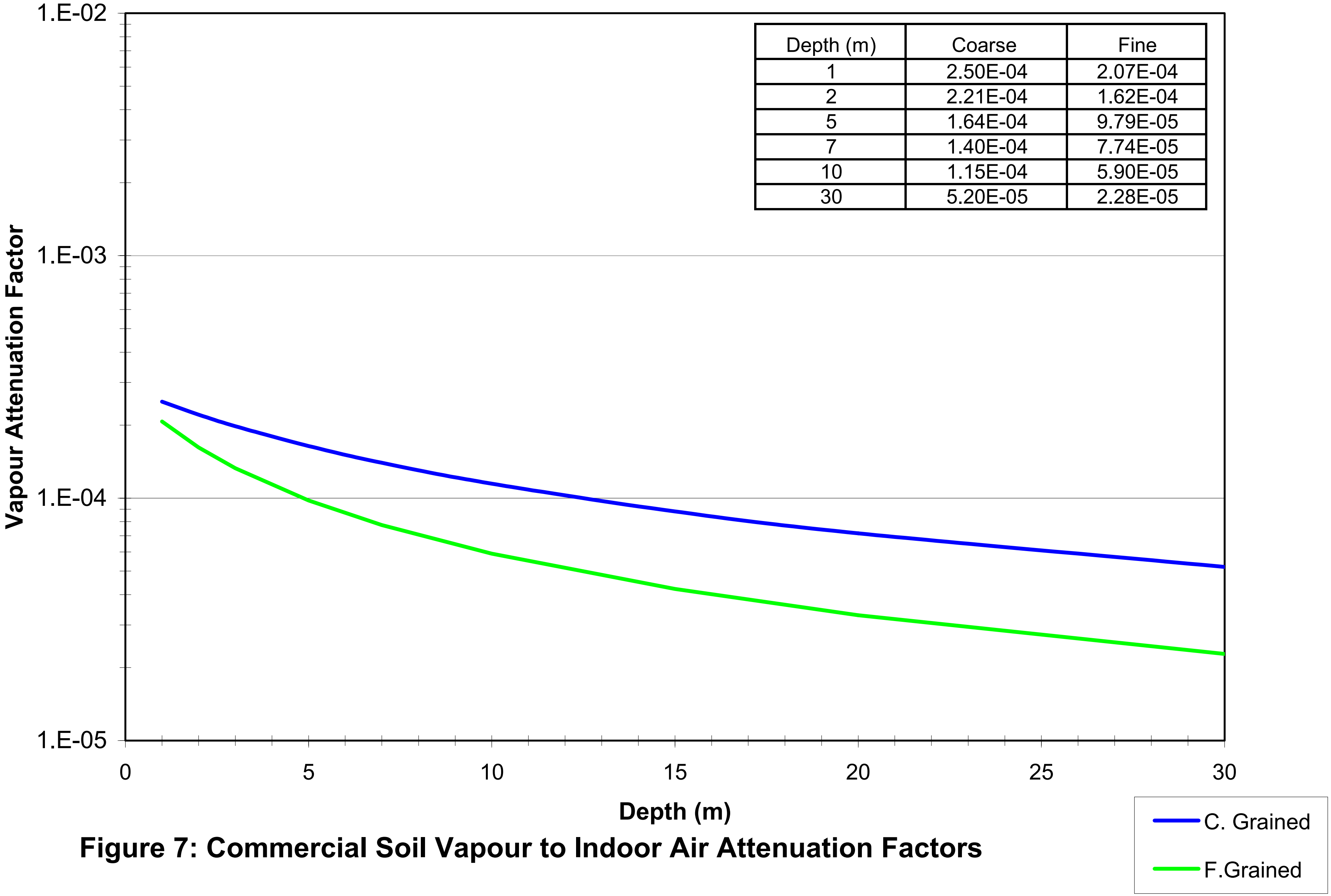
Figure 5. Residential Soil Vapour to Indoor Air Attenuation Factors

Golder Associates



Depth (m)	Coarse	Fine
1	1.63E-04	2.54E-05
2	1.50E-04	2.46E-05
5	1.21E-04	2.24E-05
7	1.08E-04	2.11E-05
10	9.20E-05	1.94E-05
30	4.68E-05	1.28E-05

Figure 6. Commercial Groundwater to Indoor Air Attenuation Factors



Depth (m)	Coarse	Fine
1	2.50E-04	2.07E-04
2	2.21E-04	1.62E-04
5	1.64E-04	9.79E-05
7	1.40E-04	7.74E-05
10	1.15E-04	5.90E-05
30	5.20E-05	2.28E-05

Figure 7: Commercial Soil Vapour to Indoor Air Attenuation Factors

4.4 STEP 4: BUILDING HEIGHT ADJUSTMENT TO VAPOUR ATTENUATION FACTOR

The vapour attenuation charts developed using the J&E model assume the following default building mixing heights:

- Residential: 3.6 m
- Commercial: 3.0 m

The residential mixing height default is based on complete mixing of vapours within the first storey, and partial mixing within the second storey of the residence. The commercial mixing height default is considered representative of mixing of vapours within a single-storey office building (see Appendix C-2).

The mixing height for vapours within a building with high ceilings or a multi-storey building could be greater as a result of mixing within the building caused by ventilation and leakage across floors. If there is information indicating that the above default mixing heights are not representative, the attenuation factors can be scaled using a linear relationship since the attenuation factor is inversely proportional to the mixing height, as follows:

Residential: Adjusted Attenuation Factor = (3.6 m / Site Specific Mixing Height) * Vapour Attenuation Factor

Commercial: Adjusted Attenuation Factor = (3.0 m / Site Specific Mixing Height) * Vapour Attenuation Factor

4.5 STEP 5: CALCULATION OF INDOOR AIR CONCENTRATION

The indoor air concentration is predicted using the measured or estimated soil vapour concentration and the vapour attenuation factor, as follows:

$$C_{air} = C_a * \text{Vapour Attenuation Factor} \qquad (1)$$

4.6 STEP 6: MASS FLUX ADJUSTMENTS TO INDOOR AIR CONCENTRATION

4.6.1 Mass Flux Adjustments for Groundwater Source

When contamination is limited to dissolved chemicals migrating in groundwater, the only source of vapours are chemicals that volatilize from groundwater. The available mass that could potentially volatilize under steady state conditions is controlled by the mass flux in groundwater flowing below the building. The development of the guidance vapour attenuation factors did not take into consideration possible mass flux limitations and instead assumed a sufficiently high contaminant mass flux from the groundwater that the vapour mass flux into the building remained constant over time. Mass flux calculations indicate that in some cases the semi-site specific attenuation factors presented in the guidance assume an unrealistic mass flux into the building, based on the available mass of chemical in groundwater.

Based on the above rationale, this guidance includes a simple mass flux check to evaluate whether the predicted indoor air concentration, for the attenuation factor selected, is realistic based on the available mass. The mass flux check is applicable when there is only a dissolved contamination source. The mass flux check, presented in Exhibit 3 and Figure 8, requires an estimate of the Darcy flux (specific discharge). The Darcy flux can be estimated from the hydraulic conductivity and hydraulic gradient and should be available for most sites at the screening stage of the process.

The mass flux assumes that all dissolved chemicals within the top 1 m of groundwater flowing below the entire width of the building will volatilize and enter the building (i.e., leaving no chemicals in shallow groundwater down-gradient of the building). In reality, dissolved plumes only lose a small portion of their mass through volatilization. In addition, it is assumed that the groundwater chemicals are not attenuated through biodegradation. The conservative assumptions are justified for screening purposes since there is uncertainty in predicting the groundwater mass transport and concentration distribution in groundwater.

As shown in Exhibit 3, if the predicted mass flux through volatilization is greater than the available mass flux in groundwater, then the predicted indoor air concentration is scaled based on the available mass flux.

4.6.2 Mass Flux Adjustments for Soil Source

The time for depletion of the contaminant source can be calculated when the available mass in soil can be reasonably estimated. The development of the guidance vapour attenuation factors did not take into consideration possible mass flux limitations and instead assumed a constant mass of chemicals is present below the building. Mass flux calculations indicate that in some cases the semi-site specific attenuation factors presented in the guidance assume an unrealistic mass flux into the building, based on the available mass in soil. To address possible mass limitations, the guidance includes a simple calculation to estimate the number of years it would take for the contamination source to be depleted (Exhibit 4). If the time for depletion is less than the assumed exposure duration, consideration should be given to conducting a detailed risk assessment.

Figure 8. Conceptual Model for Groundwater Mass Flux Calculation

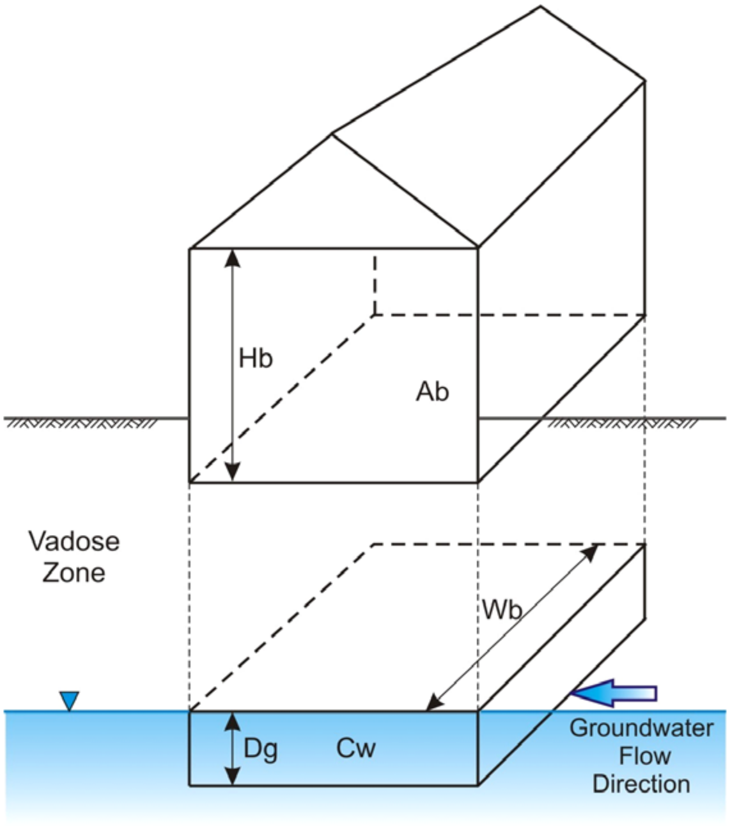


EXHIBIT 3

ADJUSTMENT OF PREDICTED INDOOR AIR CONCENTRATION BASED ON MASS FLUX CONSIDERATIONS–GROUNDWATER TO INDOOR PATHWAY[5]

$VR = ACH * A_b * H_b / UCF_1$

$Flux_p = C_{air} * VR$

$Flux_m = U * C_w * D_g * W_b * R_v * UCF_2 / UCF_3$

$C_{air}' = Flux_m / Flux_p * C_{air}$ if $Flux_p > Flux_m$

$C_{air}' = C_{air}$ if $Flux_p < Flux_m$

Parameter	Default
VR = Building ventilation rate (m^3/min)	Calculated
ACH = Air exchange rate (1/hr)	0.35 residential
	1.0 commercial
A_b = Area building (m^2)	100 residential
	300 commercial
H_b = Mixing height (m)	3.6 residential
	3.0 commercial
UCF_1 = Unit conversion factor (min/hr)	60
$Flux_p$ = Predicted flux into building (mg/min)	Calculated
$Flux_m$ = Flux from groundwater (mg/min)	Calculated
U = Darcy velocity (specific discharge) (m/yr)	Estimated
C_w = Soil water (groundwater) concentration (mg/L)	Measured
D_g = Mixing zone in groundwater for chemicals volatilizing (m)	1.0
W_b = Width of building (m)	10 residential
	15 commercial
Rv = Volatilization ratio for fraction of chemical mass in groundwater flowing below the building that volatilizes and enters buildings	1.0
UCF_2 = Unit conversion factor (L/m^3)	1,000
UCF_3 = Unit conversion factor (min/year)	525,600
C_{air} = Predicted air concentration based on Equation 1 (mg/m^3)	Calculated
C_{air}' = Adjusted air concentration (mg/m^3)	Calculated

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[5] This adjustment may only be made when there is only dissolved contamination in groundwater.

EXHIBIT 4

SOURCE DEPLETION CHECK BASED ON AVAILABLE MASS SOIL TO INDOOR AIR PATHWAY

$VR = ACH * A_b * H_b / UCF_1$

$Flux_p = C_{air} * VR$

$Mass_a = C_s * \rho_b * T_s * UCF_2 * A_b$

$Time_d = Mass_p / (Flux_p * UCF_3)$

Parameter	Default
C_{soil} = Total soil concentration (mg/kg)	Measured site specific
UCF_2 = Unit conversion factor (L/m^3)	1,000
$Mass_a$ = Available mass contaminant in soil (mg)	Calculated
T_s = Thickness of contamination source in soil (m)	Estimated
UCF_3 = Unit conversion factor (min/year)	525,600
$Time_d$ = Time for depletion of contamination source	Calculated
ρ_b = dry bulk density	Measured. Default of 1.7 g/cm^3

Note: Other parameters previously defined in Exhibit 3.

4.7 STEP 7: ASSESSMENT OF PATHWAY COMPLETENESS

The predicted indoor air concentration is compared to the target indoor air concentration. If the predicted concentration is less than the target concentration, then the SLRA Level 2 assessment concludes that there is no pathway to the receptor (NPR), and the assessment is complete.

4.8 STEP 8: BACKGROUND INDOOR AIR CHECK

If estimated health risks exceed acceptable risk levels, the user should first check whether the predicted indoor air concentrations exceed background indoor air concentrations for the chemical under consideration. Background sources of VOCs in air include building materials, consumer products, petroleum products and emissions. It is recommended that the approximate mean background concentration be used for this determination. Information on background VOC concentrations in indoor air is available in CCME (2000), Hers *et al.* (2001), USEPA (2002a), Kurtz and Folkes (2003) and Foster *et al.* (2003). If the predicted vapour concentrations in indoor air are less than the background concentrations, then the contribution to risk from inhalation of vapour is less than that associated with background VOC sources. When predicted vapour concentrations in indoor air are less than background concentrations but still indicate unacceptable risk, consideration should be given to whether additional more in-depth risk assessment is required which may include collection of soil vapour or indoor air directly.

4.9 FINAL CONSIDERATIONS

If predicted health risks exceed acceptable levels, it does not necessarily indicate that an unacceptable risk actually exists. However, it does indicate that a more detailed and comprehensive risk assessment may be necessary.

The uncertainties in the predicted exposures and risks should be discussed in the report documenting an SLRA Level 2 soil vapour analysis. These include site characterization data, the partitioning model, vapour attenuation factors and risk estimates.

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APPENDIX C-1

IDENTIFICATION OF VOLATILE COMPOUNDS OF CONCERN

TABLE OF CONTENTS

LIST OF TABLES

1 Introduction

This appendix describes the framework and methodology for the derivation of the vapour attenuation factor charts for the SLRA Level 2 evaluation of soil vapour intrusion into buildings.

2 Identification of Volatile Compounds of Concern

Table 1 shows chemicals which may be evaluated for the vapour intrusion pathway. The chemicals selected were primarily volatile and semi-volatile chemicals that may be encountered at a contaminated site. The primary source of the physical-chemical properties in Table 1 is the United State Environmental Protection Agency (USEPA, 2002b), with additional properties obtained from Oak Ridge National Laboratory (ORNL, 2004). Another key source of information is Health Canada (2003b) for tolerable concentration (TC) (mg/m^3) or inhalation unit risk factors $(mg/m^3)^{-1}$.

For the purposes of SLRA level 2, the level of toxicological concern is an incremental cancer risk greater than 10^{-5} over a lifetime exposure or a hazard index (HI) greater than 1 based on the current BC regulatory framework. It is assumed that the receptor is subject to a lifetime of exposure to the near maximum possible vapour concentration.

Table 1 does not provide an exhaustive list of volatile and toxic compounds. If a chemical is not provided or if a more defensible TRV is available that is not listed in Table 1, users can conduct their own assessment of toxicity and volatility using the equations from Exhibit I-1 and additional parameters in Table 2. The first step described in Exhibit I-1 is the prediction of the vapour concentration based on equilibrium partitioning theory using both the Henry's Law constant and pure chemical vapour pressure. The partitioning theory used to develop the relationships in Exhibit I-1 is described further in Section 5.2. The maximum vapour concentration predicted using these two approaches is divided by a dilution factor (DF) of ten (alpha of 0.1) since empirical studies indicate the minimum observed attenuation between soil vapour and indoor air is about 0.1 (USEPA, 2002a; Hers, 2004). The adjusted vapour concentration is compared to the target indoor air concentration, based on conservative assumptions for exposure.

Table 1: Physical and Chemical Properties.

	Molecular Weight [1,2] (g/mol)	Vapour Pressure (kPa)	VP Ref	Unitless Henry's Constant [1,2] (-)	Organic Carbon Partition Coefficient [1] (cm^3/g)
Acetaldehyde	4.40E+01	1.19E+00	1	3.20E-03	1.80E+01
Acetone	5.80E+01	3.04E-01	1	1.60E-03	5.80E-01
Acetonitrile	4.10E+01	1.17E-01	1	8.20E-04	1.60E+01
Acrolein	5.60E+01	3.61E-01	1	4.90E-03	2.10E+01
Acrylonitrile	5.30E+01	1.17E-01	1	3.60E-03	8.50E-01
Benzene	7.80E+01	1.25E-01	1	2.30E-01	5.90E+01
Benzyl chloride	1.30E+02	1.62E-03	1	2.10E-03	5.00E+01
1,1-Biphenyl	1.50E+02	1.18E-05	1	1.20E-02	7.80E+03
Bis(2-chloroethyl)ether	1.40E+02	2.04E-03	1	7.40E-04	7.60E+01
Bis(2-chloroisopropyl)ether	1.70E+02	1.66E-02	1	4.60E-03	6.10E+01
Bis(chloromethyl)ether	1.20E+02	3.87E-02	1	8.20E-02	1.20E+00
Bis(2-chloro-1-methylethyl)ether	1.70E+02	7.37E-04	1	4.60E-03	6.10E+01
Bromobenzene	1.57E+02	5.50E-03	1	1.50E-01	2.20E+02
Bromodichloromethane	1.60E+02	7.55E-02	1	6.60E-02	5.50E+01
Bromomethane	9.50E+01	2.13E+00	1	2.60E-01	9.00E+00
1,3-Butadiene	5.40E+01	2.78E+00	1	7.30E+00	1.20E+02
n-Butylbenzene	1.30E+02	2.63E-06	4	5.40E-01	2.80E+03
sec-Butylbenzene	1.30E+02	2.63E-06	4	7.70E-01	2.20E+03
tert-Butylbenzene	1.30E+02	2.63E-06	4	5.20E-01	2.20E+03
Carbon disulfide	7.60E+01	4.72E-01	1	1.20E+00	4.60E+01
Carbon tetrachloride	1.50E+02	1.51E-01	1	1.20E+00	1.70E+02
2-Chloroacetophenone	1.55E+02	1.00E-05	1	1.50E+00	3.30E+02
Chlorobenzene	1.10E+02	1.58E-02	1	1.50E-01	2.20E+02
2-Chloro-1,3-butadiene	8.80E+01	2.83E-01	1	1.30E+00	5.00E+01
1-Chlorobutane	MW < 200	1.33E-01	2	1.30E+00	5.00E+01
1-Chloro-1,1-difluoroethane	MW < 200	3.34E+00	2	4.10E+00	5.80E+01
Chlorodifluoromethane	MW < 200	9.54E+00	2	4.10E+00	5.80E+01
Chloroethane	6.50E+01	1.28E+00		4.50E-01	1.50E+01
Chloroform	1.20E+02	2.59E-01	1	1.50E-01	4.00E+01
Chloromethane	5.10E+01	5.66E+00	1	9.80E-01	3.50E+01
beta-Chloronaphthalene	1.60E+02	1.19E-05	1	1.30E-02	1.60E+03
o-Chloronitrobenzene	1.58E+02	2.39E-05	1	9.80E-04	6.50E+01
p-Chloronitrobenzene	1.58E+02	1.28E-04	1	9.80E-04	6.50E+01
2-Chlorophenol	1.30E+02	3.33E-03	1	1.60E-02	4.00E+02
2-Chloropropane	7.85E+01	6.78E-01	1	9.40E-02	5.10E+01
o-Chlorotoluene	1.27E+02	4.51E-03	1	1.40E-01	1.60E+02

Table 1: Physical and Chemical Properties (Cont'd).

	Molecular Weight [1,2]	**Vapour Pressure**	**VP Ref**	**Unitless Henry's Constant [1,2]**	**Organic Carbon Partition Coefficient [1]**
	(g/mol)	**(kPa)**		**(-)**	**(cm^3/g)**
Crotonaldehyde	7.01E+01	3.95E-02		1.00E+01	8.40E+02
Cumene (isopropylbenzene)	1.20E+02	5.92E-03	1	4.70E-01	2.20E+02
Cyanide (hydrogen)	2.70E+01	9.76E-01		5.30E-03	1.70E+01
Cyanogen	5.20E+01	5.66E+00	1	2.10E-01	2.60E+01
Cyanogen bromide	5.20E+01	1.59E-02	1	2.10E-01	2.60E+01
Cyanogen chloride	5.20E+01	9.61E-02	1	2.10E-01	2.60E+01
Cyclohexane	8.40E+01	1.28E-01	4	8.20E+00	1.60E+02
C6-C8 Aliphatics	1.00E+02	8.29E-05	3	5.13E+01	3.98E+03
C8-C10 Aliphatics	1.30E+02	8.29E-06	3	8.12E+01	3.16E+04
C10-C12 Aliphatics	1.60E+02	8.29E-07	3	1.24E+02	2.51E+05
C6-C8 Aromatics	9.20E+01	5.00E-05	3	2.77E-01	2.51E+02
C8-C10 Aromatics	1.20E+02	8.29E-06	3	5.13E-01	1.58E+03
C10-C12 Aromatics	1.30E+02	8.29E-07	3	1.45E-01	2.51E+03
C12-C16 Aromatics	1.50E+02	6.32E-08	3	5.56E-02	5.01E+03
n-Decane	1.42E+02	1.68E-03	4	2.80E-04	4.82E+00
Dibenzofuran	1.70E+02	3.26E-06	1	5.30E-04	7.80E+03
Dibromochloromethane	2.10E+02	2.05E-02	1	3.50E-02	4.70E+02
1,2-Dibromo-3-chloropropane	2.40E+02	7.63E-04	1	6.00E-03	2.80E+01
1,2-Dibromoethane	1.90E+02	1.47E-02	1	1.30E-02	2.80E+01
1,2-Dichlorobenzene	1.50E+02	1.93E-03	1	7.80E-02	6.20E+02
1,3-Dichlorobenzene	1.50E+02	2.83E-03	1	7.80E-02	6.20E+02
1,4-Dichlorobenzene	1.50E+02	2.29E-03	1	1.00E-01	6.20E+02
Dichlorodifluoromethane	1.20E+02	6.38E+00	1	4.10E+00	5.80E+01
1,1-Dichloroethane	9.90E+01	2.99E-01	1	2.30E-01	3.20E+01
1,2-Dichloromethane	9.90E+01	4.68E-01	1	4.00E-02	1.70E+01
1,1-Dichloroethylene	9.70E+01	8.34E-01	1	1.10E+00	5.90E+01
1,2-Dichloroethylene(cis)	9.70E+01	2.64E-01	1	1.70E-01	3.60E+01
1,2-Dichloroethylene(trans)	9.70E+01	2.64E-01	1	3.80E-01	5.30E+01
1,2-Dichloropropane	1.10E+02	7.01E-02	1	1.10E-01	4.40E+01
1,3-Dichloropropene	1.10E+02	4.47E-02	1	7.30E-01	4.60E+01
Dicyclopentadiene	1.30E+02	3.01E-03	1	4.40E-01	5.70E+02
Dimethylamine	4.50E+01	2.03E+00		3.70E-03	2.20E+00
Epiclorohydrin	9.30E+01	2.16E-02	1	1.30E-03	3.50E+00
Ethyl acetate	8.80E+01	1.23E-01	1	5.70E-03	5.90E+01
Ethyl acrylate	1.00E+02	5.08E-02	1	9.80E+00	8.40E+02
Ethylbenzene	1.10E+02	1.26E-02	1	3.20E-01	3.60E+02
Ethyl chloride	6.50E+01	1.33E+00	1	4.50E-01	1.50E+01

Table 1: Physical and Chemical Properties (Cont'd).

	Molecular Weight [1,2] (g/mol)	Vapour Pressure (kPa)	VP Ref	Unitless Henry's Constant [1,2] (-)	Organic Carbon Partition Coefficient [1] (cm^3/g)
Ethylene oxide	4.40E+01	1.72E+00	1	3.10E-03	2.20E+00
Ethyl ether	7.41E+01	7.08E-01	1	5.30E-04	1.40E+01
Ethyl methacrylate	1.14E+02	2.71E-02	1	1.00E+01	8.40E+02
Furan	6.80E+01	7.89E-01	1	2.20E-01	1.20E+01
n-Hexane	8.60E+01	1.99E-01	1	5.00E+00	8.90E+02
Isobutanol	7.40E+01	2.57E-02		4.90E-04	6.20E+01
Maleic hydrazide	1.10E+02	4.86E-11	1	2.70E-01	4.20E+01
Methacrylonitrile	6.71E+01	9.37E-02	1	3.60E-03	8.50E-01
Methomyl	1.60E+02	7.11E-09	1	1.60E+00	1.50E+01
Methyl acetate	7.41E+01	2.84E-01	1	8.40E-04	2.20E+00
Methyl acrylate	8.61E+01	1.14E-01	1	9.80E+00	8.40E+02
Methylcyclohexane	9.80E+01	6.05E-02	1	1.80E+01	2.20E+03
Methylene bromide	1.70E+02	4.93E-02		3.70E-02	2.50E+01
Methylene chloride	8.50E+01	5.72E-01	1	9.00E-02	1.20E+01
Methyl ethyl ketone	7.20E+01	1.19E-01	1	1.10E-03	4.50E+00
Methyl isobutyl ketone	1.00E+02	2.62E-02	1	5.70E-03	1.31E+02
Methyl methacrylate	1.00E+02	5.07E-02	1	1.40E-02	1.30E+01
Methyl styrene (mixture)	1.18E+02	1.97E-03	1	9.40E-02	3.60E+02
Methyl styrene (alpha)	1.18E+02	1.97E-03	1	9.40E-02	3.60E+02
Methyl tertbutyl ether MTBE	8.50E+01	3.29E-01	1	2.40E-02	6.00E+00
Nitrobenzene	1.20E+02	3.22E-04		9.80E-04	6.50E+01
N-Nitrosodi-n-butylamine	1.60E+02	3.95E-04	1	1.30E-02	2.60E+02
m-Nitrotoluene	1.37E+02	2.70E-04	2	9.80E-04	6.50E+01
o-Nitrotoluene	1.37E+02	2.47E-04	2	9.80E-04	6.50E+01
p-Nitrotoluene	1.37E+02	2.16E-04	2	9.80E-04	6.50E+01
Polychlorinated Biphenyls (high risk)	1.30E+06	3.82E-01	1	1.40E-02	4.50E+04
Polychlorinated Biphenyls (low risk)	1.30E+06	3.82E-01	1	1.40E-02	4.50E+04
<u>Polynuclear aromatic hydrocarbons</u>					
Acenaphthene	1.50E+02	3.29E-06	1	7.70E-03	4.90E+03
Acenaphthylene	1.52E+02	1.20E-06	1	5.10E-03	
Anthracene	1.80E+02	3.51E-09	1	2.27E-03	2.40E+04
Benz[a]anthracene	2.28E+02	2.50E-09	1	4.91E-04	2.31E+05
Benzo[k]fluoranthene	2.52E+02	1.26E-12	1	2.39E-05	7.87E+05
Benzo[b]fluoranthene	2.52E+02	6.58E-10	1	2.69E-05	8.03E+05
Benzo[g,h,i]perylene	2.52E+02	6.62E+01	1	1.35E-05	2.68E+06

Table 1: Physical and Chemical Properties (Cont'd).

	Molecular Weight [1,2] (g/mol)	**Vapour Pressure (kPa)**	**VP Ref**	**Unitless Henry's Constant [1,2] (-)**	**Organic Carbon Partition Coefficient [1] (cm^3/g)**
Polynuclear aromatic hydrocarbons (continued)					
Chrysene	2.30E+02	8.20E-12	1	2.14E-04	4.00E+05
Dibenz(a,h)anthracene	2.78E+02	1.84E-14	1	5.30E-06	-
Fluoranthene	2.02E+02	1.21E-08	1	3.62E-04	-
Fluorene	1.70E+02	1.11E-05	1	3.90E-03	1.40E+04
Indeno(1,2,3-c,d)pyrene	2.76E+02	1.64E-13	1	1.42E-05	-
Naphthalene	1.30E+02	1.12E-04	1	2.00E-02	1.20E+03
Phenanthrene	1.78E+02	1.47E-07	1	1.73E-03	-
Pyrene	2.00E+02	5.92E-09	1	4.80E-04	1.10E+05
Propylene oxide	5.80E+01	7.08E-01	1	2.80E-03	2.50E+01
Styrene	1.00E+02	8.42E-03	1	1.10E-01	7.81E+02
1,1,1,2-Tetrachloroethane	1.70E+02	1.58E-02	1	9.80E-02	9.30E+01
1,1,2,2-Tetrachloroethane	1.70E+02	1.75E-02	1	1.50E-02	9.30E+01
Tetrachloroethylene (PCE)	1.70E+02	2.43E-02	1	7.20E-01	1.60E+02
Tetrahydrofuran	7.20E+01	1.90E-01	1	2.90E-03	9.50E-01
Toluene	9.20E+01	3.74E-02	1	2.70E-01	1.80E+02
1,2,4-Trichlorobenzene	1.80E+02	6.05E-04	1	5.80E-02	1.80E+03
1,1,1-Trichloroethane	1.30E+02	1.63E-01	1	7.10E-01	1.10E+02
1,1,2-Trichloroethane	1.30E+02	3.03E-02	1	3.70E-02	5.00E+01
Trichloroethylene (TCE)	1.30E+02	9.08E-02	1	4.20E-01	1.70E+02
Trichlorofluoromethane	1.40E+02	1.06E+00	1	4.00E+00	1.60E+02
1,1,2-Trichloropropane	1.50E-02	4.08E-03	1	1.20E+00	5.10E+01
1,2,3-Trichloropropane	1.50E-02	4.86E-03	1	1.40E-02	5.10E+01
1,2,3-Trichloropropene	1.45E+02	5.79E-03	1	7.20E-01	5.10E+01
Triethylamine	1.01E+02	7.51E-02	1	6.09E-03	2.20E+00
1,2,4-Trimethylbenzene	1.20E+02	2.76E-03	1	2.52E-01	3.70E+03
1,3,5-Trimethylbenzene	1.20E+02	2.76E-03	1	3.59E-01	8.20E+02
Vinyl acetate	8.60E+01	1.19E-01	1	2.09E-02	5.30E+00
Vinyl bromide	1.07E+02	1.36E+00	1	5.03E-01	1.30E+02
Vinyl chloride (child/adult)	6.30E+01	3.92E+00	1	1.14E+00	1.90E+01
Xylenes	1.10E+02	1.05E-02	1	2.71E-01	4.10E+02
Chrysene	2.30E+02	8.20E-12	1	2.14E-04	4.00E+05
Dibenz(a,h)anthracene	2.78E+02	1.84E-14	1	5.30E-06	-

Table 1: Physical and Chemical Properties (Cont'd).

Reference Notes for Table 1

1. USEPA. 2002. Preliminary Remediation Goals for Region IX. Table of Physical and Chemical Properties, Available at http://www.epa.gov/region09/waste/sfund/prg/index.htm. (Region 9)

2. ORNL. 2004. Risk Assessment Information System (RAIS). Oakridge National Library. Available at http://risk.lsd.ornl.gov/rap_hp.shtml. on-line database searched 2004

3. CCME. 2000. Canada Wide Standards for Petroleum Hydrocarbons (PHCs) in soil: Scientific Rationale. Supporting Technical Document. December 2000.

4. Mackay, D., Shiu, W.Y. and Ma, K.C. 1991. Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals. Vol. I, Monoaromatic Hydrocarbons, Chlorobenzenes and PCBs. Vol. II, Polynuclear Aromatic Hydrocarbons, Polychlorinated Dioxins and Dibenzofurans. Vol. III, Volatile Organic Chemicals. Boca Raton, LA: Lewis Publishers.

Table 2: Toxicity Factors and Results of Preliminary Screening for Volatility and Toxicity

	Diffusivity in Air[1] (cm^2/s)	Diffusivity in Water[1] (cm^2/s)	Soil-Water Distribution Coefficient[1] (cm^3/g)	Water solubility[1] (mg/L-water)	RfD mg/kg-day	note	Tolerable Concentration mg/m^3	Slope Factor $(mg/kg\text{-}day)^{-1}$	note	Unit Risk $(mg/m^3)^{-1}$	TRV Reference (mg/m^3)	Classification	Target Indoor Air Concentrations Non Carcinogens C_{air}^T (mg/m^3)	Target Indoor Air Concentrations Carcinogens C_{air}^T (mg/m^3)	No NAPL Present Ca'	NAPL Present Ca'	Predicted Maximum Indoor Air Concentration C_{air} (mg/m^3)	Volatility and Toxicity Determination Using Method Outlined in Exhibit 1
Acetaldehyde	1.2E-01	1.4E-05	1.1E-01	1.0E+06	2.6E-03		5.11E-03	7.7E-03		2.2E-03	3	Carcinogen	-	4.5E-03	3.2E+05	2.2E+05	3.2E+05	Volatile/Toxic
Acetone	1.2E-01	1.1E-05	3.5E-03	1.0E+06	1.0E-01		1.99E-01			-		Non Carcinogen	2.0E-01	-	1.6E+05	7.5E+04	1.6E+05	Volatile/Toxic
Acetonitrile	1.3E-01	1.7E-05	9.4E-02	1.0E+06	1.7E-02		3.40E-02			-	3	Non Carcinogen	3.4E-02	-	8.2E+04	2.0E+04	8.2E+04	Volatile/Toxic
Acrolein	1.1E-01	1.2E-05	1.3E-01	2.1E+05	5.7E-06		1.14E-05			-	3	Non Carcinogen	1.1E-05	-	1.0E+05	8.5E+04	1.0E+05	Volatile/Toxic
Acrylonitrile	1.1E-01	1.3E-05	5.1E-03	7.9E+04	5.7E-04		1.13E-03			6.8E-02	3	Carcinogen	-	1.5E-04	2.8E+04	2.6E+04	2.8E+04	Volatile/Toxic
Benzene	8.8E-02	9.8E-06	3.5E-01	1.8E+03	8.6E-03		1.70E-02	1.4E-01		3.3E-03	2, 3	Carcinogen	-	3.0E-03	4.1E+04	4.1E+04	4.1E+04	Volatile/Toxic
Benzyl chloride	6.7E-02	7.8E-06	3.0E-01	3.3E+03	4.90E-03	oral	9.74E-03			4.9E-03	3	Carcinogen	-	2.0E-03	6.9E+02	8.9E+02	8.9E+02	Volatile/Toxic
1,1-Biphenyl	4.0E-02	8.2E-06	4.7E+01	7.5E+00			-	5.0E-02	oral	1.1E-02	3	Carcinogen	-	8.9E-04	9.0E+00	7.5E+00	9.0E+00	Volatile/Toxic
Bis(2-chloroethyl)ether	6.9E-02	7.5E-06	4.6E-01	1.7E+04			-	1.1E+00		2.5E-01	4	Carcinogen	-	4.0E-05	1.3E+03	1.2E+03	1.3E+03	Volatile/Toxic
Bis(2-chloroisopropyl)ether	6.3E-02	6.4E-06	3.7E-01	1.7E+03	4.0E-02	oral	7.95E-02			-	3	Non Carcinogen	8.0E-02	-	7.8E+02	1.2E+04	1.2E+04	Volatile/Toxic
Bis(chloromethyl)ether	8.9E-02	9.4E-06	7.2E-03	2.2E+04			-	4.1E+01		9.4E+00	2	Carcinogen	-	1.1E-06	1.8E+05	2.0E+04	1.8E+05	Volatile/Toxic
Bis(2-chloro-1-methylethyl)ether	6.3E-02	6.4E-06	3.7E-01	1.7E+03			-			1.0E-02	3	Carcinogen	-	1.0E-03	7.8E+02	5.3E+02	7.8E+02	Volatile/Toxic
Bromobenzene	7.3E-02	8.7E-06	1.3E+00	4.7E+02	2.9E+00		5.69E+00			-	3	Non Carcinogen	5.7E+00	-	7.1E+03	3.7E+03	7.1E+03	Volatile/Toxic
Bromodichloromethane	3.0E-02	1.1E-05	3.3E-01	6.7E+03	2.0E-03		8.86E-03	6.2E-02		1.4E-02	4	Carcinogen	-	7.1E-04	4.4E+04	5.1E+04	5.1E+04	Volatile/Toxic
Bromomethane	7.3E-02	1.2E-05	5.4E-02	1.5E+04	1.4E-03		2.84E-03			-	3	Non Carcinogen	2.8E-03	-	3.9E+05	8.6E+05	8.6E+05	Volatile/Toxic
1,3-Butadiene	9.8E-02	1.1E-05	7.2E-01	7.4E+02	5.7E-04		1.13E-03			-	3	Non Carcinogen	1.1E-03	-	5.4E+05	6.3E+05	6.3E+05	Volatile/Toxic
n-Butylbenzene	7.5E-02	7.8E-06	1.7E+01	1.4E+01			-			-		Not Evaluated	-	-	7.6E+02	1.4E+00	7.6E+02	Not Evaluated
sec-Butylbenzene	7.5E-02	7.8E-06	1.3E+01	1.7E+01			-			-		Not Evaluated	-	-	1.3E+03	1.4E+00	1.3E+03	Not Evaluated
tert-Butylbenzene	7.5E-02	7.8E-06	1.3E+01	3.0E+01			-			-		Not Evaluated	-	-	1.6E+03	1.4E+00	1.6E+03	Not Evaluated
Carbon disulfide	1.0E-01	1.0E-05	2.7E-01	1.2E+03	2.0E-01		3.98E-01			-	3	Non Carcinogen	4.0E-01	-	1.4E+05	1.5E+05	1.5E+05	Volatile/Toxic
Carbon tetrachloride	7.8E-02	8.8E-06	1.0E+00	7.9E+02	7.0E-04		3.10E-03	1.3E-01		2.9E-02	4	Carcinogen	-	3.4E-04	9.5E+04	9.6E+04	9.6E+04	Volatile/Toxic
2-Chloroacetophenone	7.2E-02	6.8E-06	2.0E+00	4.7E+02	8.6E-06		1.71E-05			-		Non Carcinogen	1.7E-05	-	7.1E+04	6.5E+00	7.1E+04	Volatile/Toxic
Chlorobenzene	7.3E-02	8.7E-06	1.3E+00	4.7E+02			1.00E-02			-	2	Non Carcinogen	1.0E-02	-	7.1E+03	7.3E+03	7.3E+03	Volatile/Toxic
2-Chloro-1,3-butadiene	1.1E-01	1.1E-05	3.0E-01	7.4E+02	2.0E-03		3.98E-03			-	3	Non Carcinogen	4.0E-03	-	9.6E+04	1.1E+05	1.1E+05	Volatile/Toxic
Chloroethane	1.0E-01	1.2E-05	8.8E-02	5.7E+03			-			-		Not Evaluated	-	-	2.6E+05	3.5E+05	3.5E+05	Not Evaluated
Chloroform	1.0E-01	1.0E-05	2.4E-01	7.9E+03	1.0E-02	oral	1.99E-02			2.3E-02	3	Carcinogen	-	4.3E-04	1.2E+05	1.3E+05	1.3E+05	Volatile/Toxic
Chloromethane	1.1E-01	6.5E-06	2.1E-01	8.2E+03	2.6E-02		5.11E-02	6.3E-03		1.8E-03	3	Carcinogen	-	5.6E-03	8.0E+05	1.2E+06	1.2E+06	Volatile/Toxic
beta-Chloronaphthalene	3.5E-02	8.8E-06	9.3E+00	1.2E+01	8.0E-02	oral	1.59E-01			-	3	Non Carcinogen	1.6E-01	-	1.6E+01	8.0E+00	1.6E+01	Volatile/Toxic
o-Chloronitrobenzene	7.6E-02	8.6E-06	3.9E-01	2.1E+03	2.0E-05		3.98E-05			7.1E-04	3	Carcinogen	-	1.4E-02	2.1E+02	1.6E+01	2.1E+02	Volatile/Toxic
p-Chloronitrobenzene	7.6E-02	8.6E-06	3.9E-01	2.1E+03	1.7E-04		3.40E-04			5.1E-04	3	Carcinogen	-	2.0E-02	2.1E+02	8.5E+01	2.1E+02	Volatile/Toxic
2-Chlorophenol	5.0E-01	9.5E-06	2.4E+00	2.2E+04	5.0E-03	oral	9.94E-03			-	3	Non Carcinogen	9.9E-03	-	3.5E+04	1.8E+03	3.5E+04	Volatile/Toxic
2-Chloropropane	8.0E-02	1.0E-05	3.1E-01	2.7E+03	2.9E-02		5.69E-02			-	3	Non Carcinogen	5.7E-02	-	2.5E+04	2.3E+05	2.3E+05	Volatile/Toxic
o-Chlorotoluene	7.2E-02	8.7E-06	9.6E-01	4.7E+02	2.0E-02	oral	3.98E-02			-	3	Non Carcinogen	4.0E-02	-	6.6E+03	2.4E+03	6.6E+03	Volatile/Toxic
Crotonaldehyde	9.1E-02	1.0E-05	5.0E+00	2.0E+01			-			-		Not Evaluated	-	-	2.0E+04	1.2E+04	2.0E+04	Not Evaluated
Cumene (isopropylbenzene)	7.5E-02	7.1E-06	1.3E+00	6.1E+01	1.1E-01		2.27E-01			-	3	Non Carcinogen	2.3E-01	-	2.9E+03	3.0E+03	3.0E+03	Volatile/Toxic
Cyanide (hydrogen)	1.8E-01	1.8E-05	1.0E-01	1.0E+06	2.0E-02		3.98E-02			-		Non Carcinogen	4.0E-02	-	5.3E+05	1.1E+05	5.3E+05	Volatile/Toxic

