May 24, 2011

REPORT ON:

Derivation of High Density Residential Soil and Vapour Quality Standards for Use under Contaminated Sites Regulation

Submitted to:
British Columbia Ministry of Environment
2975 Jutland Road
Victoria, BC
V8T 5J9

Submitted by:
Golder Associates Ltd.
500 – 4260 Still Creek Drive
Burnaby, BC
V5C 6C6

and

Science Advisory Board for Contaminated Sites in British Columbia
P.O. Box 3065, Stn. C
University of Victoria
Victoria, BC
V8X 3V6

REPORT

Proposal Number: 10-1436-0123

Distribution:

3 Copies - Ministry of Environment

1 E-Copy - Ministry of Environment

2 Copies - SABCS

2 Copies - Golder Associates Ltd.

Science Advisory Board for Contaminated Sites

Golder Associates

A world of capabilities delivered locally

EXECUTIVE SUMMARY

Purpose and Scope

As part of the planned omnibus updating of the environmental quality standards of the Contaminated Sites Regulation, the BC Ministry of Environment (MoE) intends to incorporate new high density residential soil and vapour numerical standards for use in high density urban areas. As a component of the program, the Ministry requires a derivation protocol for high density numerical standards for use under the CSR.

This report prepared by Golder Associates Ltd. (Golder) and the Science Advisory Board for Contaminated Sites in British Columbia (SABCS) presents a recommended protocol to derive high density residential soil and vapour quality standards for use under the CSR. This study has involved review of similar protocols in other jurisdictions, consideration of the nature of urban development, and the potential for exposure of human and ecological receptors to subsurface contamination for a defined high density land use scenario.

Currently, residential land and vapour use contaminated sites are assessed and managed under the numerical standards of the CSR using a single type of residential scenario. This scenario was primarily developed in consideration of human and ecological receptors and contaminant exposures believed representative of a single family dwelling. However, the majority of residents within high density urban areas in major urban centres in BC do not reside in single family dwellings; rather the majority reside in higher density, multi-unit complexes.

Literature Review

Guidance documents on soil standards development from Canada, New Zealand, Australia, the Netherlands and the United Kingdom were reviewed. Jurisdictions with generic soil standards addressing a high density residential land use scenario were limited to New Zealand and Australia.

The New Zealand protocol (2009) indicates there is little or no data for deriving exposure parameters for residential scenarios other than the standard (Residential 10% produce grown on site) scenario, and therefore professional judgment must be resorted to for the high density scenario. The differences between the standard and high density residential scenarios are limited to different assumptions for soil ingestion and soil adherence factors. For both factors, the New Zealand standard residential assumptions are divided by approximately a factor of two. Under the Australian guidance, a simple factor approach based on judgment is used where the residential soil standard is divided by a default exposure ratio (DER) of 0.25 to calculate the high density soil standard.

No jurisdictions were identified with high density residential standards for the soil vapour intrusion into buildings pathway. However, the Province of Ontario as part of their Modified Generic Risk Assessment (Tier 2) process provides an optional adjustment where the soil and groundwater standards for the soil vapour intrusion pathway may be multiplied by 100X for a ventilated garage scenario.

Urban Development Characteristics and Selected Bylaws

The development of meaningful high density land use standards requires an understanding of the nature of urban development and the potential for exposure to site contamination. The characteristics of urban development in British Columbia were evaluated through a review of zoning bylaws and official development plans for three cities (Vancouver, Victoria, North Vancouver), interviews with urban planners, and the observations of the authors.

The nature of urban development is highly variable and a consistent definition of "high density" urban land use does not exist within bylaws or development plans. Selected characteristics and observations of urban development are summarized below.

- The majority of recent apartment (condominium) developments in urban downtown cores include underground parking garages below the entire site. Many older apartments do not include underground parking and in areas with high water tables (*e.g.*, Richmond), underground parking garages are difficult to construct.
- Most apartment developments include small ornamental-type landscaped areas (*e.g.*, grass-strips, planters) and some developments in less dense urban areas also include small park-like and landscaped areas. Apartments relatively infrequently include children's playgrounds, although urban planners indicate inclusion of playgrounds is encouraged for larger developments. In some cases, the playground may be constructed on top of a parkade.
- Recently there has been interest in urban agriculture and integration of garden plots where plants are grown for human consumption within a higher density land use. One example is the community demonstration garden that has been constructed in Southeast False Creek (Vancouver), a moderate to high density urban area. In some cases, plants may also be grown in roof-top gardens or raised planters.

The vision incorporated in some official development plans (*e.g.*, City of Vancouver East Fraser Lands Official Development Plan), is to integrate higher density land uses within a diverse and connected open space network that includes plazas, parks, playing fields, ecological spaces, greenways, and neighbourhood greens.

BC MoE Definition

The BC MoE has defined "high density residential" land use as part of a draft version of Procedure 8 (BC MoE 2011). The draft "high density residential" land use definition is as follows:

"High Density Residential – means the type of housing at a residential complex housing multiple persons or families in:

a) Individual units, including boarding houses, apartments, condominiums, lodges, and townhouses; or

b) Institutional facilities, including residential schools, hospitals, residential day care operations, retirement homes, prisons, correctional centres and community centres, but does not include commercial hotels or motels".

The above land uses were considered in the development of the conceptual exposure model described below; however, certain land uses were excluded from the definition of high density residential land use.

Conceptual Exposure Model

A conceptual exposure model is developed, which considered the following parameters:

- Residential development type;
- Typical building characteristics;
- Type of human receptors present;
- Type of landscaping and degree of open space;
- Presence of a children's playground or area;
- Potential exposure in a children's playground;
- Potential for soil vapour intrusion into building development type compared to a residential or commercial building; and
- Type of existing standard (if applicable) that provides for equivalent protection for human soil ingestion, vapour inhalation and direct contact for soil invertebrates and plants, or identification when a new high density residential standard is warranted.

The conceptual exposure model was then used to simplify the number of exposure scenarios considered for the development of the high density residential soil and soil vapour standards, as follows:

- Residential land use would apply to detached houses, townhouses, boarding houses, residential schools, residential day care facilities and retirement homes; and
- High density or commercial land use, depending on the scenarios and exposure pathways, would apply to lodges, hospitals, apartments and condominiums (greater than three-storey's), prisons and correctional centres, and community centres (when playgrounds, fields and parks are excluded), providing there are appropriate exclusionary factors for certain site uses, as described below.

The primary focus of this report is to evaluate high density urban land use with respect to apartments and condominiums. A literature review and evaluation of issues was conducted for the soil ingestion and soil vapour intrusion pathways to provide supporting information for the conceptual exposure model and derivation protocol for high density residential standards.

Summary of Soil Ingestion Pathway Issues

The characteristics of apartment developments vary widely with respect to the potential for soil exposure. The landscaping at many apartment complexes is limited to small grass-covered strips or ornamental landscaping. However, some apartment developments include children's playgrounds, and developments in less dense urban areas may include small park-like and landscaped grass-covered areas.

A key consideration is the frequency of use of children's playgrounds and small park-like areas by children and toddlers. There are limited data on child activity patterns for children's play areas and frequency of use for high density land use. For playgrounds that are attractive areas and that encourage use by children, the frequency of use may be similar to that assumed for a detached house scenario. For areas of ornamental landscaping or small grass areas, a reduced frequency of potential exposure for children and adults is expected. Most playgrounds will be constructed with a combination of hard and soft surfaces, with imported material placed on top of existing site soils or constructed on top of a parking garage. Grass-covered areas will often be constructed on top of an imported fill layer. While the potential for exposure to underlying soil may be limited, the soil standards assume that there is the potential for exposure, and thus no adjustments for possible reduced exposure is considered warranted. However, the exclusionary factor for children's playground does not apply if the exposure pathway is cut off through a parkade or concrete slab, as described below.

Published soil ingestion rates and assumptions inherent in developing ingestion rates are reviewed, but the literature did not include soil ingestion rate studies that are specific to high density residential sites. While many health agencies have endorsed policies where the assumed daily rate of soil ingestion occurs from a site regardless of the amount of time spent in areas where ingestion could occur; it is logical to expect that the amount of soil ingested, and certainly the likelihood that soil ingestion would actually occur, would be time-dependent to some degree. This expectation, combined with a conceptual approach where hand to mouth activity as a reflection of soil ingestion rates is invoked, is used to support lower ingestion rates for child receptors where exposure frequency would be less than for a detached house scenario. Based on professional judgment, a reduced exposure time and consequent lower soil ingestion rates is considered appropriate for high density residential sites where soil is present and play is not specifically encouraged (*e.g.*, ornamental gardens, common areas with grass and landscaping), as reflected in the exposure term defined in the protocol below.

Summary of Soil Vapour Intrusion Pathway Issues

The key building factors that control soil vapour intrusion for apartment buildings are reviewed in the development of the conceptual site model. These factors are the pressure difference between the enclosed space and subsurface and soil gas advection rate, the fresh air exchange (ventilation) rate, and the mixing height for vapours inside the building. The condition of the subsurface building envelope and potential openings (*e.g.*, utilities, cracks, openings) and preferential pathways in the building (*e.g.*, elevator shafts, ducts) may also have a significant influence on soil vapour intrusion.

The main process for soil vapour intrusion into apartments is expected to be soil gas advection into depressurized parts of the lowest (subsurface) part of the building through cracks and openings in the subsurface building envelope, which may be associated with utilities (*e.g.*, drains, sumps, electrical lines), elevator pits, or separation cracks in concrete. The depressurization of the lower parts of an apartment building may occur due to the stack effect, which may be significant in taller buildings during the heating season, although modern buildings are designed to reduce the stack effect and cross-floor leakage of air. The depressurization in apartments with a significant stack effect may be as high as 30 Pascals (Pa), although typically the depressurization will be lower.

The air change rates for apartment dwellings will depend on several factors including the type of ventilation system, the size of dwelling, and the number and type of appliances. For apartments of 500 ft^2 to 1000 ft^2 with one to two bedrooms, one washroom and one kitchen, a representative average air change rate is estimated to be between 0.35 and 0.45 air changes per hour (ACH).

An underground or open-air parking garage will significantly reduce the potential for vapour migration to occupied dwellings through ventilation and dilution of vapours that potentially migrate into the garage. A parking garage will typically be negatively pressurized relative to the rest of the building airspace to avoid migration of vehicle exhaust into the building airspace. However, there may be vertical pathways for vapour movement within the building through elevator shafts or other pathways. Complicating the assessment of vapour intrusion in parking garages is that elevated levels of many volatile substances of concern for common subsurface contaminants are present in vehicle exhaust. The average ventilation rate in a parking garage will depend on the frequency of ventilation. Under the BC Building Code, when operational, the design ventilation rate works out to approximately 5 ACH. However, intermittent ventilation to meet air quality requirements is acceptable under the BC Building Code and therefore the average air change will be less than 5 ACH, with 2 to 4 ACH proposed as a reasonable range.

With respect to receptors potentially exposed to vapours and exposure frequency and duration, there are differences depending on whether the apartment has an underground parking garage as part of the site development. For the scenario with a parking garage, the primary use of the garage is parking; however, a garage may include storage units or laundry rooms. Therefore, residents would spend time in the garage parking their vehicles (and possibly conducting maintenance activities), retrieving items from storage, or doing their laundry. A maintenance worker will enter the parkade intermittently to conduct maintenance activities of elevators, ventilation systems, doors, safety equipment and other equipment. A security attendant may also enter the garage on a regular basis.

Proposed Definition of the High Density Residential Land Use Scenario

The proposed definition for the high density residential land use for the apartment and condominium scenario, based on the conceptual exposure model and rationale described in this report, is as follows:

- Three-storey or higher apartment or condominium;
- Site does not contain a children's playground, unless the playground is constructed on top of a parking garage or concrete slab; and
- Land is not used for growing plants for human consumption, unless plants are grown on roof-top gardens or in planters with concrete bottoms.

A playground is defined as an area that is primarily used for children's play (*e.g.*, containing play equipment, picnic area or other such attributes that encourage frequent use by children). For high density land use with a children's playground or garden, the residential land use standards would apply to the entire site, unless the children's play area and garden can be considered separately from the remaining site area through subdivision or other administrative tool.

A further proposed subdivision of the high density residential land use is an apartment that includes an underground parking garage or above-grade parking garage that is open to outdoor air, which is below the entire portion of the building containing dwelling units. An open-air parkade is defined as a storey of the building where at least 25% of the total area of its perimeter walls is open to the outdoors in a manner that will provide cross ventilation to the entire storey.

The definition of high density apartments and condominiums explicitly excludes townhouses or "garden apartments" defined as typically two-storey dwelling units with enclosed gardens that are specific to a dwelling unit (*i.e.*, not common space), except when townhouses are integrally connected to an apartment as part of a integrated multi-building development.

Protocol for High Density Residential Standards

A recommended protocol for high density residential standards is described that considers the following pathways: (i) soil standards protective of human health for intake of contaminated soil (soil ingestion), ii) soil standards protective of ecological health based on toxicity to soil invertebrates and plants, and iii) vapour standards protective of human health.

Soil – Human Health (Intake of Contaminated Soil)

For the purposes of development of high density residential soil standards for intake of contaminated soil, it is recommended that an exposure term (ET) of 0.5 be utilized. Currently, at residential and parkland sites, BC MoE procedures employ an ET of 1 while for commercial sites, a value of 0.33 is used. Thus, the value recommended for high density residential sites is between the commercial and residential/parkland values. The high density standards developed using this ET would apply to common areas that include landscaped grass areas, ornamental gardens and walking paths soils that are not used for play purposes. An ET of 0.5 suggests that such play activities would occur at a rate of about 50% of typical residential sites.

Soil – Ecological Health (Toxicity to Soil Invertebrates and Plants)

Modification of the CSST protocol to derive new standards for the protection of soil invertebrates and plants is not recommended. Instead, the existing commercial standards for the protection of soil invertebrates and plants are proposed for the high density residential land use. This recommendation is based on the similarity between high density residential and commercial land uses in terms of its utilization by soil invertebrates and plants:

- **Consideration of exposure pathway based on size of undeveloped area**: CSR Protocol 13 and the BC MoE Procedure "Definitions and Acronyms for Contaminated Sites" define "potential terrestrial habitat" as land that "contains over 50 m^2 (where residential land use applies at the site) and over 1,000 m^2 (where commercial or industrial land use applies at the site) of contiguous undeveloped land.[1]" High density sites are considered likely to have between 50 m^2 and 1000 m^2 of contiguous undeveloped land and therefore, terrestrial ecological receptors require some level of protection from soil contamination. Protection of soil invertebrates and plants is also a mandatory standard irrespective of land use.

- **Consideration of level of protection based on nature of receptors:** Vegetation at most high density residential land use sites is considered likely to be maintained (*e.g.*, ornamental gardens, sidewalks, hedges, planter boxes and lawns). Non-maintained, natural vegetation is likely limited in spatial extent, in part, because high density sites will tend to exist in a landscape dominated by human influences. The types of soil invertebrates and plants likely present at a high density site is considered similar to the ecological community present at commercial sites, and therefore, the level of protection afforded by the commercial standards is likely adequate for high density sites as well.

Two exceptions to the proposed adoption of commercial standards for high density residential sites should be considered: (i) a high density site used for growing plants for human consumption (with certain possible exclusions), and (ii) a high density residential site that contains a land parcel of special ecological value.

Soil Vapour – Human Health

The development of high density residential vapour standards evaluated the ET for apartment residents and parking garage users and attendants, and preliminary modeling was undertaken to estimate vapour attenuation factors between indoor air and soil vapour for apartment dwelling units and enclosed parking garages.

For the vapour intrusion pathway, the potential exposure to human receptors was considered for apartments and parking garages. The proposed ETs for these scenarios are 1.0 for apartment residents and 0.125 for parking garage users and attendants. For comparison, an ET of 0.33 is incorporated in the CSR Schedule 11 Vapour Standards for commercial land use.

A preliminary modeling study was completed using the Johnson and Ettinger model to estimate vapour attenuation factors for a first-floor apartment dwelling for an apartment without a parking garage, and for a below-grade parking garage. Using subsurface input parameter values consistent with BC MoE Technical Guidance (TG) 4, and building-relating parameters representative of an apartment, there was little difference between the attenuation factors calculated for an apartment dwelling and detached house, and thus little basis for different attenuation factors for an apartment scenario compared to current TG4 attenuation factors for residential land use. For a parking garage scenario, the estimated median attenuation factor for the parking garage airspace is approximately 50X less than the current TG 4 residential attenuation factor, for the scenario considered (1 m distance from building to soil vapour measurement point).

[1] Defined by BC MoE as "means any bare or vegetated soil, excluding (a) gravelled walkways, (b) roadways or highways and associated roadside or highway margins, (c) parking areas, (d) soil contained and isolated in planters and similar structures, and (e) storage areas at active commercial and industrial operations."

For an apartment without a parking garage, it is recommended that the current TG4 attenuation factors for residential land use be adopted for the high density residential scenario (three-storey or greater apartment).

For an apartment with an enclosed or open garage below the entire footprint of the building, it is recommended that the current TG4 attenuation factors for residential land use be reduced by a factor of 50X, with these attenuation factors applicable to the parking garage and dwelling units. It is noted that the 50X reduction factor for dwelling units above a parkade is conservative, but further analysis and modeling would be required to determine to what extent this factor could be further increased.

Implications of Recommended High Density Protocol for Soil Standards

In order to evaluate the potential implications of the recommended protocol for the matrix soil standards, the current residential soil standards are compared to the proposed high density soil standards. When the changes in matrix soil standards for the mandatory factors "intake of contaminated soil" and "toxicity to soil invertebrates and plants" are evaluated independently without consideration of other potential pathways, the following changes to the CSR Schedule 5 matrix soil standards would result:

- The high density soil standards for human health intake of contaminated soil would generally be 2X greater than the residential standards[2]; and
- The high density soil standards for toxicity to soil invertebrates and plants would be 1.3X (zinc) to 20X (ethylbenzene) greater than the residential standards.

When soil standards for groundwater used for drinking water or groundwater flow to surface water and protection of aquatic life are considered, the standards for the groundwater pathways will be lower than the proposed high density residential soil standards for many Schedule 5 substances.

When soil standards for groundwater used for drinking water and protection of human health are considered, for many Schedule 5 substances, the standard for the drinking water pathway will be lower than the proposed high density residential soil standard, although for several substances, the comparison will depend on the pH of the groundwater. Substances where the high density standard could potentially result in lower soil standards when the drinking water pathway applies are cadmium, copper, lead, sodium, pentachlorophenol and zinc. Substances where drinking water standards will be the driver are arsenic, barium, benzene, chloride, chromium, ethylbenzene, toluene, trichloroethylene and xylenes.

When soil standards for groundwater flow to surface water and protection of aquatic life is considered, there are similar considerations as for the drinking water pathway. Substances where the high density standard could potentially result in lower soil standards when the aquatic life pathway applies are cadmium, copper, ethylbenzene, lead, pentachlorophenol, toluene and zinc. Substances where aquatic life standards will be the driver are arsenic, barium, benzene, chloride, chromium, ethylene glycol and trichloroethylene.

[2] The 2X factor is approximate and should be confirmed by BC MoE.

Summary of Key Recommendations

The key recommendations of this study are summarized as follows:

1) For the apartment and condominium scenario, a high density residential land use is defined as a three-storey or higher apartment or condominium; where the site does not contain a children's playground, unless the playground is constructed on top of a parking garage or concrete slab; and land is not used for growing plants for human consumption, unless plants are grown on roof-top gardens or in planters with concrete bottoms.

2) For the human health intake of contaminated soil pathway, it is recommended that an exposure term (ET) of 0.5 be utilized.

3) For the ecological health and toxicity to soil invertebrates and plants pathway, modification of the CSST protocol to derive new standards is not recommended, instead, the existing commercial standards are proposed for the high density residential land use, excepting sites where plants are grown for human consumption and land parcels of special ecological value.

4) For the vapour intrusion pathway, for an apartment with an enclosed or open garage below the entire footprint of the building, it is recommended that the current BC MoE TG 4 attenuation factors for residential land use be reduced by a factor of 50X, with these attenuation factors applicable to the parking garage and dwelling units. The current CSR Schedule 11 Vapour standards for residential land use would apply to occupants of the apartments.

PREFACE AND ACKNOWLEDGEMENTS

This report was prepared as a collaborative effort between Golder Associates Ltd. (Golder) and the Science Advisory Board for Contaminated Sites in British Columbia (SABCS). The report authors were:

- Marc Cameron, Hemmera
- Ian Hers, Golder Associates Ltd.
- Parisa Jourabchi, Golder Associates Ltd.
- Blair McDonald, Golder Associates Ltd.
- Sam Reimer, SLR Consulting (Canada) Ltd.
- Tiona Todoruk, WorleyParsons
- Audrey Wagenaar, Golder Associates Ltd.
- Paul West, Chair Science Advisory Board for Contaminated Sites
- Ross Wilson, Wilson Scientific

The authors acknowledge the helpful input and review provided by the following representatives of the BC Ministry of Environment: Dr. Glyn Fox and Remi Odense.

DISCLAIMER

This report provides a scientific review and protocol for high density soil standards prepared for the British Columbia Ministry of Environment. Any use that a third party may make of this report, or any reliance on or decisions made based on it, are the responsibility of the third parties. We disclaim responsibility or consequential financial effects on site management, or requirements for follow-up actions and costs.

The services performed as described in this report were conducted in a manner consistent with the level of care and skill normally exercised by other members of the science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services. This report provides professional opinions and, therefore, no warranty is expressed, implied, or made as to the conclusions, advice, and recommendations offered in this report. This report does not provide a legal opinion regarding compliance with applicable laws or regulations.

This report focuses on technical and scientific aspects of standards development and while providing recommendations, should not be construed to represent BC Ministry of Environment policy on high density land use standards.

Table of Contents

TABLES

APPENDICES

1.0 INTRODUCTION

As part of the planned omnibus updating of the environmental quality standards of the Contaminated Sites Regulation, the BC Ministry of Environment (MoE) intends to incorporate new high density residential soil and vapour numerical standards for use in high density urban areas. As a component of the program, the Ministry requires a derivation protocol for high density numerical standards for use under the BC Contaminated Sites Regulation (CSR).

This report prepared by Golder Associates Ltd. (Golder) and the Science Advisory Board for Contaminated Sites in British Columbia (SABCS) presents a recommended protocol to derive high density land use residential soil and vapour quality standards for use under the CSR. This study has involved review of similar protocols in other jurisdictions, consideration of the nature of urban development, and the potential for exposure of human and ecological receptors to subsurface contamination for a defined high density land use scenario.

Currently, residential lands are assessed and managed under the numerical standards of the CSR using a single type of residential scenario. This scenario was primarily developed in consideration of human and ecological receptors and contaminant exposures believed representative of a single family dwelling. However, the majority of residents within high density urban areas in major urban centres in BC do not reside in single family dwellings; rather the majority reside in higher density, multi-unit complexes. This work builds upon and is consistent with the framework for soil standards derivation prepared by the Contaminated Sites Soil Task Group (CSST) as documented in BC MoE (1996) and the CSST review completed by SABCS (2009a and 2009b).

By nature, the derivation of soil standards is not a straightforward process, but involves policy choices on health protection. Where possible, decisions have been informed from science and data; however, judgment is part of the soil and soil vapour standards derivation process. The intention is that the high density soil standards derivation process retains flexibility for changes based on future advances in the science.

Although not explicitly considered in this study, it is recognized that the new high density residential land use standards may influence certain aspects and characteristics of future urban development in British Columbia by the requirements that will be defined, and may also have a role in promoting development of brownfields through less stringent high density residential standards. Evaluation and further refinement of the high density residential standards may be warranted to respond to desired outcomes for both urban development and human health and environmental protection.

The report is organized as follows:

- **Section 1:** Introduction and project overview.
- **Section 2:** Existing provincial soil standards framework and previous CSST reviews.
- **Section 3:** Literature search scope.
- **Section 4:** Background information review focusing on soil standards derivation protocols from selected jurisdictions.
- **Section 5:** An overview of urban development characteristics and bylaws from selected jurisdictions.

- **Section 6**: Human health soil intake pathway considerations for high density residential numerical standards.
- **Section 7**: Soil vapour intrusion pathway considerations for high density residential numerical standards.
- **Section 8**: Problem formulation and proposed high density land use definition.
- **Section 9**: Recommended protocol for derivation of high density residential numerical standards.

Sections 6 and 7 provide background information on soil intake and soil vapour intrusion, respectively, and are intended to provide supporting information for the conceptual exposure model and protocol for the derivation of high density residential standards.

2.0 EXISTING PROVINCIAL SOIL AND SOIL VAPOUR STANDARD FRAMEWORK AND CSST REVIEWS

2.1 Existing Provincial Soil and Soil Vapour Standards

The BC MoE has developed several types of soil standards as part of BC CSR (BC CSR; BC MoE 2010a). Matrix numerical soil standards are found in Schedule 5 of the BC CSR, while generic numerical soil standards are found in Schedules 4 and 10. Generic numerical vapour standards are found in Schedule 11 of the CSR.

Schedule 5 matrix numerical soil standards have been developed for the following potential exposure pathways for protection of human and environmental health:

Human Health:

- Intake of contaminated soil; and
- Protection of groundwater used for drinking water purposes;

Environmental Health:

- Toxicity to soil invertebrates and plants;
- Livestock ingesting soil and fodder;
- Major microbial functional impairment;
- Groundwater flow to surface water used by aquatic life (freshwater and marine);
- Groundwater used for livestock watering; and
- Groundwater used for irrigation.

Generic numerical soil standards in Schedule 4 were developed for substances for which there may not be sufficient toxicological information to develop standards for the exposure pathways listed above. Under Schedule 5, at a minimum there are two mandatory site specific exposure pathways that are applied: intake of contaminated soil, and toxicity to soil invertebrates and plants. Soil standards are currently available for the following land uses: agricultural, urban park, residential, commercial and industrial. Soil standards for wildlands land use have yet to be developed.

Generic numerical vapour standards were developed by the BC MoE (BC MoE 2010a) and are utilized in conjunction with Technical Guidance 4 (BC MoE 2010b) which provides attenuation factors that can be applied to measured or modelled soil vapour concentrations to predict concentrations in indoor or outdoor air at the breathing zone of receptors. The predicted air concentrations are then screened against the Schedule 11 vapour standards. Schedule 11 vapour standards are available for agricultural/urban park/residential, commercial and industrial land uses.

2.2 CSST Process

In 1996, the BC MoE prepared a document entitled "*Overview of CSST Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites*" which outlined the procedures used by the BC MoE to derive soil quality standards for protection of human and ecological health. The soil standards developed using these procedures comprise Schedule 5 (matrix numerical soil standards) of the BC CSR and are applied at contaminated sites throughout BC. The BC MoE 1996 document was based closely on the methods used by the Canada Council of Ministers of the Environment (CCME) in the development of the Canadian Soil Quality Guidelines or CSQGs (1997) at that time. The CSQGs are based on the following two CCME guidance documents:

- CCME. 1994a. "*A Protocol for the Derivation of Ecological Effects-Based and Human Health-Based Soil Quality Criteria for Contaminated Sites*".
- CCME. 1994b. "*Guidance Manual for Developing Site Specific Soil Quality Remediation Objectives for Contaminated Sites in Canada*".

The BC MoE 1996 document adopted many of the features of the above documents, but some areas were modified based on BC MoE policy. Some of the modifications made included:

- Not including background checks for volatiles in indoor air, produce, off-site dust or grazing herbivores;
- Not developing soil-to-indoor air standards;
- Use of a slightly different hydrogeological model to derive soil standards for protection of groundwater; and
- Adjustment of toxicologically-derived soil ingestion standards for arsenic, cadmium and lead to reflect the results of empirical studies on human health outcomes (clinical study factors) for these particular substances.

More recently, the SABCS conducted a review of the BC MoE 1996 document and proposed modifications for consideration by BC MoE as they evaluate the possible updating of the Schedule 5 Soil Quality Standards. Many of these proposed changes relate to a comparison to a 2006 update (CCME 2006) of the original CCME documents listed above which were used to derive the CSST protocol. The proposed modifications that are most relevant to the development of high density residential soil and soil vapour standards are summarized below. These proposed modifications were not incorporated into the derivation of the high density residential soil standard protocol because the proposed changes have not been adopted by BC MoE. The proposed modifications apply to all land uses including high density residential, and therefore a consistent approach should be followed if changes are considered.

2.2.1 Adjustment of the Tolerable Daily Intake

CCME (2006) recommends that the estimated daily intake (EDI) be subtracted from the tolerable daily intake (TDI) to derive a residual daily intake (RDI) which accounts for background exposure; however, soil allocation factors are also applied to account for exposure routes that are not considered in the calculation. SABCS (2009a) suggests the use of a RDI (*i.e.*, TDI-EDI) only in cases where data are available and accurate for threshold-acting toxicants. Otherwise, the use of soil allocation factors (*i.e.*, TDI (100%) is divided amongst up to five possible exposure pathways (soil, water, air, consumer products, food) is suggested. SABCS (2009a) recommended this adjustment to avoid double counting of background exposure. BC MoE (1996) also recommended using an allocation of the TDI rather than the RDI.

2.2.2 Correction for Background Soil Concentration

CCME (2006) recommends adding an estimate of background soil concentration to the preliminary soil quality guideline to arrive at the final soil quality guideline for human health for threshold-acting chemicals. SABCS (2009a) recommends removing this correction for background soil concentration (*i.e.*, the background concentration is not added to the preliminary soil quality guideline).

The CSST (1996) protocol used the CCME (1994b) approach with the (TDI-EDI) term and the addition of the background concentration to the resulting soil quality guideline, where a published EDI and background soil concentration were available. The BC MoE (1996) protocol also specified that a comparison be conducted using the simplified approach which involves multiplication of the TDI by a 20% allocation factor to account for multiple exposure pathways or media, and that the “most reasonable” value determined by the two approaches be selected. In cases where a published EDI and background soil concentration were not available, the approach utilizing an allocation of 20% of the TDI was used instead.

2.2.3 Adjustment of Exposure Term

CCME (2006) indicates that for non-threshold substances, an exposure term of one is assumed for all land uses as the exposure duration for even the least conservative scenarios (*i.e.*, commercial/industrial) is expected to exceed the latency period for cancer. For threshold acting substances, the exposure term is less than one. SABCS (2009a) recommends an exposure term of less than one for high density residential, commercial, industrial, parkland and wildlands land uses.

2.2.4 Adjustment of Exposure Duration

SABCS (2009a) recommends slightly different exposure durations than CCME (2006) as shown below, based on a review of current literature:

- Worker (25 years)
- Residential/Urban Parkland Land Use
  - Toddler (6 years)
  - Adult (36 years)

- Agricultural Land Use
  - Toddler (6 years)
  - Adult (52 years)

2.2.5 Revised Formula for Carcinogenic Assessment

SABCS (2009a) recommends the revision of the formula used to calculate soil standards for carcinogens so that the childhood and adult exposures are apportioned for the residential, urban parkland, and agricultural scenarios. CCME (2006) did not make recommendations for similar apportionment of childhood and adult exposures to carcinogens.

2.3 Definition of High Density Residential Land Use

The BC MoE has defined "high density residential" land use as part of a draft version of Procedure 8 (BC MoE 2011). The draft "high density residential" land use definition is as follows:

"High Density Residential – means the type of housing at a residential complex housing multiple persons or families in:

c) Individual units, including boarding houses, apartments, condominiums, lodges, and townhouses; or

d) Institutional facilities, including residential schools, hospitals, residential day care operations, retirement homes, prisons, correctional centres and community centres, but does not include commercial hotels or motels".

Further clarification on the definition of high density land use in terms of the derivation of high density residential soil and vapour standards is provided in Sections 2.4 and 8.1.