Table 2: Toxicity Factors and Results of Preliminary Screening for Volatility and Toxicity (cont'd)

	Diffusivity in Air[1] (cm^2/s)	Diffusivity in Water[1] (cm^2/s)	Soil-Water Distribution Coefficient[1] (cm^3/g)	Water solubility[1] (mg/L-water)	RfD mg/kg-day	note	Tolerable Concentration mg/m^3	Slope Factor (mg/kg-day)$^{-1}$	note	Unit Risk (mg/m^3)$^{-1}$	TRV Source (mg/m^3)	Classification	Target Indoor Air Concentrations Non Carcinogens C_{air}^T (mg/m^3)	Target Indoor Air Concentrations Carcinogens C_{air}^T (mg/m^3)	No NAPL Present Ca'	NAPL Present Ca'	Predicted Maximum Indoor Air Concentration C_{air} (mg/m^3)	Exhibit 1 Determination
Cyanogen	9.6E-02	1.0E-05	1.6E-01	8.5E+03	4.0E-02	oral	7.95E-02			-	3	Non Carcinogen	8.0E-02	-	1.8E+05	1.2E+06	1.2E+06	Volatile/Toxic
Cyanogen bromide	9.6E-02	1.0E-05	1.6E-01	8.5E+03	9.0E-02	oral	3.99E-01			-	3	Non Carcinogen	4.0E-01	-	1.8E+05	3.5E+03	1.8E+05	Volatile/Toxic
Cyanogen chloride	9.6E-02	1.0E-05	1.6E-01	8.5E+03	5.0E-02	oral	2.22E-01			-	3	Non Carcinogen	2.2E-01	-	1.8E+05	2.1E+04	1.8E+05	Volatile/Toxic
Cyclohexane	8.0E-02	9.0E-06	9.6E-01	5.5E+01			-			-		Not Evaluated	-	-	4.5E+04	4.5E+04	4.5E+04	Not Evaluated
C6-C8 Aliphatics				5.4E+00		oral	4.00E+02			-	5	Non Carcinogen	4.0E+02	-	2.8E+04	3.5E+01	2.8E+04	Volatile/Toxic
C8-C10 Aliphatics				4.3E-01		oral	1.84E+04			-	5	Non Carcinogen	1.8E+04	-	3.5E+03	4.6E+00	3.5E+03	Not Volatile/Toxic
C10-C12 Aliphatics				3.4E-02		oral	1.00E+03			-	5	Non Carcinogen	1.0E+03	-	4.2E+02	5.6E-01	4.2E+02	Not Volatile/Toxic
C6-C8 Aromatics				5.2E+02		oral	4.00E+02			-	5	Non Carcinogen	4.0E+02	-	1.4E+04	1.9E+01	1.4E+04	Volatile/Toxic
C8-C10 Aromatics				6.5E+01		oral	2.00E+02			-	5	Non Carcinogen	2.0E+02	-	3.3E+03	4.2E+00	3.3E+03	Volatile/Toxic
C10-C12 Aromatics				2.5E+01		oral	-			-	5	Not Evaluated	-	-	3.6E+02	4.6E-01	3.6E+02	Not Evaluated
C12-C16 Aromatics			7.4E-02	1.0E+04		oral	-			-		Not Evaluated	-	-	5.6E+04	4.0E-02	5.6E+04	Not Evaluated
n-Decane				5.2E-02	1.3E+00	inhal	2.64E+00				STAATS	Non Carcinogen	2.6E+00	-	1.5E-03	1.0E+03	1.0E+03	Volatile/Toxic
Dibenzofuran	6.0E-02	1.0E-05	4.7E+01	3.1E+00	4.0E-03	oral	7.95E-03			-	3	Non Carcinogen	8.0E-03	-	1.6E-01	2.3E+00	2.3E+00	Volatile/Toxic
Dibromochloromethane	9.6E-02	1.0E-05	2.8E+00	4.4E+03	2.0E-02	oral	3.98E-02			-	3	Non Carcinogen	4.0E-02	-	1.5E+04	1.8E+04	1.8E+04	Volatile/Toxic
1,2-Dibromo-3-chloropropane	2.1E-02	7.0E-06	1.7E-01	1.2E+03	5.7E-05		1.14E-04			6.9E-04	3	Carcinogen	-	1.4E-02	7.2E+02	7.7E+02	7.7E+02	Volatile/Toxic
1,2-Dibromoethane	7.3E-02	8.1E-06	1.7E-01	3.4E+03	5.7E-05		1.14E-04			6.0E-01	3	Carcinogen	-	1.7E-05	4.4E+03	1.2E+04	1.2E+04	Volatile/Toxic
1,2-Dichlorobenzene	6.9E-02	7.9E-06	3.7E+00	1.6E+02	9.0E-02		1.79E-01			-	4 /HEAST	Non Carcinogen	1.8E-01	-	1.2E+03	1.2E+03	1.2E+03	Volatile/Toxic
1,3-Dichlorobenzene	6.9E-02	7.9E-06	3.7E+00	1.6E+02			-			-		Not Evaluated	-	-	1.2E+03	1.8E+03	1.8E+03	Not Evaluated
1,4-Dichlorobenzene	6.9E-02	7.9E-06	3.7E+00	7.4E+01			9.50E-02			-	2	Non Carcinogen	9.5E-02	-	7.4E+02	1.5E+03	1.5E+03	Volatile/Toxic
Dichlorodifluoromethane	8.0E-02	1.1E-05	3.5E-01	2.8E+02	5.7E-02		1.14E-01			-	3	Non Carcinogen	1.1E-01	-	1.1E+05	3.2E+06	3.2E+06	Volatile/Toxic
1,1-Dichloroethane	7.4E-02	1.1E-05	1.9E-01	5.1E+03	1.4E-10		2.84E-10			-	3	Non Carcinogen	2.8E-10	-	1.2E+05	1.3E+05	1.3E+05	Volatile/Toxic
1,2-Dichloromethane	1.0E-01	9.9E-06	1.0E-01	8.5E+03			-	9.9E-05		2.2E-05	2	Carcinogen	-	4.5E-01	3.4E+04	2.0E+05	2.0E+05	Volatile/Toxic
1,1-Dichloroethylene	9.0E-02	1.0E-05	3.5E-01	2.3E+03	5.7E-02		1.14E-01			5.0E-02	3	Carcinogen	-	2.0E-04	2.5E+05	3.4E+05	3.4E+05	Volatile/Toxic
1,2-Dichloroethylene(cis)	7.4E-02	1.1E-05	2.1E-01	3.5E+03	1.0E-02		1.99E-02			-	HEAST	Non Carcinogen	2.0E-02	-	6.0E+04	1.1E+05	1.1E+05	Volatile/Toxic
1,2-Dichloroethylene(trans)	7.1E-02	1.2E-05	3.2E-01	6.3E+03	2.0E-02		3.98E-02			-		Non Carcinogen	4.0E-02	-	2.4E+05	1.1E+05	2.4E+05	Volatile/Toxic
1,2-Dichloropropane	7.8E-02	8.7E-06	2.6E-01	2.8E+03	1.4E-04		4.00E-04	6.8E-02		1.5E-02	HEAST	Carcinogen	-	6.5E-04	3.1E+04	3.3E+04	3.3E+04	Volatile/Toxic
1,3-Dichloropropene	6.3E-02	1.0E-05	2.7E-01	2.8E+03	3.0E-04		2.00E-03	1.8E-02		4.1E-03	4 /HEAST	Carcinogen	-	2.5E-03	2.0E+05	2.1E+04	2.0E+05	Volatile/Toxic
Dicyclopentadiene	6.7E-02	1.0E-05	3.4E+00	1.8E+03	5.7E-03		1.14E-02			-	3	Non Carcinogen	1.1E-02	-	7.9E+04	1.7E+03	7.9E+04	Volatile/Toxic
Dimethylamine	1.2E-01	1.3E-05	1.3E-02	1.0E+06			-			-		Not Evaluated	-	-	3.7E+05	3.9E+05	3.9E+05	Not Evaluated
Epiclorohydrin	8.8E-02	9.8E-06	2.1E-02	6.0E+04	2.9E-04		5.69E-04			1.2E-03	3	Carcinogen	-	8.3E-03	7.8E+03	8.5E+03	8.5E+03	Volatile/Toxic
Ethyl acetate	7.3E-02	9.7E-06	3.6E-01	8.0E+04	9.0E-01	oral	1.79E+00			-	3	Non Carcinogen	1.8E+00	-	4.6E+04	4.6E+04	4.6E+04	Volatile/Toxic
Ethyl acrylate	9.1E-02	8.6E-06	5.0E+00	2.0E+01			-			1.4E-03	3	Carcinogen	-	7.1E-03	2.0E+04	2.2E+04	2.2E+04	Volatile/Toxic
Ethylbenzene	7.5E-02	7.8E-06	2.2E+00	1.7E+02	1.0E-01		1.99E-01	-		-	4	Non Carcinogen	2.0E-01	-	5.4E+03	5.9E+03	5.9E+03	Volatile/Toxic
Ethyl chloride	1.0E-01	1.2E-05	8.8E-02	5.7E+03	2.9E+00		5.69E+00			-	3	Non Carcinogen	5.7E+00	-	2.6E+05	3.7E+05	3.7E+05	Volatile/Toxic
Ethylene oxide	1.3E-01	1.5E-05	1.3E-02	1.0E+08			-	3.5E-01		1.0E-01	3	Carcinogen	-	1.0E-04	3.1E+07	3.2E+05	3.1E+07	Volatile/Toxic

Table 2: Toxicity Factors and Results of Preliminary Screening for Volatility and Toxicity (cont'd)

	Diffusivity in Air[1] (cm^2/s)	Diffusivity in Water[1] (cm^2/s)	Soil-Water Distribution Coefficient[1] (cm^3/g)	Water solubility[1] (mg/L-water)	RfD mg/kg-day	note	Tolerable Concentration mg/m^3	Slope Factor (mg/kg-day)$^{-1}$	note	Unit Risk (mg/m^3)$^{-1}$	TRV Source (mg/m^3)	Classification	Target Indoor Air Concentrations Non Carcinogens C_{air}^T (mg/m^3)	Target Indoor Air Concentrations Carcinogens C_{air}^T (mg/m^3)	No NAPL Present Ca'	NAPL Present Ca'	Predicted Maximum Indoor Air Concentration C_{air} (mg/m^3)	Exhibit 1 Determination
Ethyl ether	7.0E-02	9.3E-06	8.4E-02	1.0E+04	2.0E-01	oral	3.98E-01			-	3	Non Carcinogen	4.0E-01	-	5.3E+02	2.2E+05	2.2E+05	Volatile/Toxic
Ethyl methacrylate	9.1E-02	8.6E-06	5.0E+00	2.0E+01	9.0E-02	oral	1.79E-01			-	3	Non Carcinogen	1.8E-01	-	2.0E+04	1.3E+04	2.0E+04	Volatile/Toxic
Furan	1.0E-01	1.2E-05	7.4E-02	1.0E+04	1.0E-03	oral	1.99E-03			-	3	Non Carcinogen	2.0E-03	-	2.2E+05	2.3E+05	2.3E+05	Volatile/Toxic
n-Hexane	2.0E-01	7.8E-06	5.3E+00	1.8E+01	5.7E-02		1.14E-01			-	3	Non Carcinogen	1.1E-01	-	9.0E+03	7.2E+04	7.2E+04	Volatile/Toxic
Isobutanol	8.6E-02	9.3E-06	3.7E-01	8.5E+04	3.0E-01	oral	5.96E-01			-	3	Non Carcinogen	6.0E-01	-	4.2E+03	8.0E+03	8.0E+03	Volatile/Toxic
Maleic hydrazide	9.0E-02	1.1E-05	2.5E-01	6.0E+03	5.0E-01	oral	9.94E-01			-	3	Non Carcinogen	9.9E-01	-	1.6E+05	2.3E-05	1.6E+05	Volatile/Toxic
Methacrylonitrile	1.1E-01	1.3E-05	5.1E-03	7.9E+04			-			-		Not Evaluated	-	-	2.8E+04	2.7E+04	2.8E+04	Not Evaluated
Methomyl	6.9E-02	1.0E-05	8.9E-02	1.7E+05	2.5E-02	oral	4.97E-02			-	3	Non Carcinogen	5.0E-02	-	2.7E+07	4.8E-03	2.7E+07	Volatile/Toxic
Methyl acetate	1.0E-01	1.0E-05	1.3E-02	1.0E+06	1.0E+00	oral	1.99E+00			-	3	Non Carcinogen	2.0E+00	-	8.4E+04	8.9E+04	8.9E+04	Volatile/Toxic
Methyl acrylate	9.1E-02	8.6E-06	5.0E+00	6.0E+01	3.0E-02	oral	5.96E-02			-	3	Non Carcinogen	6.0E-02	-	5.9E+04	4.1E+04	5.9E+04	Volatile/Toxic
Methylcyclohexane	7.0E-02	9.0E-06	1.3E+01	1.4E+01	8.6E-01		1.70E+00			-	3	Non Carcinogen	1.7E+00	-	2.5E+04	2.5E+04	2.5E+04	Volatile/Toxic
Methylene bromide	9.6E-02	1.0E-05	1.5E-01	1.2E+04	1.4E-03		5.00E-03			-	4	Non Carcinogen	5.0E-03	-	4.4E+04	3.5E+04	4.4E+04	Volatile/Toxic
Methylene chloride	1.0E-01	1.2E-05	7.0E-02	1.3E+04	6.0E-02		3.00E+00	7.5E-03		1.7E-03	4	Carcinogen	-	5.9E-03	1.2E+05	2.1E+05	2.1E+05	Volatile/Toxic
Methyl ethyl ketone	9.0E-02	9.8E-06	2.7E+02	2.7E+05	1.4E+00	oral	2.84E+00			-	3	Non Carcinogen	2.8E+00	-	3.0E+04	3.6E+04	3.6E+04	Volatile/Toxic
Methyl isobutyl ketone	7.5E-02	7.8E-06	8.0E-01	1.9E+04	8.6E-01	oral	1.70E+00			-	3	Non Carcinogen	1.7E+00	-	1.1E+04	1.1E+04	1.1E+04	Volatile/Toxic
Methyl methacrylate	7.7E-02	8.6E-06	7.9E-02	1.5E+04	-		5.20E-02			-	2	Non Carcinogen	5.2E-02	-	2.1E+04	2.1E+04	2.1E+04	Volatile/Toxic
Methyl styrene (mixture)	7.1E-02	8.0E-06	2.2E+00	3.0E+02	1.1E-02	oral	2.27E-02			-	3	Non Carcinogen	2.3E-02	-	2.8E+03	9.9E+02	2.8E+03	Volatile/Toxic
Methyl styrene (alpha)	7.1E-02	8.0E-06	2.2E+00	3.0E+02			-			-		Not Evaluated	-	-	2.8E+03	9.9E+02	2.8E+03	Not Evaluated
Methyl tertbutyl ether MTBE	8.0E-02	1.0E-05	3.6E-02	1.5E+05	-		3.70E-02			-	2	Non Carcinogen	3.7E-02	-	3.6E+05	1.2E+05	3.6E+05	Volatile/Toxic
Nitrobenzene	7.6E-02	8.6E-06	3.9E-01	2.1E+03	5.7E-04		1.14E-03			-	3	Non Carcinogen	1.1E-03	-	2.1E+02	1.6E+02	2.1E+02	Volatile/Toxic
N-Nitrosodi-n-butylamine	5.8E-02	9.7E-06	1.5E+00	1.3E+03	5.7E-04		1.14E-03			1.6E-01	3	Carcinogen	-	6.3E-05	1.7E+03	2.7E+02	1.7E+03	Volatile/Toxic
m-Nitrotoluene	7.6E-02	8.6E-06	3.9E-01	2.1E+03	5.7E-04		2.53E-03			-		Non Carcinogen	2.5E-03	-	2.1E+02	1.6E+02	2.1E+02	Volatile/Toxic
o-Nitrotoluene	7.6E-02	8.6E-06	3.9E-01	2.1E+03	5.7E-04		2.53E-03			-		Non Carcinogen	2.5E-03	-	2.1E+02	1.4E+02	2.1E+02	Volatile/Toxic
p-Nitrotoluene	7.6E-02	8.6E-06	3.9E-01	2.1E+03	5.7E-04		2.53E-03			-		Non Carcinogen	2.5E-03	-	2.1E+02	1.3E+02	2.1E+02	Volatile/Toxic
Polychlorinated Biphenyls (high risk)	1.8E-02	8.0E-06	2.8E-01	5.7E-01			-	2.0E+00		5.7E-01	3	Carcinogen	-	1.8E-05	8.0E-01	2.1E+09	2.1E+09	Volatile/Toxic
Polychlorinated Biphenyls (low risk)	1.8E-02	8.0E-06	2.8E-01	1.0E-01	1.0E-02		1.99E-02	3.5E-01		1.0E-01	3	Carcinogen	-	1.0E-04	1.4E-01	2.1E+09	2.1E+09	Volatile/Toxic
<u>Polynuclear aromatic hydrocarbons</u>																		
Acenaphthene	4.2E-02	7.7E-06	2.9E+01	3.9E+00	6.0E-02		1.19E-01			-	4	Non Carcinogen	1.2E-01	-	3.0E+00	2.1E+00	3.0E+00	Volatile/Toxic
Acenaphthylene				1.6E+01			-	-		-	-	Not Evaluated	-	-	8.2E+00	7.7E-01	8.2E+00	Not Evaluated
Anthracene	3.2E-02	7.7E-06	1.4E+02	4.3E-02	3.0E-01		5.96E-01			-	4	Non Carcinogen	6.0E-01	-	9.8E-03	2.7E-03	9.8E-03	Not Volatile/Toxic
Benz[a]anthracene	5.1E-02	9.0E-06	9.4E-03	9.4E-03			-	3.1E-01		8.8E-02	3	Carcinogen	-	1.1E-04	4.6E-04	2.4E-03	2.4E-03	Volatile/Toxic
Benzo[k]fluoranthene	2.3E-02	5.6E-06	8.0E-04	8.0E-04			-	5.5E-03		1.3E-03	2	Carcinogen	-	7.7E-03	1.9E-06	1.3E-06	1.9E-06	Not Volatile/Toxic
Benzo[b]fluoranthene	2.3E-02	5.6E-06	1.5E-03	1.5E-03			-	8.2E-03		1.9E-03	2	Carcinogen	-	5.3E-03	4.0E-06	7.0E-04	7.0E-04	Not Volatile/Toxic
Benzo[a]pyrene	4.3E-02	9.0E-06	1.6E-03	1.6E-03			-	1.4E-01		3.1E-02	2	Carcinogen	-	3.2E-04	3.0E-06	1.5E-07	3.0E-06	Not Volatile/Toxic
Benzo(g,h,i)perylene	-	-	-	2.6E-04			-	-		-	-	-	-	-	3.6E-07	8.4E-06	8.4E-06	Not Evaluated

Table 2: Toxicity Factors and Results of Preliminary Screening for Volatility and Toxicity (cont'd)

	Diffusivity in Air[1] (cm²/s)	Diffusivity in Water[1] (cm²/s)	Soil-Water Distribution Coefficient[1] (cm³/g)	Water solubility[1] (mg/L-water)	RfD mg/kg-day	note	Tolerable Concentration mg/m³	Slope Factor (mg/kg-day)⁻¹	note	Unit Risk (mg/m³)⁻¹	TRV Source (mg/m³)	Classification	Target Indoor Air Concentrations Non Carcinogens C_{air}^T (mg/m³)	Target Indoor Air Concentrations Carcinogens C_{air}^T (mg/m³)	No NAPL Present Ca'	NAPL Present Ca'	Predicted Maximum Indoor Air Concentration C_{air} (mg/m³)	Exhibit 1 Determination
Polynuclear aromatic hydrocarbons (Continued)																		
Chrysene	2.5E-02	6.2E-06	2.4E+03	1.6E-03			8.80E-04	3.1E-03		8.8E-04	3	Carcinogen	-	1.1E-02	3.4E-05	8.0E-06	3.4E-05	Not Volatile/Toxic
Dibenz(a,h)anthracene	-	-	-	2.5E-03			-	3.1E+00	-	8.8E-01	3	Carcinogen	-	1.1E-05	1.3E-06	2.2E-08	1.3E-06	Not Volatile/Toxic
Fluoranthene	-	-	-	2.1E-01	4.0E-02		7.95E-02	-			3	Non Carcinogen	8.0E-02	-	7.5E-03	1.0E-02	1.0E-02	Not Volatile/Toxic
Fluorene	6.1E-02	7.9E-06	8.3E+01	1.9E+00	4.0E-02	oral	7.95E-02	4.0E-02		9.0E-03	3	Carcinogen	-	1.1E-03	7.4E-01	8.0E+00	8.0E+00	Volatile/Toxic
Indeno(1,2,3-c,d)pyrene	-	-		2.2E-05			-	3.1E-01		8.8E-03	3	Carcinogen	-	1.1E-03	3.1E-08	1.9E-07	1.9E-07	Not Volatile/Toxic
Naphthalene	5.9E-02	7.5E-06	7.1E+00	3.1E+01	4.0E-02		7.95E-02			-	US EPA 1994	Non Carcinogen	8.0E-02	-	6.2E+01	6.1E+01	6.2E+01	Volatile/Toxic
Phenanthrene	-	-	-	1.2E+00			-					-	-	-	2.0E-01	1.1E-01	2.0E-01	Not Evaluated
Pyrene	2.7E-02	7.2E-06	6.3E+02	1.4E-01	3.0E-02		5.96E-02			-	4	Non Carcinogen	6.0E-02	-	6.7E-03	5.0E-03	6.7E-03	Not Volatile/Toxic
Propylene oxide	1.2E-01	1.3E-05	1.5E-01	4.8E+05	8.6E-03		1.70E-02	1.3E-02		3.7E-03	3	Carcinogen	-	2.7E-03	1.3E+05	1.7E+05	1.7E+05	Volatile/Toxic
Styrene	7.1E-02	8.0E-06	4.7E+00	3.1E+02			-			-	2	Not Evaluated	-	-	3.4E+03	3.6E+03	3.6E+03	Not Evaluated
1,1,1,2-Tetrachloroethane	7.1E-02	7.9E-06	5.6E-01	3.0E+03	3.0E-02		5.96E-02			7.4E-04	3	Carcinogen	-	1.4E-02	2.9E+04	1.1E+04	2.9E+04	Volatile/Toxic
1,1,2,2-Tetrachloroethane	7.1E-02	7.9E-06	5.6E-01	3.0E+03	6.0E-02		1.19E-01			5.8E-03	3	Carcinogen	-	1.7E-03	4.5E+03	1.3E+04	1.3E+04	Volatile/Toxic
Tetrachloroethylene (PCE)	7.2E-02	8.2E-06	9.3E-01	2.0E+02	-		3.60E-01			-	2	Non Carcinogen	3.6E-01	-	1.4E+04	1.8E+04	1.8E+04	Volatile/Toxic
Tetrahydrofuran	9.8E-02	1.1E-05	5.7E-03	1.0E+06			-			-		Not Evaluated	-	-	2.9E+05	5.8E+04	2.9E+05	Not Evaluated
Toluene	8.7E-02	8.6E-06	1.1E+00	5.3E+02	-		3.80E+00			-	2	Non Carcinogen	3.8E+00	-	1.4E+04	1.5E+04	1.5E+04	Volatile/Toxic
1,2,4-Trichlorobenzene	3.0E-02	8.2E-06	1.1E+01	3.0E+02	-		7.00E-03			-	2	Non Carcinogen	7.0E-03	-	1.7E+03	4.6E+02	1.7E+03	Volatile/Toxic
1,1,1-Trichloroethane	7.8E-02	8.8E-06	6.6E-01	1.3E+03	1.0E+00		1.99E+00			-		Non Carcinogen	2.0E+00	-	9.2E+04	9.0E+04	9.2E+04	Volatile/Toxic
1,1,2-Trichloroethane	7.8E-02	8.8E-06	3.0E-01	4.4E+03	4.0E-03	oral	7.95E-03	5.7E-02		1.3E-02	3, 4	Carcinogen	-	7.8E-04	1.6E+04	1.7E+04	1.7E+04	Volatile/Toxic
Trichloroethylene (TCE)	7.9E-02	9.1E-06	1.0E+00	1.1E+03	1.1E-02		2.27E-02	2.7E-03		6.1E-04	2, 3	Carcinogen	-	1.6E-02	4.6E+04	5.0E+04	5.0E+04	Volatile/Toxic
Trichlorofluoromethane	8.7E-02	1.3E-05	9.6E-01	1.1E+03	2.0E-01		3.98E-01			-	3	Non Carcinogen	4.0E-01	-	4.4E+05	6.3E+05	6.3E+05	Volatile/Toxic
1,1,2-Trichloropropane	4.0E-02	9.3E-06	3.1E-01	2.7E+03	5.0E-03	oral	9.94E-03			-	3	Non Carcinogen	9.9E-03	-	3.2E+05	2.6E-01	3.2E+05	Volatile/Toxic
1,2,3-Trichloropropane	7.1E-02	7.9E-06	3.1E-01	2.7E+03	6.0E-03	oral	1.19E-02			-	3	Non Carcinogen	1.2E-02	-	3.8E+03	3.1E-01	3.8E+03	Volatile/Toxic
1,2,3-Trichloropropene	7.1E-02	7.9E-06	3.1E-01	2.7E+03	2.2E-04		4.33E-04			-	3	Non Carcinogen	4.3E-04	-	1.9E+05	3.6E+03	1.9E+05	Volatile/Toxic
Triethylamine	1.2E-01	1.3E-05	1.3E-02	1.0E+06	2.0E-03		3.98E-03			-	3	Non Carcinogen	4.0E-03	-	6.1E+05	3.2E+04	6.1E+05	Volatile/Toxic
1,2,4-Trimethylbenzene	7.5E-02	7.1E-06	2.2E+01	5.7E+01	1.7E-03		3.38E-03			-	3	Non Carcinogen	3.4E-03	-	1.4E+03	1.4E+03	1.4E+03	Volatile/Toxic
1,3,5-Trimethylbenzene	7.5E-02	7.1E-06	4.9E+00	4.8E+01	1.7E-03		3.40E-03			-	3	Non Carcinogen	3.4E-03	-	1.7E+03	1.4E+03	1.7E+03	Volatile/Toxic
Vinyl acetate	8.5E-02	9.2E-06	3.2E-02	2.0E+04	5.7E-02		1.14E-01			-	3	Non Carcinogen	1.1E-01	-	4.2E+04	4.3E+04	4.3E+04	Volatile/Toxic
Vinyl bromide	1.0E-01	1.2E-05	7.6E-01	1.8E+04	8.6E-04		1.70E-03	1.1E-01		3.2E-02	3	Carcinogen	-	3.1E-04	9.1E+05	6.1E+05	9.1E+05	Volatile/Toxic
Vinyl chloride	1.1E-01	1.2E-06	1.1E-01	2.8E+03	2.9E-02		5.69E-02	3.1E-02		8.8E-03	3	Carcinogen	-	1.1E-03	3.2E+05	1.0E+06	1.0E+06	Volatile/Toxic
Xylenes	7.0E-02	7.8E-06	2.4E+00	1.6E+02	-		1.80E-01			-		Non Carcinogen	1.8E-01	-	4.3E+03	4.9E+03	4.9E+03	Volatile/Toxic

Table 2 Notes: [1] USEPA (2002b); [2] Health Canada (2003b); [3] ORNL (2004); [4] USEPA (2004); [5] TPHCWG (1997)

EXHIBIT I-1.

CALCULATIONS TO DETERMINE IF CHEMICAL IS VOLATILE AND TOXIC

1. Estimate Maximum Vapour Concentration

NAPL Present: $C_a^{NAPL} = UCF_1 * MW*P/(R*T)$

No NAPL Present: $C_a^{NO\ NAPL} = UCF_2 * S * H'$

Maximum Vapour Concentration: $C_a = \mathrm{Max}\ (C_a^{NAPL}, C_a^{NO\ NAPL})$

Parameter	Default
C_a^{NAPL} = Vapour concentration NAPL is present (mg/m^3)	Calculated
$C_a^{NO\ NAPL}$ = Vapour concentration NAPL not present (mg/m^3)	Calculated
MW = Molecular weight (g/mole)	Chemical specific
P = Pure chemical vapour pressure (atm)	Chemical specific
R = Gas constant (m^3-atm/K-mole)	8.21 E-05
T = Absolute temperature (K, 273^{o}C + T(^{o}C))	288
H' = Dimensionless Henry's Law Constant	Chemical specific
S = Pure chemical aqueous solubility (mg/L)	Chemical specific
UCF_1 = Unit Conversion Factor (mg/g)	1,000
UCF_2 = Unit Conversion Factor (L/m^3)	1,000
C_a = Concentration in air (mg/m^3)	Calculated

2. Calculate Maximum Indoor Air Concentration

$C_{air} = C_a * \alpha$ where $\alpha = 0.1 = 1/DL$ and DL = dilution factor

3. Calculate Target Air Concentration [1]

Carcinogen

$C_{air}^T = ILCR^T / (UR * T)$

Note: To convert from SF to UR use: $UR = SF\ (mg/kg)^{-1} * IR / BW$

Non-carcinogen ($TC_{air} = R_fC$)

$C_{air}^T = HQ^T * TC_{air} / T$

Note: To convert from R_fD to TC use: $TC = R_fD(mg/kg\text{-}day) * BW / IR$

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[1] In order to simplify the process of estimating risk for screening, carcinogens are screened using a unit risk value and non carcinogens are calculated using a tolerable concentration. It is recognized that this process is not necessarily applicable for all receptors, i.e., conversion assumes an adult for carcinogenic effects and a toddler for non carcinogenic effects; however, is used for screening. More detailed calculations are provided for estimating risk in the secondary screening process.

EXHIBIT I-1 (Cont'd).

Parameter	Default
C_{AIR}^{T} = Target concentration of contaminant in air (mg/m^3)	Calculated
DR_{IHV} = Dose rate from inhalation of volatiles (mg/kg(BW)-day)	Calculated
$ILCR^{T}$ = Target incremental lifetime cancer risk (dimensionless)	10^{-5}
HQ^{T} = Target hazard quotient	1.0
SF = Slope factor $(mg/kg\text{-}day)^{-1}$	Chemical Specific
IR = Receptor air intake rate (m^3/day) (toddler non carcinogens)	9.3
IR = Receptor air intake rate (m^3/day) (adult carcinogens)	15.8
BW Body weight (kg) (toddler non carcinogens)	16.5
BW = Body weight (kg) (adult carcinogens)	70.7
UR = Unit risk factor $(mg/m^3)^{-1}$	Chemical Specific
T = Fraction of time exposed (dimensionless)	1.0
TC_{air} = Tolerable concentration in air (mg/m^3)	Chemical specific

4. Determine if Chemical is Volatile and Sufficiently Toxic

If $C_{air} >= C_{air}^{T}$ then chemical is considered volatile for purpose of vapour SLRA and is retained for the Secondary Screening process

If $C_{air} < C_{air}^{T}$ then chemical is not considered volatile for purpose of vapour SLRA and this pathway is not considered operable

3 Characterization of Risk

A methodology of calculating risks from inhalation of volatiles is summarized below. The calculation of the risk comprises three parts: 1) calculation of a dose rate, 2) calculation of a hazard quotient for non carcinogens; and/or calculation of an incremental lifetime cancer risk (ILCR) for carcinogens, and 3) comparison with acceptable HQ (1.0) or ILCRs (1×10^{-5}). The risk equations are provided in Exhibit I-2.

A toxicity reference value (TRV) should be selected with a primary consideration being afforded to Canadian sources such as Health Canada. Other sources of TRVs include, Integrated Risk Information System (IRIS) from the USEPA, the World Health Organization (WHO). The screening chart used to determine whether a chemical is volatile and sufficiently toxic (Table 2) includes TRVs from Health Canada and other regulatory agencies. The user should select an appropriate TRV as part of the Secondary Screening process.

EXHIBIT I-2

RISK EQUATIONS

1. Calculation of Dose Rate for Chemicals with a SF or RfD provided

Carcinogen $DR_{INV} = IR \times C_{AIR} \times AF \times D_1 \times D_2 \times D_3 \times D_4 / (BW \times LE)$

Non-Carcinogen $DR_{INV} = IR \times C_{AIR} \times AF \times D_1 \times D_2 \times D_3 / (BW)$

2. Calculation of a Hazard Quotient

a) Chemicals with an Tolerable Daily Intake (TDI) or RfD $HQ = DR_{INV} / R_fD$

b) Chemicals with a Tolerable Air Concentration (TC_{air}) or RfC $HQ = C_{AIR} * T / TC_{air}$

3. Calculation of an ILCR

a) Chemicals with a SF $ILCR = DR_{IHV} * SF$

b) Chemicals with a UR $ILCR = C_{AIR} * T * UR$

If ILCR > 10^{-5} there is potential unacceptable risk due to inhalation of volatiles

If HQ > 1.0 there is potential unacceptable risk due to inhalation of volatiles

Parameter	**Default**
DR_{IHV} = Dose rate from inhalation of volatile contaminants (mg/kg(BW)-day)	Calculated
IR = Receptor air intake rate (m^3/hour)	Scenario-specific[1]
C_{AIR} = Concentration of contaminant in air (mg/m^3)	Calculated
AF = Inhalation absorption factor (unitless)	1
D_1 = Hours per day exposed (hour/day)	Scenario-specific[1]
D_2 = Days per week exposed / 7 days (dimensionless)	Scenario-specific[1]
D_3 = Weeks per year exposed / 52 weeks (dimensionless)	Scenario-specific[1]
D_4 = Total years exposed to site (years, carcinogens only)	Scenario-specific[1]
BW = Body weight (kg)	Scenario-specific[1]
LE = Life expectancy (years, carcinogens only)	56*
T = Fraction of time exposed (i.e. hours per day, days per year)	Scenario-specific[1]
TC_{AIR} = Tolerable air concentration (mg/m^3)	Chemical-specific
TDI = Tolerable daily intake (mg/kg-day)	Chemical-specific
SF = Slope factor $(mg/kg /day)^{-1}$	Chemical-specific
UR= Unit risk $(mg/m^3)^{-1}$	Chemical-specific

[1] For default values see Health Canada (2003a).

* 56 years should be used for assessment of adults only, 75 years should be used for estimates of lifetime exposure. Health Canada is currently reviewing the validity and acceptability of exposure amortization for carcinogenic substances (HC, personal communication, 2004)

4 Examples of Risk Calculations

Scenario 1

Scenario 1 illustrates a residential land use setting with a dissolved phase plume in groundwater contaminated with trichloroethylene (TCE) and vinyl chloride (VC). The depth to water table (i.e., contamination) is estimated to be 4 meters below the building foundation. The soil type is sand and gravel and an adult receptor is assessed for exposure over a period of thirty years. The partitioning equations illustrate how to estimate the soil vapour concentration from the groundwater concentration using the Henry's Law constant. Using the representative attenuation factor, the indoor air concentration is calculated. Risk estimates are provided for an adult receptor. Both of these chemicals are considered to be carcinogenic or non threshold acting chemicals. Carcinogenic end points are considered protective of non carcinogenic endpoints, and therefore, non-carcinogenic risk does not need to be considered. For carcinogenic chemicals, assessment of an adult (i.e. over 30 years) is considered protective of a toddler (exposure would be 3.5 years).