2.4 Study Scope

The scope of this protocol development and derivation is limited to modifying the components of the matrix numerical soil standards that are applicable to high density residential land use and are mandatory per CSR section 12(8), consisting of (1) intake of contaminated soil (human health) and (2) toxicity to soil invertebrates and plants (environmental health).

While groundwater is an important pathway for consideration, it is beyond the scope of the present protocol development as any potential changes to the Schedule 5 CSR standards for protection of groundwater would be applicable to all land uses, not just the high density residential soil standards.

In British Columbia, the soil vapour intrusion pathway is evaluated using the Schedule 11 generic numerical vapour standards, which are provided for agricultural/urban park/residential use, commercial use and industrial use scenarios, and the vapour attenuation factors provided in Technical Guidance 4 (BC MoE 2010b), which are provided for agricultural/urban park/residential use and commercial/industrial use scenarios. The vapour attenuation factor is defined as the indoor air concentration divided by the soil vapour concentration at the point of interest. As described in Section 9.0 of this report, a protocol is proposed for the derivation of attenuation factors to reflect high density residential building characteristics. Land use scenarios for application of the Schedule 11 standards are also discussed.

The primary focus of this protocol development (consistent with contracted work scope) with respect to land use scenarios are residential land use scenarios involving individual units, as defined in Section 2.3 above. A limited assessment of institutional scenarios has also been completed for initial consideration by BC MoE.

3.0 LITERATURE REVIEW SCOPE

3.1 Introduction

A literature review was conducted to determine whether other regulatory jurisdictions have developed soil or vapour standards for high density residential scenarios, and to obtain literature on specific technical issues. Data sources included:

- Previous CSST reviews and protocols prepared by BC MoE;
- Federal government agencies (*e.g.,* Canadian Council of Ministers of the Environment [CCME]; Environment Canada);
- Provincial government ministries of environment (*e.g.,* Ontario Ministry of the Environment, Alberta Environmental Protection);
- Primary literature (through Web of Science searches) including books and peer-reviewed journal articles; and
- International regulatory jurisdictions including various regulatory agencies within the United States, Europe, New Zealand, Australia and Japan.

The Golder Risk Assessment Network and Remediation Network (*e.g.,* risk assessors and site remediation specialists located in various countries around the world) were also utilized to solicit information on relevant regulatory contacts outside of Canada. The literature obtained for this project is listed in Appendix A. Selected literature is reviewed in Section 4.

4.0 BACKGROUND INFORMATION REVIEW

Background information from environmental agencies in Canada, United States, New Zealand, Australia, the Netherlands and United Kingdom, and research studies on child activity patterns is provided in the review below. While there is important background information on risk assessment guidance published by the U.S. Environmental Protection Agency (EPA), in common with Canadian jurisdictions, the literature review indicated no specific reference to generic high density soil standards by U.S. EPA. However, empirical vapour intrusion data published by the U.S. EPA have been consulted in determining soil vapour standards for high density land use.

4.1 Canadian Federal and Provincial Governments

Canadian federal agencies have not developed high density residential standards. Likewise, we are not aware of any Canadian provinces that have developed high density standards.

The Province of Ontario does not specifically have a high density residential standard, but as part of their Modified Generic Risk Assessment (Tier 2) process, the soil and groundwater standards for the soil vapour intrusion pathway may be multiplied by 100X for a ventilated garage scenario (Ontario MOE, 2009).

4.2 New Zealand High Density Soil Standards

New Zealand (NZ) Ministry for the Environment (MfE) recently published a background document (NZ MfE, 2010) to soil standard development that describes a risk-based methodology for deriving soil contaminant concentrations protective of human health. The land use scenarios for which soil standards have been established are:

- Rural residential/lifestyle block 10% produce;
- Residential 10% produce;
- High-density residential;
- Recreation; and
- Commercial / industrial outdoor worker.

Soil standards are developed for eight elements and six non-volatile organic compounds or groups of compounds. Soil standards are derived for the soil ingestion, produce consumption and dermal exposure pathways. Volatile compounds and the vapour intrusion pathway are not included in the soil standards. The soil standards are back-calculated assuming an acceptable hazard quotient of one for threshold substances and an acceptable incremental lifetime cancer risk of $1x10^{-5}$ when risks are summed for all applicable exposure pathways.

The NZ protocol is, in part, based on the U.S. Environmental Protection Agency (EPA) approach for the derivation of their soil screening levels, although several parameter values to the risk characterization equations are modified. The NZ age-groups are one to six years and seven to 30 years. A one to six year-old child is the critical receptor for non-threshold substances for residential and recreational scenarios. An 'adult', seven to 30 years, is the critical receptor for worker scenarios. For both the residential and industrial/commercial scenarios, the exposure duration is 20 years. For non-threshold substances, the twenty-year exposure is amortized over a lifetime, which is assumed to be 75 years.

The NZ high density scenario includes townhouse multi-unit dwellings and high-rise apartments. Multi-unit dwellings are considered less likely to have gardens than separate houses and the gardens that do exist will tend to be small ornamental gardens, limiting the opportunity for soil contact. Significant growing of vegetables is not expected and thus not included in the soil derivation protocol for the high density scenario.

The NZ protocol indicates there is little or no data for deriving exposure parameters for residential scenarios other than the standard (Residential 10% produce) scenario, and therefore professional judgment must be resorted to. The differences between the standard and high density residential scenarios are limited to different assumptions for soil ingestion and soil adherence factors. For both factors, the standard residential assumptions are divided by approximately a factor of two, as summarized in Table 1. The NZ protocol includes a detailed discussion on the basis for the selection of standard residential soil ingestion values.

Table 1: NZ Soils Standards with Different Exposure Parameters for Standard and High Density Residential Land-use

Parameter	Receptor	Residential 10% Produce	High Density Residential
Soil ingestion rate (mg/day)	Child	45	25
	Adult	25	15
Soil adherence factor (mg/cm^2)	Child	0.04	0.02
	Adult	0.01	0.005

4.3 Australia

Federal management of contaminated sites in Australia is provided by the National Environmental Protection (Assessment of Site Contamination) Measure (NEPM) (NEPC,1999a,b,c,d). One of the exposure scenarios under the NEPM is a high density scenario, defined as follows: "*Residential with minimal soil contact (includes dwellings with fully and permanently paved yard space, e.g., high-rise apartments and flats)".* The Australian soil standards for standard residential use is based on a two-year old child receptor and soil ingestion rate of 100 mg/day and body weight of 13.2 kg. The soil standards for the high density residential scenario are not calculated in detail, rather, a simple factor approach based on judgment is used where the residential standard is divided by a default exposure ratio (DER) of 0.25 to calculate the high density standard.

4.4 Netherlands Soil Standards

In the Netherlands, soil policy is administered by the Ministry of Housing, Spatial Planning and the Environment, which issues ***Soil Remediation Circular*** (last updated in 2009) describing the allowable concentrations of a wide range of contaminants in soil and groundwater, as well as describing the decision-making process to determine whether remediation is urgent or not (Rijksinstituut voor Volksgezondheid en Milieu (RIVM) (National Institute for Health and Environment), 2009). The Dutch have a single set of standards protective of human and ecological health irrespective of land uses. Within this framework, however, there are ***Target Values***, baseline concentration values below which substances are known or assumed to not affect the natural properties of soil (essentially background values); ***Intervention Values***, the maximum tolerable concentration above which remediation is required; and ***Indicative Levels for Serious Contamination*** for some specific contaminants.

The Dutch ***Soil Quality Decree*** (2007-11-22) and ***Soil Quality Regulation*** (amended 1-4-2009) apply to the use of building materials, soil and dredged materials on land, as well as aquatic sediments. The foundation of the Soil Quality Regulation is based on seven functions of soil relating to different land uses (agricultural, residential and industrial), crop consumption, and potential for children's play areas. The seven different functions were reduced to three functions to simplify the Regulation, as follows:

Background Values	Agriculture Nature conservation Vegetable gardens/allotments
Maximum Housing Value	Residential with garden; Places where children play Green areas with ecological values
Maximum Industrial Value	Other green areas, development, infrastructure and industry

The ***Soil Quality Regulation*** provides ***Background Values***, ***Maximum Housing Values*** and ***Maximum Industrial Values*** for soil.

While the Netherlands soil standards do not provide soil standards for high density use, there are useful concepts describing soil function intensity and land use (SenterNovem, 2007).

4.5 UK Environment Agency

The UK Environment Agency defines a generic residential land use scenario in the technical background for the updated Contaminated Land Exposure Assessment (CLEA) model (UK Environment Agency 2009). In this model, they indicate that for residential land use, the generic scenario assumes a typical residential property consisting of a two-storey house built on ground-bearing slab with a private garden, which consists of a lawn, flowerbeds, and a small fruit and vegetable patch. There is no provision for a high density residential land use in the CLEA model. The occupants are assumed to be parents with young children, who make regular use of the garden area. Some key assumptions amongst others are: the critical receptor is a female child (aged zero to six years old) with an exposure duration of six-years; and exposure pathways include direct soil and indoor dust ingestion, consumption of home grown produce, consumption of soil adhering to home grown produce, skin contact with soil and indoor dust, and inhalation of indoor and outdoor dust and vapours.

4.6 NCCEH Report on Child Activity Patterns

The following is a summary of the research study of child activity patterns conducted by the National Collaborating Centre for Environmental Health (NCCEH) for BC MoE (Lencar and Copes, 2009). Research into the development of a Risk Assessment Model for multi-family residential sites by the NCCEH identified knowledge gaps on time activity patterns for children under 14 years old and especially children under 6 years old. Three prior surveys were reviewed and one pilot survey of a daycare at the University of British Columbia (UBC) was conducted (referred to as UBC Child STÆPS).

The NCCEH report summarizes the results of the previous surveys by Statistics Canada General Social Survey 2005 (GSS), Health Canada's Canadian Human Activity Patterns Survey (CHAPS), and the U.S. EPA's National Human Activity Patterns (NHAPS). The key findings of the Canadian surveys in regards to the time spent outdoors by children under the age of 14 are presented in Table 2.

The CHAPS survey was conducted in 1994 and 1995 in four major metropolitan areas in Canada and includes time activity patterns for children living in detached houses, apartments and townhouses. Three different age groups under 14 were targeted: 6 years old or younger; 7 to 11 years old; and 12 to 14 years old. The time activity patterns are presented for all four areas ("Canada-wide") as well as the Vancouver metropolitan area alone (note that the number of dwellings surveyed for the Vancouver area is limited).

The GSS survey was conducted in 2005 and includes time activity patterns for children living in detached houses, and low-rise and high-rise apartments. The number of children less than 15 years of age used in the analyses is 804 for all building types (note that the number of dwellings surveyed was less than the number of children, because multiple children live in dwellings). In this survey, there is no information regarding where the garden is located (*i.e.*, proximity of garden to the residence, neighbourhood garden, balcony/patio garden).

The UBC survey (UBC Child STÆPS) was conducted in 2008 and 2009 and includes time activity patterns for detached houses, townhouses, and low-rise and high-rise apartments. Children between 18 months and 6 years old were targeted, because they were deemed to be most susceptible to coming into contact with soil. Although 80 daycares were contacted for participation in the survey across British Columbia, only 17 daycares at UBC participated (of the 220 children enrolled, only 25 parents participated in the survey for a total of 42 children). Some of the survey questions were aimed at the type of surface a child was in contact with while outside. Surfaces were categorized as natural (either grass, sand, gravel, dirt, wood, mulch); mixed natural if the child was in contact with a mixture of natural surfaces; man-made if the surface was pavement, concrete, rubber, tiles; and no contact, if the child was in a stroller or on a bike.

The results of all surveys indicate that children spend time on the order of a few hours outdoors per day, whether time spent is at home or elsewhere. For the majority of categories in all surveys, most of the time outdoors is reported to be spent not at home. Children living in detached homes and townhouses spend time outside at home either in or not in a garden. However, children living in apartments do not appear to spend time outdoors at their home. This may be a function of many apartments not having gardens or play areas as part of the apartment complex. Children living in apartments do spend time outdoors not at their homes, likely at neighbourhood or school parks. There are not large differences in the time spent outdoors in gardens by children in both detached houses and townhouses. However, the results of the UBC survey indicate that children living in detached homes are in contact with natural surfaces when in the garden, while children living in townhouses are only in contact with man-made surfaces (when interpreting these trends it is important to note that the number of respondents for the UBC survey was low and should not be considered as statistically representative of the Vancouver area).

Table 2: **Summary of Time Spent Outdoors from Available Surveys (Lencar and Copes, 2009) In Mean Number of Minutes Per Day**

Description	Outside at Home in Garden	Outside at Home not in Garden	Outside not at Home
GSS (<14 years old)			
Single detached house (N=365)	86.1(N=9)	121.0 (N=5)	94.4 (N=60)
Low-rise (<5 stories) (N=23)	-	-	117.1 (N=7)
High-rise (>=5 stories) (N=13)	-	-	27.5 (N=2)
UBC (1.5 – 6 years old)			
Single detached house (N=14)	15* (N=1)	0 (N=0)	91.6 (N=13)
Low-rise (<5 stories) (N=12)	- (-)	60 (N=1)	101.2 (N=10)
High-rise (>=5 stories) (N=3)	- (-)	- (-)	128.3 (N=3)
Townhouse or row-house (N=11)	30* (N=1)	12.5 (N=2)	156.5 (N=10)
CHAPS (≤6 years old) – Canada wide			
Single detached house (N=176)	41	5	69
Apartment (N=47)	25	4	43
Townhouse (N=22)	48	4	47
CHAPS (7-11 years old) – Canada wide			
Single detached house (N=117)	50	7	86
Apartment (N=11)	0	0	116
Townhouse (N=10)	97	0	80
CHAPS (12-14 years old) – Canada wide			
Single detached home (N=75)	25	2	102
Apartment (N=8)	0	0	124
Townhouse (N=7)	68	0	142
CHAPS (≤6 years old) – Vancouver Metropolitan Area			
Detached house (N=47)	22	10	91
Apartment (N=5)	0	3	76
Townhouse (N=6)	54	11	75

Description	Outside at Home in Garden	Outside at Home not in Garden	Outside not at Home
CHAPS (7-11 years old) – Vancouver Metropolitan Area			
Detached house (N=2)	30	0	126
Apartment (N=27)	56	14	91
Townhouse (N=4)	56	0	20
CHAPS (12-14 years old) – Vancouver Metropolitan Area			
Detached house (N=16)	21	0	60
Apartment (N=0)	-	-	-
Townhouse (N=0)	-	-	-

Notes:
The number of children for each category is shown in brackets.
*Available information on surface type indicates natural for the single detached house and man-made for the townhouse or row-house.

5.0 URBAN DEVELOPMENT CHARACTERISTICS AND SELECTED BYLAWS

The development of meaningful high density land use standards requires an understanding of the nature of urban development and the potential for exposure to site contamination. The purpose of this section of the report is to provide background information on urban development through an overview of selected aspects of zoning and development plans for three cities (Vancouver, Victoria, North Vancouver) and observations of the authors. Similar characteristics are expected for other areas of the Province of BC. A related question addressed is whether a definition of high density land use could be tied to zoning bylaws and practices.

5.1 City of Vancouver

The City of Vancouver Zoning Bylaw 3575 is a collection of regulations that govern how development may occur in the City of Vancouver. The Bylaw includes General Sections, District Schedules, Comprehensive Districts (which include Official Development Plans (ODPs)), General Schedules, Appendices and an Index. The District Schedules describe requirements for different generic land uses and include nine Multiple Dwelling District categories (*i.e.*, multiple dwellings include apartments). Official development plans are available for False Creek, False Creek North, Downtown, Central Waterfront, Downtown Eastside/Oppenheimer, First Shaughnessy, Southeast Granville Slopes, and Coal Harbour zoning areas. Under the Community Visions Program (started in 1997), planning documents have been prepared for different communities in the City that describe the type of development envisioned for each area.

Only one Multiple Dwelling District Schedule (RM-6) addresses “high-density” land use. There is no minimum number of storey’s or building height stipulated under the RM-6 schedule. There are no references to requirements or prohibitions for landscaped areas, gardens or open spaces in the RM-6 Schedule, although a children’s playground is specifically allowed as a land use. Several other Multiple District Schedules address medium-density land use.