The incremental lifetime cancer risk (ILCR) is estimated using both a slope factor and unit risk factor approach. For the slope factor approach, the dose is amortized over life expectancy and can be adjusted for fraction of time exposed. For the unit risk factor approach, there typically is no amortization as part of the risk calculations, although the risks could be adjusted by fraction of time exposed. For this example scenario, the difference is that the ILCR for the slope factor approach is a factor of 30 years/56 years (0.54) less than that calculated for the unit risk approach. Health Canada is currently reviewing the validity and acceptability of exposure amortization for carcinogenic substances (Health Canada, 2003).

Scenario 2

Scenario 2 illustrates a residential land use setting with a weathered gasoline contamination. There is non-aqueous phase liquid (NAPL) present in soil above the water table in the unsaturated zone. The top of the NAPL zone is approximately 5 m below the building foundation. The contaminants of potential concern considered for this scenario are benzene, toluene, xylenes and hexane. Since NAPL is present, the two-phase partitioning model for NAPL to vapour partitioning is used. Since the mole fractions are available, Raoult's Law is used to estimate the vapour pressure (i.e., the pure-phase vapour pressure is multiplied by the mole fraction). Since the depth to contamination is greater than 5 m below the building and there is open non-capped area surrounding the building, the vapour attenuation factors for benzene, toluene and xylenes are decreased by a factor of ten for to account for biodegradation. The receptor exposure and risk estimates are presented for an adult receptor and a toddler (for non carcinogens only). As shown in the example calculation, when a Tolerable Concentration (TC) is available for a chemical, it is directly used to estimate the HQ (HQ = C_{air}/TC). When only a Tolerable Daily Intake (TDI) is available, the HQ is estimated using the dose rate (HQ = Dose Rate/TDI).

Scenario 3

Scenario 3 illustrates a commercial land use with a coal tar contamination in soil above the water in the unsaturated zone. The depth to the top of the contamination is 2 m below the building foundation. The soil type consists of sand. The contaminant of potential concern assessed is naphthalene, which a relative volatile PAH. The measured naphthalene concentration in soil is 20 mg/kg. Since this concentration is less than the soil saturation (C_{sat}) concentration for naphthalene (373 mg/kg), the three-phase partitioning model is used to estimate the vapour concentration from a soil source. The commercial building is a warehouse with an indoor room height of 4 m. Since this is greater than the default height of 3 m and since mixing of vapours inside the entire building height is expected, the vapour attenuation factor is adjusted by multiplying the attenuation by 3 m / 4 m (0.75). Risk estimates for provide based on exposure defaults for a commercial worker.

Example Calculation fo Scenario 1

1. SITE DESCRIPTION

Scenario:	Residential
Contamination type:	Chlorinated solvent, dissolved plume
COPCs:	Trichloroethylene (TCE), vinyl chloride (VC)
Soil type:	Sand and gravel (coarse grain)
Depth to contamination below foundation:	4 m

2. PARTITIONING

$C_a = CF1 * C_w * H'$

$C_{air} = \alpha * Ca$

COPC			TCE	VC	Source
Input Parameters					
Concentration in groundwater	C_w	(mg/L)	0.09	0.004	Site data
Dimensionless Henry's Law Constant	H'	(unitless)	4.22E-01	1.11E+00	US EPA, 1996
Attenuation Factor	α		6.6E-04	8.0E-04	
Unit conversion factor	CF1	(L/m^3)	1.0E+03	1.0E+03	
Partitioning					
Concentration in soil vapour	C_a	(mg/m3)	3.80E+01	4.44E+00	
Concentration in indoor air	C_{air}	(mg/m3)	2.49E-02	3.55E-03	

3. EXPOSURE

Carcinogens

$DR_{INV} = IR * C_{air} * AF * D1 * D2/7 * D3/52 * D4 / (BW * LE)$

Exposure Parameters:	**Adult**	**Source**
Inhalation rate (IR; m3/hr)	0.658	HC, 2003
Inhalation absorption factor (AF; unitless)	1	HC, 2003
Exposure period terms:		
D1; hours/day	24	HC, 2003
D2; days/week (/7days)	7	HC, 2003
D3; weeks/year (/52 weeks)	52	HC, 2003
D4; total years (carcinogen only)	30	
Body weight (BW; kg)	70.7	HC, 2003
Life Expectancy (carcinogens only)	56	HC, 2003

Note: As per Health Canada (2003) an adult is evaluated for exposure to carcinogens

DR $_{IHV}$ (mg/kg-day)	**Adult**
Trichloroethylene	2.98E-03
Vinyl chloride	4.25E-04

4. RISK ESTIMATES

ILCR = SF * Dose (Dose is amortized over life expectancy and adjusted for time exposed)

ILCR = Air Concentration * Unit Risk * T (T = 1 when no amortization)

a. Calculation of Risks for Exposures Using Slope Factor Approach

COPC	SF (mg/kg-d)$^{-1}$	Source	DR $_{IHV}$ (mg/kg-d)	ILCR
Trichloroethylene	2.7E-03	HC, 2003	3.0E-03	8.0E-06
Vinyl chloride	3.08E-02	US EPA, 2004	0.00042525	1.3E-05
Total ILCR				2.1E-05

b. Calculation of Risks for Exposures using Unit Risk Approach

COPC	Unit Risk	ILCR using UR
	(mg/m^3)$^{-1}$	
Trichloroethylene	6.1E-04	1.5E-05
Vinyl chloride	2.9E-04	1.0E-06

Example Calculation for Scenario 2

1. SITE DESCRIPTION

Scenario:	Residential
Contamination type:	Weathered gasoline, NAPL present
COPCs:	benzene, toluene, xylenes, hexane
Soil type:	sandy silt (fine grain)
Depth to contamination below foundation:	5 m

2. PARTITIONING

C_a = 1E06 * X * P * MW / RT

$C_{air} = \alpha * C_a$

COPC			Benzene	Toluene	Xylene	Hexane	Source
Input Parameters							
Mole fraction	X	(unitless)	0.0137	0.1216	0.1247	0.0459	Johnson et al., 1990
Vapour pressure	P	(atm)	6.20E-02	1.71E-02	4.40E-03	1.02E-01	
Molecular weight	MW	(g/mol)	78.11	92.14	106.17	86.18	
Gas constant	R	(L-atm/K-mol)	8.21E-02	8.21E-02	8.21E-02	8.21E-02	
Temperature	T	(K)	288	288	288	288	
Attenuation factor	α		5.0E-04	4.5E-04	5.0E-04	5.0E-04	
Adjusted Attenuation factor	α		5.0E-05	5.0E-05	5.0E-05		
Estimated Concentrations in Soil Gas and Air							
Concentration in soil vapour	Csg	(mg/m^3)	2.81E+03	8.11E+03	2.47E+03	1.71E+04	
Concentration in air	Cair	(mg/m^3)	1.40E+00	3.66E+00	1.23E+00	8.54E+00	

Note:
1. The attenuation factor was reduced by a factor of ten for benzene, toluene and xylene as per the guidance
1 E 06 = conversion factor

3. EXPOSURE

Carcinogens

DR_{INV} = IR * Cair * AF * D1 * D2/7 * D3/52 * D4 / (BW * LE)

Non Carcinogens

DR_{INV} = IR * Cair * AF * D1 * D2/7 * D3/52/ (BW)

Exposure Parameters:	Toddler	Adult	Source
Inhalation rate (IR; m^3/hr)	0.388	0.658	HC, 2003
Inhalation absorption factor (AF; unitless)	1	1	HC, 2003
Exposure period terms:			
D1; hours/day	24	24	HC, 2003
D2; days/week (/7days)	7	7	HC, 2003
D3; weeks/year (/52 weeks)	52	52	HC, 2003
D4; total years (carcinogen only)	N/A	30	HC, 2003
Body weight (BW; kg)	16.5	70.7	HC, 2003
Life Expectancy (carcinogens only)	N/A	56	HC, 2003

Note: As per HC (2003), an adult is evaluated for carcinogens and a toddler is evaluated for non-carcinogens

DR_{INV} (D; mg/kg-day)	Toddler	Adult
Benzene	N/A	1.68E-01
Toluene	2.07E+00	N/A
Xylene	6.95E-01	N/A
Hexane	4.81E+00	N/A

4. RISK ESTIMATES

HQ =TDI / Dose   TDI = RfD

HQ = C_{air} / TC   TC =RfC

ILCR = SF * Dose or ILCR = Air Concentration * Unit Risk

a. Calculation of Risks for Exposures Using Slope Factor Approach

	Toxicity Reference Value					Risk Estimate	
COPC	**RfD (mg/kg-d)**	**TC (mg/m3)**	**SF (mg/kg-d)-1**	**Source**	**DR_{IHV} (mg/kg-d)**	**HQ (child)**	**ILCR (adult)**
Benzene	N/A	-	1.46E-02	HC, 2003	1.7E-01	N/A	2.5E-03
Toluene	2.20E-01	3.80E+00	N/A	HC, 2003	N/A	9.64E-01	N/A
Xylene	1.50E+00	1.80E-01	N/A	HC, 2003	N/A	6.85E+00	N/A
Hexane	4.70E-03	-	N/A	US EPA, 2004	4.81E+00	1.02E+03	N/A
Total ILCR							2.5E-03

b. Calculation of Risks for Exposures using Unit Risk Approach

	Toxicity Reference Value				Risk Estimate	
COPC	**[Air] (mg/m^3)**	**Unit Risk (mg/m^3)$^{-1}$**	**Source**			**ILCR (adult)**
Benzene	1.40E+00	3.3E-03	HC, 2003			4.6E-03

Example Calculation for Scenario 3

1. SITE DESCRIPTION

Scenario:	Light industrial warehouse
Contamination type:	coal tar contamination in soil
COPCs:	naphthalene
Soil type:	sand (coarse grain)
Depth to Contamination	2 m
Height of Building	4 m

2. PARTITIONING

$Ca = X * S/?_{b} *(Koc*foc *?_{b}\ B + ?w + H' * ?_{a})$

If Ct < Csat, then no NAPL present and the following applies:
$Cw = C_{t} * ?_{b} / (K_{oc} * f_{oc} *?_{b} + ?w + H' * ?a)$

$C_{air} = \alpha * Ca$

COPC			**Naphthalene**	**Source**
Input Parameters				
Concentration in soil	C_{soil}	(mg/kg)	20	
Water solubility	S	(mg/L)	3.10E+01	US EPA, 1996
soil dry bulk density	$?_{b}$	(kg-soil/L-total)	1.6	Dwyer et al., 1997
Organic carbon partition co-efficient	K_{oc}	L/kg	2.00E+03	US EPA, 1996
fraction of organic carbon	f_{oc}		0.006	Dwyer et al., 1997
Water filled porosity	?w	(L-water/L-total)	0.054	
Henry's Law Constant	H'	(unitless)	1.98E-02	US EPA, 1996
Air filled soil porosity	?a	(L-air/L-total)	0.321	
Attenuation factor	α		0.00022	
Adjusted attenuation factor	α		0.000375	
Estimated Concentration in various media				**Notes**
Concentration in groundwater	Cw	(mg/L)	1.66E+00	
Soil saturation concentration	Csat	(mg/kg)	3.73E+02	Ct < Csat
Concentration in soil vapour	Cair	(mg/m3)	3.29E+01	
Concentration in air	Cair	(mg/m3)	1.23E-02	

3. EXPOSURE

D = IR * Cair * AF * D1 * D2 * D3 / (BW)

Exposure Parameters:	**Adult Worker**	**Source**
Inhalation rate (IR; m3/hr)	0.658	HC, 2003
Concentration in air (Cair; mg/m3)	1.23E-02	
Inhalation absorption factor (AF; unitless)	1	
Exposure period terms:		HC, 2003
D1; hours/day	8	HC, 2003
D2; days/week (/7days)	5	HC, 2003
D3; weeks/year (/52 weeks)	48	HC, 2003
Body weight (BW; kg)	70.7	HC, 2003
DR $_{IHV}$ Adult Worker (mg/kg-day)	6.1E-04	

4. RISK ESTIMATES

HQ = RfD/Dose

COPC	**RfD (mg/kg-d)**	**Source**	**DR $_{IHV}$ (mg/kg-d)**	**HQ**
Naphthalene	6.7E-04	US EPA, 2004	6.1E-04	9.0E-01

HQ = Hazard Quotient
RfD = Reference Dose

APPENDIX C-2

DERIVATION OF VAPOUR ATTENUATION FACTORS FOR SCREENING LEVEL RISK ASSESSMENT GUIDANCE

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1. Introduction

This appendix describes the framework and methodology for the derivation of the vapour attenuation factor charts for the SLRA Level 2 evaluation of soil vapour intrusion into buildings. The vapour attenuation factor charts are a key part of this guidance document.

The vapour attenuation factors, defined as the indoor air concentration divided by the soil vapour concentration at some depth, are based on the results of model predictions using the Johnson and Ettinger (J&E) model (Johnson and Ettinger 1991). The attenuation factor charts enable a user of the SLRA Level 2 guidance to select an attenuation factor based on soil type (fine- or coarse-grained) and depth to contamination source for a residential or commercial land use scenario. Attenuation factor charts are provided for a groundwater contaminant source (groundwater to indoor air pathway) and soil or soil vapour contaminant source (soil vapour to indoor air pathway). The use of two adjustable parameters (soil type and depth) allow for selection of an attenuation factor that is more representative of site conditions. The attenuation factors, when used with appropriate partitioning equations, are used to estimate indoor air concentrations associated with subsurface vapour sources. The indoor air concentrations are used to predict potential risk to human health via inhalation exposure.

The vapour attenuation factor charts developed for this guidance assume no biodegradation of hydrocarbons such as benzene, toluene, ethylbenzene and xylenes (BTEX).

The input parameters for the J&E model were developed considering soil science principles, available studies of building characteristics, and expert opinion. Relatively conservative values were chosen for many J&E model inputs since the intent was to develop attenuation factors that would, in the large majority of cases, be protective of human health for a wide range of site conditions, excluding those conditions precluded from the secondary screening. However, to avoid the compounding effect of choosing conservative values for all input parameters, “typical” or mean values were chosen for some input parameters.

The J&E model was chosen to develop the attenuation factor charts since it is commonly used, is a relatively simple and easy to understand model, and incorporates the key processes for vapour intrusion into buildings. When used on a site-specific basis, the J&E model is considered to be reasonably accurate and generally compares with properly analyzed field data within one order-of-magnitude, for chemicals not subject to significant biodegradation or transformation processes (Johnson *et. al.*, 2002, Hers *et al.* 2003). Given the inherent variability associated with empirical measurements and modeling of vapour intrusion, it is not feasible to expect a model to provide a better match with empirical data.

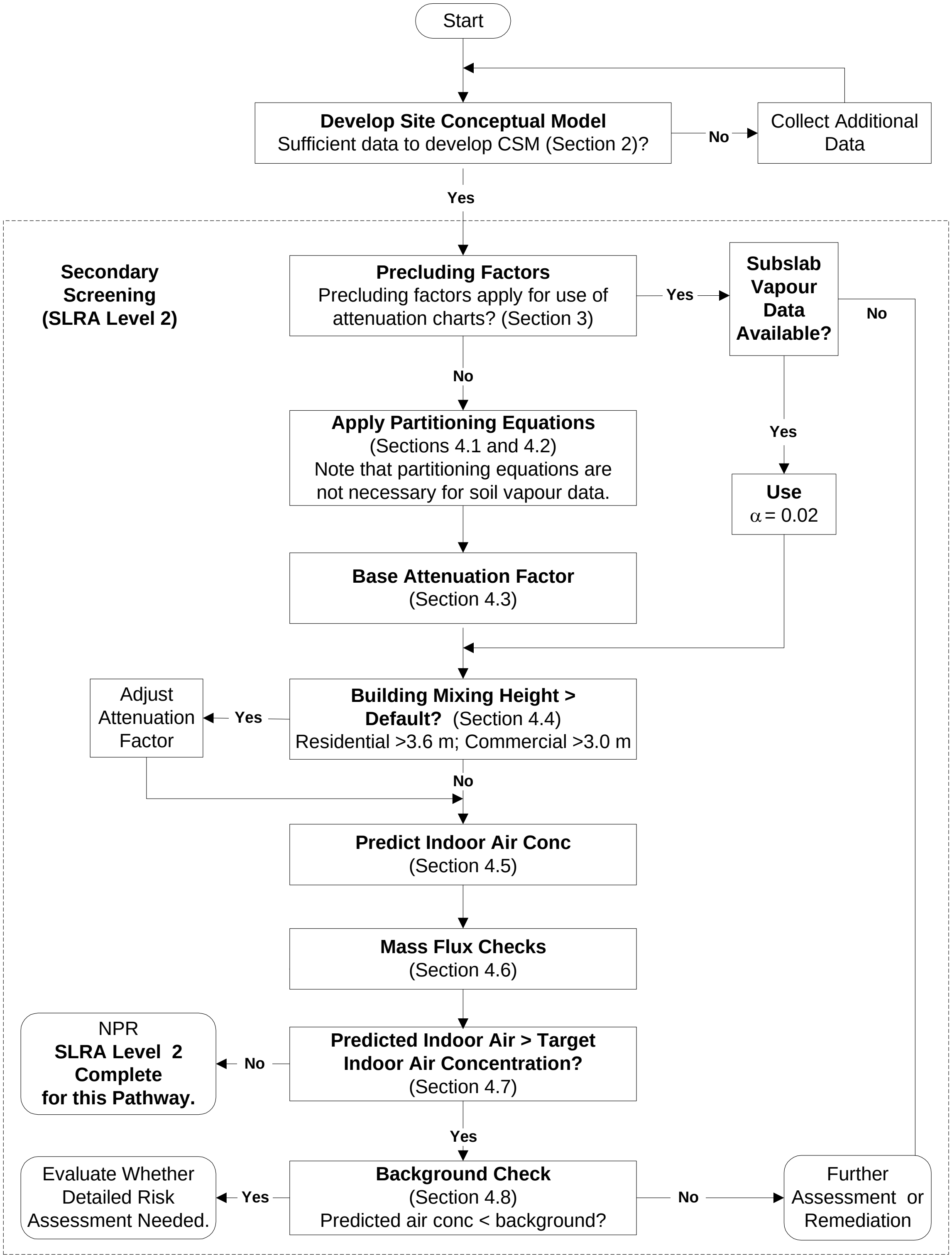
This appendix begins with a description of the J&E model and the context for use of the J&E model to derive attenuation factors. Next, the rationale for the input parameters chosen is given, and the derived attenuation factors are compared to available empirical attenuation factors calculated from field measurements. The guidance attenuation factors are reasonably protective, in that the measured attenuation factors were, in almost all cases, less than those predicted using the J&E model and incorporated in the guidance. A summary of the SLRA Vapour Intrusion Guidance is provided for convenience in Figure 1.

2. Johnson and Ettinger Model Assumptions and Use

2.1 Overview of Johnson and Ettinger Model

Johnson and Ettinger (1991) introduced a screening-level model for estimating the transport of contaminant vapours from a subsurface source into indoor air spaces. The model is a one-dimensional analytical solution that accounts for diffusive and advective transport of vapours. The J&E model estimates the *vapour attenuation factor,* which is the ratio of the vapour concentration in the indoor space to the vapour concentration at the contamination source. To facilitate use of the J&E model, the US EPA in 1997 developed spreadsheet versions of the model that also included additional calculations to estimate the partitioning between vapour source media (e.g., soil, groundwater) and soil vapour, and to estimate health risk based on the modeled indoor air concentration. A total of six spreadsheets were developed: a screening-level model for uniform geology and a more advanced version that considers multiple geologic layers for each of three potential vapour sources: groundwater, bulk soil, and soil gas. The spreadsheets were updated in 2000, 2002 and 2003. There is also commercially available computer software that includes the J&E model, or variants thereof (e.g., RISC, GSI Tool kit).

Figure 1. Flow Chart for SLRA Level 2 Vapour Intrusion Guidance



The J&E model was developed for use as a screening level tool. Consequently, it is based on a number of simplifying assumptions regarding contaminant distribution and occurrence, subsurface characteristics, transport mechanisms, and building construction.

Vapour from the contamination source is assumed to diffuse directly upward (one-dimensional transport) through homogeneous soil layers with isotropic properties to the base of a building foundation, where advection and diffusion carry the vapour through cracks in the foundation into the building. Both diffusive and advective transport processes are assumed to be at steady state; therefore, absorption and dissolution processes no longer contribute to retardation of vapour migration. Biodegradation is not considered in the base version of the J&E model, although Johnson *et al.* (1998) present algorithms for vapour intrusion that account for first-order biodegradation.

Contaminants are assumed to be homogeneously distributed at their source. The base version of the J&E model assumes an infinite contamination source, which results in source concentrations that remain constant over time. Variations of the J&E model are available that include an option to consider a depleting soil contamination source when the groundwater or soil concentrations are below the aqueous solubility limit or soil saturation concentration. Partitioning relationships commonly used with the Johnson and Ettinger model are described in Section 4.0.

2.2 J&E Model Variability

Model variability for the purposes of this discussion is defined as the aggregate range in model predictions that result from model sensitivity and uncertainty in input parameters. Model sensitivity is the relative variation in output caused by varying an input parameter. Of greatest significance are parameters that are uncertain (i.e., vary over a large range) and to which the model is sensitive. When site specific data is properly used and constrained to reasonable ranges, the overall variation in attenuation factors predicted by the J&E model is about one order-of-magnitude, which is considered reasonable for a screening level model (Hers *et al.*, 2003).

A qualitative ranking of the model variability (uncertainty combined with sensitivity) for J&E model inputs is provided in Table 1. Model parameters with moderate to high variability include:

- Water-filled porosity and capillary transition height for contaminated groundwater vapour sources;
- Q_{soil} and soil-air permeability for shallow contamination and depressurized building;
- Building crack ratio and crack moisture content for a shallow contamination scenario for a building that is not depressurized; and,
- Building air change rate and building mixing height for all scenarios.

Building-related parameters with low uncertainty and sensitivity include foundation area, depth to base of foundation, and foundation slab thickness.

As described in Johnson (2002), the potential pitfalls in selecting unrealistic parameter ranges as part of a sensitivity analysis can be avoided through the use of parameters such as the moisture saturation (S_m), which is the water-filled porosity divided by the total porosity ($S_m = \theta_w/\theta_T$), or the ratio of Q_{soil} to the building ventilation rate (Q_{soil}/Q_{build}). Both these parameters typically vary over a defined range depending on soil properties and building conditions.

3. Partitioning Relationships

3.1 Partitioning Model When NAPL Is Not Present

Source soil vapour concentrations can be predicted using either groundwater or soil chemistry data or directly measured. A *three-phase* model describing partitioning between the sorbed, soil-water and soil-air phases is typically assumed when no non-aqueous phase liquid (NAPL) is present. The equilibrium partitioning of a chemical between the soil water and the soil-air phases is described by Henry’s Law:

$$C_a = UCF * H' * C_w \qquad (1)$$

Table 1
Qualitative Uncertainty and Sensitivity Analysis for Inputs Used for Johnson Ettinger Model

	Parameter Sensitivity and Uncertainty			
Input Parameter	**Shallower Contamination Building Underpressurized**	**Deeper Contamination Building Underpressurized**	**Shallower Contamination Building Not Underpressurized**	**Deeper Contamination Building Not Underpressurized**
Soil Properties				
Unsaturated Zone Water-filled Porosity	Low to Moderate	Moderate to High	Moderate to High	Moderate to High
Total Porosity	Low	Low	Low	Low
Capillary Transition Zone Water-filled Porosity	Low to Moderate	Moderate to High	Moderate to High	Moderate to High
Capillary Transition Zone Height	Low to Moderate	Moderate to High	Moderate to High	Moderate to High
Qsoil	Moderate to High	Low to Moderate	N/A	N/A
Soil air permeability	Moderate to High	Low to Moderate	N/A	N/A
Soil Bulk Density	Low	Low	Low	Low
Henry's Law Constant (for single chemical)	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Free-Air Diffusion Coefficient (single chemical)	Low	Low	Low	Low
Building Properties				
Building Depressurization	Moderate	Low to Moderate	N/A	N/A
Building Air Change Rate	Moderate	Moderate	Moderate	Moderate
Building Mixing Height	Moderate	Moderate	Moderate	Moderate
Subsurface Foundation Area	Low to Moderate	Low to Moderate	Low to Moderate	Low to Moderate
Building Crack Ratio	Low	Low	Moderate to High	Low to Moderate
Crack Moisture Content	Low	Low	Moderate to High	Low to Moderate
Building Foundation Slab Thickness	Low	Low	Low	Low
Depth to Base of Foundation	Low	Low	Low	Low

Note: Attenuation factor inversely proportional to building mixing height and build air change rate

Table 2
Johnson and Ettinger Model Input Values for Derivation of Attenuation Factor Charts

Input Parameter	Units	Residential	Commercial
Soil and Chemical Properties			
Coarse-Grained (SCS Sand)			
Unsaturated Zone Water-filled Porosity	cm^3/cm^3	0.054	0.054
Total Porosity	cm^3/cm^3	0.375	0.375
Capillary Transition Zone Water-filled Porosity	cm^3/cm^3	0.253	0.253
Capillary Transition Zone Height	cm	17	17
Fine-Grained (SCS Loam)			
Unsaturated Zone Water-filled Porosity	cm^3/cm^3	0.148	0.148
Total Porosity	cm^3/cm^3	0.399	0.399
Capillary Transition Zone Water-filled Porosity	cm^3/cm^3	0.332	0.332
Capillary Transition Zone Height	cm^3/cm^3	37.5	37.5
Effective soil gas permeability	cm^2	Not Used	$1x10^{-7}$
Qsoil	L/min	5 (empirical)	4.3 (calculated)
Soil Temperature	^oC	15	15
Soil Bulk Density		chemical specific	chemical specific
Henry's Law Constant		chemical specific[1]	chemical specific[1]
Free-Air Diffusion Coefficient		chemical specific	chemical specific
Building Depressurization	Pa	Not Used	2
Building Air Change Rate	hr^{-1}	0.3	1
Building Mixing Height - Basement scenario	m	3.66	N/A
Building Mixing Height - Slab-on-grade scenario	m	2.44	3
Building Footprint Area - Basement Scenario	m^2	100	N/A
Building Footprint Area - Slab-on-Grade Scenario	m^2	100	300
Subsurface Foundation Area - Basement Scenario	m^2	180	N/A
Subsurface Foundation Area - Slab-on-Grade Scenario	m^2	106	370
Depth to Base of Foundation - Basement Scenario	m	2	N/A
Depth to Base of Foundation - Slab-on-Grade Scenario	m	0.15	0.5
Perimeter Crack Width	mm	1	1
Building Crack Ratio - Slab-on-Grade Scenario	dimensionless	0.00038 (calculated)	0.0002 (calculated)
Building Crack Ratio - Basement Scenario	dimensionless	0.0002 (calculated)	N/A
Crack Dust Water-Filled Porosity	cm^3/cm^3	Dry	Dry
Building Foundation Slab Thickness	m	0.1	0.15

Notes:
1. Henry's Law constant adjusted for temperature based on method provided in Superfund User’s Guide for the J&E Model.

where C_a is the soil-air concentration (mg/m^3), H' is the dimensionless Henry's Law Constant, C_w is the soil-water concentration (mg/L), and UCF (1000 L/m^3) is a unit conversion factor. Henry's Law is applicable for most organic contaminants that are sparingly soluble (the mole fraction of that contaminant in water is less than 0.001).

For partitioning between the sorbed and aqueous phases, a linear absorption model based on the soil organic matter content is typically used to predict the sorbed concentration under equilibrium conditions:

$$C_s = K_{oc} * f_{oc} * C_w \tag{2}$$

Where C_s is the sorbed concentration (mg/kg), K_{oc} is the organic carbon-water partitioning coefficient (mg/kg-OC per mg/L-water) and f_{oc} is the fraction organic carbon. This linear sorption model has been experimentally verified for common non-polar or slightly polar organic compounds (Karickhoff *et al.*, 1979; Chiou *et al.*, 1983) when fraction organic carbon (f_{oc}) is greater than about 0.001 (Schwarzenbach and Westall, 1981).

Based on a phase mass balance, the soil-air concentration is related to the total soil concentration as follows:

$$C_a = 1000 * C_{soil} * H' * \rho_b / (\theta_w + K_{oc}*f_{oc}*\rho_b + H'*\theta_a) \tag{3}$$

where C_{soil} is the total soil concentration (mg/kg) (all phases), ρ_b is the dry bulk density (g/cm^3), θ_w and θ_a are the water- and air-filled porosities (dimensionless).

3.2 Partitioning Model When NAPL is Present

For a pure chemical, NAPL will not be present at concentrations below the soil saturation limit. The soil saturation limit is estimated by the following equation (USEPA, 1996; ASTM E1739-95):

$$C_{sat,soil} = S * (\theta_w + K_{oc}*f_{oc}*\rho_b + H'*\theta_a) / \rho_b \tag{4}$$

where S is the pure-chemical solubility (mg/L).

When NAPL is present, a *two-phase* partitioning model is used. The partitioning between NAPL and air phases is proportional to the vapour pressure of the compound, which for a pure chemical is:

$$C_a = 10^6 * MW * P / RT \tag{5}$$

where P is the vapour pressure (atm), MW is the molecular weight (g/mole), R is the gas constant (0.08205 L-atm/K-mole) and T is the absolute temperature (^oK).

3.3 Partitioning Models for Multi-Component Mixtures

When multi-component mixtures are present, partitioning based on Raoult's Law is typically used to quantify the effective solubility of an individual chemical in the mixture under equilibrium conditions, as follows:

$$C_{w,i} = X_i * S_i \tag{6}$$

where i denotes component i in the mixture and X_i is the mole fraction of the component i in the NAPL mixture. The mole fraction can be estimated as follows:

$$X_i = W_i/MW_i / \Sigma\, W_j/MW_j \tag{8}$$

where W_i is the mass fraction (kg/kg) and MW_i is the molecular weight. For petroleum hydrocarbons, the mole fraction can be approximated through the following relationship:

$$X_i = C_{soil,i} /TPH * MW_{TPH} / MW_i \tag{9}$$

Where $C_{i,soil}$ is the concentration of the individual compound in soil (mg/kg), TPH is the total petroleum hydrocarbon concentration in soil (mg/kg), MWTPH is the average molecular weight of the petroleum hydrocarbon, and MW_i is the molecular weight of the compound.

For mixtures of miscible chemicals that are fractionally soluble in water, the concentration at which NAPL will be present is a function of the mixture composition. The soil saturation limit for the mixture is (Brost and deVaull, 2000).

$$\Sigma\ [\ C_{sat,soil,T} * W_i * \rho_b / S_i * (\theta_w + K_{oc}*f_{oc}* \rho_b + H'*\theta_a)\ ] \qquad (10)$$

where $C_{sat,soil,T}$ is the soil saturation limit for the NAPL mixture. The soil saturation limit for an individual compound is:

$$C_{sat,soil,i} = W_i * S * (\theta_w + K_{oc}*f_{oc}* \rho_b + H'*\theta_a) / \rho_b \qquad (11)$$

For chemicals that are solids at room temperature the subcooled liquid solubility should be used in place of the solid solubility.

3.4 Four-Phase Model

A four-phase model for partitioning between the sorbed, aqueous, soil-air and NAPL phases has recently been developed and applied to the vapour intrusion pathway (Park and San Juan, 2000). This model is not used for this guidance, but has been adopted by some regulatory jurisdictions in the US (State of Washington, US EPA Region 9). The four-phase model more accounts for mass and volume conservation between all four phases and enables more accurate estimation of mole fraction in the NAPL phase, for a multi-component mixture. The disadvantage is that it is more computationally complex. Comparisons between the three- and two-phase models, described above, and the four-phase model indicate that the three- and two-phase models, in almost all cases, provide for conservative predictions.

4. Derivation and Use of Vapour Attenuation Factors

4.1 Justification for Input Parameters

Residential and Commercial Soil-Dependent Properties

The soil-dependent properties for the coarse- and fine-grained soil fractions were derived using a sand and loam as representative soil types. Test data according to the US Soil Conservation Service (SCS) system of soil texture classification was used to obtain soil properties for sand and loam. Coarse-grained soils (sand) are defined as having a mean grain size larger than 75 μm, while fine-grained soils (loam) are defined as having a mean grain size smaller than 75 μm.

The van Genuchten (VG) water retention model (van Genuchten, 1980) was used to approximate moisture contents based on fitted parameters for test data on US SCS soils. Soil above the water table is divided into two zones for the purposes of estimating soil moisture (i) the unsaturated zone, and (ii) capillary transition zone.

For the unsaturated zone, the default value for soil moisture was a value equal to half-way between the residual saturation value and field capacity, using the VG model-predicted values derived using model curve-fit parameters computed by Schaap and Leij (1998) for US SCS soil types.

For the capillary transition zone ($\theta_{w,cz}$), the moisture content is the water-filled porosity at the inflection point in the water retention curve where $d\theta_w/dh$ is maximal, where θ_w and h equal the water-filled porosity and matric suction, respectively. Vapour-phase diffusion becomes negligible once the water-filled porosity exceeds the $\theta_{w,cz}$. The height of the capillary zone is estimated using an equation for capillary rise in a tube (Fetter 1994), and mean particle size for the SCS soil textural classifications (Nielson and Rogers, 1990). The bi-linear model for estimation of moisture content is graphically shown in Figure 2.

Soil types coarser than SCS sand were also considered (e.g., sand and gravel), but were found to have little effect on the calculated attenuation factor. This is because the water-filled porosity assumed for SCS sand is already quite low. For the unsaturated zone, the default water-filled porosity for sand used to derive the coarse-grained attenuation factor was 0.054. This corresponds to a relative saturation (water-filled porosity/total porosity) value of 0.14, which reflects the good drainage characteristics of sand.

Residential Q_{soil} (Default Value = 5L/min)

The soil gas advection rate (Q_{soil}) into a building is a function of the soil air permeability, building depressurization, building foundation properties and building size. Building pressures are affected by temperature, wind and operation of the heating, ventilation and air conditioning (HVAC) system inside a building. When indoor air is warmer than outdoor air, warm air tends to rise within a building causing the lower regions of the building to be under negative pressure, causing soil gas and outdoor air to infiltrate into the building. The differential pressure caused by wind loading can also result in a negatively pressurized building. Depressurization of a building through HVAC operation is typically caused by an imbalance between the intake airflow (coming into the building) and relief air flow (exiting the building), which can result from leaking supply air ducts, restricted or insufficient return air, or unbalanced exhaust systems. Building depressurization values are compiled in Table 3.

The method often used with the J&E model for estimating Q_{soil} through the building envelope is an analytical solution for two-dimensional soil gas flow to a small horizontal drain (Nazaroff 1992) ("Perimeter Crack Model"). The use of this model can be problematic in that Q_{soil} values are sensitive to soil-air permeability and consequently a wide range in flows can be predicted.

An alternate empirical approach is to select a Q_{soil} value on the basis of published literature values from tracer tests. When soil gas advection is the primary mechanism for tracer intrusion into a building, Q_{soil} can be estimated according to a mass balance approach by measuring the concentrations of a chemical tracer in indoor air, outdoor air and in soil vapour below a building, and measuring the building ventilation rate (Fischer *et al.* 1996; Garbesi *et al.* 1993; Rezvan *et al.* 1991; Garbesi and Sextro, 1989). The Q_{soil} values measured using tracer techniques were compared to predicted rates using the Perimeter Crack Model, and were found to compare reasonably well for sites with coarse-grained soils (i.e., within one order of magnitude) (Hers *et al.*, 2002). Although the Q_{soil} predicted by models and measured using field tracer tests are uncertain, the results suggest that a "typical" range for houses on coarse-grained soils is on the order of 1 to 10 L/min. A disadvantage with the tracer test approach is that there are only limited data, and there do not appear to be any tracer studies for field sites with fine-grained soils.

Figure 2.
Model Used to Estimate Water-Filled Porosity in Soil

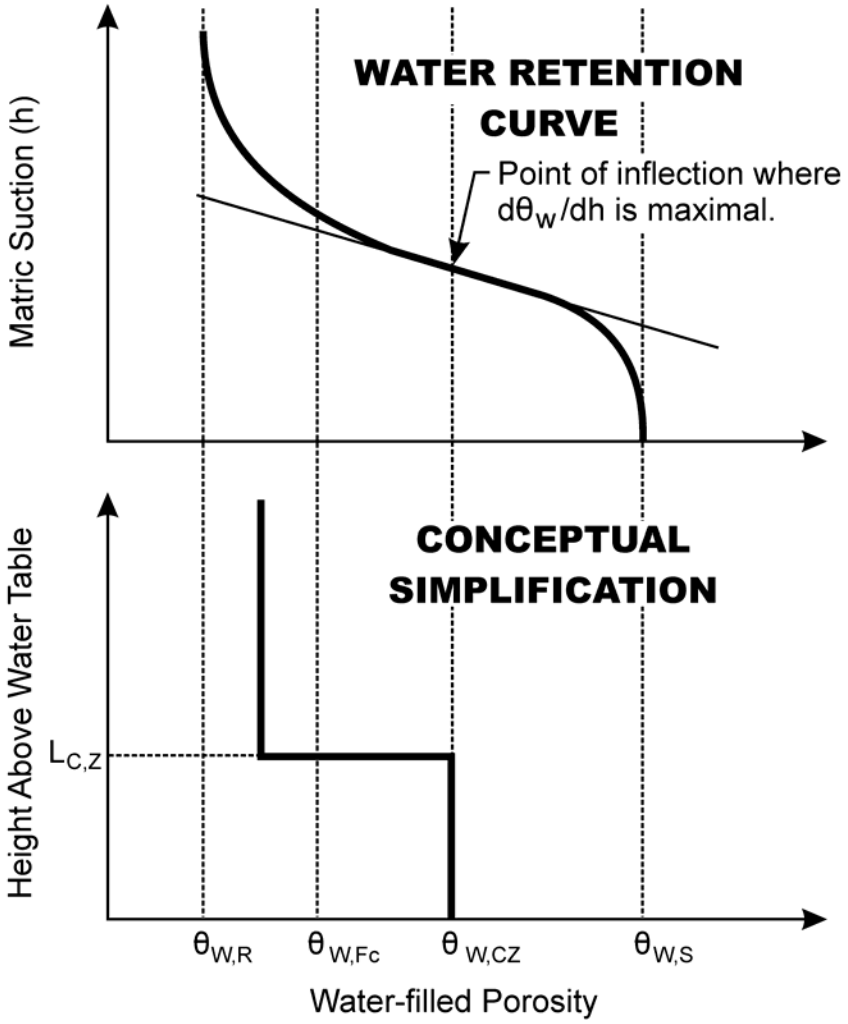


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Table 3
Survey of Building Depressurization Relative to Atmospheric Pressure

Reference	Data Type	Location	Building Type & Number	Measure-ment Date	Measurement Statistic	Depressuri-zation (Pa)	Comments
19 [1]	Measured	Netherlands	Houses with Crawlspace	N/A		~ 2 ~ 2	Between indoor space and crawlspace Between crawlspace and soil
14	Measured	Canada	Houses: Halifax (12), Ottawa/Hull (16), Winnipeg(12) ,Vancouver (12)	Winter 93	range average for house	-5 to 15 0.5 to 8.5	Mix older & newer houses, most houses had forced air heating system & basement, depressurization correlated to house construction (full, partial basement, slab on grade) & climate
9	Measured	Spokane River Valley, WASH, USA	House (14)	Winter	average	2 to 6	
7	Measured	Chicago, Ill., USA	House (1)	Feb 17 to June 1, 1982	range	0.6 to 4.3	Basement ΔP decreased between Feb. & June 1
20	Predicted	Alameda, California, USA	Small commercial building (1)	N/A	range	1 to 4	Predicted based on wind loading
8	Predicted	Portland, Or	2-storey house with basement	N/A		~ 2 ~ 2	Predicted based on wind Predicted based on stack effect
47	General reference	N/A	Houses	N/A		up to 10	upper range associated with extreme weather conditions
18	Guidance	Canada	slab-on-grade house	N/A	range	1 to 3	range mild to severe winter, without chimney
			slab-on-grade house		range	3 to 5	range mild to severe winter, with chimney
			1 to 2 storey house		range	4 to 6	range mild to severe winter, without chimney
			1 to 2 storey house		range	8 to 10	range mild to severe winter, with chimney
			3 storey house		range	7 to 9	range mild to severe winter, without chimney
			3 storey house		range	13 to 15	range mild to severe winter, with chimney

Notes:
[1] references Put and Meijer, 1989 (report in Dutch)
[2] if the house has a fresh air intake duct or combustion air supply, reduce differential pressures by 2 Pa. If the house has a fireplace, central exhaust system or other large or frequently used exhaust equipment, increase the differential pressures by 2 Pa.

It is also important to recognize that the advective zone of influence for soil gas flow induced by building depressurization is limited to soil immediately adjacent to the building foundation. There is some data on pressure coupling that provides insight on the extent of the advective flow zone. For example, Garbesi *et al.* (1993) report a pressure coupling between soil and experimental basement (i.e., relative to that between the basement and atmosphere) equal to 96% directly below the slab, between 29% and 44% at 1 m below the basement floor slab, and between 0.7% and 27% at a horizontal distance of 2 m from the basement wall. At the Chatterton site in Canada, the pressure coupling immediately below the building floor slab ranged from 90% to 95%, and at a depth of 0.5 m was on the order of 50%. These results indicate that the advective zone of influence will likely be limited to a zone within 1 m to 2 m of the building foundation.

Since the advective flow zone is relatively limited in extent, the soil type adjacent to the building foundation is of importance. In many cases, coarse-grained imported fill is placed below foundations, and either coarse-grained fill, or disturbed, loose fill is placed adjacent to the foundation walls. Therefore, a conservative approach for the purposes of the guidance is to assume that soil gas flow will be controlled by coarse-grained soil, and not to rely on the possible reduction in flow that would be caused by fine-grained soils near the house foundation.

A Q_{soil} of 5 L/min was chosen to derive the attenuation factor charts, based on the following rationale:

- This value is within the range of experimental tracer test values for Q_{soil}, and is considered representative of a typical residential single family dwelling;
- The Perimeter Crack model predicts a Q_{soil} of about 5 L/min using the guidance defaults for foundation size and crack wide, soil-air permeability representative of sand ($k = 10^{-7}$ cm^2), and building depressurization of about 4 Pa.
- The ratio of Q_{soil} to building ventilation rate (Q_{build}), based on the guidance default values is 0.0028, which compares favourably to available tracer test data in Table 4, and to values recommended by Johnson (2002). Since the building ventilation rate is approximately

proportional to the building size, the use of Q_{soil}/Q_{build} indirectly takes into account the building size.

Commercial Q_{soil} (Default Value = 4.3 L/min)

For commercial buildings, there are large variation in size, design, and construction. As a result, prediction of soil gas advection is highly uncertain. There are also little, if any, empirical data on soil gas advection rates into commercial buildings.

HVAC systems are typically designed to control the pressure inside commercial buildings. Neither excessive depressurization, nor pressurization of buildings is desirable based on energy consumption, moisture problems, and practical considerations relating to opening or closing of doors. According to Stanke (2002), the net pressure inside the building relative to outside should range from slightly negative to neutral during cold weather (minimizing exfiltration) to slightly positive during warm weather (minimizing infiltration). For multi-storey buildings in colder climates, it is difficult to avoid some depressurization of the ground floor space as a result of the stack effect. There are several case studies indicating negative pressures can occur in commercial buildings as a result of leaking ducts and/or unbalanced exhaust. Withers and Cummings (2000) report measured negative pressures of –14 Pa, -2.7 Pa and –19 Pa in three small commercial buildings located in Florida. The Canadian Building Digest (NRC-IRC CBD-107) indicates that significant negative pressures (several hundred pascals) can theoretically develop in multi-storey buildings unless controlled through building ventilation and measures to control vertical air leakage between floors in buildings. The pressure inside a building may also vary temporally. For example, during the day when the HVAC system is on, the building may be positively pressurized; however, during evening hours, the pressure inside the building may become negative if the HVAC system is turned off due to the influence of environmental factors such as temperature and wind. While there is significant uncertainty for building pressurization and Q_{soil}, it is clear that there is the potential for negatively pressurized commercial buildings, and that predictive modeling of vapour intrusion into commercial buildings should include a soil gas advection component.

Table 4
Measured Soil Gas Advection Rate into Buildings from Tracer Studies

Study	Building	Soil Type	Tracer	ΔP	Q_{soil}/Q_{build}	Q_{soil} (L/min)	Q_{soil}/Area (L/m^2)	Q_{soil}/Area-ΔP (L/m^2-Pa)
In Progress	House w\basement	M. Sand	PHCs[3]		0.00729927	3.3	N/A	N/A
Hers (on-going study, 2003)	House w\ basement&crawlspace	Sand	MTBE, cyclo-hexane, 224-trimethyl-pentane	0.6	0.0039 to 0.0084	N/A	N/A	N/A
Hers (on-going study, 2003)	Houses w\ basement	Sand & gravel	TCE	4 (avg)	0.001 to 0.0064	N/A	N/A	N/A
Olson & Corsi (2001)	House w\basement Paulsboro	Sand, some silt	SF_6	3.6 to 6.2	0.003 to 0.01	5.8 to 6.7	0.18 (6.2 Pa)	0.03
Mose & Mush-rush (1999)	Houses Virginia	N/A	Radon	N/A	0.003 to 0.02	N/A	N/A	N/A
Hers (Chatterton) (1998)	Experimental Greenhouse	M. Sand	BTX	10 to 30	0.00009 to 0.0005	0.52 to 2.8	N/A	0.001 to 0.005
Fischer et al. (1996)	Small Commercial Building	F. Sand	SF_6	10	0.0002 to 0.0004	4.5	0.018	0.006
Garbesi et al. (1993)	Small Experimental Basement	F. Sand	N/A	20	N/A	20		0.04
Little et al. (1992)	Houses USA	N/A	Radon	N/A	0.0016 (Avg)	N/A	N/A	N/A
Garbesi & Sextro (1989)	House w\basement	Sandy Loam to Loamy Sand	SF_6	30	~0.001	67 (Best)	N/A	0.01(Best)
Rezvan et al. (1989)	Houses	Gravel	Rn	N/A	0.0079 to 0.045	17 to 96[2]	N/A	N/A

1 Estimated by Fischer et al (1996) from wind-loading (Qbuilding not available)
2 Estimated using assuming values for house volume (366 m3) and AEH (0.35/hr) (Qbuilding not available)
3 Cyclohexane, MTBE, Pentane, 2,2,4-Trimethylpentane

Since there is no empirical basis for estimating Q_{soil}, the Perimeter Crack model using the defaults provided in Table 2 was used to calculate Q_{soil} (4.3 L/min). The assumed building depressurization was 2 Pa. The Q_{soil}/Q_{build} ratio for the default commercial building was 0.00029, which is about an order-of-magnitude less than that assumed for the residential scenario.

The calculated Q_{soil} for a commercial building is slightly lower than the assumed value for a residential house (4.3 L/min versus 5 L/min), despite the commercial building being significantly larger than the residential building. This is considered reasonable since less soil gas advection would be expected for a commercial building based on the expected building depressurization and foundation for a commercial building, which would tend to be of better quality than a residential foundation. A lower Q_{soil}/Q_{build} ratio is also consistent with the lower soil gas advection rate and greater dilution of soil gas expected for a commercial building.

Residential Building Air Change Rate (Default Value = 0.35 hr^{-1})

Ventilation has three components (Nazaroff, 1992):

1. infiltration, or uncontrolled leakage of air into a building through openings in the building envelope;
2. natural ventilation through open windows and doors; and
3. mechanical ventilation provided by fans.

Ventilation rates reported in the literature vary significantly with results from 27 studies summarized in Table 5. Two broad trends suggested by the data are a general reduction in ventilation rates over the past two decades and lower ventilation rates for houses in cold climates. In regions with relatively cold climates, the recent trend has been to construct “air-tight” houses with reduced ventilation rates to minimize energy consumption and costs (e.g., “R-2000” houses in Canada; Gusdorf and Hamlin, 1995). For houses with high energy efficient systems and that typically have mechanical ventilation supplied through a heat recovery ventilator, ventilation rates may be as little as 0.1 air changes per hour (ACH) (Fellin and Otson, 1996).

Table 5
Survey of Building Ventilation Rates

Reference	Data Type	Location	Building Type & Number	Measurement Date	Measurement Statistic	Air Exchange (ach)	Comments
Residential Houses							
NREL, 2002	Measured SF_6	San Antonio	2 houses	Aug-00	Range	0.2 to 0.3	When AC on (measurements taken in summer)
					Range	0.05 to 0.15	When AC off (measurements taken in summer)
LBNL, 2001	Measured SF_6	Florida	11 houses	Fall 1997 to Spring 1998	Range	0.14 to 0.78	Lower ACH were obtained in homes with HRV
Otson and Zhu, 1997	Measured PFT	Greater Toronto, ONT, Canada	Houses (44)	Feb. 12 to Apr. 9, 1996	average	0.45	
					median	0.4	
Murray and Burmaster, 1995	Measured PFT	U.S. Region 1	Houses (467)	All seasons	mean	0.4	5th and 95th percentile = 0.1, 0.95
		U.S. Region 2	Houses (1496)	All seasons	mean	0.55	5th and 95th percentile = 0.14, 1.38
		U.S. Region 3	Houses (332)	All seasons	mean	0.55	5th and 95th percentile = 0.15, 1.25
		U.S. Region 4	Houses (1549)	All seasons	mean	0.98	5th and 95th percentile = 0.21, 2.82
		U.S. Region 1	Houses (161)	Winter	mean	0.36	5th and 95th percentile = 0.08, 0.90
		U.S. Region 1	Houses (254)	Spring	mean	0.44	5th and 95th percentile = 0.14, 1.06
		U.S. Region 1	Houses (5)	Summer	mean	0.82	5th and 95th percentile = 0.27, 2.01
		U.S. Region 1	Houses (47)	Fall	mean	0.25	5th and 95th percentile = 0.1, 0.58
SRC, 1995	Measured PFT	Saskatoon, SASK, Canada	Houses (20)	1993 - 1994 (9 months)	minimum	0.08	all houses had natural gas forced air heating systems and chimneys connected to the natural gas furnaces
					average	0.2	
					maximum	0.43	
Fellin and Otson, 1993	Measured PFT	Canada	Houses (24)	1992 to 1993	average	0.34	most measurements in fall and winter months
SRC, 1992	Measured PFT	Saskatoon, Regina SASK, Tillsonburg, ONT, Canada	Houses (44)	Jan. 14 to Feb. 11, 1991	average	0.34	
					median	0.31	
Rothweiler et al., 1992	Measured N_2O	Switzerland	Houses (10)	N/A	10th percentile	0.06	new houses or renovated houses
					50th percentile	0.16	
					90th percentile	2.06	
Panadian et al., 1993	Measured PFT	USA	Houses (4000)	Mostly 80's early 90's	average	2	all regions (std. dev. = 3.3)
					average	3.3	southwest
					average	0.6	northeast
					average	0.4	northwest
					average	0.5	winter, all regions
					average	1.9	spring, all regions
					average	5.4	summer, all regions
					average	0.4	fall, all regions
Lewis and Zweidinger, 1992	Measured SF_6	Boise, Idaho, USA	Houses (10)	Nov. 15, 1986 to Feb. 4, 1987	average	0.45	
					median	0.45	
Mailahn et al., 1989.	Measured PFT&HFB	Berlin, Germany	Houses (10)	Sept. 1986 to Apr. 1987	average	1.01	older houses had statistically significant higher ach (1.2) then newer houses (0.88)
					median	1.02	
Mueller et al., 1988.	Measured	USA	Houses	N/A	typical range	0.5 - 1.5	typical houses
						0.5 - 0.8	new or energy efficient houses, some as low as 0.2
Walkinshaw, 1987	Measured	ONT, Canada	Houses (70)		range	0.06 - 0.77	lowest ach occurred in summer with windows closed in R-2000 houses
			R-2000 Houses (?)		range	0.34 - 0.37	

Table 5
Survey of Building Ventilation Rates

Reference	Data Type	Location	Building Type & Number	Measure-ment Date	Measurement Statistic	Air Ex-change (ach)	Comments
Boman and Lyberg, 1986.	Measured	Sweden	Detached & row houses	1974-1982	average	0.17	no mechanical ventilation, 1975 and later
			3-storey appartments	1974-1982	average	0.78	no mechanical ventilation, with fireplace, 1940-1960
Gerry et al., 1986	Measured		Houses (typical)		typical range	0.7 - 1.1	
			Recently built houses		typical range	0.5 - 0.8	
Parker, 1986	Measured	Bangor, Washington	2-storey, four unit building (4)		range	0.24 - 0.91	electric heating
Lamb, 1985	Measured PFT	Eastern Washington, USA	Houses (10)		range	0.3 - 1.0	during typical meterological conditions extended use of doors caused ach to exceed 3
ASHRAE, 1985	Measured	USA	Houses	N/A	typical range	0.2 to 2	
					median	0.5, 0.9	median values for 2 studies
Grimsrud et al., 1982	Mostly Predicted	North America	Houses (312)	N/A	average	0.63	mostly predicted using LBL model
					median	0.5	(stack & wind effect)
Gusdorf and Hamlin, 1995	Predicted AIM-2 HOT-2000	Canada	Houses (47)	Annual Average	average	0.36	R-2000 houses, high energy efficiency houses
					median	0.34	use heat recovery ventilators
					minimum	0.14	
					maximum	0.68	
CMHC, 1997	Guidance	Canada	Wood frame pre 1945	N/A	typical range	0.5-1	Estimated heating season natural ventilation
					typical range	None	Estimated mechanical ventilation
			Wood frame 1946-1960	N/A	typical range	0.2-0.4	Estimated heating season natural ventilation
					typical range	None	Estimated mechanical ventilation
			Wood frame 1961-1980	N/A	typical range	0.15-0.3	maybe 0.2 intermittent
			Airtight new house	N/A	typical range	0.05-0.1	0.3 installed capacity
Otson et al., 1996	Guidance	Canada	Houses	N/A	low	0.1	low
					typical	0.3	typical
Commercial Buildings							
Ekberg (1994)	Measured SF$_6$	Malmo, Goteburg, Sweden	Office buildings (4)	Jan. 90 to Dec. 91	range	3.2 to 4	measured during periods of mechanical ventilation
Sheldon et al., 1988	Measured SF$_6$	Washington D.C., USA	Old-age home	Winter 83		1.72 +/-0.41	high ach attributed to excessive heating
			School	1983		0.85 +/- 0.31	and cold outdoor temperatures
			Office	July 1983		0.61+0.32	
			Office	Sept. 1983		0.52+0.25	
Dols and Persily (1995)	Measured SF$_6$	Portland, Oregon	Office Building (7 stories, floor area of 34,600 m2)	Aug 6., 1991 Jan. 13, 1992	Measured @ min intake fresh air	0.45	Designed to ASHRAE 62-1981, which is approximately 0.18 ACH for an office building
					~ 10th to 90th building air change	0.6 to 1.9	the percent outdoor air generally ranged between 70 and 100 % of total building air exchange rate
Fang and Persily (1995)	Measured SF$_6$	Overland, Missouri	Office Building (7 stories, floor area of 32,500 m2)		Measured @ min intake fresh air	0.3	
					Measured @ max intake fresh air	2.6	
NRC - CNRC	-	Canada	Office Building		0.5		

Standards in Canada and the U.S. both specify minimum ventilation rates for residential dwellings. In Canada, the minimum required ventilation rate under the CSA F326 standard for "*Residential Mechanical Ventilation Systems*" depends on the number and types of rooms in the house but usually works out to about 0.3 ACH. In the US, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) 62-2001 standard recommends an outside air ventilation rate of not less than 7.5 L/s per person, and also not less than 0.35 ACH. It appears that mechanical ventilation systems are quite frequently operated at less than the design or installed capacity (SRC, 1995; Figley, 1997; Gusdorf and Hamlin, 1995).

Results from 22 studies for which building air change data are available are summarized in Hers *et al.* (2001). There is a wide variation in ventilation rates ranging from about 0.1 air changes per hour (ACH) for energy efficient "air-tight" houses (built in cold climates) (Fellin and Otson, 1996) to over 2 ACH (ASHRAE (1985); upper range). In general, ventilation rates will be higher in summer months when natural ventilation rates are highest. Several Canadian studies indicate average air change rates in houses between 0.34 and 0.45 ACH. One of the most comprehensive studies of U.S. residential air change rates (sample size of 2,844 houses) was conducted by Murray and Burmaster (1995). The data set was analyzed on a seasonal basis, and according to climatic region. When all the data was analyzed, the 10th, 50th and 90th percentile values were 0.21, 0.51 and 1.48 ACH. Air change rates varied depending on season and climatic region. For example, for the winter season and coldest climatic area (Region 1, Great Lakes area and extreme northeast US), the 10th, 50th and 90th percentile values were 0.11, 0.27 and 0.71 ACH. In contrast, for the winter season and warmest climatic area (Region 4, southern CA, TX, Florida, Georgia), the 10th, 50th and 90th percentile values were 0.24, 0.48 and 1.13 ACH. While building air change rates would be higher during the summer months, vapour intrusion during winter months (when house depressurization is expected to be most significant) would be of greatest concern. An air change rate of 0.35 hr^{-1} was selected to represent the lower end of these distributions.

Commercial Building Air Change Rate (Default Value = 1 hr^{-1})

The data set for commercial buildings is relatively limited (Table 5). The actual ventilation rate often varies depending on operational conditions inside the building. Fang and Persily (1995) and Dols and Persily (1995) report air changes that ranged between about 0.3 ACH, measured when the HVAC system was providing the minimum intake of fresh air, to about 2.6 ACH, measured when the HVAC system was providing the maximum intake of fresh air.

The ASHRAE Standard 62-2001 provides minimum ventilation rates for different types of commercial and institutional buildings. For example, for offices, the minimum outdoor air ventilation requirement for office space is 10 L/s (20 cfm) per person, which corresponds to an air change rate of about 0.72 ACH. An earlier ASHRAE Standard 62-1981 had a lower ventilation requirement that corresponded to an air change of about 0.18 ACH. The default ventilation rate selected for a commercial building was 1 ACH.

Residential Building Mixing Height (Default Value = 2.44 m for Slab-on-Grade Scenario; = 3.66 m for Basement Scenario)

The J&E model assumes that subsurface vapours are completely mixed within the building air space, which is determined by the building area and mixing height. The building mixing height will depend on a number of factors including the building height, the HVAC system operation, environmental factors such as indoor-outdoor pressure differentials and wind loading, and seasonal factors. For a single-storey house, the variation in mixing height can be approximated by the room height. For a multi-storey house or apartment building, the mixing height will be greatest for houses with HVAC systems that result in significant air circulation (e.g., forced-air heating systems). Mixing heights would likely be less for houses with electrical baseboard heaters. It is likely that the mixing height, to some degree, is correlated to the building air change rate.

There are little data available that provide for direct inference of mixing height. There are few sites, with a small number of houses where indoor air concentrations were above background, and where both measurements at ground level and the second floor were made (CDOT, Redfields, Eau Claire, Juniper). Persons familiar with the data sets for these sites indicate that in most cases a fairly significant reduction in concentrations (factor of two or greater) was observed between the first and second floor level. For the CDOT site apartments, there was an approximate five-fold reduction between the concentrations measured for the first floor and second floor units (Mr. Jeff Kurtz, EMSI, personal communication, June 2002). A fairly significant reduction (factor of two or greater) was observed at the Redfields site in homes where multiple indoor air quality tests were made. At one site (Eau Claire, “S” residence), the indoor trichloroethene (TCE) concentrations were similar in both the basement and second floor of the house. At the Juniper site, the ratio between basement and second floor concentrations in five homes ranged between 0.6 and 3.7 (average of 1.9). Less mixing would be expected for an apartment since there are less cross-floor connections than for a house. The value chosen for a basement house scenario (3.66 m) would be representative of a two-fold reduction or attenuation in vapour concentrations between floors.

Commercial Building Mixing Height (Default Value = 3 m)

The default commercial building mixing height (3 m) is considered a representative value for a single-storey building. The mixing height for a multi-storey commercial building would be greater as a result of mixing within the building caused by ventilation and leakage across floors.

As part of a SLRA, little detailed information on building conditions is likely to be available. However, if there is information clearly indicating that the default mixing height is not representative, the attenuation factors in the guidance can be easily scaled using a linear relationship since the attenuation factor is inversely proportional to the mixing height. For example, if the building under evaluation is a warehouse structure with high ceilings with no significant thermal stratification, there is the option to adjust the attenuation factor, as follows:

Adjusted Attenuation Factor = (3.0 m / Site Specific Mixing Height) * Attenuation Factor

This scaling procedure is also addressed in the example calculation section.

Residential Crack Width (Default Value = 1 mm) and Crack Ratio (Default Value = 0.0002 for Basement House; = 0.00038 for Slab-on-Grade House)

The crack width and crack ratio are related. Assuming a square house and that the only crack is a continuous edge crack between the foundation slab and wall ("perimeter crack"), the crack ratio and crack width are related as follows:

$$\text{Crack Ratio} = \frac{4\left(\text{Crack Width}\right)\sqrt{S\text{ubsurface Foundation Area}}}{S\text{ubsurface Foundation Area}}$$

Crack Ratio = Crack Width x 4 x (Subsurface Foundation Area)^0.5 / Subsurface Foundation Area

There is a slight difference in crack ratio for the two scenarios based on the slight difference in subsurface foundation area. However, this difference has no effect on the calculated attenuation factors.

There is little information available on typical values for crack width or crack ratio. One approach used by radon researchers is to back-calculate crack ratios using a model for soil gas flow through cracks and the results of measured soil gas flow rates into a building. For example, the back-calculated values for a slab/wall edge crack based on soil gas-entry rates reported in Nazaroff (1992), Revzan *et al.* (1991) and Nazaroff *et al.* (1985) range from about 0.0001 to 0.001. Another possible approach is to measure crack openings although this, in practice, is difficult to do. Figley and Snodgrass (1992) present data from ten houses where edge crack measurements were made. At the eight houses where cracks were observed, the cracks widths ranged from hairline cracks up to 5 mm wide, while the total crack length per house ranged from 2.5 m to 17.3 m. Most crack widths were less than 1 mm. The suggested defaults for crack ratio in regulatory guidance, literature and models also vary. In ASTM E1739-95, a default crack ratio of 0.01 is used. The crack ratios suggested in the VOLASOIL model (developed by the Dutch Ministry of Environment) range from 0.0001 to 0.000001. The VOLASOIL model values correspond to values for a "good" and "bad" foundation, respectively. The crack ratio used by

Johnson and Ettinger (1991) for illustrative purposes ranged from 0.001 to 0.01. The selected default values (Table 2) fall within the ranges observed.

Commercial Crack Width (Default Value = 1 mm) and Crack Ratio (Default Value = 0.0002 for Slab-on-Grade Building)

The default crack width for a commercial building is 1 mm. For slab-on-grade scenario, this corresponds to a crack ratio of 0.0002 using the default building area of 180 m^2.

Residential Building Area (Default 10 m by 10 m) and Subsurface Foundation Area for Basement (Default Value = 180 m^2)

The residential building area, area corresponds to a building with a 1076 ft^2 footprint, is a subjectively chosen default value. However, the building area chosen is considered appropriate based on the Q_{soil} input selected, which is linked to building area through the Q_{soil}/Q_{build} relationship.

The default building area chosen is similar to the (i) default values used in the Superfund User's Guide for the J&E Model **(9.61 m by 9.61 m or 92.4 m^2**), and (ii) default values used by the State of Michigan, as documented in Part 201, Generic Groundwater and Soil Volatilization to Indoor Air Inhalation Criteria: Technical Support Document (**10.5 m by 10.5 m or 111.5 m^2**). The Michigan guidance document indicates that the 111.5 m^2 area approximately corresponds to the 10th percentile floor space area for residential single family dwellings, based on statistics compiled by the U.S. Department of Commerce (DOC) and US Department of Housing and Urban Development.

Commercial Building Area (Default 20 m by 15 m) and Subsurface Foundation Area (Default Value = 310.5 m^2)

Commercial buildings vary in size and there is little basis for selection of a representative building area. The default area chosen is the same as that used for the CCME CWS-PHC (June, 2000).

4.2 Considerations Relating to Foundation Type

Vapour attenuation factors were calculated for both a basement and slab-on-grade scenario for the input parameters in Table 2. Both scenarios assumed a Q_{soil} of 5 L/min since cracks, drains and other foundation openings may exist for both foundation types. There was little difference in attenuation factor between the basement and slab-on-grade scenarios (less than 10 percent). The reason why relates to the building foundation area and volume. The mass flux into the building is approximately proportional to the foundation area (180 m^2 for basement and 106 m^2 for slab-on-grade). The indoor air concentrations are proportional to the flux divided by the building mixing volume (366 m^3 for basement and 244 m^3 for slab-on-grade). Although the flux is higher for the basement scenario, there is also greater dilution, which results in attenuation factors similar to the slab-on-grade scenario. Provided that the Qsoil for each scenario is the same, the balancing effect of flux area and dilution volume can also be expressed through the foundation area to enclosed space ratio. Since there was little difference between the basement and slab-on-grade scenarios, only attenuation factors for the basement scenario are provided.

4.3 Considerations Relating to Use of Benzene as Surrogate Chemical

The guidance attenuation factor charts are based on physical-chemical properties for benzene, but are applied to all chemicals with the assumption that their properties are sufficiently similar to benzene for screening purposes.

Diffusive transport is the only process incorporated in the attenuation factor estimation affected by chemical-specific properties (free-air diffusion coefficient and Henry’s Law constant). Advective transport of soil gas is not affected by chemical-specific properties. The diffusion rate (i.e., flux) is directly proportional to the attenuation factor when there is no advective transport into the building (i.e., a two-fold increase in diffusion rate results in a two-fold increase in the attenuation factor). When there is advective transport, the relative importance of diffusion diminishes. Fortunately, the chemical-specific variation in the effective diffusion coefficient is, in most cases, not significant relative to other sources of uncertainty since the free-air diffusion coefficients generally vary by only a factor of two for most volatile organic compounds. This is small relative to the order-of-magnitude range of values expected from a screening-level model.

To further evaluate the significance of physical-chemical properties on diffusion, the depth-integrated effective diffusion coefficient, calculated for a two-layer soil profile (capillary transition zone and unsaturated zone), was compared for several VOCs (Figure 3). The "overall" depth-integrated effective diffusion coefficient was calculated for four scenarios comprising two different SCS soil types (Sand and Loam) and two different depths to contamination source (1.5 m and 6.1 m). The effective diffusion coefficient is less for a smaller depth to contamination since the relative effect of the capillary fringe on the overall effective diffusion coefficient is greater. The effective diffusion coefficient for the capillary fringe is low due to high moisture content, and the fact that aqueous diffusion coefficients are typically about 4 orders-of-magnitude lower than gaseous diffusion coefficients.

The results indicate that for most VOCs, the effective diffusion coefficient is less than a factor of two greater than or less than that for benzene, consequently the change in vapour attenuation ratio would also be less than a factor of two. Chemicals with significantly higher effective diffusion coefficients, such as phenol ($H' = 1.6 \times 10^{-5}$), acetone ($H' = 1.6 \times 10^{-3}$), and pentachlorophenol ($H' = 1 \times 10^{-6}$) could have significantly higher effective diffusion coefficients; however, the low Henry's Law constants result in very low source vapour concentrations compared to health-based reference concentrations meaning these chemicals will, in most cases, not be of concern. For comparison, the dimensionless Henry's Law constant for benzene is 0.23. When NAPL is present, the relevant physical-chemical property affecting the source vapour concentration is the vapour pressure. Therefore, at sites where NAPL is present, it may be appropriate to compare the vapour concentration from the Henry's Law constant calculation to that based on vapour pressure as a final check, for chemicals that have significantly different properties compared to those of benzene.

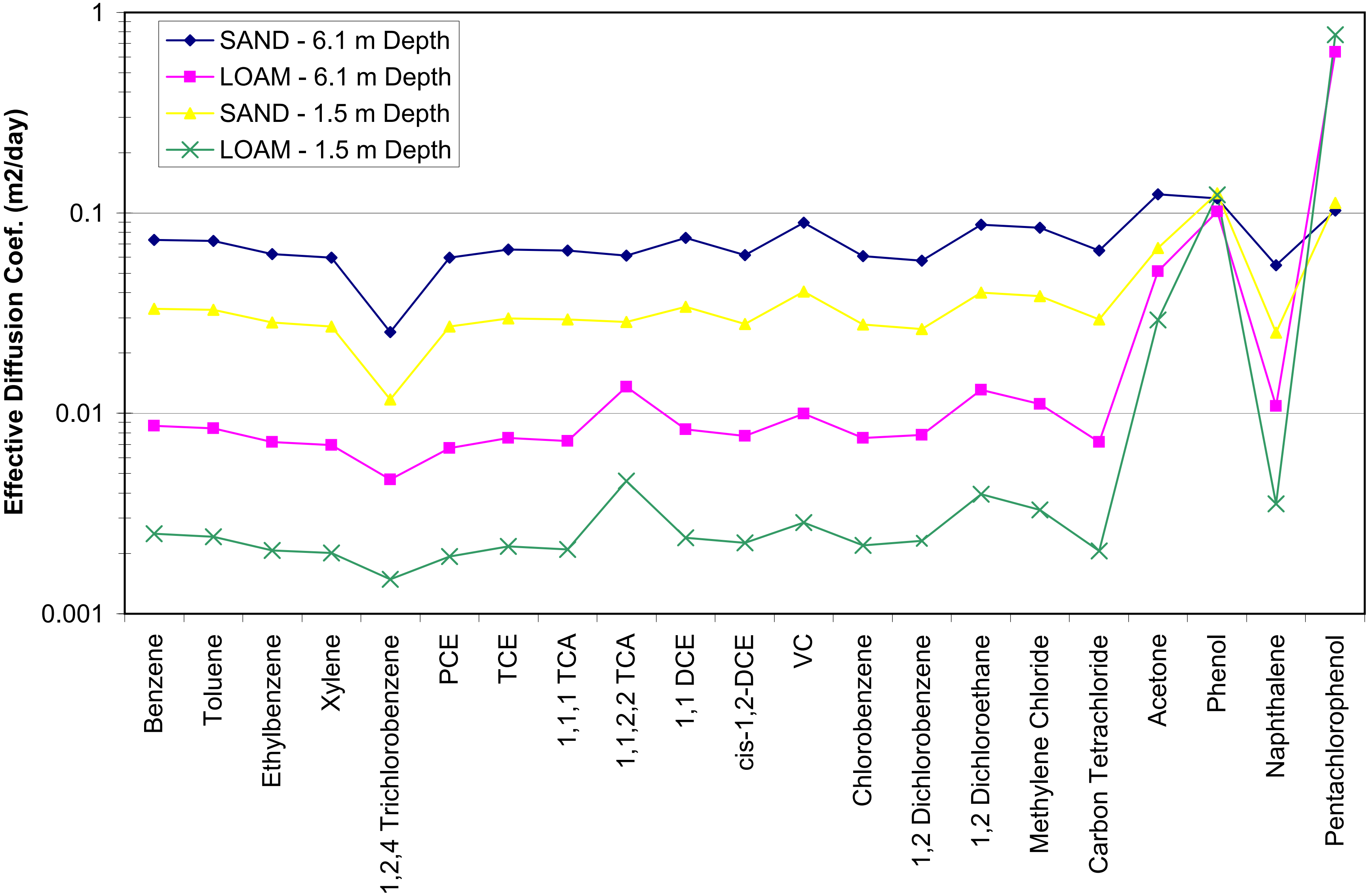

Figure 3. Comparison Effective Diffusion Coefficient for Selected Chemicals

4.4 Considerations Relating to Transport Through Capillary Transition Zone

The derivation of the attenuation factor chart for a groundwater contamination source assumed that the top boundary for contamination was the water table. This is the typical assumption when the J&E model is used for a groundwater source. Chemical transport through the capillary transition zone is limited to diffusion in both soil vapour and pore water.

There are other potential mechanisms for chemical mass transport through the capillary transition zone, which could result in greater chemical flux than that predicted through diffusion alone. They include fluctuations in the water table level and lateral flow of contaminated groundwater through the capillary fringe. These mechanisms are not part of the J&E model.

It was hypothesized that the potentially non-conservative aspects associated with not including other chemical mechanisms for transport in the capillary transition zone (i.e., in addition to diffusion) are counter balanced by input values for the J&E model that under estimate moisture content, and hence over estimate the diffusive transport rate. To test this hypothesis, model predictions for different boundary conditions and input parameters were compared to predictions using the conventional model described above. Specifically, the (i) top boundary for the contamination source was assumed to be the top of the capillary fringe, and (ii) more realistic moisture contents were used to estimate diffusive flux rates by integrating the water retention curve, as opposed to the approximation based on the bi-linear water-filled porosity profile. The results indicated similar diffusive flux rates for the conventional model with a contamination source at the water table, and the alternate model described above with the contamination source at the top of the capillary fringe.

4.5 Considerations Relating to Mass Flux in Groundwater

When contamination is limited to dissolved chemicals migrating in groundwater, the only source of vapours are chemicals that volatilize from groundwater. The available mass that could potentially volatilize under steady state conditions is controlled by the mass flux in groundwater flowing below the building. The development of the vapour attenuation factors did not take into consideration possible mass flux considerations and instead assumed an infinite mass of chemicals is always present below the building.

Mass flux calculations indicate that in some cases the semi-site specific attenuation factors presented in the guidance assume an unrealistic mass flux into the building, based on the available mass of chemical in groundwater. A preliminary evaluation of mass flux was conducted based on a simplified modeling scenario with results presented in Table 6. The calculation assumes that all dissolved chemicals within the top 1 m of groundwater flowing below the entire width of the building will volatilize and enter the building (i.e., leaving no chemicals in groundwater down-gradient of the building) (Figure 4). In reality, dissolved plumes only loose a small portion of their mass through volatilization. The assumed Darcy velocity (specific discharge) was 100 m/year, which corresponds to a groundwater velocity of about 400 m/year, or about 1 m/day. The assumed groundwater velocity is representative of relatively fast moving groundwater at sites with coarse-grained soils. The assumed groundwater to indoor air attenuation factor was 0.001. Both the mass flux entering the building through volatilization and available mass through groundwater transport to below the building were compared. The example calculation results indicate that for trichloroethylene, the mass volatilized is less than the available mass; however, for hexane, the available mass in groundwater is insufficient. The results suggest that based on the upper bound attenuation factor of 0.001, there could be mass flux restrictions for volatile chemicals, even when the rate of groundwater flow is relatively fast.

Based on the rationale listed above, this guidance includes a simple mass flux check to ensure that the predicted indoor air concentration, based on the attenuation factor selected, is not unrealistic based on the available mass. The mass flux check is applicable when there is only a dissolved contamination source.

Table 6 Example Calculations Illustrating Mass Flux Limitations for Dissolved Contamination Source[1]

Parameter	**Trichloro-ethylene**	**n-Hexane**
Assumed groundwater cone (C_w, mg/L)	0.1	0.1
Assumed Darcy velocity (U, m/year)	100	100
Maximum available groundwater flux for volatilization ($Flux_m$, mg/min)	0.19	0.19
Assumed vapour attenuation factor	0.001	0.001
Temperature-corrected Henry's Law Constant (H^1,-)	0.22	2.81
Predicted soil vapour concentration (C_a, mg/m^3)	22	281
Predicted indoor air concentration (C_{air}, mg/m^3)	0.022	0.281
Predicted vapour flux into building ($Flux_p$, mg/min)	0.046	0.59
Ratio Predicted/Available Flux ($Flux_p$/$Flux_m$)	0.24	3.1

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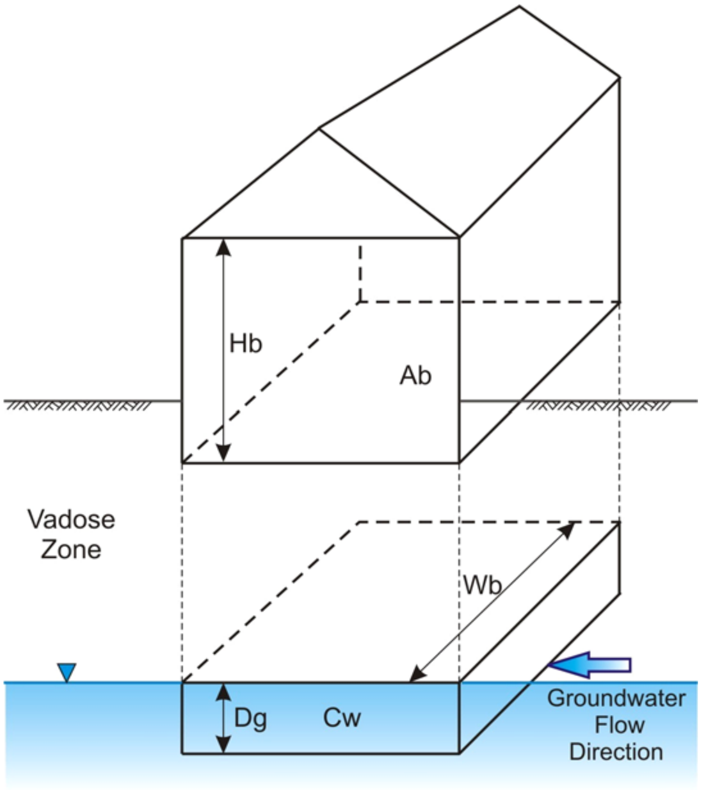
[1] Calculations are for defaults provided in Exhibit 4 and conservatively assume all dissolved chemicals in top 1 m of groundwater flowing below building volatilize and enter building.