Recent City of Vancouver ODPs provide insight about the nature of new multiple dwelling developments. The East Fraser Lands ODP (Adopted by Bylaw No. 9393, December 12, 2006) describes an open space network that is to “consist of a diverse and connected open space network to include urban plazas, large civic parks, active playing fields, ecological spaces, greenways, and neighbourhood greens”. The ODP also describes that on residential streets “…building setbacks are to provide for front entry gardens and a comfortable transition from public to private space while enabling a close relationship between dwelling and street.”

Schedule A of the Southeast False Creek Official Development Plan (April 2007) includes a reference to landscaping as follows;“…further goals, at the time of CD-1 re-zonings, are to seek edible landscaping within public spaces in specified locations, and to explore other opportunities, through design guidelines, for garden plots”. A report by Holland Barrs Planning Group (2007) describes how urban agriculture (UA) could be part of the Southeast False Creek development.

The City of Vancouver “*High-Density Housing for Families with Children Guidelines*” (1992) indicates that “landscaping should be designed to create varied spaces within a large common open space and to use a mixture of hard and soft surfaces. Materials should be selected to be interesting and safe.”

Mr. Neal LaMontagne, City of Vancouver planner (personal communication, February 9, 2011) indicated that the re-zoning requirements for new developments are considered on a site specific case. The urban design perspectives are considered rather than a specific ratio of green space to development area for the re-zoning of each development. Many new high density developments include a playground; however, the location of a playground depends on the scale of the land area (*e.g.*, a playground may be situated above a parking garage due to space limitations).

There is also a new trend towards incorporating urban gardens with edible plants in high density developments (*e.g.*, Southeast False Creek and East Fraser Lands), for which the City Council adopted guidelines in 2009 to specifically address shared garden plots and edible landscaping (City of Vancouver, 2009). As part the design considerations, the guidelines specifically state "Soil should be tested for toxins (heavy metals, salinity and hydrocarbons) prior to being used in garden plots."

5.2 City of Victoria

The City of Victoria Zoning Bylaw 80-159 includes General Regulations, Definitions, Common Zones (that apply to larger districts or areas) and Uncommon Zones (that apply to a very few lots). In the Definitions, a "high density multiple dwelling" is defined as a "multiple dwelling that is not less than 21 metres in height". A "multiple dwelling" is defined as a building containing three or more single family residences. No additional references to "high density" were noted in the City of Victoria zoning documents reviewed.

Under Common Zones, there are five categories for multiple dwelling areas. For several Multiple Dwelling Zones, there are requirements for the maximum lot coverage for buildings. For example, under R3-1 and R3-2 Zones, Multiple Dwelling District, the maximum coverage is 20 to 30% depending on the number of storeys. For several Common Zones, there are also requirements for open site space and landscaping. For example, under R3-AM-1 and R3-AM-2 Zones, Mid-Rise Multiple Dwelling District, at least 30% of a site shall be open site space with landscaping (excluding driveways). No specific reference to children's play areas were noted in the City of Victoria zoning bylaws reviewed.

5.3 City of North Vancouver

Mr. Gary Penway, City of North Vancouver planner (personnel communication, January 20, 2011) indicated that there are different "levels" that guide development, which are linked to characteristic building types and maximum floor space ratios (fsr) described in the official development plan. Levels 1 and 2 apply to detached houses, duplexes or triplexes. Townhouses and garden apartments fall under Levels 3 and 4 categories, respectively. Mid-rise and high-rise developments are designated as Levels 5 and 6, respectively. Some garden apartments include an underground parking garage, while many mid-rise and high-rise apartments include an underground parking garage that is present across the entire property. Mr. Penway indicates children's play areas are part of many larger developments, but that in many cases the play area is situated on top of the parking garage. Given affordability issues, there are an increasing number of families with children living in apartments.

The City of North Vancouver Zoning Bylaw 6700 (1995) includes the following definitions for land use:

- **“High-Density Apartment Residential Use"** means a Residential Use where the Building or Buildings on a Lot are each Used For three or more Dwelling Units, in accordance with the regulations for High-Density Apartment Use specified in this bylaw;
- **"Medium-Density Apartment Residential Use"** means a Residential Use where the Building or Buildings on a Lot are each Used For three or more Dwelling Units, in accordance with the regulations for Medium-Density Apartment Residential Use specified in this bylaw; and
- **"Garden Apartment Residential Use"** means a Residential Use where the Building or Buildings on a Lot are each Used For three or more Dwelling Units in accordance with the regulations for Garden Apartment Use as specified by this bylaw.

For each land use, the size, shape and size requirements for buildings are specified. For garden apartment land use, the maximum lot coverage for above-grade buildings is 35% (*i.e.*, no more than 35% of the lot may be covered by buildings). An underground parking garage may extend below the entire property. For both low-rise and high-rise land use, the maximum lot coverage is 50%. There are also minimum set-backs for buildings from property lines. Garden apartments are a maximum of two storeys, low-rise apartments are a maximum of three storeys, while high-rise apartments are greater than three storeys. No specific reference to children’s play areas and gardens were noted in the City of North Vancouver zoning bylaws reviewed.

5.4 Discussion

Zoning bylaws and official development plans reviewed indicate that there is no consistent definition of high density land use. Instead, there is a spectrum of land uses under the multiple dwelling categories, with differing requirements depending on jurisdiction and zoning district. A high density land use definition tied to zoning definitions (for jurisdictions with such a definition) would be relatively restrictive and would preclude medium density land use consisting of several storey apartments.

Zoning bylaws, development plans and observations indicate that medium to high density development should not be viewed as necessarily associated with lot-line to lot-line development and paved surfaces. Instead, the characteristics of medium to high density land use developments vary. Recent developments in the City of Vancouver include medium to high density use combined with open space and landscaped areas. Some developments combine podium-style developments where there is a row of townhouses with small gardens in front of multi-storey apartments. Recently, there has been greater interest in urban agriculture and integration of garden plots within a higher density land use. Land use planning is variable among municipalities and the extent of integration of development into natural landscapes (sustainability practices) depends on the community consensus.

Many new high rise apartments include an underground parking garage, which is often below the entire building footprint. However, many older apartments in, for example, the west end of Vancouver, do not include an underground parking garage. In Richmond, apartments do not typically include underground parking due to the high (shallow) water table.

Townhouse developments also vary significantly. Older townhouse units often include small gardens where it is possible to grow small quantities of vegetables. Newer townhouse developments, in some cases, are completely covered with buildings and parking areas and do not include any landscaped areas.

6.0 HUMAN HEALTH SOIL INTAKE PATHWAY CONSIDERATIONS FOR HIGH DENSITY RESIDENTIAL STANDARD

In the case of soil intake by humans, many soil quality guidelines in Canada and international jurisdictions are based on the results of a series of tracer element studies that were published over the last 20 years. Based on the most recent analyses, average soil ingestion rates reported in the tracer studies would seem to be in the range of 30 to 40 mg/day for toddlers and children up to 8 years of age (Stanek and Calabrese, 2000; Stanek *et al.*, 2001; Davis and Mirick, 2006). For adults, soil tracer studies have been much less extensive; however, average soil ingestion rates for non-occupationally exposed adults seem to range from 10 mg/day (Stanek *et al.*, 1997) to 38 mg/day (Davis and Mirick, 2006). In the case of both the BC MoE and Health Canada approaches for standards setting, the average soil ingestion rates have been assumed to be 80 mg/day for toddlers and 20 mg/day for adults (BC MoE, 1996 (CSST Procedures); Health Canada, 2009). This is in contrast to the U.S.EPA assumed soil ingestion rate for toddlers of 200 mg/day (U.S. EPA, 2008a).

In directly using the results of the tracer element studies, a dilemma that arises is that these studies provide little insight as to how soil ingestion might relate to the amount of time spent in the outdoor environment, or in a relevant outdoor micro-environment (*e.g.*, playground or sandbox). As a result, many health agencies (*e.g*., Health Canada, 2009) have endorsed policies where the assumed daily rate of soil ingestion occurs from a site regardless of the amount of time spent in areas where ingestion could occur; however, it is logical to expect that the amount of soil ingested, and certainly the likelihood that soil ingestion would actually occur, would be time-dependent to some degree.

A review of the literature has not found any soil ingestion rate studies that are specific to high density residential sites. Nevertheless, it is possible to make an argument that lower soil ingestion rates should apply to soils that are less likely to be contacted on an "hours per day" and/or "days per week" basis. This approach of using hand to mouth activity as a reflection of soil ingestion rates dates back as far as Hawley (1985), but can be updated with more recent input parameters and consideration of both deterministic and probabilistic techniques. Expressed in its most simple form, soil ingestion rates can be estimated as follows:

Soil Ingestion = Soil Adherence to Hands x Surface Area Inserted into Mouth x Frequency of Hand to Mouth Activities x Hours per Day in Contact with Soil

A more complicated version of this equation has been proposed by Wilson *et al.* (in preparation); however, the general attributes of the equation suggest that soil ingestion rates are likely to be time-dependent and likely a function of hand-to-mouth activity. Other researchers that have supported soil ingestion rates as a time-dependent function include Özkaynak *et al.* (2011).

Although it was considered to be beyond the scope of this document to critically review and derive new soil ingestion rate estimates for high density residential sites, the following concepts were considered to be reasonable for time spent in contact with soil:

- Based on professional judgment, it would seem that the areas within high density residential sites where play is encouraged (*e.g.*, backyards of townhomes, playgrounds) could be used at roughly the same intensity as typical residential and parkland sites. As a result, there seems to be little justification for altering the time spent and/or soil ingestion rates for these areas.

- For other areas of high density residential sites where soil is present and play is not specifically encouraged (*e.g.*, ornamental gardens, common areas with grass and landscaping), it would seem that the hours per day and perhaps days per week in contact with outdoor soils would be lower than typical residential and parkland uses. At such areas, there seems to be a lower likelihood of a toddler specifically sitting down and playing in the soil and having as much hand-to-mouth activity as in areas where play activities are encouraged. As a result, there does seem to be justification for reducing the time spent and/or soil ingestion rates for these areas.

Consequently, it was concluded that for high density residential sites where play areas do not exist, the human health soil intake pathway could be considered to be lower than at typical residential or parkland sites. Specific values for consideration are discussed in Section 8.2.3.1.

7.0 SOIL VAPOUR INTRUSION PATHWAY CONSIDERATIONS FOR HIGH DENSITY RESIDENTIAL STANDARD

The purpose of this section of the report is to review background information on factors that affect soil vapour intrusion into high density residential buildings focussing on apartments or condominiums, with a comparison to detached buildings provided for baseline purposes. Gaseous emissions arising from water or sediment, per the CSR Section 1 definition of "vapour" are not considered to be operable pathways at typical high density urban sites, or are captured as part of soil vapour.

The key building factors that control soil vapour intrusion are the pressure difference between the enclosed space and subsurface, the fresh air exchange (ventilation) rate, and the mixing height for vapours inside the building. The condition of the subsurface building envelope and potential openings (*e.g.*, utilities, cracks, openings) and preferential pathways in the building (*e.g.*, elevator shafts, ducts) may also have a significant influence on soil vapour intrusion and indoor vapour concentrations.

The primary codes governing ventilation rates and building pressures for various occupancies in British Columbia are the National Building Code of Canada (2010) and BC Building Code (2006, with amendments to October 2010), which in turn reference ANSI/ASHRAE 62.1, "*Industrial Ventilation – A Manual of Recommended Practice*" by the American Conference of Governmental and Industrial Hygienists (ACGIH) and CAN/CSA-F326 as minimum requirements. These standards identify air quality, ventilation rates and zone pressures for all commercial, institutional, research and residential occupancies, although the BC Building Code does not specifically reference health care facilities, retirement homes, prisons and correctional facilities. Health care facilities are governed by CSA Z317.2 "*HVAC For Health Care Facilities*". Standards for ventilation rates and air quality for retirement homes, prisons and correctional facilities are usually provided by the provincial authority having jurisdiction, but may sometimes simply refer back to ANSI/ASHRAE 62.1.

7.1 Detached House and Townhouse

7.1.1 Ventilation

Ventilation of buildings occurs through three processes:

- mechanical or forced ventilation;
- natural ventilation through open windows or doors; and
- infiltration or unintentional introduction of air through cracks or other openings due to pressure differentials.

In Canada, the minimum required outdoor air 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 air changes per hour (ACH). In the U.S., the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) 62.2-2007 residential standard for whole building ventilation rate is 5 CFM/person (2.5 L/s/person) plus 0.06 CFM/ft^2 (0.3 L/s/m^2) (ASHRAE, 2007a).[3] The BC Building Code Part 9 specifically references CAN/CSA-F326 as the minimum standard for dwelling units so it can be assumed that new residential construction will comply with this code. Mechanical ventilation through the use of a heat recovery ventilator is required to meet minimum ventilation rates in energy-efficient "tight" houses (*e.g.,* "R-2000" or "Energy Star" in Canada). However, mechanical ventilation systems are often operated at less than the design or installed capacity (Figley, 1997; Hamlin and Gusdorf, 1995). For example, energy-efficient houses that have mechanical ventilation supplied through a heat recovery ventilator may have ventilation rates as low as 0.1 ACH (Fellin and Otson, 1996).

7.1.2 Building Pressures

Detached houses or townhouses may be positively or negatively pressurized relative to ambient air depending on building construction and operation, and weather conditions. Numerous factors affect pressures including temperature differences between indoor and outdoor air, the number of storeys, degree of air leakage between floors, heating system type and operation, and the presence of chimneys, flues, exhaust fans, vents, elevator shafts and sumps.

Of particular importance is the "stack effect" that occurs during the heating season as a result of hot air rising in a building and leaving near the top of the building (*e.g.,* through a chimney, leaky attic, exhaust vent). This creates a negative pressure in the building (below the neutral pressure line), thus drawing outdoor air and soil gas into the building through openings within the lower regions of the building (*i.e.*, doors, windows, cracks and openings in building foundation). When outdoor temperatures are greater than indoor temperatures, the pressure regime is reversed.

The force of wind on the side of a building will cause a positive pressure on the windward side of the building and a negative pressure on the lee side, thus potentially resulting in a depressurised building. Inadequate fresh-air for furnace combustion or leaking ducts may also result in negative pressures.

Literature studies indicate that building depressurizations (relative to ambient air) during the heating season for houses with basements typically range from 2 to 10 Pa, but may be as high as 15 Pa (Figley, 1997; Hers *et al.*, 2001). Experience on monitoring houses in Canada during the heating season indicates that, on average, basements of houses are depressurized relative to outdoor air. There is often a diurnal pattern to pressure data, but considerable data scatter may be introduced by the operation of the furnace or weather conditions. During warmer weather, variable positive and negative pressures may be observed during the day, but on average, the pressure may be near neutral.

[3] Assumes natural infiltration credit of 2 CFM/100 sq.ft. (if not applicable add 2 CFM/100 sq. ft.). The calculated air change rate is 0.3 ACH for a 1000 sq.ft. single storey house with 4 person occupancy and 8 ft. ceiling.

The CSA F326 standard for "*Residential Mechanical Ventilation Systems*" requires that the ventilation system, when operating at full capacity and at the same time as an appliance and any other exhaust devices with a capacity of 75 L/s or greater, not depressurize the residence more than 5 Pa. This limit (of 5 Pa) may be exceeded if the combustion appliance has been rated for a higher level of depressurization. The F326 standard also limits the positive pressure to 10 Pa that may be brought about by intake flows that are greater than exhaust flows. The BC Building Code in Section 9.32.4 (Additional Protection Against Depressurization) has provisions for additional make-up air when an appliance discharges air to the exterior of the building at a rate exceeding 0.5 ACH, when there is a vented appliance subject to back drafting or when the building is in an area where soil gas is deemed to be a problem.