Figure 4. Conceptual Model for Groundwater Mass Flux Calculation



4.6 Considerations Relating to Contaminant Source Depletion in Soil

The time for depletion of the contamination source can be calculated when the available mass in soil can be reasonably estimated. The development of the guidance vapour attenuation factors did not take into consideration possible mass flux considerations and instead assumed an infinite mass of chemicals is present below the building. Mass Flux calculations indicate that in some cases the semi-site specific attenuation factors presented in the guidance assume an unrealistic mass flux into the building, based on the available mass in soil and partitioning equations used to predict vapour concentrations from a soil contamination source.

A preliminary evaluation of source depletion was conducted based on a simplified modeling scenario with results presented in Table 7. The scenario assumes that there is a uniform 3 m thick soil contamination layer above the water table. Based on the predicted mass flux into the building for the assumed vapour attenuation factor, the time for mass depletion is calculated for trichloroethylene and hexane. The calculated time for source depletion is about 2 years for trichloroethylene and 2 months for hexane. The short time for source depletion highlights the conservative nature of the partitioning model use to estimate soil vapour concentrations from a soil source, and why the guidance gives preference to use of soil vapour to estimate potential health risk from vapour intrusion.

To address source depletion limitations, the guidance includes a simple calculation to estimate the number of years it would take for the contamination source to be depleted (Exhibit 5). If the time for depletion is less than the assumed exposure duration, consideration should be given to conducting a detailed risk assessment

Table 7
Example Calculations Illustrating Source Depletion Calculation for Soil Contamination Source

Parameter	**Trichloroethylene**	**n-Hexane**
Assumed soil concentration (C_{soil}, mg/kg)	10	10
Assumed thickness soil contamination (T_s, m)	3.0	3.0
Available contaminant mass	4.8×10^6	4.8×10^6
Assumed vapour attenuation factor	0.001	0.001
Predicted soil vapour concentration (C_a, mg/m^3)	2,047	29,563
Predicted indoor air concentration (C_{air}, mg/m^3)	2.05	29.6
Predicted vapour flux into building ($Flux_p$, mg/min)	4.3	62
Time for source depletion ($Time_d$, yr)	2.1	0.15

5. Comparison of Guidance Vapour Attenuation Factors to Field Data

A comprehensive evaluation of field studies providing information on vapour attenuation factors was conducted (Tables 8 to 11). The purpose of this evaluation was to compare the SLRA attenuation factors to measured attenuation factors. The field studies include sites contaminated with chlorinated solvents and petroleum hydrocarbons. The type of available data varied. For some sites, only groundwater data near to houses was available. At other sites, there was soil vapour data for adjacent to a house, and/or subslab soil vapour data from below the foundation slab. Three different attenuation factors were estimated depending on the available data:

Groundwater to Indoor Air Attenuation Factor

α_g = Measured indoor air conc. / (Measured groundwater conc. * Henry's Law Constant)

Soil Vapour to Indoor Air Attenuation Factor

α_v = Measured indoor air conc. / Measured soil vapour concentration at defined depth

Subslab Vapour to Indoor Air Attenuation Factor

α_{ss} = Measured indoor air conc. / Measured subslab vapour concentration

This comprehensive empirical evaluation of vapour attenuation factors was important since model validation is essential for development of technically sound guidance.

Table 8
Summary of Empirical Vapour Attenuation Factors

						Groundwater-Indoor Air Alpha				Soil Vapor-Indoor Air Alpha				Sub-slab - Indoor Air Alpha				
Site & Reference	Contaminant or Tracer	Building and Foundation Type	Soil Conditions	Depth (m)	Chemical	Source Concentration (ug/L)	N Indoor Air	α_g Statistic	Measured α_g	Source Concentration (ug/L mg/m^3)	N Indoor Air	α_v Statistic	Measured α_v	Source Concentration (ug/L mg/m^3)	N Indoor Air	α_v Statistic	Measured α_v	Comments
CHLORINATED SOLVENT SITES																		
CDOT HDQ Site Colorado Johnson et al. (2000)	chlorinated solvents, dissolved plume	mostly apartments, few SFRs, mostly slab-on-grade, few crawl-spaces & basements, AC mostly window units, heating natural gas,baseboard, and/or fireplaces	weathered & fractured claystone above water table	4.6	1,1 DCE	10-10,000	115-150	Geom	4.8E-06									1. High quality dataset, pathway definitive in terms of indicating subsurface vapor intrusion. intrusion. 2. a_m values for houses above plume with DCE groundwater concentration > 10 ug/L
								90th	2.0E-05									
					TCE	3-3,000		Geom	1.4E-05									
								90th	7.0E-05									
					1,1,1 TCA	10-10,000		Geom	1.7E-05									
								90th	6.6E-05									
					1,1 DCA	1-1,000		Geom	6.2E-05									
								90th	3.4E-04									
					above 3 CS			Geom	1.2E-05									1. Average for 3 chlorinated solvents (CS)
								90th	5.2E-05									"
Redfields Site Colorado Envirogroup (1999)	chlorinated solvents, dissolved plume	SFRs, built 50's and 60's, mostly basements or crawlspaces, no combustion air intakes	clay & silt, some sand layers, mostly sand or silt near WT	6.1 to 7.3	1,1 DCE	10-1,000	65	50th	1.1E-05									1. High quality dataset, pathway definitive indicating vapor intrusion. 2. Alpha values for houses above plume with DCE groundwater conc. > 10 ug/L, analysis limited to first block of homes tested (~ 100)
								Avg	5.9E-05									
								90th	1.5E-04									
								Max	6.9E-04									
Redfields Site Colorado, Folkes et al. (AEHS, 2004)	chlorinated solvents, dissolved plume	SFRs, built 50's and 60's, mostly basements or crawlspaces, no combustion air intakes	clay & silt, some sand layers, mostly sand or silt near WT		1,1 DCE	ND(1) to 970 Avg = 182, Median = 82	687	50th	4.8E-05									1. High quality dataset, pathway definitive indicating vapor intrusion. 2. Alpha values for larger plume area, 3. Geometric mean = 4E-05
								Avg	1.6E-04									
								90th	~ 2.0E-04									
								Max	5.2E-03									
Hamilton Site Colorado (2001), unpublished	chlorinated solvents, dissolved plume	SFRs built 50's mostly basements	primarily sand & & gravel, some clay & silt layers gravel at WT	9.7 to 11	1,1 DCE	15-30	32	50th	6.8E-05									1. Groundwater characterisation limited number wells, houses selected for analysis limited to first 2 homes along X street (ie., closest to wells)
							32	90th	1.4E-04									
Lowry (Air Force Base) Site Colorado, USA Versar (2000)	chlorinated solvents, dissolved plume	SFR: mostly basements some crawlspaces	silty sand to silt, generally silty sand near	6.1 to 7	1,1 DCE	1.4-1.9	13	Med	9.3E-06					> 0.005	11	Med	6.7E-04	1. Groundwater characterisation limited, α_g analysis limited to homes nearest well (UA2, 3, 4 and 5), all data included, therefore TCE alpha likely biased high 2. For α_{ss}, only homes (n=6) with significant concentrations below slab included in analysis due to background interference, TCE alpha likely biased high 3. For crawlspace alpha, included all homes, therefore likely biased high, median and 90th TCE crawlspace alpha's were 0.3 and 0.9
							13	Avg	1.0E-04					> 0.005	11	Avg	1.7E-03	
							13	90th	4.0E-04					> 0.005	11	90th	3.9E-03	
							13	Max	6.2E-04					> 0.005	11	Max	8.3E-03	
				6.1 to 7	TCE	120-170	13	Med	2.2E-05					> 0.5	21	Med	6.2E-04	
							13	Avg	1.8E-04					> 0.5	21	Avg	2.7E-03	
							13	90th	7.1E-04					> 0.5	21	90th	8.3E-03	
							13	Max	1.2E-03					> 0.5	21	Max	1.4E-02	
Juniper Site	chlorinated solvents, dissolved	SFR: mostly basements few crawlspaces, small to medium sized, 40-60's	sand & gravel	4 to 5	TCE	100-1500	56	Avg	3.0E-04		56	Avg	9.7E-04	2.3-42	8	Avg	4.4E-03	1. High quality dataset, pathway definitive in terms of indicating vapor intrusion.
							56	Med	1.3E-04		56	Med	4.6E-04		8	Med	7.0E-03	
							56	90th	7.5E-04		56	90th	2.4E-03		8	Max	2.0E-02	
Mountain View Site California Wu (2000)	chlorinated solvents, leach-field & dissolved^5	SFRs, built 1998, at-grade construction with moisture vapor barrier	mostly silty/ clayey sand & gravel, some sand or silt lenses	1.5	TCE					84	14	Max	2.8E-04					1. Contamination source not well defined, limited groundwater and soil vapor data, only one house with elevated indoor TCE (32 ug/m3)
										84	14	2nd^6	<1.3E-5					
				10.7	TCE	735	14	Max	7.80E-05									
						735	14	2nd	<3.6E-5									
Eau Claire Site Michigan MDEP	chlorinated solvents			0.6	TCE	300-2400	3	Avg	6.90E-05									1. Maximum indoor TCE concentrations (19 ug/m3) and cis-1,2-DCE (7.4 ug/m3) likely above typical background levels based on literature comparisons
				to				Max	1.50E-04									
				1.2	cis-1,2-DCE	28-1200	3	Avg	5.0E-04									
								Max	1.1E-03									
Endicott Site New York	chlorinated solvents	75 % residential, 25 % commercial/mixed pre WWII vintage	sand & gravel	6 to 12 from ground surface	TCE									>100*75 % background	117	50th	2.5E-03	1. High quality dataset, vapor intrusion definitive 2. Attenuation factors at concentrations below about 100*75% background found to be dependent on concentration, likely as a result of background
																75th	1.6E-03	
					111 TCA									>100*75% background	61	50th	3.6E-03	
																75th	1.9E-03	
Raymark Site, CT DiGuilio (AEHS, 2004)	chlorinated solvents	SFRs, 50-100 yr old, 1/2 to 4 inch concrete slab, edge crack visible	coarse sand, soil-air permeability ~ 10 to 100 Darcy		TCE/11DCE												10-2 to 10-4	1. Subslab alpha verbal communication D. Diguilio 2. Radon tracer study indicates Qsoil ranges from ~ 3 to 25 L/min, Qsoil/Qbasement (exfiltration) ~ 1 to 5 percent
Uncasville Site CT US EPA database	chlorinated solvents		sand	2.4	PCE	190, 38	2	Max	8.7E-04	1.5, 0.28	2	Max	8.9E-02					1. Indoor PCE concentrations (44 and 25 ug/m3) above typical background levels, but not within reported background range
								Min	3.0E-04			Min	2.9E-02					

Table 8
Summary of Empirical Vapour Attenuation Factors

						Groundwater-Indoor Air Alpha				Soil Vapor-Indoor Air Alpha				Sub-slab - Indoor Air Alpha				
Site & Reference	**Contaminant or Tracer**	**Building and Foundation Type**	**Soil Conditions**	**Depth (m)'**	**Chemical**	**Source Concentration (ug/L)**	**N Indoor Air'**	**α_g Statistic**	**Measured α_g**	**Source Concentration (ug/L mg/m^3)**	**N Indoor Air'**	**α_v Statistic**	**Measured α_v**	**Source Concentration (ug/L mg/m^3)**	**N Indoor Air'**	**α_v Statistic**	**Measured α_v**	**Comments**
Alliant Site Colorado	chlorinated solvents				TCE	280	2	Max	< 4.0E-05									1. Maximum indoor TCE (1.2 ug/m3) relatively low, within typical background levels
MADEP 1 US EPA database	chlorinated solvents	House w\ basement 1525 A, 1525B Marble	f. to m. sand	2.1	TCE	890	2	Max	< 5.4E-04									
MADEP 2 US EPA database	chlorinated solvents	House w\ basement 1503 George	f. to m. sand, gravel	2.7	TCE	800	1	N/A	< 7.1E-05									
Norgate Hills, Norgate Tx US EPA database	chlorinated solvents	Dry cleaner strip mall commercial building			PCE					421	1	N/A	< 3.10E-04					
Lakeside Village, Houston, US EPA database	chlorinated solvents	Dry cleaner strip mall commercial building			PCE	24	1	N/A	< 2.0E-06	11,000	1	N/A	< 3.3E-06					
Former Davis Manufacturing Oakland, California US EPA database	chlorinated solvents	SFR, full basement (1.7 m below grade), 55 m2 footprint, 2-storey high 849 Main Street	sand & gravel	~ 0.4 gdw may intersect foundation	cis-1,2-DCE	28,000	1	N/A	3.4E-06	0.52	1	N/A	3.1E-02					1. Shallow contamination source (<1.5 m) 2. Max cis-12-DCE = 16 ug/m3, likely above back ground
Grants Solvent Site, Cibola, New Mexico Lowe et al. (AEHS, '04)	chlorinated solvents	Houses, 2 slab-on-grade, 2 basement, 2 crawlspace	sand	0.9 to 1.5	TCE					>200 to 30,000	6	Max	2.2E-02					
Lockwood Solvent Site Montana, McReynolds (AEHS, 2004)	chlorinated solvents	Single family residences modular & mobile homes some with crawlspaces	Silty sand to silty clay, sandy gravel & bedrock saturated	2.4 to 4	TCE	>50 to 630	17	90th	3.0E-04									1. Pathway analysis used to filter TCE data below 50 ug/L
Massachusetts Fresh Water Lens Site McAlary et al (AEHS, 2004)	chlorinated solvents	Building 1:	sand	2	TCE	660 to 1,700	5	Avg	< 1.2E-05	450 to 1,300 ppbV	3	Avg	3.8E-04					1. Gdw well Building 1 ~ 40 m u/g (higher conc. area) soil gas point beside Building 1, Gdw well Building 2 '~ 20 m d/w, soil gas ~ 40 m d/g
								Max	< 2.0E-05			Max	5.9E-04					
		Building 2:				320 to 870	5	Avg	< 4.0E-05	280 to 650 ppbV	3	Avg	3.8E-03					
								Max	< 8.2E-05			Max	8.6E-03					
Central California Dry Cleaner Site Goldberg & Nichols (AEHS, 2004)	chlorinated solvents	Commercial building slab-on-grade 6000 ft2	Interbedded fine grained deposits to 7.6 m depth, coarse grained to 15.2m	~ 15 to gdw but source could be in vadose zone	PCE	5,000 to 85,000		S-GW	5.4E-06	max 39,490		S-SGd	1.0E-05	Assume depth to source for was 1.5 m (samples collected 0 to 3 m)				1. Indoor PCE source area = 150 to 380 ug/m3 2. Indoor PCE non-source area = 1.6 to 35 ug/m3 3. Sealing floor cracks/seams & HVAC off/on did not significantly reduce vapor intrusion, but SVE did
								NS-GW	1.6E-05			NS-SGd	4.8E-05					
Commercial Building CA, Wozniak (AEHS, 2004)	chlorinated solvents	Commercial building, 1 storey, built '65, sewer below building	Low permeability alluvial deposits, sand & gravel layers	4.3	TCE	~ 100	6	Avg	1.4E-05									1. Average indoor air Section 2 = 0.9 ug/m3, background = 0.3 ug/m3 (subtract background to calc. α) 2. TCE above crack 17 & 49 ug/m3, 20-60 X dilution 3. Pressurinzing building significantly reduced conc.
Sydney Industrial Site Heggie & Stavropoulos (AEHS, 2004)	chlorinated solvents	Industrial building, 6 bays 3020 yard2 8 inch thick structural slab-on-grade	Residual clays to 5 to 7 m, overlying fractured shale bedrock	~ 5 to 7	TCE									740	1		3.0E-05	1. Calculated alpha using max indoor TCE /subslab TCE, location of max subslab and indoor TCE were near to each other, other alpha's provided not meaningful, alpha highly approximate
"Mass. DEP Sites" USA, Fitzpatrick & Fitzgerald (1996)	chlorinated solvents	N/A (19 sites)			CS					N/A	N/A	N/A	2E-6 to to 1E-1					1. High a_m associated with highly permeable building envelopes (earthern floor, block walls, & sumps)
Raymark, CN DiGuilio AEHS (2004)	chlorinated solvents	SFR, 50 to 100 years 1/2 to 4 inch slab, edge crack visible	coarse sand 10 to 100 darcies		TCE/11DCE								1E-02 - 1E-04					1. Subslab alpha personal communication D. Diguilio 2. Radon tracer tests indicates Qsoil ~ 3 to 25 L/min Qsoil/Qbuilding (exfiltration) ~ 1 to 5 %
UK Runcorn Site	Hexachloro butadiene	Houses	Fill, very poorly consolidated, porous	~ 70	HCBD						35	Avg	1.0E-01					1. Advective transport could be significant at this site as a result of highly permeable fill, deep water table, topographic high combined with wind and thermal effects
											35	Med	5.8E-02					
											35	90th	3.0E-01					
											35	Max	6.4E-01					
PETROLEUM HYDROCARBON SITES																		
Virginia (Motiva) Site, Fan and Quinn (2000)	petroleum HC, NAPL above water	SFR, basements, attached garages, cement block foundations	claystone saprolite k ~ 0.01 darcy	0.5	benzene					410	13	50th	< 8.3E-06					

Table 8
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Site & Reference	Contaminant or Tracer	Building and Foundation Type	Soil Conditions	Depth (m)	Chemical	Source Concentration (ug/L)	N Indoor Air	α_g Statistic	Measured α_g	Source Concentration (ug/L mg/m^3)	N Indoor Air	α_v Statistic	Measured α_v	Source Concentration (ug/L mg/m^3)	N Indoor Air	α_v Statistic	Measured α_v	Comments
Chatterton Site	BTX	research	surface silt to	1.4	benzene					15,000	3-4	Avg	< 5.3E-07	diffusion case				C1: ΔP= 0 Pa, η = 3.3E-4
Delta, B.C.	petro-	greenhouse	f. sand, under-		toluene					20,000	3-4	Avg	< 1.9E-06	"				C1: ΔP= 0 Pa, η = 3.3E-4
Canada	chemical	slab-on-grade	lain by		benzene					15,000	3-4	Avg	4.0E-07	advection case				C2: ΔP= 2.5 Pa, η = 1E-4
Hers et al. (1998)	plant,	poured concrete	m.sand with		toluene					20,000	3-4	Avg	5.9E-07	"				C2: ΔP= 2.5 Pa, η = 1E-4
Hers et al.(2000a)	NAPL	2 mm edge crack	k ~ 10 darcies		benzene					15,000	3-4	Avg	9.9E-05	"				C3: ΔP= 10 Pa, η = 1E-4
	above				toluene					20,000	3-4	Avg	1.3E-04	"				C3: ΔP= 10 Pa, η = 1E-4
	water				benzene					15,000	3-4	Avg	7.2E-06	"				C4: ΔP= 10 Pa, η = 3.3E-4
	table				toluene					20,000	3-4	Avg	3.4E-05	"				C4: ΔP= 10 Pa, η = 3.3E-4
					benzene					15,000	3-4	Avg	5.8E-06	"				C5: ΔP= 30 Pa, η = 3.3E-4
					toluene					20,000	3-4	Avg	2.2E-05	"				C5: ΔP= 30 Pa, η = 3.3E-4
Paulsboro Site	gasoline	SFR	sand, some	2.74	benzene	5350	1	N/A	< 1.2E-06	630	1	N/A	< 3.2E-06					1. Vapor probe BD-16 used to calc. soil vapor alpha
New Jersey, Laubacher et al. (1997)	NAPL above	basement (house #106)	silt		ethylbenzene	980	1	N/A	< 1.3E-05	1800	1	N/A	< 4.4E-06					2. Modeled predicted alpha for benzene
	water table				toluene	11250	1	N/A	< 2.6E-06	250	1	N/A	< 1.2E-05					3. Additional data for benzene (N=15 homes)
					xylenes	7800	1	N/A	< 7.9E-06	900	1	N/A	< 1.9E-05					indicates soil vapor alpha < 1.6E-06
Alameda (Air Station)	gasoline	small commercial	sand	0.7	benzene					200	1	N/A	< 9.0E-06					1. Significant decrease in vapor concentrations be-
Site, California	NAPL above	building, slab-on-grade	k ~ 1 to	0.7	iso-pentene					28,000	1	N/A	< 9.0E-07					tween source and underside of foundation
Fischer et al.(1996)	water table	poured concrete	3 darcy															
"Mass. DEP Sites"	petroleum	N/A	N/A	N/A	benzene					N/A	-	N/A	1E-5 to					
USA, Fitzpatrick	hydrocarbon	(3 sites)											4E-5					
& Fitzgerald (1996)																		
Midwest School Site	petroleum HC	Built 50's, at-grade	sand & gravel,	~ 3	benzene					N/A	N/A	N/A	HC-like					1. Crawlspace conc.: benzene ~ 8.3 mg/m3
USA, Moseley	NAPL above	construction, crawl-	discontinuous		total HC								odours					total HC ~ 500 mg/m3
and Meyer (1992)	water table	space, large paved area	clay lenses										~~ 1E-4					
MADEP 3	petroleum	House w\ basement	f. to m. sand	2.4	benzene	2885	2	Max	< 1.3E-05									1. Average groundwater concentration used
US EPA database	hydrocarbon	12092 B Marble			toluene	545	2	Max	< 2.0E-04									for B6 & 130U to calculate alphas
		13345 A Malden #226			ethylbenzene	1750	2	Max	< 4.6E-06									2. Mean gdw alphas: B = 1.2E-05, T = 1.5E-04,
		13345 B Malden #228			xylene	1250	2	Max	< 3.6E-05									E = 3.8E-06, X = 3.1E-05
MADEP 4	petroleum	House w\ basement	sand, sm. gravel	3.4	benzene	274	1	N/A	5.6E-05									1. Concentrations indoor air relatively low (3 to 8
US EPA database	hydrocarbons	11707 Quincy			ethylbenzene	1880	1	N/A	7.0E-06									ug/m3), within typical background levels
					toluene	4650	1	N/A	6.3E-06									
					xylene	8590	1	N/A	3.5E-06									
MADEP 5	petroleum	House w\ basement	sand	2.4	benzene	2550	2	Max	< 6.1E-06									1. Concentrations indoor air relatively low (3 to 8
US EPA database	hydrocarbon	2797 A Tewks			toluene	979.5	2	Max	< 1.3E-05									ug/m3), within typical background levels
		2797 B Tewks			ethylbenzene	4980	2	Max	< 5.6E-06									
					xylene	1875.5	2	Max	< 9.7E-06									
MADEP 6	petroleum	House w\ basement	sand, some gravel	0.8	benzene	1536	1	N/A	5.2E-05									1. Concentrations indoor air elevated (B = 26 ug/m3,
US EPA database	hydrocarbon	0907A Hull			toluene	842	1	N/A	3.8E-04									T = 87 ug/m3, 100 = ug/m3), above typical
					xylene	3810	1	N/A	9.5E-05									background levels
MADEP 7	petroleum	House w\ basement	f. to m. sand,	2.7	benzene	3500	1	N/A	< 8.846E-07									1. Concentrations indoor air relatively low (1 to 2
US EPA database	hydrocarbon	1019 Lynnf	some gravel		toluene	15700	1	N/A	< 4.683E-07									ug/m3), within typical background levels
					ethylbenzene	1100	1	N/A	< 7.974E-06									
					xylene	13900	1	N/A	< 2.607E-07									
South Philadelphia	petroleum	two-storey residential	sand & gravel at	5 to 7	benzene				Residential	1,300 to 2,800	8	Max	4.0E-06					1. Vapor conc. predicted from NAPL = 1,300 to
Jeng et al.	hydrocarbon	duplexes, slab-on-grade	water table, silt layer	from ground						200 to 1,200	8	Max	4.0E-06					2,800 (check), measured vapor conc. 200 - 1,200mg/m3
(AEHS, 2004)	LNAPL	industrial building	closer to building	surface														2. No discernable difference in benzene in above
Environ		w\ crawlspace & basement																plume and background buildings

Table 8
Summary of Empirical Vapour Attenuation Factors

						Groundwater-Indoor Air Alpha				Soil Vapor-Indoor Air Alpha				Sub-slab - Indoor Air Alpha				
Site & Reference	Contaminant or Tracer	Building and Foundation Type	Soil Conditions	Depth (m)^1	Chemical	Source Concentration (ug/L)	N Indoor Air^2	α_g Statistic	Measured α_g	Source Concentration (ug/L mg/m^3)	N Indoor Air^2	α_v Statistic	Measured α_v	Source Concentration (ug/L mg/m^3)	N Indoor Air^2	α_v Statistic	Measured α_v	Comments
Stafford, NJ Sanders and Hers (AEHS, 2004)	petroleum hydrocarbon	House w\ basement	sand	1.5	benzene	12000	1	N/A	< 3.0E-06		1	N/A	< 1.2E-05		1	N/A	ND	
					toluene	43000	1	N/A	< 8.3E-07		1	N/A	< 8.6E-06		1	N/A	ND	
					ethylbenzene	3500	1	N/A	< 9.9E-06		1	N/A	ND		1	N/A	ND	
					xylene	24000	1	N/A	< 3.9E-06		1	N/A	ND		1	N/A	ND	
					MTBE	590000	1	N/A	1.1E-05		1	N/A	2.2E-05		1	N/A	7.2E-03	
					224 TMP	NT	1	N/A	ND		1	N/A	3.6E-04		1	N/A	7.2E-03	
					cyclohexane	<25000	1	N/A	ND		1	N/A	1.2E-04		1	N/A	8.4E-03	
TRACER AND FLUX CHAMBER TESTS																		
Central California Site, Garbesi & Sextro (1989)	SF_6	SFR, basement poured slab, block walls coated with asphalt	sandy loam to loamy sand, k = 0.1 to 10 darcies	sub-slab	SF_6									N/A	N/A	N/A	~ 1E-3	1. ΔP = 30 Pa
Alameda Site Fischer et al. (1996)	SF_6	small commercial, slab on-grade, concrete	sand, k = 1 to 3 darcy	sub-slab	SF_6									N/A	N/A	N/A	2E-4 to 4E-4	1. ΔP ~ 3 (estimate based on wind loading)
U.S. Sites Little et al.(1992)	radon	SFRs	N/A	sub-slab	radon									N/A	N/A	N/A	1.6E-3^7	
Spokane River Valley Sites, WA Rezvan et al. (1992)	radon	SFRs (14), 8 houses slab-on-grade, 6 basement	highly permeable sand & gravel, k ~ 200 darcies	sub-slab	radon									N/A	N/A	N/A	~ 7.9E-3 to to 4.5E-2	1. Winter conditions, mean house volume = 500 m^3, ACH = 0.5/hr)

Notes: 1 Depth to contamination from underside of foundation slab; 2 N = Number of indoor air samples tested; 3 Best estimate unless otherwise noted; 4 Upper range; 5 Contamination likely in unsaturated zone; 6 2nd highest α_m value; 7 Alpha (α) estimated using mean radon content of soil combined with appropriate emanation constant divided by radon concentration in U.S. homes (55 Bq m-3); 8 N/A = not available or applicable, SFR = single family residence, SF_6 = sulpher hexafluoride, V = vapor, V_{ss} = sub-slab, G = ground water, bgs = below ground surface, HC = hydrocarbon, AC = air-conditioning, INS = insufficient data, ACH = air exchanes per hour, WT = water table, CS = chlorinated solvents.

Table 9. Residential Vapour Attenuation Factors
Chlorinated Solvent Sites

					Alpha's		
Site	Chemical	Data Quality	Stat-istic		Ground water	Soil Vapor	Subslab Vapor
CDOT, CO	3 CS	1	90th		5.2E-05	N/A	N/A
Redfields, CO	11 DCE	1	90th		1.2E-04	N/A	N/A
Hamilton Sunstrand, C	11 DCE	1	90th		1.4E-04	N/A	N/A
Lowry, CO	TCE/11DCE	1	90th		7.1E-04	N/A	1.4E-02
Juniper	TCE	1	90th		8.0E-04	2.4E-03	2.0E-02
Endicott, NY	TCE	1	75th		N/A	N/A	1.9E-03
Runcorn, UK	HCBD	1	90th		N/A	3.0E-01	N/A
Raymark, CN	11 DCE/TCE	1	Range		N/A	N/A	10^{-2} - 10^{-4}
MAPEP 1	TCE	2	Max	<	5.4E-04	N/A	N/A
MAPEP 2	TCE	2	Max	<	7.1E-05	N/A	N/A
Uncasville, CT	PCE	2	Max	<?	8.7E-04	8.9E-02	N/A
Alliant, CO	TCE	2	Max	<	4.0E-05	N/A	N/A
Mountain View, CA	TCE	2	Max		7.8E-05	2.8E-04	N/A
Lockwood, Montana	TCE	2	90th		3.0E-04	N/A	N/A
Grants, Cibola, NM	TCE	2	Max		N/A	2.2E-02	N/A
Former Davis Manu [1]	*cis-12-DCE*	*2*	*Max*		*3.4E-03*	*3.1E-02*	*N/A*
Eau Claire, MI [1]	*TCE*	*2*	*Max*		*1.5E-04*	*N/A*	*N/A*

[1] Depth to contamination less than 1 m

Table 10. Empirical Residential Vapor Attenuation Factors
Petroleum Hydrocarbon Sites

					Alpha's		
Site	Chemical	Data Rank	Stat-istic		Ground water	Soil Vapor	Subslab Vapor
MADEP 3	BTEX	2	Max	<	2.0E-04	N/A	N/A
MADEP 4	BTEX	2	Max	<	5.6E-05	N/A	N/A
MADEP 5	BTEX	2	Max	<	1.3E-05	N/A	N/A
MADEP 6	BTEX	2	Max		3.8E-04	N/A	N/A
MADEP 7	BTEX	2	Max	<	8.0E-06	N/A	N/A
Paulsboro, NJ	BTEX	1	Max	<	1.3E-05	1.9E-05	N/A
Alameda, CA	BTEX	2	Max	<	9.0E-06	N/A	N/A
Stafford, NJ	BTEX	1	Max	<	9.9E-06	1.2E-05	N/A
Stafford, NJ	MTBE	1	Max		1.1E-05	2.2E-05	N/A
Stafford	224 TMP	1	Max		N/A	3.6E-04	N/A
Chatterton (ΔP=0 Pa),	BTX	1	Max	<	N/A	1.9E-06	N/A
Chatterton (ΔP>=10 Pa	BTX	1	Max		N/A	1.3E-04	N/A
Motiva, Virginia	BTEX	2	Max	<	N/A	8.3E-06	N/A
South Philadelphia, PA	Benzene	2	Max	<	N/A	4.0E-06	N/A

Table 11. Commercial Vapour Attenuation Factors
Chlorinated Solvent Sites

Site	Chemical	Data Rank	Statistic		Alpha's		
					Ground water	Soil Vapor	Subslab Vapor
Commercial Site, CA	TCE	1	Avg		1.4E-05	N/A	N/A
Norgate Hills, TX	PCE	2	Max	<	N/A	3.10E-04	N/A
Lakeside Village, TX	PCE	2	Max	<	2.0E-06	3.3E-06	N/A
Central CA Dry Cleane	PCE	2	Max		5.4E-06	1.0E-05	N/A
Sydney AUS Industrial,	TCE	2	Max		N/A	N/A	3.0E-05

5.1 Sources of Uncertainty for Vapour Attenuation Factors

There are numerous sources of uncertainty for estimation of vapour attenuation factors:

- Groundwater and soil vapour concentrations are not directly measured below buildings, but are interpolated values;
- Spatial variability in groundwater concentrations, including often steep concentration gradients;
- Lateral migration of soil vapour away from groundwater contamination sources;
- Spatial variability in subslab soil vapour concentrations;
- Temporal variability (tends to be greatest for indoor air measurements);
- Variability caused by sampling and analysis procedures; and,
- Background sources of VOCs (ambient air, building materials, consumer products, occupant related sources).

As a result of uncertainty, it is important to carefully screen empirical data and filter out data that could lead to erroneous conclusions. In addition, for large data sets where indoor air measurements are available for multiple homes, it may be appropriate to use a statistical approach (e.g., an upper percentile of the attenuation factor distribution) to select a representative upper bound attenuation factor since the upper tail of the attenuation factor distribution may be populated with upwardly biased measurements due to errors in the data. For this reason, a 90th percentile attenuation factor is selected as a conservative yet non-extreme value to account for possible errors and bias in the data.

5.2 Empirical Data Analysis Methods

The attenuation factor study involved compilation of available data from a number of sources (research programs conducted by Golder Associates, consultant reports, US EPA). The data for each site was evaluated to determine the reliability of each data set and evidence for vapour intrusion, and to filter out non-reliable data.

5.2.1 Vapour Source Strength Screening

The first step of the screening process was to evaluate whether the source vapour concentrations below the building were too low to practically be able to measure indoor vapour concentrations based on analytical detection limits, or to distinguish indoor vapour concentrations from background concentrations, based on reasonable vapour intrusion rates. Case studies indicate that the most reliable data for estimation of vapour attenuation factors is where source vapour concentrations below buildings are relatively high. Empirical observations indicate that attenuation factors generally increase as source concentrations decrease, likely as a result of the confounding influence of background sources of VOCs, and greater uncertainty associated with estimation of source concentrations near the periphery of a plume.

Data was retained for the attenuation factor study only when the measured source soil vapour concentrations were about 100 X greater than the typical background concentration, for the chemical under consideration. Estimated vapour concentrations predicted from groundwater were only retained when the soil vapour concentration was 1000 X greater than background. The rationale for this screening criteria is that the vapour-derived indoor air concentration would be indistinguishable from the background concentration for source strength concentrations less than the criteria given above, even assuming conservative (high) vapour attenuation factors. It is noted that most sites included in the study had source concentrations that were much higher 100 X background (vapour source) or 1000 X background (groundwater source).

For some sites where indoor air quality was tested in a large number of homes, a secondary screening step based on source concentrations was performed to filter out less reliable attenuation factor calculated for homes at the periphery of the plume. For example, for the CDOT and Redfields site, only data for houses with interpolated 1,1-DCE groundwater concentrations greater than 10 μg/L were retained.

5.2.2 Evaluation of Background VOC Sources

The second step of the screening process was to evaluate the possible influence of background VOC sources on measured indoor air concentrations. Measurements in homes with documented sources of chemicals clearly representing a significant background source (e.g., open gasoline containers, recent painting or use of glues) were generally not used. The measured indoor air concentrations were compared to literature background air concentrations, and to indoor air concentrations measured in nearby control homes located outside of the plume area, for case studies where this information was available.

Where available, subslab vapour concentrations were compared to indoor air concentrations to evaluate the significance of the indoor air measurements. Based on the expected dilution of soil gas due to building ventilation, data indicating less than 100 X attenuation between subslab vapour and indoor air concentrations (for representative data) suggests a background component to the indoor air concentration.

Empirical vapour attenuation factors are more reliable for chemicals with typically low background indoor air concentrations, such as 1,1-dichloroethene (DCE) and TCE. Since there are few, if any, background sources of 1,1-DCE, this chemical can be an effective tracer for measuring soil vapour intrusion. For chemicals with elevated background indoor air concentrations such as benzene and tetrachloroethene, the empirical vapour attenuation factors are less reliable since the background component can have a significant effect on the vapour attenuation factor. An example calculation is provided below to illustrate the effect of background on the empirical vapour attenuation factor for benzene, based on possible source vapour concentrations for a gasoline-contaminated site and typical vapour attenuation factors .

- Background benzene indoor air concentration ($C_{background}$) = 5 $\mu g/m^3$ (Reference);
- Source benzene vapour concentration (C_{source}) = 350,000 $\mu g/m^3$ (average based on three published case studies; Fisher *et al.* 1996, Ririe and Sweeney, 1998, Laubacher *et al.* 1997);
- Vapour Attenuation Factor = 1×10^{-5} (a reasonable value based on data presented in Table 6, assuming no biodegradation), and;

- The calculated vapour-derived indoor benzene concentration (C_{vapour}) is 3.5 μg/m^3.

Based on the above, an empirical vapour attenuation factor that reflects both the vapour and background component is:

$\alpha = (C_{vapour} + C_{background}) / C_{source}$

$\alpha = 2.4 \times 10^{-5}$

The empirical attenuation factor for this example is 2.4 times higher than the “true” vapour-derived attenuation factor illustrating the potential effect of background on the measured vapour attenuation factor.

5.2.3 Vapour Pathway Analysis

The second step of the screening process was an analysis of relationships between data to determine whether there is evidence for vapour intrusion. This integrated analysis of data is referred to as “vapour pathway analysis”, and can include the following aspects:

1. Spatial relationships between the groundwater plume, soil vapour plume and measured indoor air concentrations in homes (is there a consistent pattern?).

2. Correlation between estimated groundwater or soil vapour concentrations below a home, and measured indoor air concentration (is there a positive correlation?).

3. The concentration ratios for different chemicals with similar fate and transport properties at sites with multiple contaminants (are the concentration ratios similar in groundwater, soil vapour and indoor air?)