7.1.3 Building Envelope and Preferential Pathways

Soil vapour can migrate through small cracks and openings in the building envelope. Soil vapour intrusion rates may vary depending on type of foundation, which include basement, slab-on-grade, crawlspace or earthen floor construction. For houses with concrete slab construction, there is often a perimeter edge crack between the foundation wall and slab. Utility penetrations of the building envelope, drains and sumps, and expansion joints also represent potential entry points for soil vapour intrusion.

7.2 Apartments

7.2.1 Ventilation

Past practices for the design of ventilation rates for apartment dwelling units was typically based on providing sufficient make-up fresh air to match exhaust rates for bathroom and kitchen fans. The make-up air is introduced into hallways under positive pressure and air enters dwelling units through the crack below the door or via a grille. The fans typically exhaust air from the dwelling units through a wall or ceiling vent. In some cases, where a central continuously-operating washroom exhaust system is installed, a heat recovery ventilator is used to pre-heat incoming fresh air. The BC Building Code; however, has identified that this system is not effective in ensuring that minimum ventilation rates are maintained through all dwelling units and has appended section 6.2.2.2 to **recommend** that the central corridor ventilation be ducted to each dwelling unit and **require** that each room within the dwelling unit be mechanically ventilated to CAN/CSA-F326 to ensure ventilation throughout the unit even when the exhaust fans are not operational.

The minimum air exchange rate based on CAN/CSA-F326 will vary depending on the number of rooms within the dwelling units but will work out to 64 cfm (30 L/s) of supply air for a two bedroom 800 ft^2 apartment. The corridor make up air unit, however, is usually sized to make up the air exhausted by the washroom fan and the range hood for a total of 136 cfm (65 L/s) per dwelling unit. The minimum dwelling unit ventilation rate will be ducted into the unit, with the remainder supplied to the corridor to provide the minimum ventilation rate in the corridor while keeping the pressure in the dwelling unit negative in relation to the corridor, thus preventing cooking or smoking odours from infiltrating into the corridor. If the washroom fan were operating continuously then the dwelling unit would realize approximately 0.6 ACH. Exhaust fans within the dwelling unit, however, operate intermittently, so the average total air exchanged within the dwelling unit would be less than 0.6 ACH, but likely greater than ventilation rate estimated for a detached dwelling (0.3 ACH). Units constructed to older versions of the building code that use systems that supply outside air into the corridor and rely on exhaust fans to draw it into the dwelling unit will realise approximately the same ventilation rate, but not necessarily throughout the entire dwelling unit. The fresh make-up air will tend to short cycle via the shortest path to the exhaust fan.

Given that air exchange will occur through natural ventilation and infiltration, a representative range is considered to be 0.35 to 0.45 ACH.

7.2.2 Building Pressures

Consideration of building pressures is an important part of apartment building design. There are code requirements with respect to pressurization of certain parts of the building; for example, stairwells should be positively pressurized for fire protection and underground parking garages should be negatively pressurized with respect to the above-grade building to avoid entrainment of vehicle exhaust in the building airspace.

Good design practice addresses comfort and odour issues. Apartment dwellings are typically designed to be under a slightly positive pressure relative to outdoor air to the extent possible to avoid cold air drafts, but at the same time at a slight negative pressure relative to hallways to minimize odour issues. Excessive positive pressures are not desirable because warm, moist air will be forced through the exterior building envelope causing moisture accumulation or condensation and structural problems.

Notwithstanding the above codes and practices, pressure gradients caused by the stack effect present a significant challenge for ventilation design and pressure control. Particularly for tall buildings, the goal for building design is to avoid excessive positive or negative pressures during cold temperature extremes, with some practitioners suggesting +/-30 Pa as a reasonable goal with respect to limits for more extreme conditions. Web-based literature cites accounts of odour issues in buildings where occupants can smell second-hand cigarette smoke from dwellings that are several storeys below, whistling noises in elevator lobbies, and moisture problems in the top floor of buildings where moisture-laden warm air moves through the building envelope often causing mould and material decay problems (*e.g.*, Woods, 2011). To reduce the stack effect, tall buildings incorporate a design practice involving the provision of airtight interior and exterior partitions, or compartmentalization of individual dwellings and floors, and the installation of in-suite ventilation systems (CMHC, 2005). To achieve compartmentalization, a unit air tightness of 2 L/(s-m^2) at 75 Pascals has been proposed (Lstiburek, 2005). The above measures reduce cross-floor or vertical leakage in buildings and the stack effect, although compartmentalization of certain parts of the building (*e.g.*, elevator shafts, garbage chute, ground floor entrance lobbies) may be more difficult (CMHC, 2005). Processes for air movement in buildings are summarized in Figure 1.

There is limited measurement data on the differential pressure between apartment buildings and outdoor air. Kalamees *et al.* (2010) report results of monitoring for a six-storey apartment located in Finland where data obtained in February through April on the daily average air pressure difference over the building envelope indicated a pressure on the first floor of -11 Pa (relative to outdoor air), on average, and pressure of -2 Pa on the fourth floor. Research by Richards (2005) includes detailed measurements for an eleven-storey apartment building in Saskatoon, Saskatchewan, Canada. When the outdoor temperature was -12^{o}C and wind speed was

7 km/hour, the pressure difference between the hallway and outdoor air was -12 Pa at the ground floor. Proskiw and Phillips (2008) report the results of characterization of the pressure regime and air movement patterns in multi-unit residential buildings in Winnipeg, Manitoba, Canada. Although no pressure data is reported, during the winter the neutral pressure line generally ranged between 0.7 to 0.9 times the height of the building, meaning most of the building was depressurized relative to outdoor air. CMHC (2005) report the operation of in-suite exhaust fans created a “significant” negative pressure in the suites tested (but no pressure data are provided).

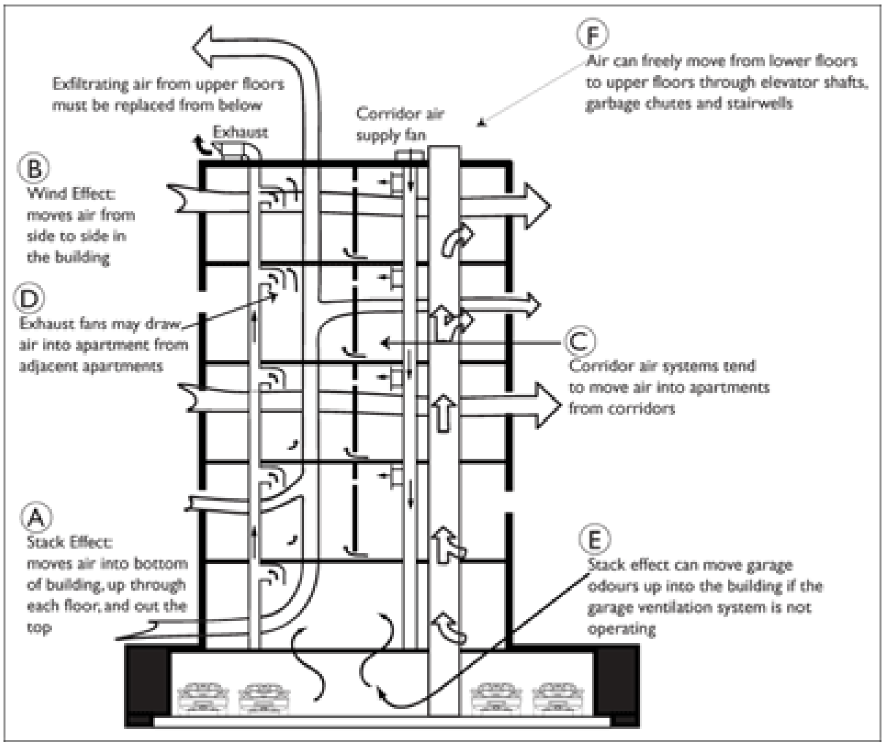

Figure 1: Processes for Air Movement within Buildings (CMHC, 2005)
http://www.cmhc-schl.gc.ca/en/co/reho/reho_002.cfm

7.2.3 Building Envelope and Preferential Pathways

For apartment building slabs, greater attention is usually paid to sealing cracks and expansion joints compared to detached houses, which would tend to reduce but not necessarily eliminate soil vapour intrusion. Utilities represent potential entry points for soil vapour intrusion regardless of building type. Many apartments will have perimeter drainage systems with sumps and catch basin networks that may act as preferential pathways.

Elevator shafts may represent both a preferential pathway for soil gas intrusion at the base of the building (a drain is often present in the elevator pit) and for upward movement of air within the building.

7.3 Parking Garages

Ventilation of enclosed parking garages is governed by the BC Building Code (Section 6.2.2.3). The ventilation systems as specified in the code are primarily concerned with limiting CO and NO_2 exposure in the garage and preventing infiltration of the same gases into adjacent dwelling areas. The ventilation system must provide a continuous supply of outdoor air of 0.75 cfm/ft^2 (3.9 L/s per m^2) during operating hours resulting in approximately 5 ACH for a 10 ft ceiling and must maintain a negative pressure in the parking garage relative to adjoining dwelling spaces. The code does, however, allow the system to be operated at a lower ventilation rate and have the higher rate activated by CO and NO_2 sensors. The low level ventilation rate is only required to maintain the pressure differential between the garage and adjacent dwelling spaces, which can be achieved with rates as low as 0.25 ACH during periods of non critical CO and NO_2 levels. The system would therefore operate at the low level ventilation rate on a continuous basis with intermittent periods of high level operation. While the BC Building Code references ASHRAE 62.1, with respect to parking garages it overrides in Section 6.2.2.1 the ASHRAE 62.1 requirement for continuous ventilation and supply of 0.75 cfm/ft^2 to a parking garage.

The BC building code does not specify a requirement for a vestibule at the elevator in the parking garage levels. ANSI/ASHRAE 62.1 points out that a combination of stack effects and poor sealing elevator doors can make it difficult to control the differential spaces between the garage and adjacent spaces resulting in air flows into the dwelling spaces. This must be considered when investigating possible vapour intrusion since most buildings will be constructed to meet minimum code requirements and not include elevator vestibules at parking garage levels.

For garages with intermittent high level of ventilation, the estimation of a representative air exchange rate requires consideration of hours of operation. If the garage with 10 ft. ceiling was ventilated at a high rate (5 ACH) for two hours per day, seven days a week and low rate (0.25 ACH) for remainder of the time, the average air change rate would be 0.64 ACH, not accounting for natural ventilation and infiltration (some parking garages may have open doors that lead to natural ventilation). If the high rate hours of operation were to increase to 4 hours per day, the average air change rate would increase to 1.04 ACH.

There is little measurement data of ventilation rates in parking garage; however, one study involving testing of seven garages to determine if design ventilation rates (5 L/s-m^2) were being met in garages was conducted by Krarti and Ayari (2001) with results presented in Table 3. The air exchange for the parking garages was estimated using a tracer (sulphur hexafluoride). As shown, the air change rates were variable ranging from as little as 1 to 8 ACH.

A representative range for air exchange for parking garages is considered to be 2 to 4 ACH.

Table 3: Summary of Ventilation Field Testing Results for Seven U.S. Parking Garages

ID	Location	ACH (Tracer)	Ventilation Rate (L/s-m^2) (Tracer)	Ventilation Rate (cfm/ft^2) (Tracer)	Maximum CO (ppm)	Average CO (ppm)
A	Denver	2.2-4.2	1.78	0.35	16	7
B	Denver	5.0-7.0	4.57	0.90	20	4
C	West Plains N.Y.	0.0-2.6	1.11	0.22	40	15
D	West Plains N.Y.	3.6-4.5	3.0	0.59	19	12
E	West Plains N.Y.	5.8-8.8	5.68	1.12	25	14
F	Rochester, MN	7.77	5.28	1.04	10	9
G	Mahtomedi, MN	0.9-1.02	2.43	0.48	12	1

Some parking garages may be open to outdoor air and thus will be ventilated naturally. Under the Ontario Building Code, an open-air storey of a parking garage is defined as: "*open-air storey means a storey in which at least 25% of the total area of its perimeter walls is open to the outdoors in a manner that will provide cross ventilation to the entire storey*."

7.4 Case Studies

7.4.1 Golder CMHC Study

Golder Associates was retained by Canada Mortgage and Housing Corporation (CMHC) to conduct a research project titled *Safe Housing on Lightly Contaminated Lands* (Golder, 2003). As part of this project, Golder conducted a study of vapour intrusion at an apartment at the Pacific Place site in Vancouver, B.C. The apartment includes three levels of underground parking. The ventilation system of the parking garage has a low and high fan setting and operates several hours a day when triggered based on carbon monoxide sensors. When operating, the design air change rate is 3 ACH (low fan setting) and 6 ACH (high fan setting).

A tracer test involving injection of helium below the ground floor slab of half the parkade (552 m^2) was conducted to evaluate the soil gas entry rate into the parkade. The test was conducted with the ventilation fan on a low setting and the measured pressure difference between parkade and outdoor air at -2.7 Pa (*i.e.*, the parkade was depressurized). The tracer test was conducted after the construction of the parkade was complete but prior to sealing of the concrete floor. The soil gas entry rate calculated from the tracer test was 3.3 L/min, which corresponds to 0.0060 L/m^2 of parkade area, or 0.0022 L/m^2-Pa when this is normalized to the pressure difference.

7.4.2 Confidential Study

A study was completed in the Metro Vancouver area that evaluated the ventilation rate within a parkade below a multi-story residential complex. A Vane Anemometer was used to measure the face velocity at the fan intake. A number of evenly spaced velocity readings were collected across the intake area and used to estimate an average air velocity. The average velocity was multiplied by the intake area and a fan flow rate was determined. The fan volume per hour was divided by the total parkade volume to estimate air changes for the parkade. Using this methodology, the estimated air changes ranged between 2.2 to 3.5 ACH.

7.5 Summary

Several key conditions influencing soil vapour intrusion are summarized for primary residential land use scenarios in Table 4.

Table 4: Summary of Conditions Influencing Soil Vapour Intrusion

Building Type	Typical Air Exchange Rate	Typical Building Pressures	Typical Building Envelope Conditions
Detached houses/townhouses	For homes of 2000 ft² to 5000 ft² with three to five bedrooms, two washrooms and one kitchen, the average air changes will be between 0.30 and 0.35 air changes per hour. The air change rate requirement will vary by the size of the house and the occupancy.	The pressure differences between building and ambient air can range between ±10 Pa, but may be a high as ±15 Pa for extreme weather conditions.	House building envelopes are leaky and the amount of leakage will depend on the construction and age of house.
Apartments	For apartments of 500 ft² to 1000 ft² with one to two bedrooms, one washroom and one kitchen, the average air changes will be between 0.35 and 0.45 air changes per hour.	The pressure differences can range between ±30 Pa, or even greater range at extreme weather conditions.	Expectation likely for reduced openings and more consistent construction practices compared to detached houses.
Enclosed Parking garages	Will depend on frequency of ventilation, under BC Building Code, intermittent ventilation to meet air quality requirements is acceptable; when operational, the design ventilation rate works out to approximately 5 ACH; the average air change will be less than 5 ACH, with 2 to 4 ACH proposed as reasonable range.	Parking garage pressure should be lower than dwellings above the parking garage.	Expectation likely for reduced openings and more consistent construction practices compared to detached houses.

Note: Residential schools and residential day cares are considered similar to detached house/townhouse category. Consideration of institutional land use scenarios is beyond the scope of the assessment in this table.

8.0 PROBLEM FORMULATION CONSIDERATIONS

8.1 Background and Technical Approach

This section of the report provides a summary of the conceptual exposure model for multiple land use scenarios that could conceivably be identified as a high density land use. There is no consistent definition or conceptual understanding of what constitutes a high density land use and the specific exposure pathways can vary widely depending on the specific urban development. A clear definition of each scenario is important to determine if the scenario has already been addressed under an existing land use, or if the scenario is sufficiently different to warrant separate consideration under a new high density land use. Scenarios that are functionally similar to existing land use exposure pathways should be excluded from consideration under the new high density land use to reduce unnecessary overlaps in land use definitions. An initial qualitative evaluation of the potential land uses proposed for high density land use under BC MoE Procedure 8 is provided in Table 5. This qualitative review considers the following exposure pathways:

- Soil ingestion by humans - As discussed in Section 2, the current CSR human health intake standards are based on exposure to a toddler through ingestion of soil (an adult receptor is also considered but exposure to a toddler is the driver and results in lower standards for most substances). For this reason, the qualitative evaluation below focuses on potential exposure frequency and landscaping, open space, and children's play areas.

- Soil vapour intrusion - The potential for soil vapour intrusion is assessed in terms of similarities between the building types considered, and detached houses, apartment buildings and commercial buildings. These three building types are chosen as reference buildings because there are already vapour attenuation factors derived for residential (detached house) land use and for commercial land use, and because an apartment building is selected as the default building type for the high density residential land use classification.

- Protection of soil invertebrates and plants - This exposure pathway is assessed in terms of similarities to residential or commercial land use. In general, the presence of vegetation used for human consumption (*e.g.*, vegetable gardens, fruit trees) is consistent with residential land use, while an emphasis on maintained ornamental landscaping is generally consistent with commercial land use. The likely spatial extent of undeveloped land may also be a factor that is considered when assessing the validity of the exposure pathway consistent with the B.C. screening-level risk assessment guidance (Protocol 13). Under Protocol 13, a screening process is provided for identifying potential terrestrial habitat. One of the questions under this screening process asks whether the site contains over 50 m^2 (where residential land use applies) or 1,000 m^2 (where commercial or industrial land use applies) of contiguous undeveloped land (vegetated land or bare ground). In Table 5, this screening question is used as a ***starting point*** to consider whether the development is similar to residential or commercial land use, given typical landscaping.

Table 5: Summary of Conceptual Exposure Model

Land Use Type	Description of Typical/ Characteristic Building(s)	Receptors and Exposure Pathways					Equivalent existing land use (if applicable)		
		Human Receptors	Landscaping and Open Space	Children's Play Area	Potential Exposure Frequency in Children's Play Area or Landscaped Area (when present)	Qualitative Evaluation of Vapour Intrusion Potential Relative to Baseline (detached house or apartment)	Soil Ingestion	Vapour Inhalation	Protection of Soil Invertebrates and Plants
Detached house or duplex (current residential scenario)	Typically one-two storey building, often including basement or crawlspace	Child and adult residents	Lawns and gardens (may include vegetable garden)	Yard	High frequency of use, potentially daily year round	Detached House	Residential	Residential	Similar to residential. Site may have greater than 50 m^2 of undeveloped land. Plants grown on-site may be consumed by residents.
Townhouse	Typically one to two-storey connected dwellings, sometimes including basement or crawlspace	Child and adult residents	Small lawns and gardens, lawns (may include small vegetable garden), some newer developments have limited or no landscaped or open space	Yard, if part of townhouse unit, many townhouse complexes also have children's playground	High frequency of use, potentially daily year round	Similar to detached house	Residential	Residential	Similar to residential. Site may have greater than 50 m^2 of undeveloped land. Plants grown on-site may be consumed by residents.
Boarding house (residential)	Multiple units in detached larger house	Child and adult residents	Same as detached house	Same as detached house	Same as detached house	Detached house	Residential	Residential	Similar to residential. Site may have greater than 50 m^2 of undeveloped land. Plants grown on-site may be consumed by residents.

Land Use Type	Description of Typical/ Characteristic Building(s)	Receptors and Exposure Pathways					Equivalent existing land use (if applicable)		
		Human Receptors	Landscaping and Open Space	Children's Play Area	Potential Exposure Frequency in Children's Play Area or Landscaped Area (when present)	Qualitative Evaluation of Vapour Intrusion Potential Relative to Baseline (detached house or apartment)	Soil Ingestion	Vapour Inhalation	Protection of Soil Invertebrates and Plants
Lodges[1]	Detached one or two-storey building	Adult workers, overnight guests and visitors	Minimal	Unlikely	Not applicable	Similar to commercial	Commercial or high density residential	Commercial or high density residential	Similar to commercial. Likely to be minimal undeveloped land, which typically would be less than 1000 m^2.
Apartments and Condominiums	Three-storey or higher buildings, which may include underground parking but do not include commercial at ground level	Child and adult residents	Ornamental landscaping, small grass strips, some developments may have small grass covered park-like areas. Vegetable gardens are not likely in most applications.	Some developments include children's playground	Moderate to high frequency, potentially daily up to seven days a week, but typical frequency is expected to be less than that for detached homes	Apartment	High density residential	High density residential	Similar to commercial in most instances with minimal undeveloped land; larger areas of undeveloped land, if present, are likely rarely greater than 1000 m^2.
Residential Schools	School building with dormitory; small school may be situated in house or house-like building	Child students and adult teachers	Play fields, ornamental landscaping, vegetable garden	Most will include children's playground	Moderate to high frequency, up to five days a week, but not year round	May be similar to detached house in some cases	Residential	Residential	Similar to residential. Site may have greater than 50 m^2 of undeveloped land. Plants grown on-site may be consumed by residents.

Land Use Type	Description of Typical/ Characteristic Building(s)	Receptors and Exposure Pathways					Equivalent existing land use (if applicable)		
		Human Receptors	Landscaping and Open Space	Children's Play Area	Potential Exposure Frequency in Children's Play Area or Landscaped Area (when present)	Qualitative Evaluation of Vapour Intrusion Potential Relative to Baseline (detached house or apartment)	Soil Ingestion	Vapour Inhalation	Protection of Soil Invertebrates and Plants
Hospitals	Typically larger multi-storey buildings	Child and adult patients, and adult workers	Ornamental landscaping, small grass strips	Some hospitals include children's playground	Low to moderate frequency, a few days a week, but only for a few months	Similar to commercial	High density residential	Commercial	Similar to commercial in most instances; larger areas of undeveloped land, if present, may be greater than 1000 m^2.
Residential day care	Typically detached house (see above) or house-sized purpose-built building	Child and adult residents and child patrons	Lawns and gardens, may include vegetable garden	Yard, may include playground	Moderate to high frequency, for child residents daily potentially up to seven days a week, child patrons daily up to five days a week	Similar to detached house	Residential	Residential	Similar to residential. Site may have greater than 50 m^2 of undeveloped land. Plants grown on-site may be consumed by residents.
Retirement homes	Range of building types, while typically similar to apartment, could include townhouse type developments	Adult residents, visitors and workers	Ornamental landscaping, small grass strips, some developments may include small park-like areas, although rare, may include vegetable garden	Unlikely	Low to moderate frequency, a few days a week by adult residents and workers of garden areas, where present	Similar to apartment, except when smaller townhouse developments	Residential	Residential (assuming townhouse developments could be present)	Similar to residential. Site may have greater than 50 m^2 of undeveloped land.

Land Use Type	Description of Typical/ Characteristic Building(s)	Receptors and Exposure Pathways					Equivalent existing land use (if applicable)		
		Human Receptors	Landscaping and Open Space	Children's Play Area	Potential Exposure Frequency in Children's Play Area or Landscaped Area (when present)	Qualitative Evaluation of Vapour Intrusion Potential Relative to Baseline (detached house or apartment)	Soil Ingestion	Vapour Inhalation	Protection of Soil Invertebrates and Plants
Prisons and correctional centres	Range of building types	Adult inmates and workers	Ornamental landscaping, often will include exercise or play field, possibly include vegetable gardens, could be highly variable	Not applicable	Moderate to high frequency inmates, daily up to seven days a week by inmates of exercise areas	Similar to apartment	High density residential	High density residential	Potential land use is highly variable, therefore difficult to define.
Community centres	Moderate to larger building, often multi-storey, building may be situated on or beside school grounds or urban park	Adult workers, adult and child patrons	Play field, parks and larger landscaped areas often present, but often are part of adjacent school or park), ornamental landscaping also present, vegetable gardens unlikely (community garden may be present)	Most will include children's playground	Low to high by child patrons ranging from infrequent visits to five days per week (*e.g.*, summer programs), workers may use park areas daily five days a week	Similar to commercial	High density residential (when playgrounds, fields and parks are excluded)	Commercial	Similar to commercial when attached play field, parks and landscaped areas are not included; given variability in land use potential ecological exposure is difficult to characterize. May have greater than 1000 m^2 of undeveloped land.

Note:
1. Lodge interpreted as fraternal lodge, consistent with City of Vancouver bylaw definition, with characteristics similar to a commercial building, and that the lodge is not used for overnight sleeping purposes.

The preliminary conclusions of the above analysis are that:

- Residential land use would apply to detached houses, townhouses, boarding houses, residential schools, residential day care facilities and retirement homes.
- High density or commercial land use, depending on scenarios and exposure pathways, would apply to lodges, hospitals, apartments and condominiums (greater than three-stories), prisons and correctional centres, and community centres (when playgrounds, fields and parks are excluded), providing there are appropriate exclusionary factors for certain site uses, as further described in Section 8.3.

8.2 Summary for Individual Scenarios

The exposure considerations are described in greater detail for the detached house or duplex, townhouse and apartment residential scenarios. The discussion was limited to these scenarios based on agreed-upon scope of work for this project. As warranted, it is recommended that further evaluation of other scenarios be conducted to better define land use characteristics.

8.2.1 Detached House or Duplex

The detached house or duplex scenario is the residential default for the CSST protocol and therefore does not fit the category of high density urban land use, but represents the baseline scenario to which other land use scenarios are compared to.

8.2.2 Townhouses

8.2.2.1 Ingestion of Soil

There are many townhouses with enclosed gardens (separate from common areas), where the ground cover may vary (*e.g.*, grass, dirt, flower beds, small vegetable plots), and where children may play on a frequent basis (*i.e.*, same frequency as a detached house). Many townhouse developments also include a children's playground in a common area. The characteristics of the playgrounds vary but usually they are constructed on top of imported materials consisting either of hard surfaces (*e.g.*, asphalt play courts) or softer surfaces (*e.g.*, gravel, wood chips, rubber mats). Particularly older townhouse complexes constructed when land costs were lower also may include a grass play field beside the playground. There would be potential for exposure to subsurface contaminated soils in townhouse gardens, and potentially also exposure in playgrounds and adjoining grass-covered parks where there is a minimal surface cover of non-contaminated imported materials.

Based on the above, no adjustment of the CSST procedures are recommended for evaluation of potential human health risks from soils. It is recommended that townhouses should be addressed in a manner similar to typical residential sites (ET = 1.0).

8.2.2.2 Vapour Inhalation

There is little basis for different vapour attenuation factors compared to a detached house. Construction practices and ventilation rates will be similar for townhouses and detached houses, and some townhouses include basements. The receptors and exposure assumptions are identical to the detached house or duplex scenario.

8.2.2.3 Protection of Soil Invertebrates and Plants

A townhouse shares the same ecological exposure pathways as a single-family home. This land use scenario may still have sufficient undeveloped land (*i.e.*, greater than 50 square meters per Protocol 13) to allow for ecological receptors for residential land uses. The installation of gardens or other plantings for human consumption is plausible and therefore, this scenario is equivalent to the existing residential land use. As a result, there are no recommendations for adjustment of the CSST procedures.

8.2.3 Apartments and Condominiums

8.2.3.1 Ingestion of Soil

The characteristics of apartment developments vary widely. The landscaping at many apartment complexes is limited to small grass-covered strips or ornamental landscaping. Many new high-rise apartment complexes have underground parking that extends from lot-line to lot-line, although many older apartments (*e.g.*, west end of Vancouver) do not have below-grade parking. Although less common, there are, nonetheless, a significant number of apartment complexes that include somewhat larger grass-covered lawns and landscaped areas. Examples include apartments in the Steveston area of Richmond with grass-covered areas, water features and benches, similar small park-like areas that have been developed at apartments along the Fraser River in east Vancouver, and in the southeast False Creek area of Vancouver. At some sites, these landscaped areas are built up where imported fill has been used to “shape” the landscape, while at other sites the landscaped ground surface is approximately at the historical grade of lands that were developed.

Many apartment complexes include a children’s playground, which is encouraged as part of larger developments. The playgrounds are typically constructed on top of imported materials consisting either of hard surfaces (*e.g.*, asphalt play courts) or softer surfaces (*e.g.*, gravel, wood chips, rubber mats). A key consideration is the frequency of use of children’s playgrounds and small park-like areas by children and toddlers. There are limited data on child activity patterns for children’s play areas and frequency of use for high density land use. The Lencar and Copes (2009) study involved a survey of parents of children that used a daycare at the University of British Columbia and found that children living in high density apartments did not spend time at “home” outside (either in a garden or not in a garden), but did spend time outside of the home in parks and gardens. The study was limited in the number of families interviewed, and also it is not known whether families interviewed resided in apartments with playgrounds. Intuitively, one would expect factors influencing frequency of use would include the attractiveness of the play areas, proximity to the apartment unit, and perhaps proximity of other nearby competing parks. Compared to a detached house scenario, where the garden is steps away, a playground or park at an apartment complex is not as accessible and thus typically a reduced frequency of use and exposure compared to a detached house scenario is expected. Although uncommon, there may nonetheless be some children who live in apartments and use playground areas with the same frequency as children living in detached houses. There is, however, less potential for tracking in of soil and dust for apartments compared to detached houses, although this pathway is not explicitly considered in the soil standard development. For areas of ornamental landscaping or small grass areas, a reduced frequency of potential exposure for children and adults is expected.

The next question is the potential for exposure to subsurface contaminants in soil via ingestion under this scenario. Most playgrounds will be constructed with a combination of hard and soft surfaces with imported material (as discussed above under the townhouse scenario) placed on top of native soils or constructed on top of a parking garage. Grass-covered areas will often be constructed on top of an imported fill layer. There would be relatively limited potential for toddlers to come into direct contact with underlying native soil unless the playground was constructed with limited imported fill (minimal thickness of cover), or surface materials were disturbed. Grass sod kept in good condition will likewise reduce the potential for exposure compared to bare-ground condition. For detached houses, land use is more uncontrolled and there are a greater range of potential scenarios under which toddlers could come into contact with soil. While there are differences in the typical land use and potential for exposure to toddlers for high density land use as compared to detached houses, the expectation is that there will be some apartment complexes where the potential for exposure to underlying contaminated soils will exist. Therefore, there is a limited basis for differentiating soil contact assumptions by a toddler for a high density residential playground compared to detached house residential land use scenario.

While inclusion of vegetable gardens or edible landscaping as part of a high density scenario is infrequent, there is interest in including such land use consistent with more sustainable development practices. One example is the community demonstration garden that has been constructed in Southeast False Creek (Vancouver), a moderate to high density urban area. Since consumption of produce from gardens is not included in the current CSST protocol, it is also assumed not to be a land use that would be allowed under a high density land use scenario.

In summary, there are considered to be two potential options for definition of high density land use that either include or exclude a children's playground. If a children's playground is included, it would be difficult to rationalize adjustment of the exposure frequency and soil ingestion rates relative to the current residential standards. If a children's playground is excluded, a reduction in exposure frequency and ingestion rates is considered warranted based on justification described in Section 9.

8.2.3.2 Vapour Inhalation

The main process for soil vapour intrusion into apartments is expected to be soil gas advection into depressurized parts of the lowest (subsurface) part of the building through cracks and openings in the subsurface building envelope, which may be associated with utilities (*e.g.*, drains, sumps, electrical lines) or separation cracks in concrete. As discussed in Section 7, during the heating season, the lower parts of an apartment building may be depressurized due to the stack effect, which may be significant for taller buildings. Diffusive transport through building materials may also occur to a lesser degree. Elevator shafts often include a sump with a drain hole at the bottom to allow any water present to drain away, which may allow entry of sub-surface vapours. The movement of the elevator itself can cause a pressure differential that may facilitate soil vapour entry. Elevator shafts can also represent conduits for inter-floor migration of vapours. Other conduits for soil vapour transport within buildings could include service shafts, garbage shoots and ducts.

The air change rates for apartment dwellings will depend on several factors including the type of ventilation system, the size of dwelling, and the number and type of appliances. As indicated in Section 8, a representative range of air change rates for an apartment dwelling is considered to be 0.35 to 0.45 hr^{-1}.