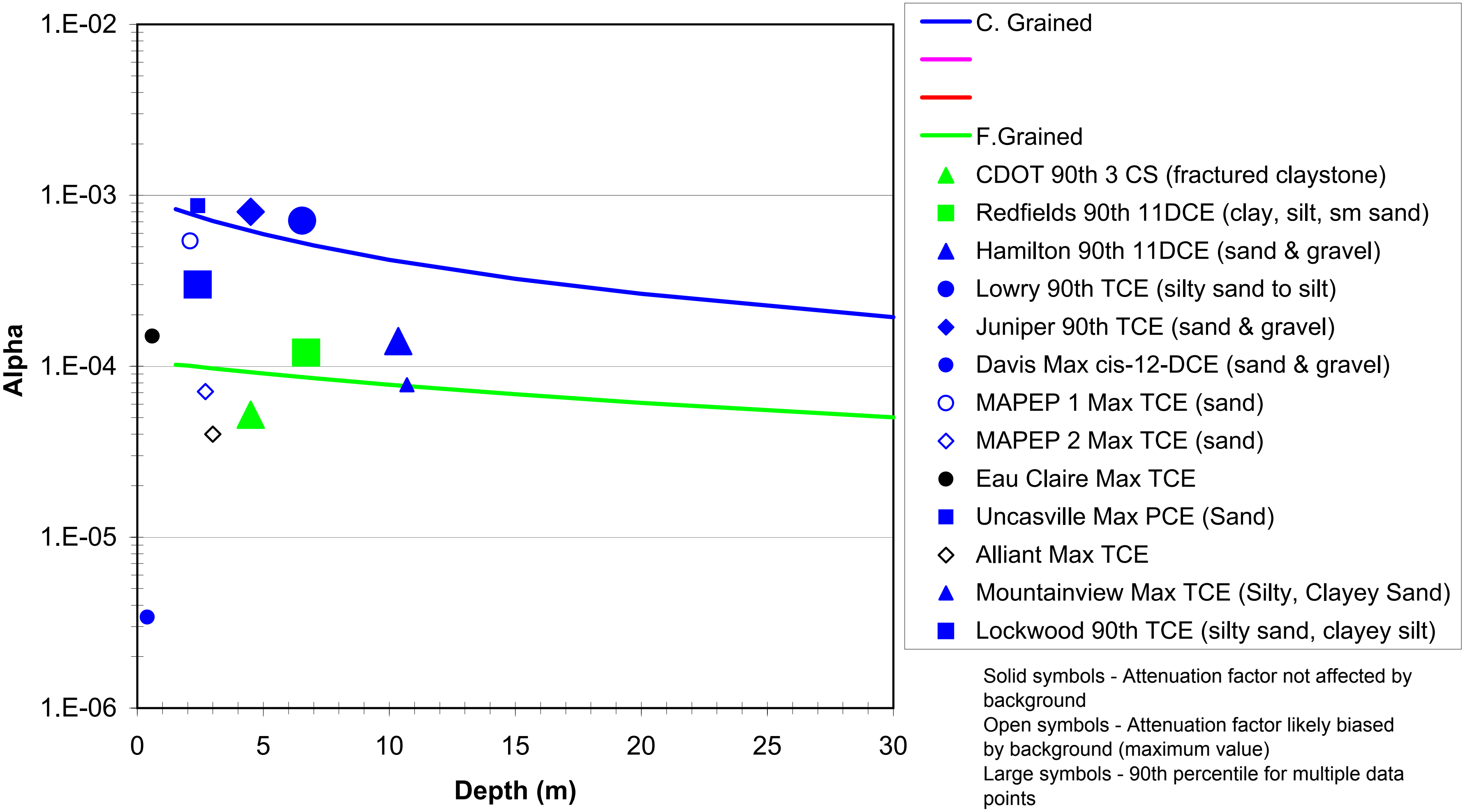
When available, soil vapour profiles and subslab vapour concentrations can also be used to evaluate the potential for vapour intrusion. For example, there may be a low potential for significant vapour intrusion, if there is a significant decrease in vapour concentrations with increasing distance from the vapour source, or if subslab vapour concentrations below a building are low.

As a result of the inherent uncertainty in vapour attenuation factor data, statistically significant correlations between data are not expected. Instead, the evaluation is based on qualitative trends in data that point to support vapour intrusion.

5.3 Empirical Vapour Attenuation Factors

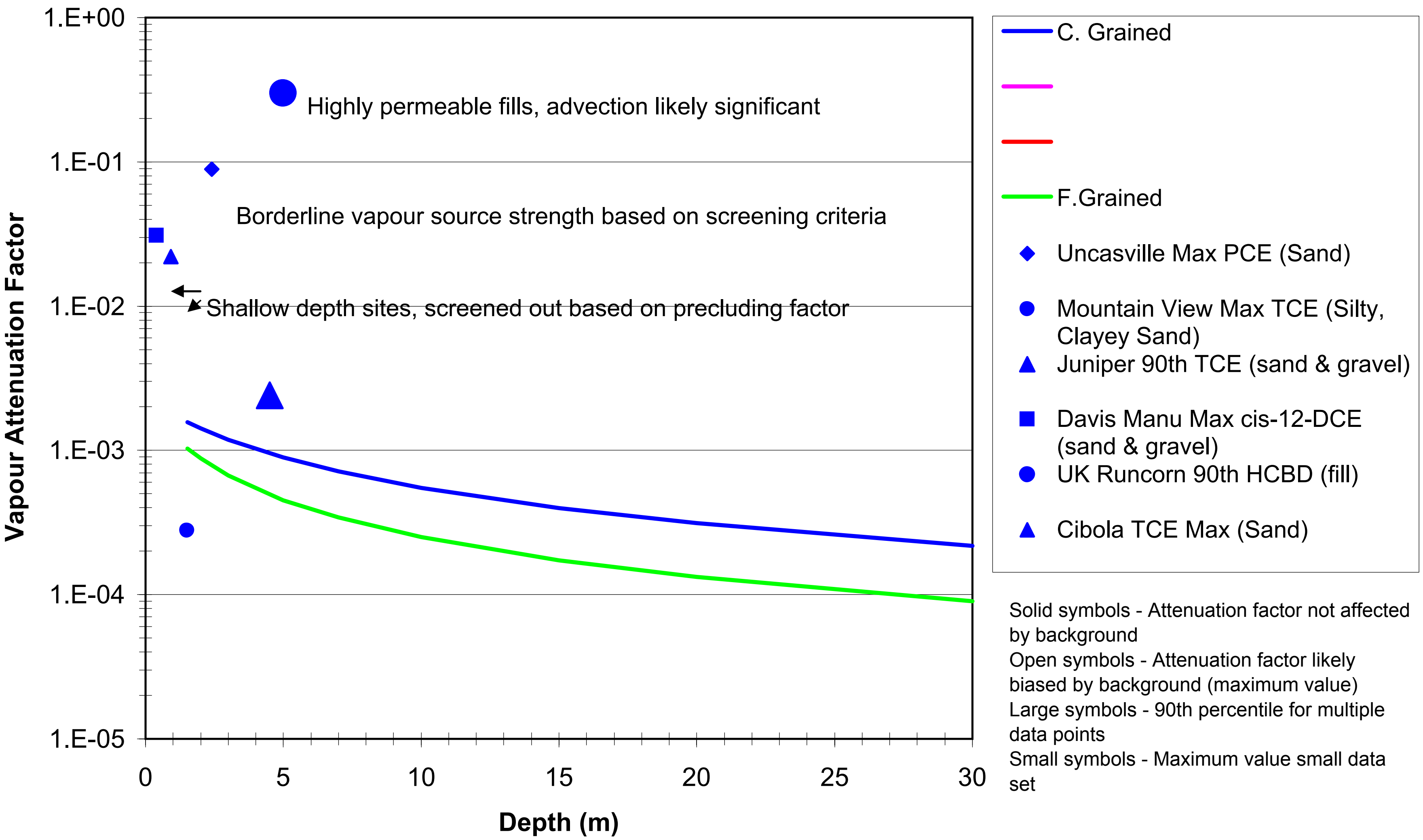
The above screening process was used to estimate a single upper bound attenuation factor for each case study site based a balance of evidence approach (Tables 8 to 11). For sites with greater than 10 to 20 data points (cut off depending on the site), a 90th percentile attenuation factor was calculated. For sites with less than 10 to 20 data points, a maximum attenuation factor estimated for all site chemicals was retained. For data where the analysis suggested that the measured indoor concentrations were influenced by background indoor sources, the empirical attenuation factor is flagged to indicate it is a possible maximum attenuation factor. In addition, vapour attenuation factors for sites with unique characteristics were also flagged. For example, the relatively high attenuation factors for the “UK site” (Table 8) are thought to have been caused by soil gas advection through highly permeable fill deposits below houses. Overall, the analysis is considered conservative in that it is unlikely that the attenuation factor for individual homes at a site would exceed the site-wide upper bound attenuation factor chosen.

The empirical attenuation factors are compared to the SLRA guidance attenuation factors in Figures 5 to 11. The attenuation factors for sites with multiple data points (90th percentile values), which generally indicate a more reliable data set, are shown using large symbols while sites with a lesser number of data points are shown using smaller symbols. Solid symbols are used when background sources in indoor air are unlikely to have had a significant effect on the vapour attenuation factor. Open symbols are used when background source could have had a significant effect on the attenuation factor



Solid symbols - Attenuation factor not affected by background
Open symbols - Attenuation factor likely biased by background (maximum value)
Large symbols - 90th percentile for multiple data points
Small symbols - Maximum value small data set

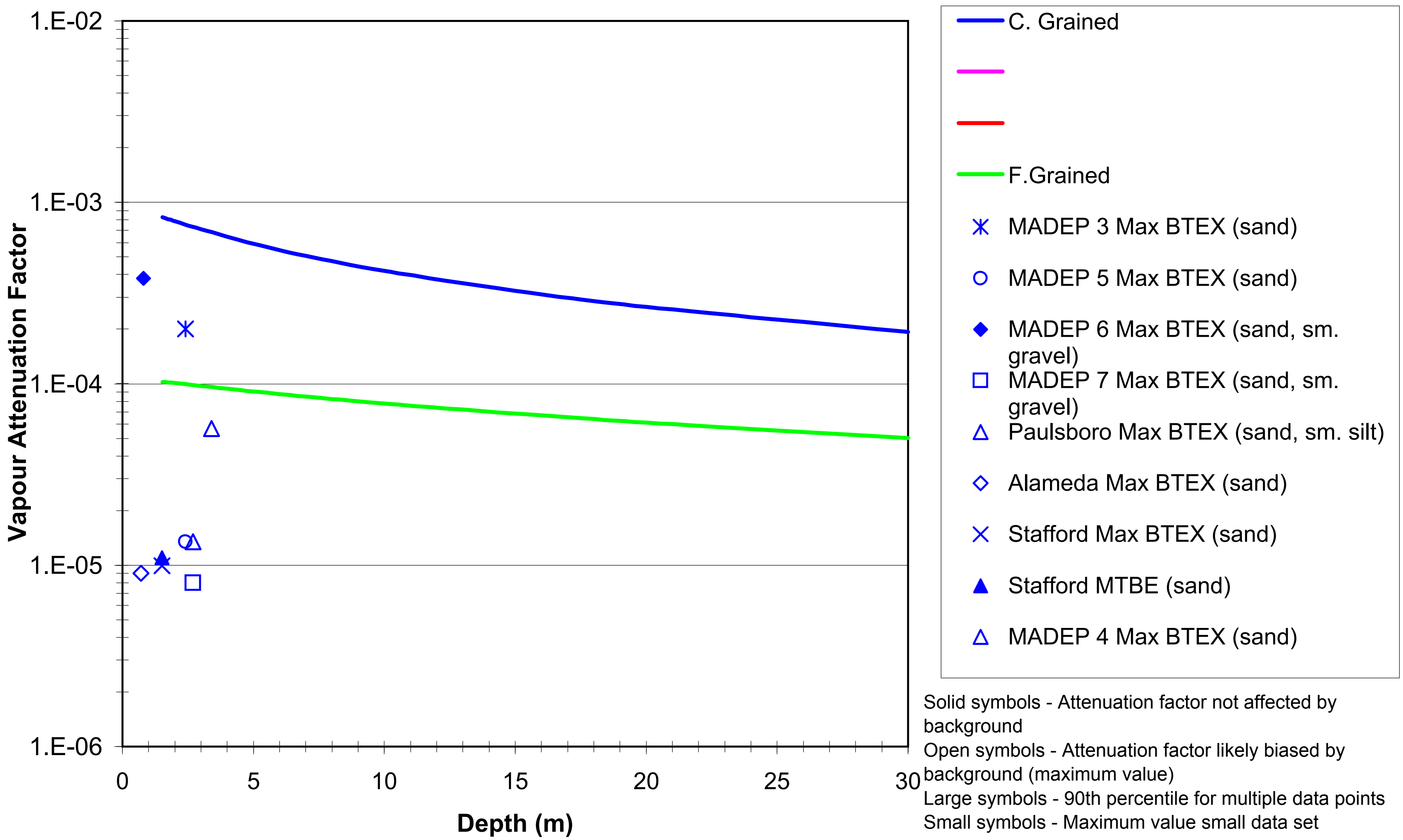
Figure 5. Residential Groundwater to Indoor Air Attenuation Factors Chlorinated Solvent Data



Solid symbols - Attenuation factor not affected by background
Open symbols - Attenuation factor likely biased by background (maximum value)
Large symbols - 90th percentile for multiple data points
Small symbols - Maximum value small data set

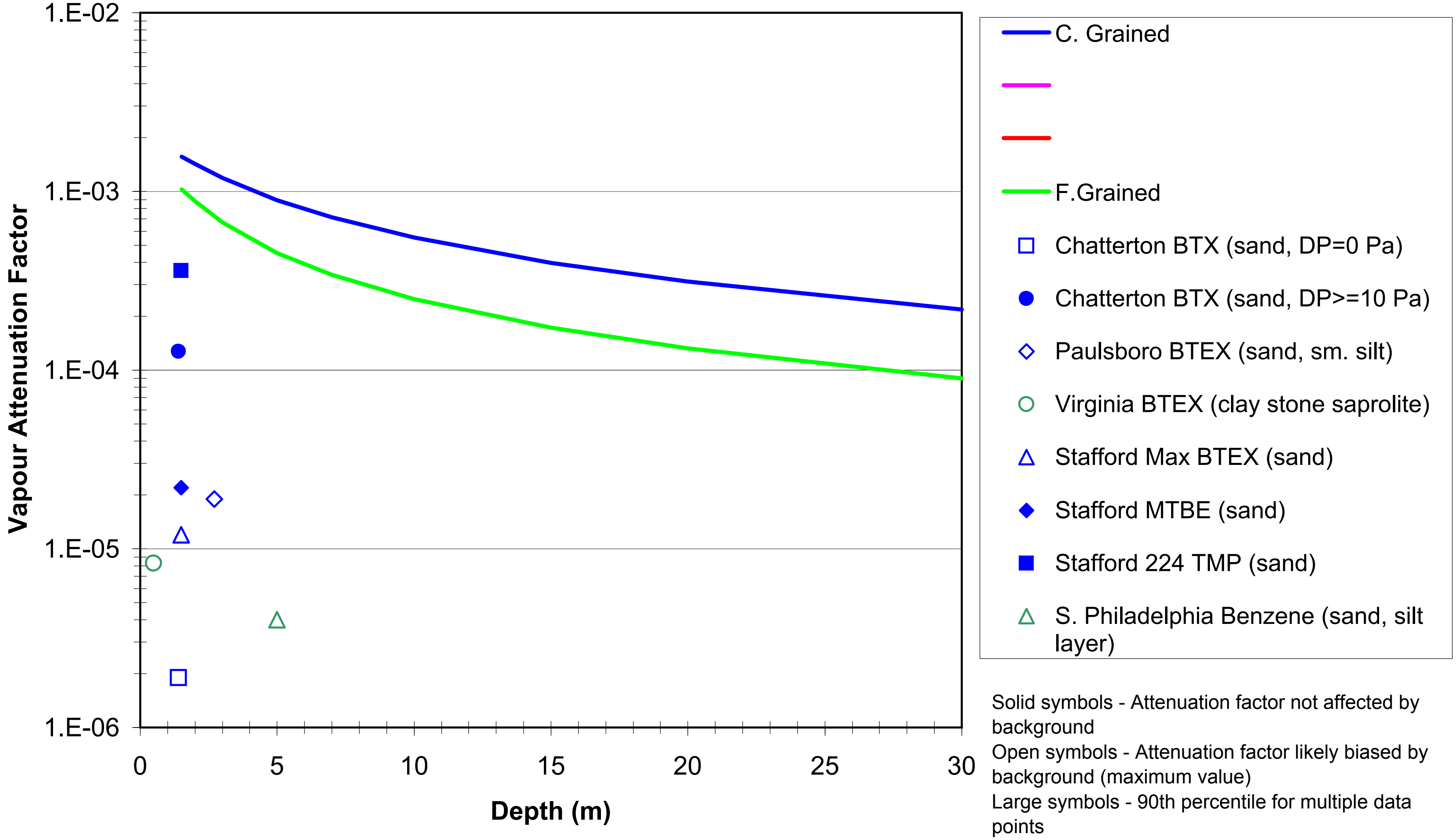
Figure 6. Residential Soil Vapour to Indoor Air Attenuation Factors Chlorinated Solvents & HCBD Data

Golder Associates



Solid symbols - Attenuation factor not affected by background
Open symbols - Attenuation factor likely biased by background (maximum value)
Large symbols - 90th percentile for multiple data points
Small symbols - Maximum value small data set

Figure 7. Residential Groundwater to Indoor Air Attenuation Factors
Petroleum Hydrocarbon Data



Solid symbols - Attenuation factor not affected by background
Open symbols - Attenuation factor likely biased by background (maximum value)
Large symbols - 90th percentile for multiple data points
Small svmbols - Maximum value small data set

Figure 8. Residential Soil Vapour to Indoor Air Attenuation Factors
Petroleum Hydrocarbon Data

Golder Associates

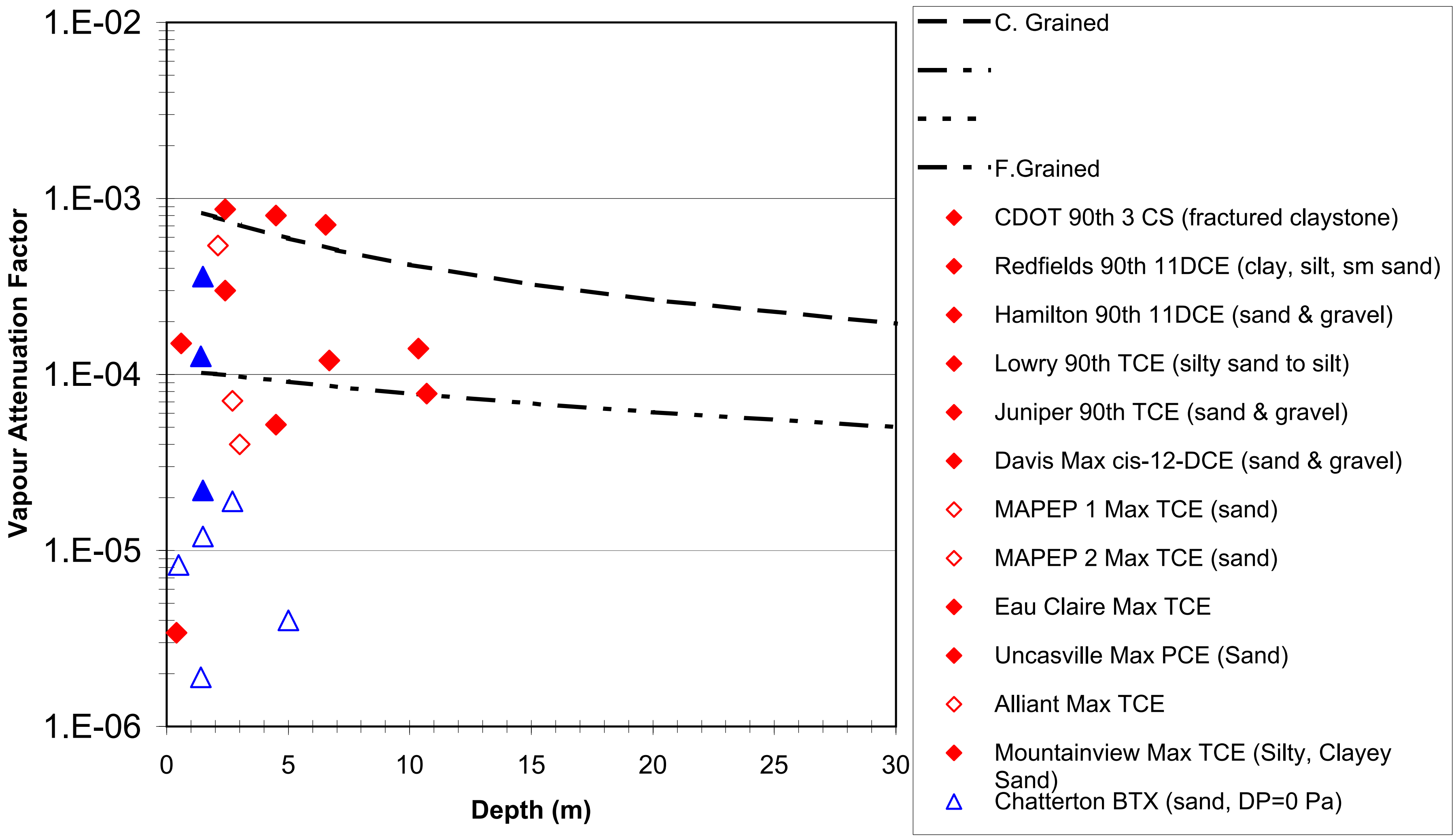
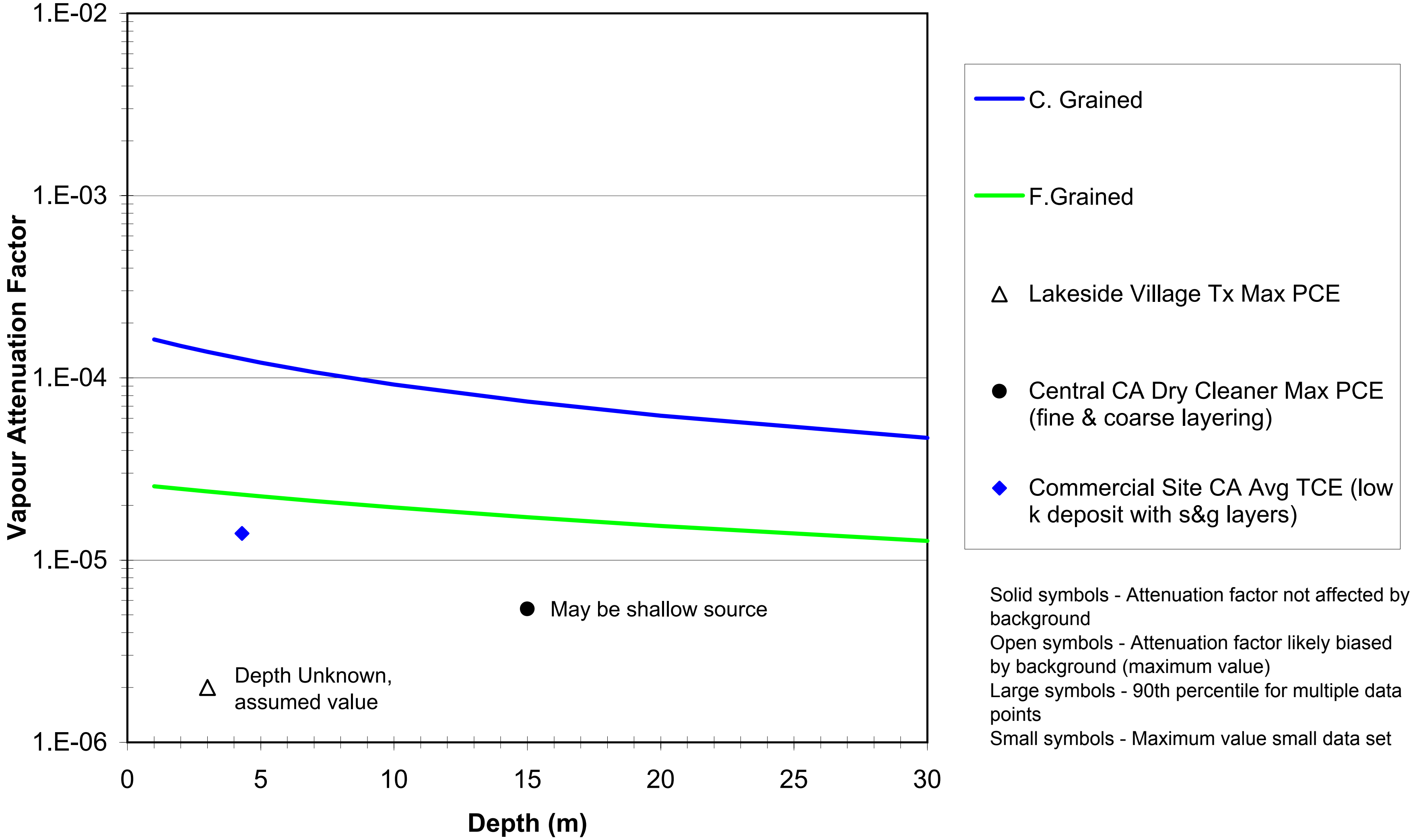
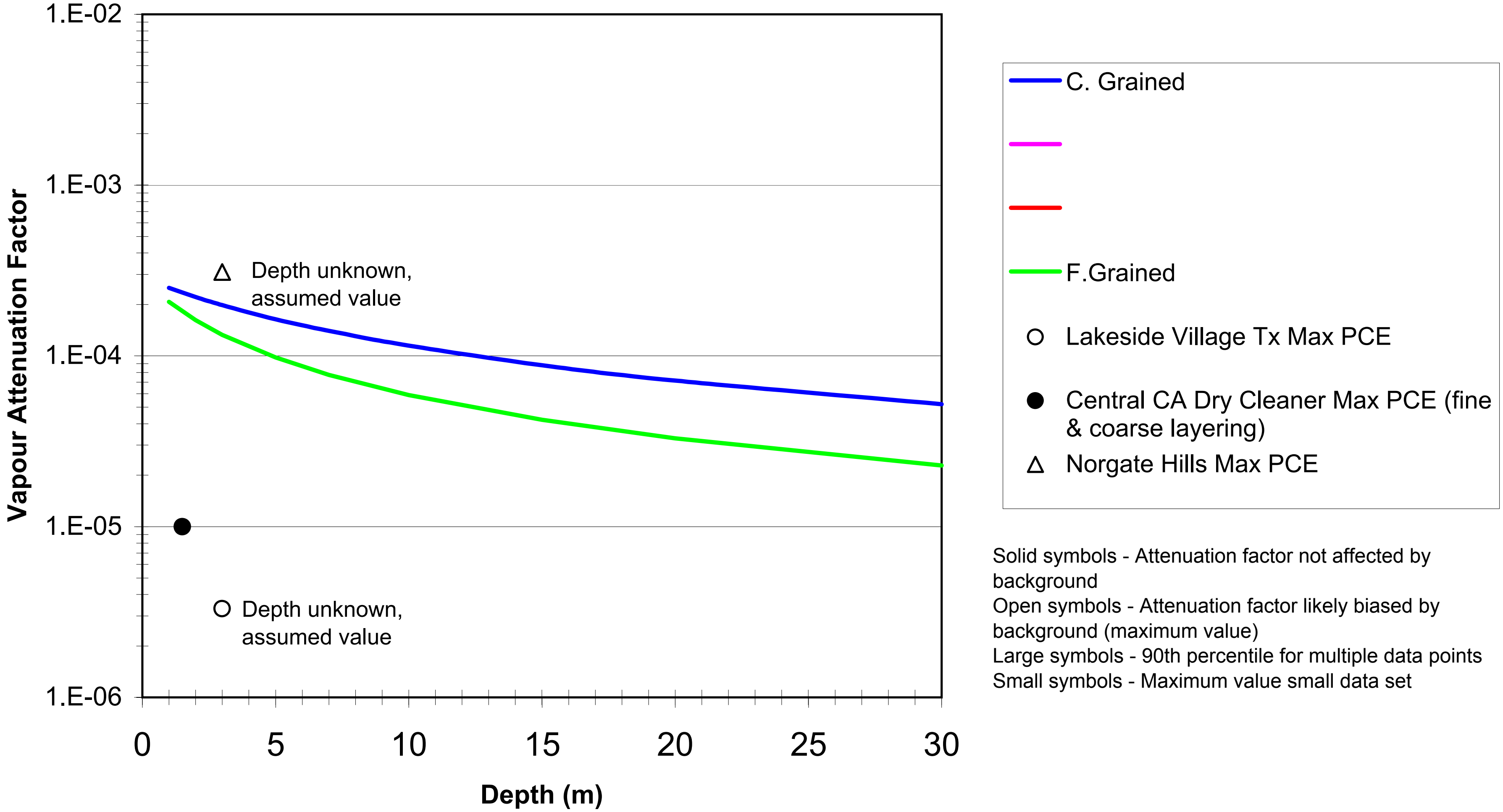


Figure 9. Residential Groundwater to Indoor Air Attenuation Factors All Data



Solid symbols - Attenuation factor not affected by background
Open symbols - Attenuation factor likely biased by background (maximum value)
Large symbols - 90th percentile for multiple data points
Small symbols - Maximum value small data set

Figure 10. Commercial Groundwater to Indoor Air Attenuation Factors Chlorinated Solvent Data



Solid symbols - Attenuation factor not affected by background
Open symbols - Attenuation factor likely biased by background (maximum value)
Large symbols - 90th percentile for multiple data points
Small symbols - Maximum value small data set

Figure 11. Commercial Soil Vapour to Indoor Air Attenuation Factors Chlorinated Solvent Data

The case study sites evaluated were as follows:

Residential	**Commercial**
Chlorinated Solvent– 17 sites	Chlorinated Solvent – 5 sites
Petroleum Hydrocarbon – 11 sites	Petroleum Hydrocarbon - None

Residential Site Data

Chlorinated Solvents

For residential sites impacted with chlorinated solvents, approximately half the sites had multiple attenuation factor measurements representing relatively high quality data sets. The other half had only a relatively small number of measurements. At most sites, the vapour pathway analysis or comparisons to background for chemicals with low background, such as 1,1-DCE or TCE, indicated vapour intrusion was occurring. Vapour attenuation factors for these sites were considered to be reasonably accurate.

The empirical attenuation factors were similar to or lower than the SLRA guidance groundwater to indoor air vapour attenuation factors (Figure 5). The maximum groundwater to indoor air attenuation factor was about $1x10^{-3}$.

When the guidance soil vapour to indoor air factors were evaluated, there were several sites where the empirical factors were higher than the guidance factors. However, the database is relatively limited and for several sites there were mitigating circumstances, as notated on Figure 6. There may be other underlying reasons why the soil vapour to indoor air factors do not appear to be as reliable as for groundwater. Methods for soil vapour testing are not as well established as for groundwater. There is greater potential for generating false negative results for soil vapour as a result of poor sampling and analysis techniques or contamination sources that are missed.

Petroleum Hydrocarbons

For residential sites impacted with petroleum hydrocarbons, there was only limited data (i.e., one to two buildings) for all sites. In addition, in most cases, it was not possible to distinguish the measured indoor air concentration from possible background sources. Therefore, the empirical vapour attenuation factors are possible maximum values. One exception was data collected for the Stafford, New Jersey site where through concurrent air, subslab and vapour testing it was shown that vapour intrusion was significant for several compounds (e.g., MTBE, cyclohexane and 224–trimethylpentane), but not for BTEX vapours, which were biodegraded within the vadose zone before reaching the building foundation as a result of oxygen below the foundation slab.

In most cases, the empirical attenuation factors were at least one order-of-magnitude lower than the SLRA guidance groundwater to indoor air vapour attenuation factors (Figures 7 and 8). The maximum empirical groundwater to indoor air attenuation factor was about $3.8\text{x}10^{-4}$; however, the depth to the contamination source for this site was only 0.8 m below the building foundation; therefore, this site does not strictly apply based on the minimum 1 m depth precluding factor. The next highest vapour attenuation factor was $5.6\text{x}10^{-5}$.

The general trend suggests a difference between chlorinated solvent and BTEX vapour attenuation factors (Figure 9), which may be a result of biodegradation occurring at some sites. There is unfortunately only limited high quality data sets that conclusively indicate biodegradation is causing attenuation of vapour plumes below buildings.

Commercial Site Data

For commercial sites, the data quality was generally relatively poor and number of data points were limited (Figures 10 and 11). Therefore, findings for commercials are preliminary. The results indicate that in all cases the empirical attenuation factors were less than the SLRA attenuation factors.

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Screening-Level Risk Assessment (SLRA)

Level 2

HABITAT MODULE – ASSESSMENT OF TERRESTRIAL WILDLIFE HABITAT

TABLE OF CONTENTS

List of Tables

1 INTRODUCTION

For sites where concentrations of contaminants are in excess of the CSR standards for “toxicity to soil invertebrates and plants”, two levels of terrestrial habitat assessment can be conducted under the Screening Level Risk Assessment process[1] (assessment of aquatic habitats, see definition in SLRA Level 1, must proceed to DRA or remediation). The first level is conducted as part of the SLRA Level 1 assessment and consists of a generic screening questionnaire within which the approach is not receptor specific. The second level is conducted as part of the SLRA Level 2 assessment and evaluates the potential for on-site terrestrial habitat to be used by specific receptor species. Professionals applying SLRA Level 2 should do so in conjunction with guidance provided in “Recommended Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia” by the Ministry of Environment, Lands and Parks, 1998 (Tier 1 Guidance).

Based on specific generic criteria for undeveloped land on the site (e.g., presence of bioaccumulative substances (see definitions in SLRA Level 1); zoning; habitat size and connectivity; proximity and distance to sensitive habitat), the SLRA Level 1 phase screens out sites that clearly have limited, to no habitat potential (i.e. sites that are not suitable to terrestrial wildlife). As shown in Figure 3 of the SLRA Level 1 Module (Appendix 3), the SLRA Level 1 habitat assessment process establishes one of the following four conclusions:

1. There are no issues related to wildlife habitat at the site;
2. There is potential wildlife habitat at the site and further assessment is required by use of a Level 2 screening process (SLRA Level 2);
3. A detailed risk assessment is required, i.e., as a Level 1 detailed risk assessment (as per current Ministry protocols for a Tier 1 Ecological Risk Assessment), or a Level 2 detailed risk assessment; or
4. Remediation of the site to numeric standards.

---

[1] The evaluation is limited to identifying suitable habitat (or lack thereof) for terrestrial wildlife. Aquatic receptors in surface water including wetlands, lakes, and streams are beyond the scope of the screening level risk assessment process.

Sites where a potential habitat is identified in the SLRA Level 1 process must continue to the SLRA Level 2 habitat assessment process. The SLRA Level 2 terrestrial habitat assessment must be completed by a professional biologist (R.P.Bio.) or qualified Risk Assessor with sufficient knowledge of local wildlife ecology. The procedure to conduct the SLRA Level 2 habitat assessment is described in this module.

2 PROCEDURE FOR SLRA LEVEL 2 TERRESTRIAL HABITAT ASSESSMENT

Site-specific habitat conditions may indicate the need for an SLRA Level 2 to determine whether a site contains "suitable habitat" for specific local species. As noted above, a registered professional biologist (R.P.Bio.) or qualified risk assessor with sufficient knowledge of local ecology and habitat requirements of ecological receptors is required to conduct the three following steps of the SLRA Level 2 assessment according to any applicable Resources Information Standards Committee (RISC) standards (http://srmwww.gov.bc.ca/risc/index.htm).

The procedure parallels the problem formulation sections and the "effects assessment- site observation" sections noted in the Tier 1 Ecological Risk Assessment protocol.

2.1 STEP 1: DETERMINING SITE RECEPTORS

Receptor groups to be considered vary depending on land use and biogeoclimatic zone of the site. ***Table 1 indicates those wildlife receptors that must be considered on the basis of the different land uses (other receptors may be considered as deemed appropriate by the professional biologist or qualified risk assessor).*** It is noted that a listing of terrestial plants would be compiled during the site visit by the professional biologist or qualified risk assessor. The professional biologist or qualified risk assessor should also refer to the Tier 1 Guidance for assistance in evaluating receptor groups and selecting specific species as receptors[2]. The professional biologist or risk assessor should refer to the Tier 1 Guidance, Appendices C, D and E to obtain species lists for biogeoclimatic zones.

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[2] Note that Table 1 receptor groups for consideration are more extensive than found in Tier 1 Guidance. Table 1 should be considered a more current list of potential receptor groups to be evaluated in the Level 2 Habitat Assessment.

Table 1 Recommended Receptors of Interest Based on Current Land Use[3]

Footnotes indicate where there are disparities between Level 2 workshop recommendations and Tier 1

Wildlife receptors	Industrial	Commercial	Residential	Agricultural	Urban park
Terrestrial salamanders	Yes	Yes	Yes	Yes	Yes
Frogs/Toads	Yes	Yes	Yes	Yes	Yes
Reptiles	Yes	Yes	Yes	Yes	Yes
Waterfowl	If adjacent to water[4,5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If Adjacent to water[4, 5]	If adjacent to water[4, 5]
Marsh birds/Waders	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]
Upland game birds	No	No	No	Yes[5, 6, 7,8]	Yes[5, 6, 7,8]
Raptors (eagles, hawks, falcons, owls)	Yes[5, 6, 9,10]	Yes[5, 6, 9, 10]	Yes[5, 6,10,11]	Yes[5, 6, 7]	Yes[5, 6, 7]
Shorebirds	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]
Songbirds	Yes[5, 6,9,12]	Yes[5, 6,9,12]	Yes[5, 6, 11,13]	Yes[5, 6, 7,14]	Yes[5, 6, 7,14]
Seabirds	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]	If adjacent to water[4, 5]
Insectivorous mammals	Yes[5, 6, 9]	Yes[5, 6,9]	Yes[5, 6,11]	Yes[5, 6, 7]	Yes[5, 6,7]
Small herbivorous mammals[15]	Yes[5, 6,9]	Yes[5, 6,9,16]	Yes[5, 6, 11,16]	Yes[5, 6,7]	Yes[5, 6, 7]
Bats	No	No	Yes[5, 6, 11]	Yes[5, 6, 7]	Yes[5, 6,7]
Small/medium carnivores[17]	No	No	Yes[5, 6, 11,18]	Yes[5, 6, 7,18,19]	Yes[5, 6, 7,19]
Large carnivores	No	No	No	Yes[5, 6, 7,19]	Yes[5, 6, 7,19]

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[3] Other receptor species may be designated as deemed appropriate by the professional biologist or qualified risk assessor.

[4] Tier 1 states shorebirds, wading birds, waterfowl and seabirds are not considered for terrestrial ERA

[5] Tier 1 considers all species listed as threatened, endangered or sensitive

[6] Tier 1 states that species are present only if there is vegetation at the Site

[7] Tier 1 states that species may be residents or migrants

[8] Tier 1 states "may be considered"

[9] Tier 1 states that species must be a resident species for at least one season

[10] Tier 1 states "only if threatened or endangered species" at indicated land use

[11] Tier 1 states that species must be resident species or at least present for breeding season

[12] Tier 1 does not consider cavity dwellers, birds that eat foliar invertebrates or hummingbirds at indicated land use

[13] Tier 1 does not consider hummingbirds; all other birds with exceptions as noted "may be considered"

[14] Tier 1 excludes hummingbirds but includes cavity dwellers if there are trees on site

[15] Tier 1 states that non-native pest species (e.g. rats and house mice) are not of concern

[16] Tier 1 states that rabbits and large rodents (e.g. beavers) do not have to be considered for the indicated land use

[17] Omnivores (coyotes, fox, skunk and raccoon) are included in this receptor group

[18] Tier 1 states that cats may be considered

[19] Tier 1 does not consider aquatic mustelids and marine mammals for indicated land use

Wildlife receptors	**Industrial**	**Commercial**	**Residential**	**Agricultural**	**Urban park**
Ungulates	No	No	No	Yes[5, 6, 7]	Yes[5, 6, 7]
COSEWIC listed species (evaluate individually)	Yes	Yes	Yes	Yes	Yes
Earthworms[20]	Yes	Yes	Yes	Yes	Yes
Terrestrial Plants: check those that apply (i.e., found on site)					
Trees-coniferous					
Trees- deciduous					
Shrubs					
Herbs – forbs					
Herbs -grasses					
Mosses, liverworts					
Lichens					
Fungi					
Red or Blue listed species (Gov. of BC – CDC)					
COSEWIC listed species	Yes	Yes	Yes	Yes	Yes

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[20] Tier 1 requires consideration of earthworms, as representative of soil invertebrates, at all sites

2.2 STEP 2: PROVIDE RATIONALE FOR SELECTING RECEPTOR

Using Table 1 as a reference, the assessor must complete Table 2, which involves specifying the land use and geographic location of the site, along with the choice of receptor groups and rationale behind selection/omission of groups.