An underground parking garage below the building will significantly reduce the potential for vapour migration to occupied dwellings through ventilation and dilution of vapours that potentially migrate into the garage. Likewise, above-grade parking that is open to outdoor air will result in significant dilution of vapours. A parking garage will typically be negatively pressurized relative to the rest of the building airspace to avoid migration of vehicle exhaust into the building airspace. However, there may be vertical pathways for vapour movement within the building as described above. Complicating the assessment of vapour intrusion in parking garages is that elevated levels of many volatile substances of concern for common subsurface contaminants are present in vehicle exhaust.

With respect to receptors potentially exposed to vapours and exposure frequency and duration, there are differences depending on whether the apartment has an underground parking garage as part of the site development. For a scenario without a parking garage, the first occupied floor of the apartment is often at ground level. The apartment may include a basement used for storage or other purposes (*e.g.*, washing facility). The exposure frequency and duration for apartment dwellers is expected to be similar to a detached house scenario. The exposure frequency for receptors using a basement as described above would be relatively limited.

For the scenario with a parking garage, the primary use of the garage is parking; however, a garage may include storage units or laundry rooms. Therefore, residents would spend time in the garage parking their vehicles, retrieving items from storage, or doing their laundry. Residents may also spend time on vehicle maintenance activities in the garage.

A maintenance worker will enter the parkade intermittently to conduct maintenance activities of elevators, ventilation systems, doors, safety equipment and other equipment. Some garages may include an office for maintenance personnel. A security attendant may also enter the garage on a regular basis.

A parkade may or may not have an attendant, who would spend the majority of a work shift in a booth or kiosk by the entrance/exit, which typically has an independent ventilation system. However, given that the parking attendant is typically in a ventilated booth (required due to vehicle exhaust), potential exposure to volatiles from subsurface contamination is considered inconsequential and is not further considered in the soil vapour standard development process. It is also noted that potential exposure of workers to volatile chemicals from vehicles (but not subsurface contaminants) would be addressed through provisions of WorkSafe BC (http://www.worksafebc.com).

Given the significant differences between an apartment with and without an underground parking garage, both scenarios have been carried through the soil vapour protocol derivation process. Consideration could be given to developing standards for both scenarios.

8.2.3.3 Protection of Soil Invertebrates and Plants

As discussed in Section 8.2.3.1, apartment buildings vary widely in how they occupy a site. Many buildings will tend to maximize their footprint on the available land surface and have limited landscaping constructed in planters or on top of underground structures, and/or have relatively small areas of ornamental landscaping. In effect, these apartments are similar to commercial land use.

A smaller number of apartment building sites may have more undeveloped land. Although installation of vegetable gardens in soils (*i.e.*, not in roof-top gardens or concrete-bottom planters) as part of a high-rise apartment building is relatively infrequent, it may occur in limited instances if there is available land set aside for this purpose. As a result, these buildings would have similar ecological exposure pathways and “potential terrestrial habitat” as a single-family house.

No adjustment of the CSST procedures is recommended for apartment buildings to specifically address ecological protection, and instead, the existing commercial standards for the protection of soil invertebrates and plants are proposed for the high density residential land use. This recommendation is based on the similarity between high density residential and commercial land uses in terms of its utilization by soil invertebrates and plants. The framework for establishing the appropriate standard for ecological protection should also consider whether there are gardens where plants are grown for human consumption or designated land area of special ecological value, as further described in Section 9.2.

8.3 Summary and Discussion

The proposed definition for the high density residential land use for the apartment and condominium scenario, based on the above conceptual exposure model and rationale, is as follows:

- Three-storey or higher apartment or condominium;
- Site does not contain a children’s playground, unless the playground is constructed on top of a parking garage or concrete slab; and
- Land is not used for growing plants for human consumption, unless plants are grown on roof-top gardens or in planters with concrete bottoms.

A playground is defined as an area that is primarily used for children’s play (*e.g.*, containing play equipment, picnic area or other such attributes that encourage frequent use by children).

A further proposed subdivision of the high density residential land use is an apartment that includes an underground parking garage or above-grade parking garage that is open to outdoor air, which is below the entire portion of the building containing dwelling units. An open-air parkade is defined as a storey of the building where at least 25% of the total area of its perimeter walls is open to the outdoors in a manner that will provide cross ventilation to the entire storey.

For high density land use with a children's playground or garden, the residential land use standards would apply to the entire site, unless the children's playground and garden can be considered separately from the remaining site area through subdivision or other administrative tool. Consideration should also be given to whether the above exclusionary factors (*e.g.*, children's playground, gardens) warrant a notification on the certificate of compliance or other administrative procedure. This process of subdividing or considering a large property as a mosaic of land parcels with varying levels of protection under a development plan process is also relevant for ecological pathways: it allows for environmentally sensitive areas to be afforded a more conservative level of protection (*e.g.*, residential) even if the majority of the site is high density residential. The number of instances where this mosaic approach would apply is likely limited because the majority of high density residential sites will be placed in landscapes that have already been significantly altered by other developments.

The definition of high density apartments and condominiums explicitly excludes townhouses or "garden apartments" defined as typically two-storey dwelling units with enclosed gardens that are specific to a dwelling unit (*i.e.*, not common space), except when townhouses are integrally connected to an apartment as part of a integrated multi-building development.

If the high density residential land use is also to be applied to other scenarios (*e.g*., community centres, hospitals, lodges, prisons and correctional centres), similar restrictions for children's playground and vegetable gardens would be required.

9.0 PROTOCOL FOR HIGH DENSITY RESIDENTIAL STANDARDS

A recommended protocol for high density residential standards is described that considers the following pathways: (i) soil standards protective of human health for intake of contaminated soil (soil ingestion), ii) soil standards protective of ecological health based on toxicity to soil invertebrates and plants, and iii) vapour standards protective of human health.

9.1 Soil - Human Health (Intake of Contaminated Soil)

The proposed soil intake values for apartments and condominiums follow from the discussion and proposed definition for high density residential land use, which excludes a children's playground, where reduced ingestion rates are supported. Although mathematically similar to reducing soil ingestion rates, it was determined that adjustment of the ET (exposure term) was the more straightforward approach for addressing this issue.

For the purposes of development of high density residential standards, it was judged that an ET of 0.5 was a reasonable estimate. Currently, at residential and parkland sites, CSST procedures employ an ET of 1 while for commercial sites, a value of 0.33 is used. This effectively means that year-round soil ingestion rates from residential/parkland sites are assumed to be 80 mg/day for toddlers and 20 mg/day for adults, while values of 26 and 6.6 mg/day are assumed for commercial sites. Thus, the value recommended for high density residential land use scenario is between the commercial and residential/parkland values. Although there is not very much specific guidance on time spent at outdoor (non-play) areas at high density residential sites, this ET value was considered to be reasonable for a number of reasons. Commonwealth of Australia (2001) recommended ET values between 0.25 for residential sites with minimal opportunity of contact with soils and 0.5 for parks. Thus, our recommendation of an ET of 0.5 for high density residential land use is on the conservative side of the Commonwealth of Australia (2001) recommendations.

It is stressed that standards developed using this ET of 0.5 would apply to soils that are not used for play purposes. These standards will apply to common areas that include landscaped grass areas, ornamental gardens and walking paths. In recommending this ET, a lower likelihood that children would play in these areas as compared to typical residential or parkland settings is presumed. However, it is stressed that this ET does not mean we have assumed such play activities would never occur. Instead, an ET of 0.5 suggests that such play activities would occur at a rate of that at about 50% of typical residential and parkland sites.

From the literature, estimates of time spent outdoors have included:

- Richardson (1997) where mean values are 1.42 h for teens, 1.43 h for adults and 1.32 h for seniors.
- Canadian Human Pattern Activity Survey (Leech *et al.,* 1997) which reported average time spent outdoors of 1.8 h/d for children less than 11 years old, 2.1 h/d for youths (11-17) and 1.3 h/d for adults. A later report comparing the Canadian data to U.S. data (Leech *et al.,* 2002) reported values of 2.69 h/d for children, 1.48 h/d for youths and 1.16 h/d for adults; the reason for the different values is not clear.
- U.S. EPA (2008a) also provides data on time spent outdoors for children. Recommended values for different age groups are 139 minutes/day for 6-12 months; 36 minutes/day for 1-2 y; 76 minutes/day for 2-3 y; 107 minutes/day for 3-4 y; 107 minutes/day for 4-6 y; and 132 minutes/day for 6-11 y.

Thus, an ET of 0.5 is effectively assuming that a person is spending between 30 to 60 minutes per day in contact with non-play area soils.

Based on professional judgement and failure to identify specific alternatives, an ET of 0.5 seems reasonable and adequately protective of human health. Once again, in recommending this ET, it is considered to be less likely that children would play in these areas; however, it is stressed that this ET does not mean we have assumed such play activities would never occur but, instead, would occur at a rate of about 50% of typical residential and parkland sites.

9.2 Soil –Ecological Health (Toxicity to Soil Invertebrates and Plants)

Modification of the CSST protocol to derive new standards for the protection of soil invertebrates and plants is not recommended. Instead, the existing commercial standards for the protection of soil invertebrates and plants are proposed for the high density residential land use. This recommendation is based on the similarity between high density residential and commercial land uses in terms of its utilization by soil invertebrates and plants:

- **Consideration of exposure pathway based on size of undeveloped area**: CSR Protocol 13 and the MoE Procedure "Definitions and Acronyms for Contaminated Sites" define "potential terrestrial habitat" as land that "contains over 50 m^2 (where residential land use applies at the site) and over 1,000 m^2 (where commercial or industrial land use applies at the site) of contiguous undeveloped land.[4]" High density sites are considered likely to have between 50 m^2 and 1,000 m^2 of contiguous undeveloped land and therefore, terrestrial ecological receptors require some level of protection from soil contamination. Protection of soil invertebrates and plants is also a mandatory standard irrespective of land use.

- **Consideration of level of protection based on nature of receptors:** Vegetation at most high density residential land use sites is considered likely to be maintained (*e.g.*, ornamental gardens, sidewalks, hedges, planter boxes and lawns). Non-maintained, natural vegetation is likely limited in spatial extent, in part, because high density sites will tend to exist in a landscape dominated by human influences. The types of soil invertebrates and plants likely present at a high density site is considered similar to the ecological community present at commercial sites, and therefore, the level of protection afforded by the commercial standards is likely adequate for high density sites as well.

Two exceptions to the proposed adoption of commercial standards for high density residential sites should be considered:

- High density site used for growing plants for human consumption: Many of the possible high density scenarios in Table 5 have the potential for vegetable gardens. BC MoE (1996) notes that the assumption for commercial lands is that food growing will not be a primary activity. Gardens are not consistent with the conceptual model for commercial sites. In the event that a garden is present, it may be appropriate to apply residential standards to the entire high density site, unless:
  - The garden is a roof-top garden or in a planter with a concrete bottom;

[4] Defined by BC MoE as "means any bare or vegetated soil, excluding (a) gravelled walkways, (b) roadways or highways and associated roadside or highway margins, (c) parking areas, (d) soil contained and isolated in planters and similar structures, and (e) storage areas at active commercial and industrial operations."

- The garden has an area smaller than a Ministry-adopted *de minimus* value. No specific *de minimus* value is proposed but the area could be between 50 and 1,000 m^2 consistent with the screening-level risk assessment guidance in Protocol 13 (it is noted for purposes of human health protection a vegetable garden of any size would result in a residential land use designation); or
- A mechanism (to be defined by the Ministry) is adopted to apply residential standards to the garden area only and commercial standards to the remainder of the site.

- High density residential site contains a land parcel of special ecological value: Most high density sites exist in urbanized landscapes; however a small number of sites may contain sensitive ecological habitat that warrants a higher level of protection than the level afforded by commercial standards for the protection of soil invertebrates and plants. Examples may include setbacks required under the B.C. Riparian Areas Regulation (RAR). Note that similar issues may exist for other land uses (*e.g.*, an industrial site may also have riparian zone setbacks) and therefore, it may be best to consider these types of sites on a one-off basis rather than through a change in regulation.

9.3 Soil Vapour – Human Health

In British Columbia, the protocol for assessment of the soil vapour intrusion pathway involves consideration of vapour attenuation factors for soil vapour intrusion published in Technical Guidance 4 and the CSR Vapour Standards for different land uses (residential[5], commercial and industrial). There are several different potential combinations for attenuation factors and land use receptors depending on whether the apartment has an underground parkade or podium-style above-grade parkade that is ventilated by outdoor air, as shown in the matrix in Table 6.

[5] The residential Vapour Standard also includes agricultural and urban park land uses.

Table 6: High Density Soil Vapour Intrusion Standards Matrix

	Apartment without Parking Garage	Apartment with Underground Parking Garage or Above-grade Open Air Parkade	
	Dwelling Unit	***Dwelling Unit***	***Garage***
Vapour Attenuation Factor (AF)	Possible New Attenuation Factors ("AF1")	Possible New Attenuation Factors ("AF2")	Possible New Attenuation Factors ("AF3")
Vapour Standard Land Uses	Sch. 11 Residential Standard	Sch. 11 Residential Standard	Possible new Vapour Standard based on garage exposure

As shown in Table 6, there are potentially three different sets of vapour attenuation factors that could be estimated based on whether there is an underground or above-grade parking garage present below the building dwelling units. The vapour attenuation factor for a first-floor apartment dwelling that is directly constructed on soil would be different than the attenuation factor for a dwelling unit on the first (ground) floor above an underground or above-grade parking garage because of the dilution of vapours that would occur in the garage. For dwelling units, the receptors and exposure frequencies for residents in apartment units and houses are considered to be the same. For an apartment with parking garage, a reduced exposure frequency is expected. The matrix in Table 6 adds to the complexity of contaminated site assessment and thus, selection of a subset of cases may be warranted for the protocol adopted by BC MoE.

9.4 Garage Use Receptor Considerations

As discussed in Section 8, potential receptors using a parking garage include residents parking vehicles, retrieving items from storage lockers, doing laundry in rooms located on the same level as the garage, and conducting vehicle maintenance. Residential receptors using the garage may include both adults and children. Maintenance workers will enter the parkade intermittently to conduct maintenance activities and at some parking garages, a security attendant may also enter the garage on a regular basis.

The residents are expected to enter a parking garage on a more frequent basis than maintenance workers or security attendants. A white paper completed for the Risk Forum (Todoruk *et al.*, 2009) identified the following scenario for resident exposure within a parkade:

- For week days (5 days per week, 52 weeks per year) - four events per day, 15 minutes per event for a total of 1 hour daily; and
- For weekends (2 days per week, 52 weeks per year) - 1 event per day, 8 hours per event for a total of 8 hours.

The rationale for selecting this hybridized exposure duration was that an individual would be anticipated to make four trips daily plus complete chores, laundry and vehicle maintenance on weekends. This results in an exposure term (ET) of 0.125.

While derivation of new vapour standards for a new land-use garage sub-category could be considered, to reduce complexity, consideration could also be given to adopting commercial land use vapour standards for this exposure scenario. This approach is conservative, but not overly so because the ET assumed in the derivation of the commercial standard is 0.33.

9.4.1 Vapour Attenuation Factors

There are significant challenges to the derivation of vapour attenuation factors for a high density residential land use scenario involving apartments. As previously described in this report, the building processes affecting vapour intrusion are complex, seasonally dependent, and vary widely depending on building and environmental conditions. There has been little published research on evaluation of vapour intrusion into apartments or similar buildings.

9.4.1.1 Prediction of Vapour Intrusion

Two approaches for the prediction of vapour intrusion and derivation of vapour attenuation factors are; (i) use of a mathematical model for estimating fate and transport, and (ii) adoption of empirical factors based on field studies, as described below.