Table 2 is meant as a working table used to provide the background information required to first select the wildlife receptors group and then specific species for which habitat characteristics will be evaluated in Step 3. Within Table 2:

- The second column (“Included in the SLRA Level 2”) is essentially the list of wildlife receptors noted in Table 1, based on the land use.
- The information to complete the third column (“Observed in this SLRA’) is obtained during a visit to the site under investigation and includes observed wildlife as well as indicators including, but not restricted to, tracks, scat, or nests.
- The information to complete the fourth column (“Observed other source”) would be obtained from local or on-site sources, if available, (e.g., sources may include individuals who have lived or worked on the site).
- The fifth column (”Not observed-potential high/low/nil”) indicates the potential of the presence of species that have not been observed during the site visit, nor indicated by local or on-site sources. The potential for a receptor’s presence is evaluated on the basis of an office review of available information on potential receptor groups (e.g. biogeoclimatic zone lists, COSEWIC species lists etc.). The receptor identification should also consider the rules (specified for each land-use) as shown in Appendix I of the Tier I ERA protocols.
- The last column (“Comment”) provides a professional opinion based on observations and review of available information, regarding the likelihood of the receptor being present on the site.

Any COSEWIC listed species that may be present in the vicinity of the site must be listed and considered individually. Guidance for identifying COSEWIC species and their geographic range is available at: HTTP://WWW.COSEWIC.GC.CA/ENG/SCT5/INDEX_E.CFM.

Table 2. Choice of Wildlife Receptors - Worksheet

Land Use/Zoning: ____

Location of site: ____

Wildlife receptors[21]	Included in Level 2	Observed this SLRA	Observed other source	Not Observed Potential high/low/nil	Comment
Terrestrial salamanders					
Frogs/Toads					
Reptiles					
Waterfowl					
Marsh birds/Waders					
Upland game birds					
Raptors (eagles, hawks, falcons, owls)					
Shorebirds					
Songbirds					
Insectivorous mammals					
Small herbivorous mammals					
Bats					
Small/medium carnivores					
Large carnivores					
Ungulates					
Shrubs					
Grasses					
Ornamentals					
Trees-coniferous					
Trees- deciduous					
Herbs and forbs					
Mosses, lichens and fungi					
Other					
Red- or Blue-listed species (Gov. of BC – CDC)					
COSEWIC listed species (evaluate as individuals)					

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[21] Subject to revision pending discussion with BCMOE as indicated in Table 1

2.3 STEP 3: ASSESSMENT OF HABITAT SUITABILITY

The next step of the SLRA Level 2 process involves evaluating the undeveloped land on site in terms of habitat suitability for each of the selected receptor groups[22] (i.e., are the habitat requirements present for each receptor group?). For each receptor group (including any COSEWIC listed species), the assessor must complete the decision matrices in Table 3. To complete the table, three decisions are required of the professional biologist or qualified risk assessor:

- The first decision is based on the size of the undeveloped land and whether or not it is suitable for the receptor in question. Factors such as the home range of the species should be considered while evaluating the size criterion. The Professional biologist or qualified risk assessor should refer to the references listed in Tier 1 Guidance, Appendices J and K for assistance in evaluating suitability of undeveloped land. A "yes" answer indicates that the undeveloped land is large enough to support (area must for ≥50% of the organisms home range) the receptor in question, and a "no" indicates that the land is too small to support the receptor.
- For the second decision, the assessor must evaluate the degree of fragmentation of the undeveloped land in terms of the specific habitat requirements of the receptor. A "yes" answer indicates that the land is sufficiently connected or in sufficient proximity of additional habitat features, and a "no" would indicate that the undeveloped land is isolated from any additional habitat requirements of the receptor.
- The assessor should state his or her professional opinion as to whether the vegetation at the site is stressed due to site conditions or whether the vegetative conditions are typical for that geographic area at the time of the site inspection. Consideration should be given to such aspects as sites that are subject to physical impacts by: traffic; storage of products on land such as lumber, pipes, etc.; or, maintenance requirements such as those of the Fire Code of Canada that require vegetation at many industrial sites to be controlled.

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[22] See background information attached to Level 1 documentation relating to habitat size, connectivity and quality.

- The final decision addresses the quality of the undeveloped land. This may include types of vegetation, presence or absence of important habitat features for the receptor, percent cover and extent of human disturbance or degradation of the land. The professional biologist or qualified risk assessor should also consider reasonable future potential of the land to become acceptable habitat.

Based on the results of these three decisions, the assessor should state his or her professional opinion about whether or not the receptor species in question is likely to use the undeveloped land as habitat, and whether further assessment by use of a detailed risk assessment process[23] is required. The assessors must also provide comments justifying their decisions.

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[23] As noted previously, there will be two levels of detailed risk assessment (DRA). The Level 1 Ecological DRA will follow protocols of the BCMOE's "Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia". If required, a Level 2 DRA would follow a Level 1 DRA, and would include provision for more complex risk assessment protocols.

Table 3. Decision Matrix re: habitat suitability

Receptor Group: ___________________________________

Observed on site or potential for presence on site: Yes ________ No ________

Note: Yes indicates that the habitat or habitat characteristic is favourable for a species

Habitat Size	Connectivity of fragments	Quality	Move to Ecological Risk Assessment
Yes	Yes	Not applicable	**Yes**
		Not applicable	**Yes**
		Yes	**Yes**
	No	No	**No**
No	Yes	Yes	**Yes**
		No	**No**
	No	Not applicable	**No**
		Not applicable	**No**

Ecological Risk Assessment required? Yes ________ No _________

Physical signs of deleterious impacts on plants or invertebrates?
Yes__________ No_______

Comments:

3 CONCLUSION OF SLRA LEVEL 2 ASSESSMENT

The outcome of the SLRA Level 2 habitat assessment will be one of the following:

1) No further action is required under the habitat evaluation (i.e. sites do not contain any habitat for wildlife receptors), or
2) A Level 1 detailed ecological risk assessment (as per current Ministry protocols for a Tier 1 Ecological Risk Assessment), is required for the selected receptor groups, with the option of subsequently providing a Level 2 Detailed Risk Assessment.

An owner of a site could proceed with remediation:

- To numerical standards to preclude the need for a detailed risk assessment; or
- To risk based standards (target concentrations) derived using receptor specific toxicological reference values; or
- To risk based standards using risk management measures that minimize exposure and associated risk.

Screening Level Risk Assessment (SLRA)

Summary Procedure

1 SLRA LEVEL 1

A flow chart summarizing the SLRA level 1 guidance is shown in the Figure 1, 2 and 3. Application of this guidance document involves the completion of a screening questionnaire. The questionnaire is divided into general questions, human exposure questions and ecological exposure questions, except for urban park, which has no ecological-specific questions.

The guidance is divided into the four applicable land use categories. Agricultural use is not eligible for SLRA Level 1 screening. Each land use may present specific characteristics that require a unique series of questions. Identify the land use applicable to the subject site and use the applicable questionnaire, which are given in text format in the Appendices 4-7. Specific considerations for each land use are provided in the following subsections:

Section 2.3 – residential
Section 2.4 – urban park
Section 2.5 – commercial
Section 2.6 – industrial

The questionnaires for all but urban park are divided into three series of questions. They include: general questions, human exposure questions and ecological exposure questions. Begin by completing the general questions. Completion of the human and ecological questions will depend on answers to the general questions. Urban park has only two questionnaires because the ecological risks at urban parks are addressed by the general questions. Progression through the questionnaire is guided by the answers to the questions.

If after completing the general questions, further analysis or exiting the process has not been prescribed, then the assessment continues with the human and/or ecological exposure questionnaires. Both must be completed to complete SLRA Level 1 if the general questionnaire directs to them. Upon completion of each question of the questionnaire, a brief narrative should be presented explaining the rationale for each response, as discussed in the introduction to the SRA tools. Appendix 2 provides a case study example of the question-specific rationales and the SLRA Level 1 documentation.

A few other general instructions apply to SLRA Level 1:

a) The questions apply only to contaminants/contamination as defined in the CSR, i.e., substances that exceed applicable standards at the site. Only those regulated substances that exceed applicable standards for the receptors at the designated land use should be considered in the questionnaire.

b) Selection of the applicable land use category is completed by the assessor.

c) Agricultural land uses are not assessed in SLRA Level 1 because evaluation of ecological risks at agricultural sites is too complex to address in SLRA Level 1. Proceed to SLRA Level 2, DRA or site remediation for agricultural lands.

d) Current and reasonable potential future conditions and land uses as specified in the CSR, Section 12, Subsection 5 must be considered. If conditions change, then SLRA Level 1 should be re-applied to the new site conditions. Examples of changes that may occur include: the addition or removal of a building, excavation and soil mixing due to utility installation or maintenance, transition from one land use type to another such as agriculture to industrial, gradual weathering of a barrier.

e) Contamination deeper than one metre is assumed to remain below one metre. If construction or utility excavation work occurs, SLRA Level 1 should be revisited based on new site conditions.

f) Barriers over contamination sources or areas where contamination may migrate may prevent exposures. Where a barrier is identified, it must be permanent for current and reasonable potential future use and will be maintained as such. While it is unlikely that barriers would cover entire urban parklands, it is possible that barriers may cover contaminant source areas in this land use. As a result, a question about barriers is included for all land uses.

g) Any requirements related to the Hazardous Waste Regulation and High Risk Ranking are not addressed or met by SLRA Level 1.

h) Critical definitions and notations are provided in Section 2.2.

Figure 1. Flow Chart for Implementation of SLRA Level 1

GENERAL QUESTIONS

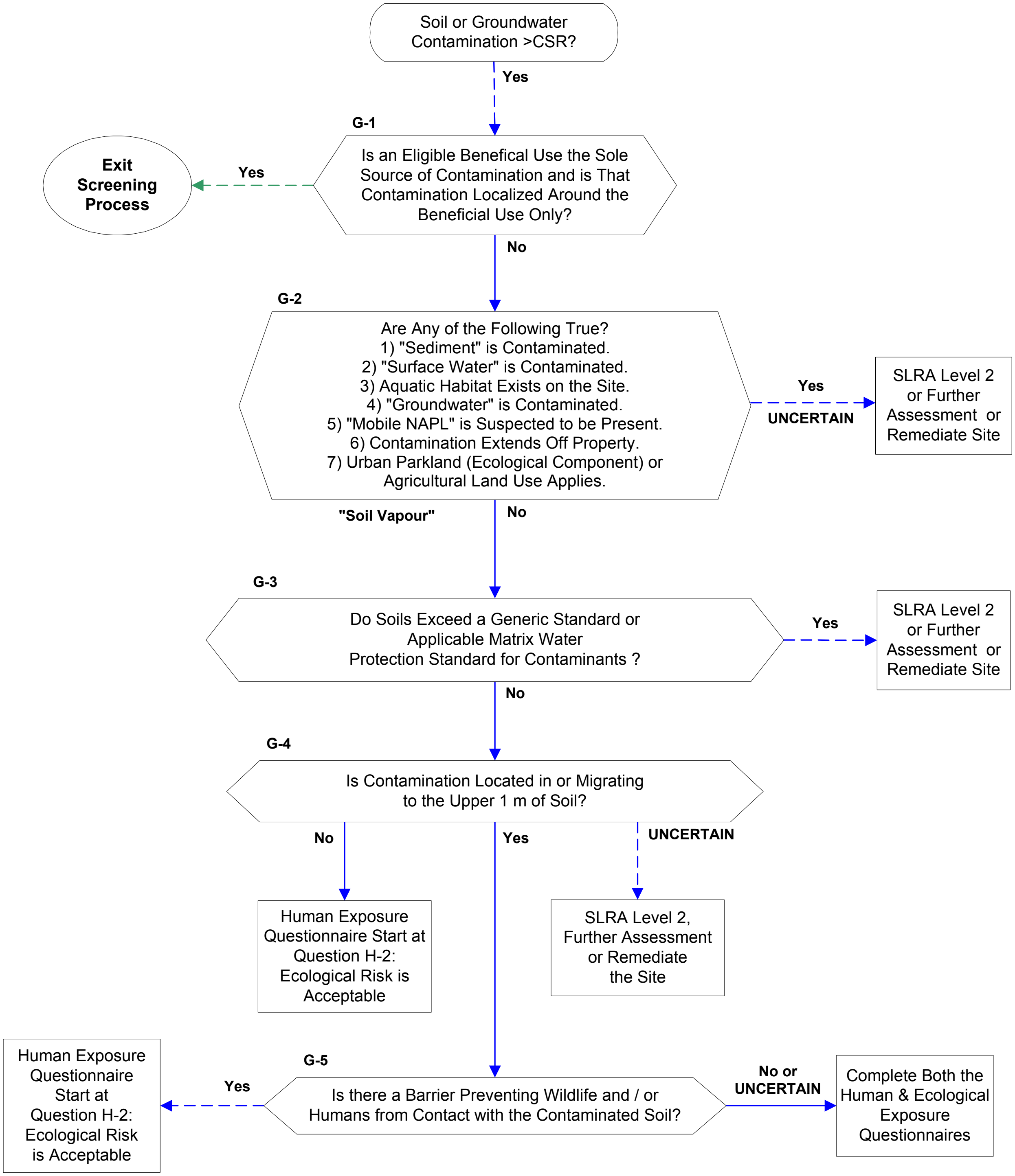


Figure 2. Flow Chart for Implementation of SLRA Level 1

HUMAN EXPOSURE QUESTIONNAIRE

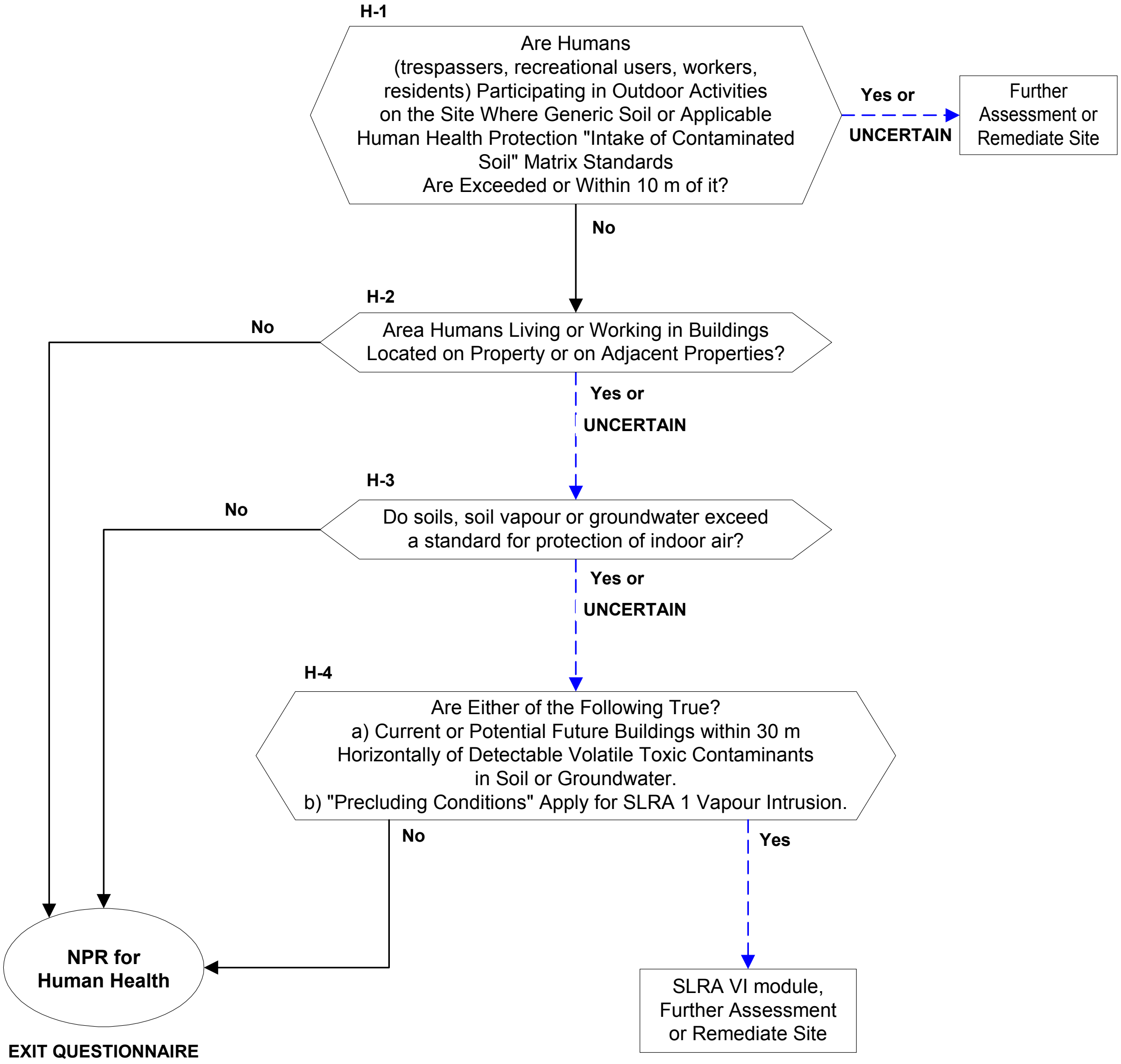
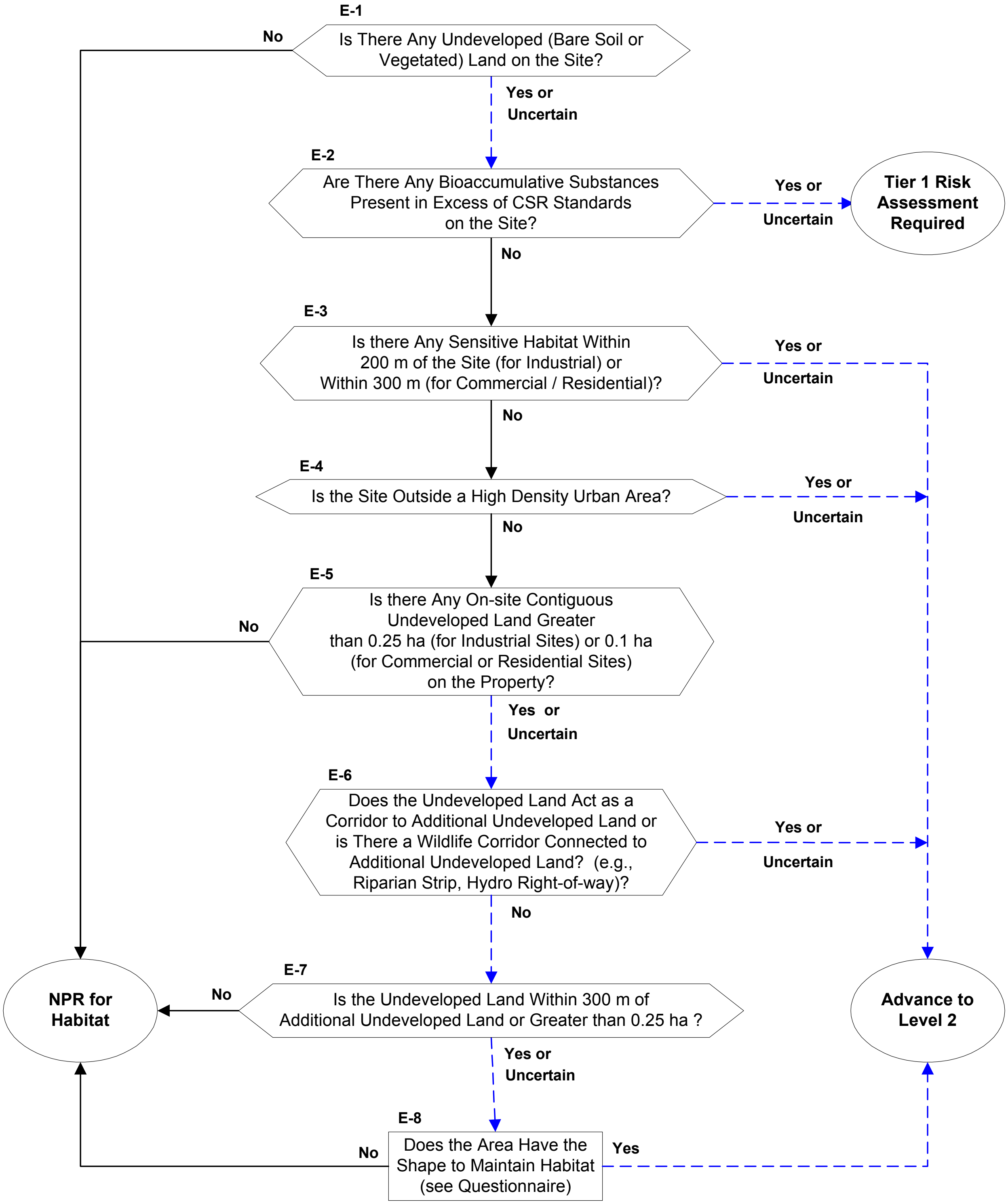


Figure 3. Flow Chart for Implementation of SLRA Level 1

ECOLOGICAL EXPOSURE QUESTIONNAIRE



2 SLRA LEVEL 2 SOIL AND GROUNDWATER

2.1 PRECLUDING FACTORS FOR SLRA LEVEL 2 SOIL MODULE

The SLRA Level 2 soil and groundwater modules cannot be applied if any of the following precluding factors exists.

- Soil or groundwater contamination occurs in fractured bedrock
- If the measured concentration of metals or other inorganics (e.g., arsenic) in groundwater exceeds applicable Schedule 6 standards, SLRA Level 2 cannot be applied.
- The contaminant of potential concern (COPC) is an ionizing organic compound and the soil pH is either less than 4.9 or greater than 8.0.
- Potentially mobile nonaqueous phase liquid (NAPL) exists in soil or groundwater. For the purposes of this document, NAPL is defined by a) physical observations of NAPL in wells, as expressed by the presence of sheens or appreciable product thicknesses, and b) exceedance of the NAPL indicator standards of the MOE. The SAB's Hydrogeological Assessment Tools can be applied for a more through assessment of LNAPL mobility.

2.2 PRECLUDING FACTORS FOR SLRA LEVEL 2 GROUNDWATER MODULE

The SLRA Level 2 Groundwater Module cannot be used if any of the following are true:

- the site assessment does not conform to the minimum standards set out in Section 2.3.3.
- the receiving environment is a water supply aquifer (i.e., DW, IW, LW) *and* the groundwater plume has travelled beyond the property boundary.

- the distance between the contaminated site[1] and a potential receiving environment is less than 30 m.
- the compound in question decays to harmful[2] daughter products that have been detected in groundwater. For example, if trichloroethylene (trichloroethene or TCE) is a contaminant of concern, then groundwater must be analyzed for cis-1,2-dichloroethylene (DCE) or vinyl chloride (VC) concentrations. If daughter products are detected in any well, further assessment or remediation is required, because concentrations of the daughter products may increase with distance from the source.
- the contamination extends to the base of the aquifer. Vertical transport can be assessed using the Hydrogeological Assessment Tools.

2.3 INITIAL STEP FOR SLRA LEVEL 2 SOIL AND GROUNDWATER MODULES: DETERMINATION OF APPLICABLE RECEPTORS FOR GROUNDWATER PROTECTION

2.3.1 Risk to Aquatic Life

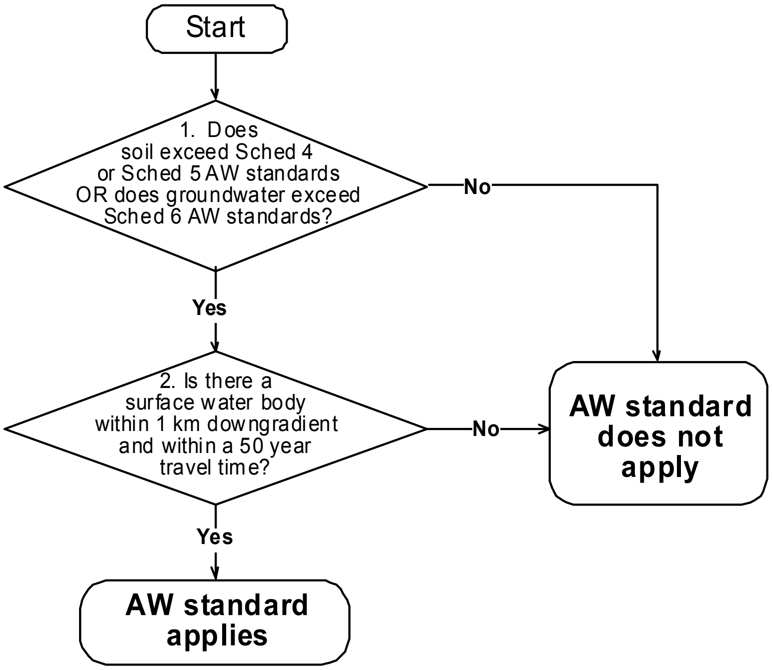
This process is illustrated in Figure 4.

---

[1] As defined by the CSR. The site dimensions will generally *not* be the same as the property size.

[2] Harmful is interpreted as compounds with degradation products that have Schedule 6 groundwater standards.

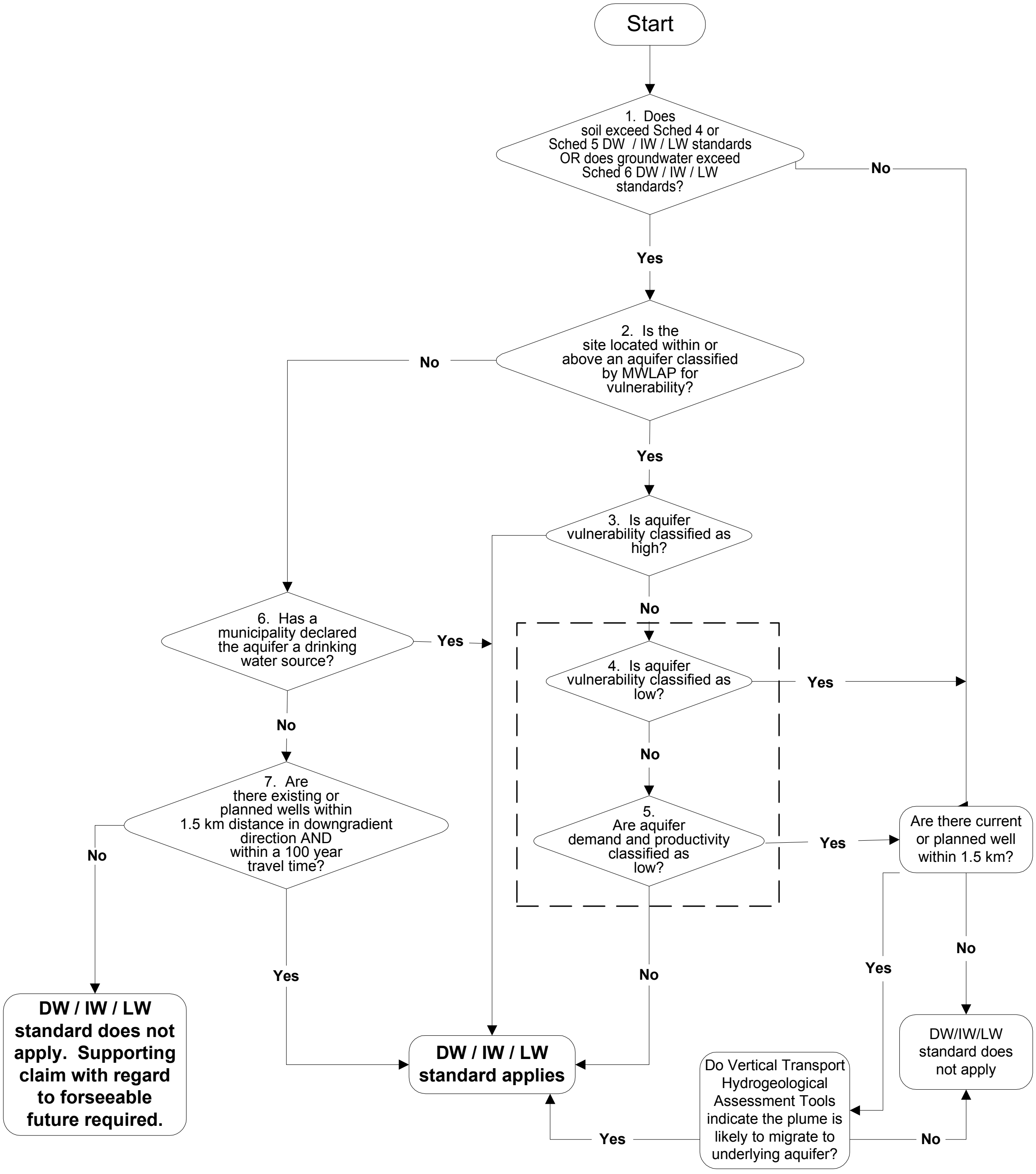
Figure 4. **Questionnaire for Determining if AW Standard Applies**



2.3.2 Risk to Drinking Water, Irrigation Supply or Livestock Watering

The water supply questionnaire is illustrated in Figure 5.

Figure 5. Questionnaire for Determining if DW, IW, or LW Standard Applies[3]



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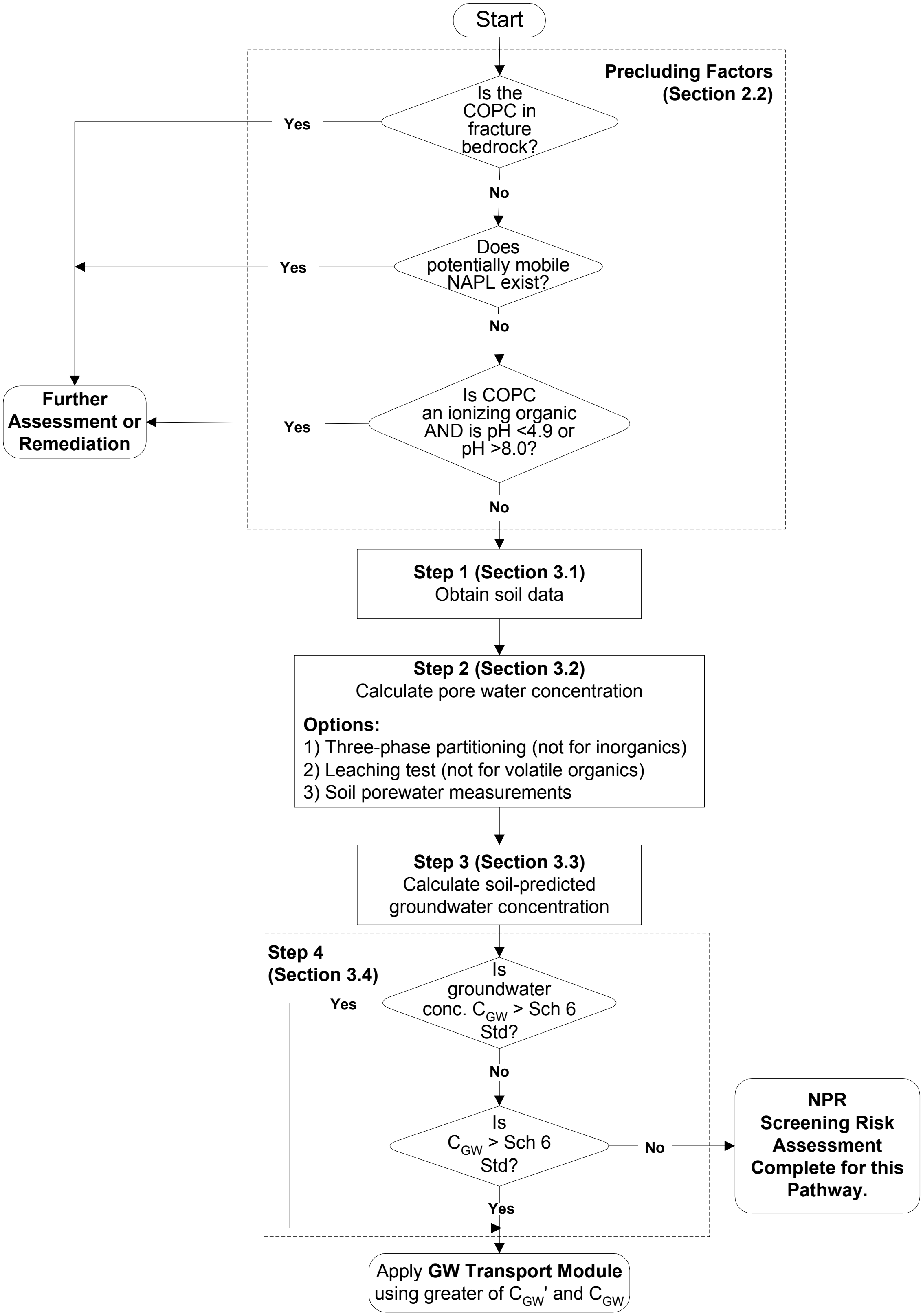
[3] The BC MOE is not in favour of using this aquifer classification system at this level of assessment, however the SAB feels it is important to include aquifer vulnerability and this method is proposed for discussion purposes.

2.4 PROCEDURE FOR SLRA LEVEL 2 SOIL MODULE

Two processes are modeled in this evaluation: 1) prediction of the concentration of the contaminant in pore water at the contaminant source, and 2) mixing of contaminated pore water with groundwater at the water table. Figure 6 illustrates the steps and decision-making process of the Soil Module.

Figure 6. Soil Module Flowchart



2.5 STEP 1: ATTAIN DATA FOR SLRA LEVEL 2 SOIL MODULE

As a prerequisite to SLRA Level 2, a detailed site investigation (DSI) must be completed for the site in accordance with Ministry-approved procedures.

2.6 STEP 2: CALCULATE SOIL PORE WATER CONCENTRATION AT SOURCE

Methods for predicting soil pore water concentrations are distinct for organic contaminants and metals. For organic contaminants, there are two options available for predicting the soil pore water concentration at the source: (1) three-phase partitioning and (2) leaching tests (with the exception of volatiles). For metals, the only option available for predicting contaminant pore water concentration is leaching tests[4].

2.6.1 Three-phase Partitioning for Organic Contaminants

Equilibrium partitioning among three phases is computed for organic contaminants[5]; these three phases are soil water, soil air and soil matrix (soil solid). The three-phase partitioning equation is shown in Equation 3.1.

$$C_L = \frac{C_S}{K_d + \left(\dfrac{\theta_w + H_{cc}\theta_a}{\rho_b}\right)} \qquad \text{Equation 3.1}$$

where C_S is the measured soil concentration at the source[6] (mg/kg), C_L is the predicted soil pore water concentration at the source (mg/L), K_d is the soil matrix-to-soil water distribution coefficient (L/kg), H_{cc} is the dimensionless Henry's constant, ρ_b is the bulk density (kg/L), θ_w is the water-filled porosity, and θ_a is the air-filled porosity.

The soil matrix-to-soil water distribution coefficient, K_d, is the product of the soil organic carbon-water partition coefficient, K_{oc}, and the fraction of organic carbon, f_{oc}.

---

[4] Justification for this decision is provided in Appendix B-1

[5] Justification for limiting the use of the three-phase model to organics is provided in Appendix A

[6] As determined by Guidance 1 of the MWLAP.

SLRA Level 2 permits the use of a site-specific f_{oc} measured during the site investigation. The f_{oc} value must be determined from a soil sample, collected from outside of the contaminated area that is suitable for the soil-to-groundwater pathway evaluation. For example, if the contaminant of concern is within an unsaturated hydrostratigraphic unit, the soil sample should also be from the appropriate unsaturated soil. If a default value is required, f_{oc} =0.001 g/g is to be used.

For individual non-ionic hydrophobic organic compounds (e.g., benzene and naphthalene), the K_{oc} values in Table B-2-1 (Appendix B-2) are used. For ionizing organic hazardous substances (e.g., pentachlorophenol and benzoic acid), the K_{oc} values in Table B-2-2 (Appendix B-2) are used. Table B-2-2 provides K_{oc} values for three different pHs. To select the appropriate K_{oc} value, the soil pH must be measured. If the soil pH falls between the pH values provided, an appropriate K_{oc} value for chlorinated phenols is calculated using the equations provided in Appendix B-2. In addition, suitable K_{oc} values from the scientific literature are permissible for organic contaminants not listed in Appendix B-2. When selecting a K_{oc} value from the literature, the practitioner is responsible for choosing the most conservative (i.e., minimum) K_{oc} value appropriate for the site. The values for Henry's law constant in Equation 3.1 can be obtained from the scientific literature.

Finally, site data are recommended for soil bulk density, soil volumetric water content, and soil air content. Alternatively, a suitable value based on soil composition and geology may be applied (e.g., values presented hydrogeology textbooks[7]). If a default is required, ρ_b is 1.7 kg/L, θ_w is 0.3, and θ_a is 0.2.

Equation 3.1 may be used to establish soil concentrations for any organic hazardous substance where potentially mobile NAPL is not suspected and may be used to calculate both unsaturated and saturated zone soil pore water concentrations.

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[7] For instance, Fetter, C.W. 2001. *Applied Hydrogeology*. 4th ed. Prentice-Hall. 598pp., Schwartz, W., and H. Zhang. 2002. *Fundamentals of Ground Water*. 1st ed. John Wiley & Sons. 592pp., or Freeze, R. Allen and John A. Cherry, *Groundwater*, Prentice-Hall, 1979.

2.6.2 Leaching Tests

If measured groundwater concentrations for metals are above applicable Schedule 6 standards then further assessment or remediation applies immediately and there is no need to proceed with SLRA Level 2. Furthermore, if the soil pH is less than 5, (e.g., when acid mine drainage is occurring) leaching tests are not permitted under SLRA Level 2, and risk assessment for the site must follow DRA protocols. In addition, leaching tests cannot be used for volatile organics.

If all measured groundwater concentrations are below applicable Schedule 6 standards, then leaching tests may be used to assess the potential for groundwater impacts from soils that exceed the Schedule 4 and 5 standards for metals. The soil samples for use in the leaching test must come from the source area and must be taken as close as possible to the highest measured soil values. The maximum allowable distance from the highest measured soil value is 2 m if the metals source zone is a definable, relatively uniformly distributed population of contaminants. For the case that the source zone consists of randomly distributed contaminants, which vary across spatial scales of centimetres rather than metres, the number of soil samples to be subjected to leaching tests must be commensurate to the heterogeneity of the soil concentrations.

When using any leaching test, the analytical methods used for analysis of the effluent shall be sufficiently sensitive to quantify hazardous substances at concentrations equal to the applicable Schedule 6 standards.

For a predicted groundwater metals concentration to be considered protective of groundwater, the leaching test solution concentration shall be less than or equal the applicable Schedule 6 standard.

If the site-specific soil pH is greater than 5.5, SLRA Level 2 requires that the USEPA’s Method 1312, Synthetic Precipitation Leaching Procedure (SPLP) be applied. The SPLP should be used with a weak acid (Fluid #3, with a pH of 5) as the leaching solution to represent acid rain in the western United States. The application of the SPLP leaching test is region specific and is considered conservative in the context of SLRA Level 2 where there is no exceedance of numeric standards in groundwater, but soil-predicted concentration are higher than standards for groundwater protection.

If the site-specific soil pH is between 5 and 5.5, the USEPA Method 1311, Toxicity Characteristic Leaching Procedure (TCLP) shall be used instead. The TCLP uses Fluid #1 (with a pH of 4.93) to represent organic acids generated by biological degradation processes. This test is intended to represent situations where acidic conditions are present due to biological degradation such as in municipal solid waste landfills.

2.6.3 Porewater Measurements

Direct measurements of soil porewater are permitted for SLRA Level 2. These measurements should be collected below the suspected zone of soil contamination.

2.7 STEP 3: PREDICT GROUNDWATER CONCENTRATION

The final process considered in the Soil Module is the mixing of soil pore water, which has a contaminant concentration C_L, with ambient groundwater. An empirically-derived dilution factor can be applied to predict C_{gw}', the *soil-predicted groundwater concentration:*

$$C_{gw}' = \frac{C_L}{\mathrm{DF}}, \text{ and} \qquad \text{Equation 3.2}$$

where DF is the dilution factor (dimensionless).

For SLRA Level 2, there are two permitted ways of computing the dilution factor.

2.7.1 Default Mixing at the Water Table

A DF of 20 is recommended in the US EPA’s 1996 Soil Screening Guidance for soil contamination in the unsaturated zone for sites less than 0.5 acres (2000 m^2) in area. Review of the EPA justification for the default dilution factor suggests that DF=20 is appropriate for small sites *except* in the following cases:

1. When the evaluation is for impacts to an aquatic life receiving environment.[8]
2. When soil contamination is located at or below the groundwater table in saturated soils. In these cases, DF=1.
3. When the contaminant concentration upstream of the source is greater than zero[9].

As noted in point 2 above, soils which are below the water table must be evaluated with a DF of one. The elevation of the water table for the purposes of determining the dilution factor is defined as the highest possible elevation in cases where the water table fluctuates seasonally. In order for DF to be greater than one, a minimum buffer zone of 1 m between the water table and the source is required to provide an additional safety factor.[10]

2.7.2 Site Specific Dilution Factor

If the default dilution factor of 20 is not applied, a site specific dilution factor can be determined from the following equation:

$$DF = 1 + \frac{Vd}{IL} \qquad \text{Equation 3.3}$$

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[8] Implicit in the US EPA's default DF is the assumption that the receiving environment is a water supply well with a well screen below the water table. The additional dilution related to flow vertically downward from the water table cannot be assumed for aquatic receiving environments.

[9] In these cases DF could be reduced as a weighted average according to the upstream concentration.

[10] The capillary fringe in fine-grained soils can be as high as 1 m. Within the capillary fringe, the soil water content is equal to the porosity in spite of the fact that the water pressure is less than atmospheric pressure. A seminal source of moisture characteristic data for predicting capillary rises in typical unconsolidated materials is van Genuchten, M. Th., 1980, "A closed-form equation for predicting the hydraulic conductivity of unsaturated soils," *Soil Science Society of America Journal,* 44:892-898.

where:

	Definition	Constraint
V	Darcy flux at the site (m/yr)	site specific measurement
L	length of the source parallel to the direction of groundwater flow (m)	site specific measurement
I	region-specific infiltration (m/yr)	The region specific infiltration value is derived from the precipitation records for representative local climatological stations. A methodology is provided in the SAB's Hydrogeological Assessment Tools. As a default, the infiltration rate may be calculated as the total annual precipitation minus an annual average evapotranspiration of 0.46 m/yr. *However, the accuracy of the assessment will tend to be poor if regional data is not used.* If the computed infiltration rate is less than or equal to zero, DF=1.
d	mixing zone depth (m)	A default mixing zone depth of 0.5 m is permissible for use under SLRA Level 2. Equation 3.4 can be used to derive a site specific value
d_a	aquifer thickness (m) for equation 3.4	site specific estimate based on all available site geological data

The site specific derivation of the mixing zone depth is the sum of the predicted mixing due to vertical dispersivity along the length of the flow path ($d_{\alpha v}$) and the mixing due to the downward velocity of the infiltrating water (d_{Iv}).[11]

$$d = d_{\alpha v} + d_{Iv}$$

$$d = 0.044L^{1.23} + d_a\left\{1 - e^{\left(-\frac{LI}{Vd_a}\right)}\right\} \qquad \text{Equation 3.4}^{12}$$

2.8 STEP 4: EVALUATE RESULTS OF SLRA LEVEL 2 SOIL MODULE APPLICATION

Once a soil-predicted groundwater concentration is calculated, it may be used in two different ways:

- If the potential for soil to contaminate groundwater, as measured by soil predicted groundwater concentration is sufficiently low, and groundwater is not

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[11] In computing the first term in Equation 3.4, the vertical dispersivity was estimated to be 0.056 times the longitudinal dispersivity (Gelhar and Axness, 1981) and longitudinal dispersivity was estimated by the Neuman (1990) relationship for travel distances less than 100 m.

[12] Derivation of equation 3.4 is provided in Appendix D and in USEPA 1996 section 2.5.5.

contaminated, then the soil to groundwater pathway can be screened out of the regulatory process as NPR by a simple numerical comparison.

- If the site cannot be screened out in this simple manner, the likelihood of contaminants reaching a receiving environment needs to be evaluated more specifically.

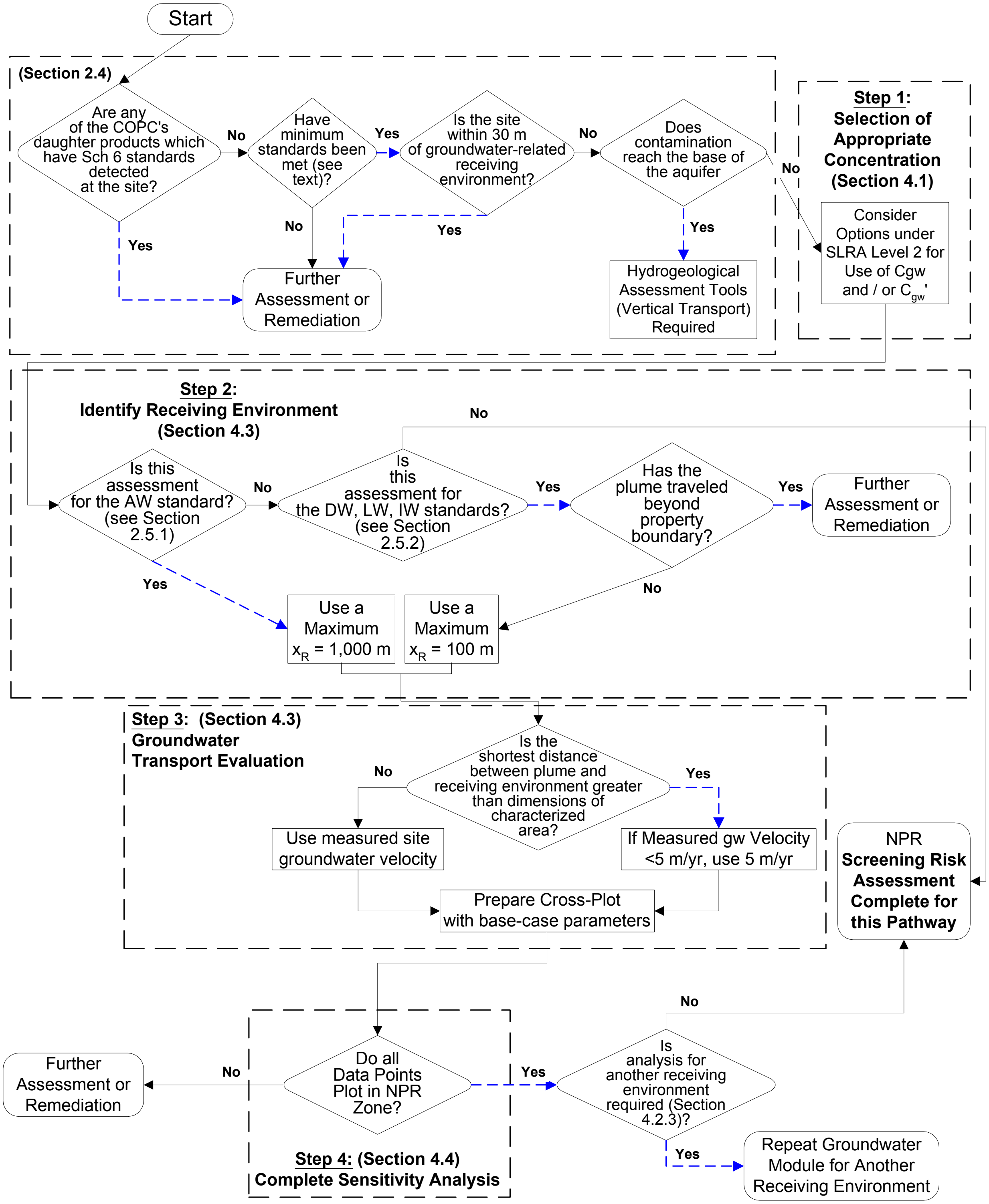
The former process involves comparing the soil-predicted groundwater concentration to the applicable numerical standard. If the soil predicted groundwater concentration is less than the applicable standard, then the groundwater pathway can be screened out of the regulatory process for that contaminant of concern for the soil-to-groundwater pathway. Numerical screening can be used for AW, DW, IW and LW receiving environments. Any soil predicted groundwater concentration which is greater than numerical standards must be carried forward to the groundwater module (Section 4).

For non-volatile compounds, the soil-predicted groundwater concentration can be disregarded if all measured groundwater concentrations are below the standard and if in soil pore water inferred from leaching tests has concentrations less than the applicable standards. Direct pore water measurements collected in the unsaturated or saturated zone depending on the location of the contamination[13], may also be used in lieu of soil-predicted groundwater concentrations.

2.9 PROCEDURE FOR SLRA LEVEL 2 GROUNDWATER MODULE

The SLRA Level 2 screening process for groundwater transport is illustrated in Figure 7. The precluding factors are described in Section 2.4, while the four steps of the SLRA Level 2 assessment are described in this section. As discussed below in Section 4.2.3, there will be situations in which the SLRA Level 2 Groundwater Module must be completed twice for a given compound at a site. In these cases, the assessment will be completed for *both* the aquatic receiving environment and groundwater receiving environment. An example of the use of the Groundwater Module is presented in Appendix B-7.

Figure 7. Flow Chart Showing Key Decision Points of Groundwater Module



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[13] Application of the dilution factor would not be permitted in this case.

2.10 STEP 1: SELECTION OF APPROPRIATE CONCENTRATION

In a risk management-based approach to site screening, contaminant levels at the source should be assessed in relation to the attenuation processes that will take place as contaminants migrate toward a receiving environment. NPR sites are those for which $C(x_R)$, the predicted concentration at the receiving environment, is predicted to be lower than a regulatory standard, C_{sched_6}, in one of two ways:

1) If the measured contaminant concentration, C_{gw}, (and/or the soil-predicted groundwater concentration at the source, C_{gw}', if necessary[14]) is less than C_{sched_6}, the site can be screened out of the regulatory process.

2) If the measured contaminant concentration at the source, C_{gw} (and/or the soil-predicted groundwater concentration at the source, C_{gw}', if necessary[15]) is greater than C_{sched_6}, then the site can be screened out of the regulatory process as a low risk site only if the natural attenuation processes are sufficient to reduce $C(x_R)$ below C_{sched_6} at the receiving environment.

2.11 STEP 2: IDENTIFICATION OF USEABLE GROUNDWATER RESOURCES

Current and foreseeable future uses of groundwater are explicitly considered in the SLRA Level 2 Groundwater Module. The procedures for water quality standards designed to protect groundwater supply (i.e., drinking water, livestock watering or irrigation water) and sites which may become subject to one of these water quality designations within the foreseeable future are separate from the transport procedure for sites which are subject to aquatic life protection standards. For the purposes of the SLRA Groundwater Module, foreseeable future use of groundwater supply is defined in Question 7 of Section 2.5.

2.12 STEP 3: COMPUTE DIMENSIONLESS NUMBERS FOR DATA AND PLOT ON CROSS-PLOT

In this step, two dimensionless factors, S_I and S_{II}, are computed using the maximum source-area groundwater concentration or, if necessary, the soil-predicted groundwater concentration (see

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[14] See Section 4.1 of SLRA Groundwater Module for a discussion of when C_{gw}' must be included in the analysis.

[15] See Section 4.1 of SLRA Groundwater Module for a discussion of when C_{gw}' must be included in the analysis.

Section 4.1). The dimensionless factor S_I describes the level of contamination. If the concentration of a contaminant of concern in a well is equal to the standard, S_I equals zero. If the concentration is one order of magnitude higher than the standard, S_I equals one. If the concentration is two orders of magnitude lower than the standards, S_I equals negative two. The dimensionless factor S_{II} is a measure of the degree of attenuation that may be expected to occur between the source and the receiving environment. The higher the S_{II}, the greater the attenuation that occurs along a groundwater flow path. These two dimensionless factors are defined as:

$$S_I = \log_{10}\left(\frac{\mathrm{C}_{\mathrm{gw}}}{\mathrm{C}_{\mathrm{sched\_6}}}\right) \quad \text{and} \quad S_{II} = \frac{0.22x_R}{\alpha_L}\left[\left(1+\frac{4\lambda\alpha_L R}{v}\right)^{\frac{1}{2}} - 1\right]$$

where x_R is the distance to the receiving environment, C_{gw} is the highest groundwater concentration at the source[16], α_L is the longitudinal dispersivity, λ is first-order decay constant, R is the retardation factor, and v is the linear groundwater velocity. The retardation factor is defined as $R=1+\rho_b K_{oc} f_{oc}/n$, where ρ_b is the bulk density, K_{oc} is the organic carbon-water partition coefficient, f_{oc} is the fraction organic carbon, and n is the porosity.

The longitudinal dispersion coefficient is defined as

$$\alpha_L = Ax_R^H$$

For x_R less than 100 m, A is 0.0175 and H is 1.46
For x_R greater than 100 m, A is 0.32 and H is 0.83.

Refer to Table 1 (in Section 4.3) for default and limiting values of f_{oc} and v.

A discussion of the use of conservative first-order decay constants in the context of SLRA Level 2 is provided in Appendix B-5. First-order decay constants for SLRA Level 2 can be found in Appendix B-6.

In the SLRA Level 2 Groundwater Module, the base case S_I and S_{II} are computed using the input values shown in Table 1.

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[16] If C_{gw}' is higher than C_{gw}, C_{gw}' is used instead of C_{gw} to predict the risk at the receiving environment.

Table 1. Parameters Used to Calculate Base-Case S_I and S_{II} Pair

C_{gw} (C_{gw}')	Highest measured source concentration or soil-predicted groundwater concentration, if higher.
x_R	Distance from source to receiving environment. Use measured value from edge of source area
v	The site-specific linear velocity is calculated at the site investigation stage. If the distance between the downgradient-most groundwater sample and the receiving environment exceeds the longitudinal dimension of the site investigation, the minimum groundwater velocity allowable under SLRA Level 2 is 0.014 m/day or 5 m/yr.
α_L	$\alpha_L = Ax_r^G$ • For x_R less than 100 m, A is 0.0175 and the exponent G is 1.46 • For x_R greater than 100 m, A is 0.32 and the exponent G is 0.83
K_{oc}	From Appendix B-2 or peer-reviewed scientific literature if not listed in Appendix B-2.
f_{oc}	Site-specific f_{oc} is measured outside of the contaminated area in soil suitable for evaluating the groundwater transport pathway. However, if the measured f_{oc} exceeds 0.02 g/g, then a value of 0.02 g/g must be used. If a default value is required, f_{oc} =0.001 g/g will be used.
n	A conservative site-specific value can be used or suitable textbooks can be consulted for a value representative of the geologic medium.
ρ_b	Site specific ρ_b can be used, or the default value of 1.7 g/cm^3
λ	From Appendix B-6
pH	groundwater pH is required only when pH dependence affects contaminant fate or transport (e.g., for ionizing organic compounds).

Pairs of S_I and S_{II}, are plotted on a cross-plot (shown in Figure 7 of the main document).

1. If any of the data points plot in the "receiving environment impact" zone, then the site cannot be classified as NPR (no risk to receiving environment). Further risk assessment may be conducted using the Detailed Risk Assessment (DRA) protocol, or the site can be remediated.
2. If all of the base-case data points plot in the "NPR" zone, then the sensitivity analysis must be carried out (Step 3).

Sites are considered to have no pathway to the receiving environment if either

- S_I is less than zero (i.e., the site is not contaminated) or
- $S_I < S_{II}$ (i.e., the degree of attenuation between the source and the receiving environment is sufficient to result in a concentration at the receiving environment which is less than the Schedule 6 standard).

Pairs of S_I and S_{II} are plotted on a standardized *cross-plot*.

2.13 STEP 4: COMPLETE SENSITIVITY ANALYSIS

The next step of the SLRA Level 2 Groundwater Module is the sensitivity analysis. In this single-parameter sensitivity analysis, the "worst case" value of a single parameter is substituted for the base case or "best estimate" value, with all the other parameters fixed at the average or base case[17].

The parameters for which a single-parameter sensitivity analysis is required are shown in Table 2. The critical uncertainty range ("worst case") for each site-derived parameter (upper *or* lower bound) is described in the right-most column of Table 2. The uncertainty associated with the distance to the receiving environment and the fraction organic carbon can be estimated either with statistics (as two times the standard deviation of the mean) or as the worst measurement. If the pH and/or groundwater velocity have a normally or log-normal distribution, statistics (for example using probability paper) may also be used.

Table 2. Parameters and Uncertainty Ranges Required for Sensitivity Analysis

Parameter	"Worst Case" Perturbation
Distance to receiving environment , x_R	x_R - Δx_R
Velocity, v	$v+\Delta v$
Fraction organic carbon, f_{oc}	f_{oc} -Δf_{oc}
pH	case-specific. The objective is to minimize K_{oc}

For example if the average site groundwater velocity is determined to be 10 m/yr and the upper bound uncertainty associated with this parameter is 5 m/yr, then 10 m/yr would be used for the "base case" and 15 m/yr would be used as the "worst case" in the sensitivity analysis.

2.14 EVALUATE RESULTS OF SLRA LEVEL 2 GROUNDWATER MODULE APPLICATION

If all cross-plot points fall into the "NPR" zone, the groundwater-to-receiving environment pathway does not exist. Screening-level risk assessment is complete for this pathway. If any

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[17] A more complex uncertainty analysis may be beyond the scope of SLRA Level 2.

points fall in the receiving environment impact zone, further assessment of this pathway or remediation is required for this compound.

3 SOIL AND GROUNDWATER CLEAN-UP LEVELS

Under SLRA Level 2 one can calculate site-specific soil and groundwater cleanup targets that are protective of groundwater for drinking water, livestock, irrigation and aquatic life receiving environments.

If a more flexible site-specific soil cleanup target for the protection of groundwater is desired than that provided by SLRA Level 2, the SAB's Hydrogeological Assessment Tools or a detailed risk assessment (DRA) is recommended.

3.1 SITE SOIL CLEAN-UP LEVELS

The methods for evaluating the soil-to-groundwater exposure pathway can be used to calculate protective soil concentrations. The practitioner can work backwards from target groundwater concentrations (either the Schedule 6 groundwater standards or groundwater concentration determined to be protective of all potential receiving environments in the Groundwater Module) to calculate protective soil concentrations.

3.2 SITE GROUNDWATER CLEAN-UP LEVELS

To compute the site-specific groundwater cleanup level, the dimensionless factors are used. The objective is to find the value of S_I (and hence C_{gw}) such that the condition $S_I < S_{II}$ is ensured throughout the site. The cleanup standard is the lesser of the computed $C_{cleanup}$ from Equation 6.1 and the solubility[18] of the compound.

$$C_{\text{cleanup}} = C_{\text{sched\_6}} \times 10^{S_{II}} \qquad \text{Equation 6.1}$$

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[18] The site-specific solubility of the compound must be assessed. SLRA Level 2 does not provide a table of solubilities.

The base case S_{II} *computed from site data* is used when computing the cleanup standard for remediation.

Note that the use of S_{II} when setting site cleanup values is distinct from the use of S_{II} during the screening decision process. In the screening decision process, a sensitivity analysis on the input values to S_{II} is required. Such a requirement would be onerous for setting remediation targets.

4 SLRA LEVEL 2 SOIL VAPOUR INTRUSION

A flow chart summarizing the SLRA guidance framework for vapour intrusion is provided in Figure 8. The first step in the vapour intrusion assessment protocol is the development of a site conceptual model.

4.1 DEVELOP CONCEPTUAL SITE MODEL

See details in Section 2.

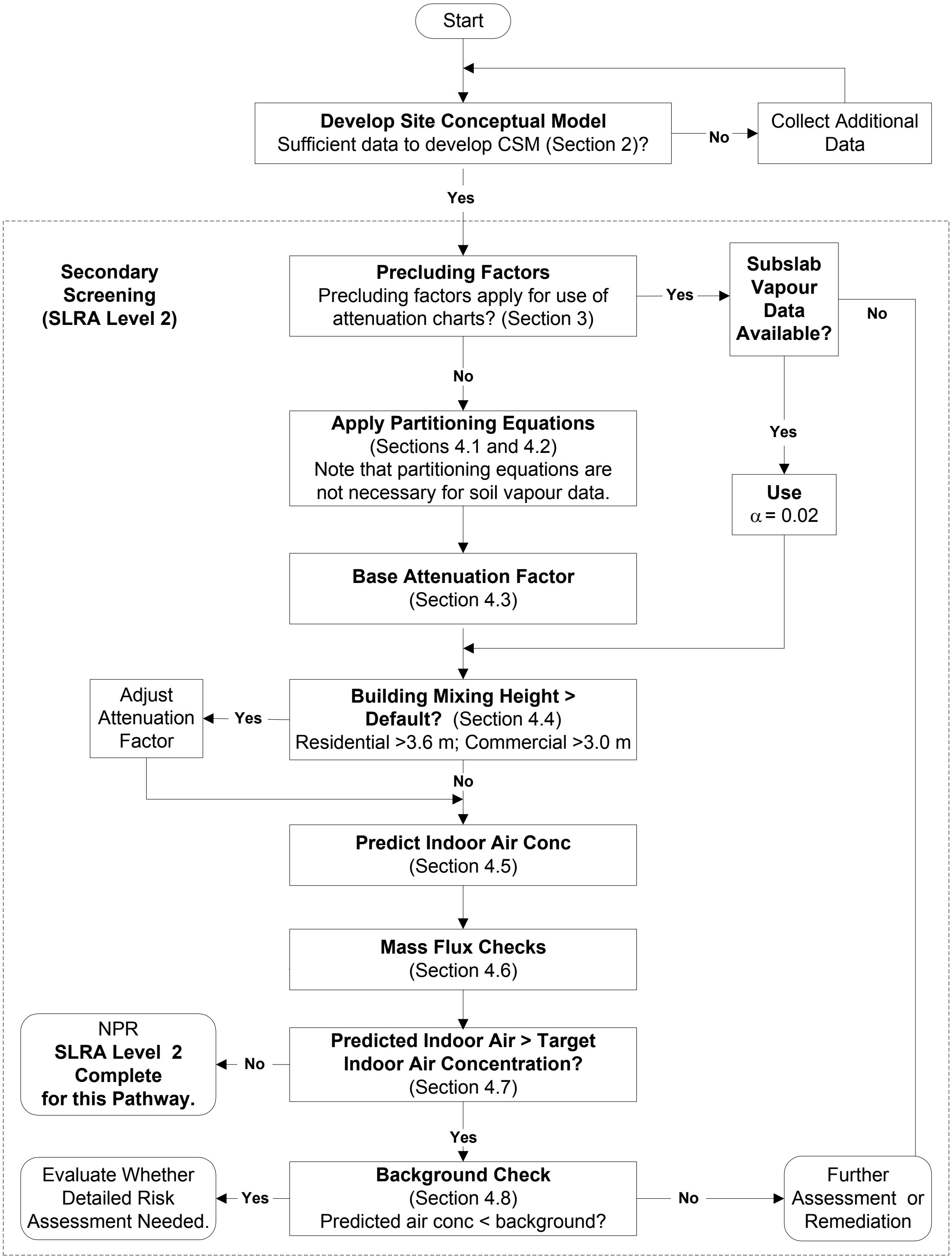
4.2 PRECLUDING FACTORS

- Assess industrial sites only if subsurface chemicals different from those used in workplace
- Contaminant source is within 1 metre of building foundation
- Building has unlined crawl space or earthen basement and contamination is less than 5 m below the building.
- Building is constructed on vertically fractured bedrock, karst, cobbles
- Anthropogenic utility conduit is in direct contact with contaminant source
- NAPL is present but poorly characterized and distribution is uncertain

4.3 SUBSLAB DATA

If one of these precluding factors applies, then subslab vapour data can be used to evaluate the vapour intrusion pathway. Refer to Section 3.3.

Figure 8. Flow Chart for SLRA Vapour Intrusion Guidance



4.4 COMPUTE SOIL VAPOUR CONCENTRATIONS

Use soil vapour or groundwater. The use of soil data in this screening process will likely result in large uncertainties. Partitioning equations can be found in Section 4.2.

4.5 SELECT BASE VAPOUR ATTENUATION FACTORS

The vapour attenuation factor is the ratio of vapour concentration in the indoor space to the vapour concentration at the contamination source. It is dependent upon the depth of the soil vapour contamination source, the land use, and the soil type.

4.6 ADJUST VAPOUR ATTENUATION FACTOR FOR BUILDING HEIGHT

If the mixing height is greater than 3.6 m for a residential building or 3.0 m for a commercial building, correct the attenuation factor for the mixing height.

4.7 CALCULATE INDOOR AIR CONCENTRATION

The indoor air concentration is predicted using the measured or estimated soil vapour concentration and the vapour attenuation factor, as follows:

$$C_{air} = C_a * \text{Vapour Attenuation Factor}$$

4.8 ADJUST INDOOR AIR CONCENTRATION TO ACCOUNT FOR MASS FLUX

If the available mass flux predicted exceeds the available mass flux via groundwater transport or if the contaminant vapour source is being depleted, make mass flux correction.

4.9 ASSESS PATHWAY COMPLETENESS

The predicted indoor air concentration is compared to the target indoor air concentration. If the predicted concentration is less than the target concentration, then the SLRA Level 2 assessment concludes that there is no pathway to the receptor (NPR), and the assessment is complete.

4.10 BACKGROUND INDOOR AIR CHECK

The user should check whether the predicted indoor air concentrations exceed background indoor air concentrations for the chemical under consideration.

5 SLRA LEVEL 2 HABITAT

For sites where concentrations of contaminants are in excess of the CSR standards for "toxicity to soil invertebrates and plants", two levels of terrestrial habitat assessment can be conducted under the Screening Level Risk Assessment process[19] (assessment of aquatic habitats, see definition in SLRA Level 1, must proceed to DRA or remediation). The first level is conducted as part of the SLRA Level 1 assessment and consists of a generic screening questionnaire within which the approach is not receptor specific. The second level is conducted as part of the SLRA Level 2 assessment and evaluates the potential for on-site terrestrial habitat to be used by specific receptor species. Professionals applying SLRA Level 2 should do so in conjunction with guidance provided in "Recommended Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia" by the Ministry of Environment, Lands and Parks, 1998 (Tier 1 Guidance).

Based on specific generic criteria for undeveloped land on the site (e.g., presence of bioaccumulative substances (see definitions in SLRA Level 1); zoning; habitat size and connectivity; proximity and distance to sensitive habitat), the SLRA Level 1 phase screens out sites that clearly have limited, to no habitat potential (i.e., sites that are not suitable to terrestrial wildlife). As shown in Figure 3 of the SLRA Level 1 Module (Appendix 3), the SLRA Level 1 habitat assessment process establishes one of the following four conclusions:

1. There are no issues related to wildlife habitat at the site;
2. There is potential wildlife habitat at the site and further assessment is required by use of a Level 2 screening process (SLRA Level 2);
3. A detailed risk assessment is required, i.e., as a Level 1 detailed risk assessment (as per current Ministry protocols for a Tier 1 Ecological Risk Assessment), or a Level 2 detailed risk assessment; or
4. Remediation of the site to numeric standards.

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[19] The evaluation is limited to identifying suitable habitat (or lack thereof) for terrestrial wildlife. Aquatic receptors in surface water including wetlands, lakes, and streams are beyond the scope of the screening level risk assessment process.

Sites where a potential habitat is identified in the SLRA Level 1 process must continue to the SLRA Level 2 habitat assessment process. The SLRA Level 2 terrestrial habitat assessment must be completed by a professional biologist (R.P.Bio.) or qualified Risk Assessor with sufficient knowledge of local wildlife ecology. The procedure to conduct the SLRA Level 2 habitat assessment is described in this module.

Site-specific habitat conditions may indicate the need for an SLRA Level 2 to determine whether a site contains “suitable habitat” for specific local species. As noted above, a registered professional biologist (R.P.Bio.) or qualified risk assessor with sufficient knowledge of local ecology and habitat requirements of ecological receptors is required to conduct the three following steps of the SLRA Level 2 assessment according to any applicable Resources Information Standards Committee (RISC) standards (http://srmwww.gov.bc.ca/risc/index.htm).

The procedure parallels the problem formulation sections and the “effects assessment- site observation” sections noted in the Tier 1 Ecological Risk Assessment protocol.

5.1 STEP 1: DETERMINING SITE RECEPTORS

Receptor groups to be considered vary depending on land use and biogeoclimatic zone of the site. ***Table[20] 1 indicates those wildlife receptors that must be considered on the basis of the different land uses (other receptors may be considered as deemed appropriate by the professional biologist or qualified risk assessor).*** It is noted that a listing of terrestial plants would be compiled during the site visit by the professional biologist or qualified risk assessor. The professional biologist or qualified risk assessor should also refer to the Tier 1 Guidance for assistance in evaluating receptor groups and selecting specific species as receptors[21]. The professional biologist or risk assessor should refer to the Tier 1 Guidance, Appendices C, D and E to obtain species lists for biogeoclimatic zones.

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[20] All Table referred to are shown in the main Habitat document.

[21] Note that Table 1 receptor groups for consideration are more extensive than found in Tier 1 Guidance. Table 1 should be considered a more current list of potential receptor groups to be evaluated in the Level 2 Habitat Assessment.

5.2 STEP 2: PROVIDE RATIONALE FOR SELECTING RECEPTOR

Using Table 1 as a reference, the assessor must complete Table 2, which involves specifying the land use and geographic location of the site, along with the choice of receptor groups and rationale behind selection/omission of groups.

Table 2 is meant as a working table used to provide the background information required to first select the wildlife receptors group and then specific species for which habitat characteristics will be evaluated in Step 3. Within Table 2:

- The second column ("Included in the SLRA Level 2") is essentially the list of wildlife receptors noted in Table 1, based on the land use.
- The information to complete the third column ("Observed in this SLRA') is obtained during a visit to the site under investigation and includes observed wildlife as well as indicators including, but not restricted to, tracks, scat, or nests.
- The information to complete the fourth column ("Observed other source") would be obtained from local or on-site sources, if available, (e.g., sources may include individuals who have lived or worked on the site).
- The fifth column ("Not observed-potential high/low/nil") indicates the potential of the presence of species that have not been observed during the site visit, nor indicated by local or on-site sources. The potential for a receptor's presence is evaluated on the basis of an office review of available information on potential receptor groups (e.g., biogeoclimatic zone lists, COSEWIC species lists etc.). The receptor identification should also consider the rules (specified for each land-use) as shown in Appendix I of the Tier I ERA protocols.
- The last column ("Comment") provides a professional opinion based on observations and review of available information, regarding the likelihood of the receptor being present on the site.

Any COSEWIC listed species that may be present in the vicinity of the site must be listed and considered individually. Guidance for identifying COSEWIC species and their geographic range is available at: http://www.cosewic.gc.ca/eng/sct5/index_e.cfm.

5.3 STEP 3: ASSESSMENT OF HABITAT SUITABILITY

The next step of the SLRA Level 2 process involves evaluating the undeveloped land on site in terms of habitat suitability for each of the selected receptor groups[22] (i.e., are the habitat requirements present for each receptor group?). For each receptor group (including any COSEWIC listed species), the assessor must complete the decision matrices in Table 3. To complete the table, three decisions are required of the professional biologist or qualified risk assessor:

- The first decision is based on the size of the undeveloped land and whether or not it is suitable for the receptor in question. Factors such as the home range of the species should be considered while evaluating the size criterion. The Professional biologist or qualified risk assessor should refer to the references listed in Tier 1 Guidance, Appendices J and K for assistance in evaluating suitability of undeveloped land. A "yes" answer indicates that the undeveloped land is large enough to support (area must for ≥50% of the organisms home range) the receptor in question, and a "no" indicates that the land is too small to support the receptor.
- For the second decision, the assessor must evaluate the degree of fragmentation of the undeveloped land in terms of the specific habitat requirements of the receptor. A "yes" answer indicates that the land is sufficiently connected or in sufficient proximity of additional habitat features, and a "no" would indicate that the undeveloped land is isolated from any additional habitat requirements of the receptor.
- The assessor should state his or her professional opinion as to whether the vegetation at the site is stressed due to site conditions or whether the vegetative

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[22] See background information attached to Level 1 documentation relating to habitat size, connectivity and quality.

conditions are typical for that geographic area at the time of the site inspection. Consideration should be given to such aspects as sites that are subject to physical impacts by: traffic;

- storage of products on land such as lumber, pipes, etc.; or, maintenance requirements such as those of the Fire Code of Canada that require vegetation at many industrial sites to be controlled.
- The final decision addresses the quality of the undeveloped land. This may include types of vegetation, presence or absence of important habitat features for the receptor, percent cover and extent of human disturbance or degradation of the land. The professional biologist or qualified risk assessor should also consider reasonable future potential of the land to become acceptable habitat.

Based on the results of these three decisions, the assessor should state his or her professional opinion about whether or not the receptor species in question is likely to use the undeveloped land as habitat, and whether further assessment by use of a detailed risk assessment process[23] is required. The assessors must also provide comments justifying their decisions.

The outcome of the SLRA Level 2 habitat assessment will be one of the following:

1) No further action is required under the habitat evaluation (i.e., sites do not contain any habitat for wildlife receptors), or

2) A Level 1 detailed ecological risk assessment (as per current Ministry protocols for a Tier 1 Ecological Risk Assessment), is required for the selected receptor groups, with the option of subsequently providing a Level 2 Detailed Risk Assessment.

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[23] As noted previously, there will be two levels of detailed risk assessment (DRA). The Level 1 Ecological DRA will follow protocols of the BCMOE's "Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia". If required, a Level 2 DRA would follow a Level 1 DRA, and would include provision for more complex risk assessment protocols.

An owner of a site could proceed with remediation:

- To numerical standards to preclude the need for a detailed risk assessment; or
- To risk based standards (target concentrations) derived using receptor specific toxicological reference values; or

To risk based standards using risk management measures that minimize exposure and associated risk.

Glossary for SLRA Terms

NPR – No pathway to receiving environment. For a specific pathway, a site is classified as NPR if either:

- the site is not contaminated;
- the degree of attenuation between the source and the receiving environment is sufficient to result in a concentration at the receiving environment which is less than the Schedule 6 standard; or
- in the case of terrestrial impacts, the receiving environment does not function as a terrestrial habitat.

Applicable Standard – The particular pathway of concern for each COPC has a corresponding numerical standard. A number of standards exists under schedule 5, soil matrix standards, and schedule 6, groundwater standards, while one standard exists under schedule 4, generic soil standards. For evaluation of the risk posed by contaminant concentrations where more than one standard exits, the applicable standard refers to the numerical standard being evaluated. The predicted or measured concentration at a receiving environment or receptor is compared to a standard appropriate for each pathway of concern. A number of pathways may be of concern at a site for the same COPC and each pathway is evaluated independently by comparing to a corresponding standard.

Contaminant – Any physical, chemical, biological, or radiological substance found in air, water, soil or biological matter that has a harmful effect on plants or animals; harmful or hazardous matter introduced into the environment

Contaminant Concentration – The maximum concentration measured in the media of interest. The contaminant concentration for vapour intrusion is different. In this case, the groundwater concentration under the building, which is the source of upward vapour migration, is used rather than the maximum dissolved groundwater concentration..

Contaminant of Potential Concern (COPC) – Any contaminant that potentially occurs in environmental media at levels shown to pose a risk to ecological receptors or human health.

Contaminant plume – A volume of a substance dissolved in groundwater. Plumes can be described by the volume of water they occupy and the direction they move.

Contaminated site (versus property) – The contaminated site consists of the source and contaminant plume derived from the source. The contaminated site is distinct from the property. The contaminated site can extend beyond the property boundary or can be a small portion of the property.

Contaminant source – the location from which contaminants are discharged or emitted. The source of a contaminant is the first part of an exposure pathway. In the Soil/Groundwater Module, the contaminant source encompasses the portion of the medium (e.g., soil) with concentrations that exceed the CRS standards and are therefore expected to contribute to the development of a contaminant plume. In the Vapour Intrusion Module, the contaminant source encompasses the portion of the medium (e.g., soil vapour, groundwater) with detectable concentrations that are therefore potential sources of vapour which migrate into enclosures.

Endpoint – A measured response of a receptor to a stressor.

Exposure pathway – An exposure pathway is the route a chemical can be expected to travel from a source to a receiving environment that can be affected by that chemical.

Mobile NAPL – NAPL that is not held in static equilibrium via capillary, viscous and gravity forces.

NAPL – a term given to several chemical groups of liquid-phase contaminants which maintain a separate phase when they come into contact with water.

Pore water – The water that occupies the spaces between sediment particles.

Receiving environment – The environmental medium (air, soil, surface water or groundwater) that may be exposed to contaminants.

Receptor – A plant or animal that may be exposed to a stressor.

Residual NAPL – NAPL that is held in pore spaces and as films or lenses on solid and water surfaces and contributes negligibly to NAPL advection.

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