9.4.1.1.1 Modeling Approaches

A range of mathematical and numerical models have been developed for the vapour intrusion pathway, but the authors are not aware of a model that has been specifically developed for apartment buildings and that has been evaluated through comparison of model predictions to field data. The conceptual site model that underlies most vapour intrusion modeling and radon research is a detached house scenario. While there are models that simulate the movement of contaminants within different compartments within a building (*e.g.*, COMIS, http://lbl.gov/comis), there has been limited research involving the use of coupled models where chemical transport in the subsurface and within multiple compartments of a building has been simulated. One exception is a focussed study where vapour intrusion involving a two-compartment building model was evaluated (Olson and Corsi, 2001). While the use of more complex models for apartment vapour intrusion may not necessarily be warranted, the point here is that there has been little research on this topic. The development of new models is beyond the scope of this project, and as described below, the Johnson and Ettinger (1991) model has been used for this purpose.

9.4.1.1.2 Empirical Approaches

Apartments

U.S.EPA (2008b) has compiled empirical data on vapour attenuation factors in a database incorporating data from sites across the United States. Most of the residential data is for detached houses, with limited data for apartment buildings. A review of the U.S. EPA database indicates that there is empirical attenuation factor data from five sites with either apartment buildings or apartment/townhome buildings (none of these site data are for buildings with parking garages). A statistical summary of the empirical attenuation factors for these building types is provided in Table 7. There are only two data points for the soil vapour-to-indoor air pathway where external soil vapour samples were obtained (this is the data that should be compared to the BC TG4 attenuation factors). There is insufficient data to draw conclusions for comparison purposes, but as the empirical database is expanded, this may become a future line-of-evidence for evaluation.

Table 7: Empirical Vapour Attenuation Factors for Apartments and Apartments/Townhomes from U.S. EPA (2008b) Database

Site	Attenuation Factor	Chemical	Number	Minimum	Maximum	Median
Billings	GW-Indoor Air	PCE	2	1.4E-05	2.1E-05	1.8E-05
	SS-Indoor Air	PCE	2	2.8E-04	1.7E-03	9.8E-04
CDOT	GW-Indoor Air	TCE & 11DCE	12	1.8E-06	9.0E-04	1.2E-05
Endicott	SS-Indoor Air	TCE	7	5.7E-04	2.2E-03	1.5E-03
Jacksons	GW-Indoor Air	PCE	1	4.7E-04	4.7E-04	4.7E-04
	SS-Indoor Air	PCE	1	8.4E-.03	8.4E-03	8.4E-03
	SG-Indoor Air	PCE	2	1.3E-04	2.3E-04	1.8E-04
Onion Park	SS-Indoor Air	TCE & PCE	11	5.0E-04	3.3E-02	3.2E-03

Notes:

GW- Indoor Air = groundwater-to-indoor air attenuation factor (indoor air divided by soil vapour concentration predicted from groundwater using Henry's Law constant, SS – Indoor Air = subslab soil gas-to-indoor air attenuation factor, SG – Indoor Air = soil gas (external probe)-to-indoor air attenuation factor.

Parkade Case Study

A study was completed in the Metro Vancouver area that evaluated attenuation of volatile hydrocarbon vapours from sub-slab vapour probes into indoor air within a parkade below a multi-story residential complex during two sampling events. Multiple samples were collected across the site during each sampling event. It was considered likely that indoor air contained contaminants of potential concern (COPCs) from vehicle traffic including benzene, toluene, ethylbenzene and xylenes (BTEX) and volatile petroleum hydrocarbons (VPH_v). To limit the potential for background to influence sample results, a dynamic flux sampling methodology was applied that included a three volume purge of the flux chamber prior to sample collection. Detectable concentrations of BTEX and VPH_v were not found in equipment blanks (*i.e.*, a sample collected in an area with potential for COPCs in ambient air, but not over cracks within the parkade) which supported this methodology.

The dynamic flux sampling method applied air at a flow rate within the chamber that simulated measured air change rates (ACH) of the parkade (estimated as 2.2 to 3.5 ACH). An empirically-derived attenuation factor for compounds evaluated was found to range from 1.1×10^{-6} to 3.3×10^{-6}.

Summary

The empirical database for apartment residential land use is insufficient to enable empirical data to be used as the primary means of deriving attenuation factors, but these data can be used for model comparisons.

9.4.1.2 Modeling of Vapour Attenuation Factors

The model scenarios, description, input parameters and results are described below.

9.4.1.2.1 Scenarios and Model Description

The Johnson and Ettinger model is used to estimate vapour attenuation factors for two scenarios:

- First-floor apartment dwelling, for apartment without underground parking garage, where the first-floor is 0.5 m below grade (first-floor air/soil vapour concentration) (AF1 in Table 6); and
- Underground parking garage, which is one to two-levels high (underground parking garage air/soil vapour concentration) (AF3).

The Johnson and Ettinger (1991) model is a one-dimensional analytical model for steady state diffusive transport within subsurface soil, advective and diffusive transport through the subsurface building envelope, and uniform and instantaneous mixing of vapours within a single building compartment.

9.4.1.2.2 Model Inputs

The TG4 attenuation factors for residential and commercial land uses were derived using the Johnson and Ettinger (1991) model and input parameters describe in a report prepared by Golder Associates for SABCS (Golder, 2010). The approach for identifying model input parameters for this study is to consider subsurface soil properties and building-related inputs separately. For subsurface soil properties, the model inputs for residential and commercial land uses are identical, and thus the same input values have been adopted for high density residential land use. For building-related parameters, generic input parameters have been established for the above two scenarios, as listed in Table 8. For input parameters to which the model is relatively sensitive (air change rate, building mixing height, building depressurization and soil gas advection rate, or "Q_{soil}"), a range of input values were developed that correspond to a low and high attenuation factor. The approach for input parameter selection was to keep the range relatively constrained and within the typical values expected for an apartment and parkade, with the rationale described in Table 8. For selection of Q_{soil} for an apartment dwelling, the approach was to calculate the ratio of Q_{soil}/Q_{build} and to constrain this ratio within reasonable ranges based on published data as further described in Golder (2010) and Johnson (2005). Given the lack of published data for parking garages, the perimeter crack model was used to estimate the Q_{soil} for this scenario for a reasonable range of parkade depressurizations.

Table 8: Rationale for Building Parameters for Apartment Dwelling and Parkade

Parameter	Apartment Dwelling	Parkade
Air change rate	**0.35 to 0.45 hr^{-1}**: Based on estimated air change rate from building code.	**2 to 4 hr^{-1}**: Based on estimated air change rate from building code and measured data.
Vapour mixing height	**3 to 3.6 m**: The expectation is that there will be little cross-floor mixing of vapours in newer buildings (design requirement to reduce stack effect), therefore range is constrained.	**3 to 6 m**: The range reflects mixing in one to two-storey parking garage
Building width and length	**8.6 m x 8.6 m**: Reflects representative 800 sq. ft. dwelling and likely limited lateral mixing between dwelling units. Model is only moderately sensitive to this parameter.	**30 m x 30 m**: Estimate for parking garage.
Depth to foundation below grade	**0.5 m:** Reasonable value for first floor that is slightly below grade	**3 m:** Reasonable value for one-storey below grade parking garage.
Thickness of foundation	**0.15 m**: Same as commercial building assumption. Model is not sensitive to this parameter.	**0.15 m**: Same as commercial building assumption. Model is not sensitive to this parameter.
Crack ratio (dimensionless)	**2.09×10^{-4}**: Same as commercial building assumption. Model is not sensitive to this parameter when advection is assumed.	**2.09×10^{-4}**: Same as commercial building assumption. Model is not sensitive to this parameter when advection is assumed.
Building depressurization	N/A	**5 to 10 Pa:** Best estimate based on available data; upper value of 10 Pa is not as high as a possible upper value based input by mechanical engineers. However, when fans are on and depressurization is high, the air change range will also be high, thus it is would be overly conservative to assume both high depressurization and low ventilation rate.
Soil gas advection rate	**5 to 7 L/min**: The rationale for this range was to select range that would result in upper Q_{soil}/Q_{build} value similar to the residential default and lower value that was approximately half this value.	**16 to 32 L/min**: Q_{soil} was calculated from the assumed building depressurization; this approach was taken given the lack of empirical Q_{soil}/Q_{build} values for parking garages.

Table 9: Model Inputs and Estimated Vapour Attenuation Factors for Apartment Scenario

Input Parameter	Residential Building –TG4 Attenuation Factor Values	Commercial Building –TG4 Attenuation Factor Values	High Density Residential Building – Proposed Values Dwelling - Low	High Density Residential Building – Proposed Values Dwelling - High	High Density Residential Building – Proposed Values Garage - Low	High Density Residential Building – Proposed Values Garage - High
Air change rate (hr^{-1})	0.35	1	0.45	0.35	4	2
Building depressurization (Pa)	N/A	N/A	N/A	N/A	5	10
Vapour Mixing height (m)	3.6	3	3.6	3	6	3
Building width (m)	10	15	8.6	8.6	30	30
Building length (m)	10	20	8.6	8.6	30	30
Subsurface foundation area for VI (m^2)	180	335	91.2	91.2	1260	1260
Depth to base building foundation (m)	2	0.5	0.5	0.5	3	3
Thickness of foundation (m)	0.1	0.15	0.15	0.15	0.15	0.15
Crack Width (mm)	1	1	0.55	0.55	2.19	2.19
Crack Ratio (-)	2.22E-04	2.09E-04	2.09E-04	2.09E-04	2.09E-04	2.09E-04
Crack Area (m^2)	4.00E-02	7.00E-02	1.91E-02	1.91E-02	2.63E-01	2.63E-01
Building ventilation rate Q_{build} (m^3/min)	2.1	15	1.5	1.5	360	90
Soil gas advection Q_{soil} (L/min) - Assumed[1]	10	7	5	7	---	---
Soil gas advection Q_{soil} (L/min) - Calculated[2]	N/A	N/A	N/A	N/A	16.0	31.9
Q_{build} (L/min)	2100	15000	1997	1294	360000	90000

Input Parameter	Residential Building –TG4 Attenuation Factor Values	Commercial Building –TG4 Attenuation Factor Values	High Density Residential Building – Proposed Values Dwelling - Low	High Density Residential Building – Proposed Values Dwelling - High	High Density Residential Building – Proposed Values Garage - Low	High Density Residential Building – Proposed Values Garage - High
Perimeter Crack Model Calculations (to give identical Q_{soil} as above)						
Soil-air Permeability (cm^2)	1.00E-07	1.00E-07	1.00E-07	1.00E-07	N/A	N/A
Air Viscosity (g/cm-s)	1.79E-04	1.79E-04	1.79E-04	1.79E-04	N/A	N/A
Building depressurization (Pa)	9.8	3.3	4.9	6.8	N/A	N/A
Soil gas advection rate Qsoil (L/min)	10	7.0	5.0	7.0	N/A	N/A
Summary Parameters						
Q_{soil}/Q_{build} (-)	4.76E-03	4.67E-04	2.50E-03	5.41E-03	4.43E-05	3.55E-04
Q_{soil}/Surface Area (L/m^2-min)	5.56E-02	2.09E-02	5.48E-02	7.68E-02	1.27E-02	2.53E-02
Q_{soil}/Surface Area -Pressure (L/m^2-Pa-min)	5.67E-03	6.33E-03	1.12E-02	1.13E-02	2.53E-03	2.53E-03
Vapour Attenuation Factors (at 1 m distance from building to soil vapour point, benzene as surrogate)						
Calculated vapour attenuation factor	N/A	N/A	1.52E-03	2.84E-03	3.88E-05	2.73E-04
TG 4 vapour attenuation factor	2.80E-03	3.70E-04	N/A	N/A	N/A	N/A

Notes: VI = vapour intrusion

Green	Parameters that were varied for estimation of attenuation factors
Yellow	Parameters that were fixed for estimation of attenuation factors
Light blue	Parameters that were calculated from other inputs

[1]Assumed value to provide desired Q_{soil}/Q_{build}
[2]Calculated using perimeter crack model

9.4.1.2.3 Preliminary Model Results

The model input parameters and preliminary model results are presented in Table 9.

For the residential apartment dwelling scenario, the range of attenuation factors calculated for a distance of 1 m between the building and soil vapour measurement point is 1.52×10^{-3} to 2.84×10^{-3}, compared to a TG4 attenuation factor of 2.80×10^{-3}. The lower attenuation factor is approximately half the TG4 residential attenuation factor.

For the parking garage scenario, the range of attenuation factors calculated for a distance of 1 m between the building and soil vapour measurement point is 3.88×10^{-5} to 2.73×10^{-4}, compared to a TG4 residential attenuation factor of 2.80×10^{-3}. The estimated vapour attenuation factors for a parking garage are between 11 and 72 times lower than the TG4 residential attenuation factor. From additional scenarios run (not shown), an approximate median value is on the order of 5.6×10^{-4}, or 50 times lower than the residential attenuation factor.

9.4.1.3 Discussion

For the residential apartment dwelling without a parking garage, there is little difference in the attenuation factors for the residential detached house and apartment scenarios, as expected given the similarities in key building parameters (*e.g.*, air change rate, building depressurization and soil gas advection rates). The development of new attenuation factors for an apartment scenario is not considered warranted as a result of this small difference.

For the parking garage scenario, there is a significant reduction in the garage attenuation factor (about 50X), and modification of attenuation factors for the apartment parking garage scenario would likely be warranted. For an apartment with a parking garage below the entire building, additional dilution and attenuation of vapours would occur between the parking garage and first-floor dwelling. If warranted, the attenuation could be estimated using a multi-compartment modification of the Johnson and Ettinger model that has been developed by Golder Associates (Hers *et al*., in-progress). This model accounts for reduction in flux through ventilation of the first compartment (*e.g*., garage, crawlspace), enabling the concentration in the second compartment to be estimated.

10.0 CONCLUSIONS AND RECOMMENDATIONS

A comprehensive evaluation of matrix numerical soil standards and soil vapour standards and soil vapour-to-indoor air attenuation factors has been completed for the proposed high density residential land use pathway. A conceptual exposure model is developed for high density residential land use, receptor and exposure assumptions are described, and attenuation factors for soil vapour intrusion into buildings are estimated. On the basis of this evaluation, high density residential land use is defined and a protocol for the derivation of high density standards has been developed.

10.1 Definition of High Density Residential Land Use

The BC MoE has defined “high density residential” land use as part of a draft version of Procedure 8 (BC MoE 2011). The draft “high density residential” land use definition is as follows:

“High Density Residential – means the type of housing at a residential complex housing multiple persons or families in:

a) Individual units, including boarding houses, apartments, condominiums, lodges, and townhouses; or

b) Institutional facilities, including residential schools, hospitals, residential day care operations, retirement homes, prisons, correctional centres and community centres, but does not include commercial hotels or motels”.

These above land uses were considered in the development of the conceptual exposure model described below; however, certain land uses were excluded from the definition of high density residential land use.

A conceptual exposure model is developed which considered the following parameters:

- Residential development type;
- Typical building characteristics;
- Type of human receptors present;
- Type of landscaping and degree of open space;
- Presence of a children’s playground or area;
- Potential exposure in a children’s playground;
- Potential for soil vapour intrusion into building development type compared to a residential or commercial building; and
- Type of existing standard (if applicable) that provides for equivalent protection for human soil ingestion, vapour inhalation and direct contact for soil invertebrates and plants, or identification when a new high density residential standard is warranted.

The conceptual exposure model was then used to simplify the number of exposure scenarios considered for the development of the high density residential soil and soil vapour standards, as follows:

- Residential land use would apply to detached houses, townhouses, boarding houses, residential schools, residential day care facilities and retirement homes; and
- High density or commercial land use, depending on the scenarios and exposure pathways, would apply to lodges, hospitals, apartments and condominiums (greater than three-storey's), prisons and correctional centres, and community centres, provided there are appropriate exclusionary factors for certain site uses, as described below.

The resulting proposed definition for the high density residential land use for the apartment and condominium scenario, based on the above problem formulation and rationale, is as follows:

- Three-storey or higher apartment or condominium;
- Site does not contain a children's playground, unless the playground is constructed on top of a parking garage or concrete slab; and
- Land is not used for growing plants for human consumption, unless plants are grown on roof-top gardens or in planters with concrete bottoms.

A playground is defined as an area that is primarily used for children's play (*e.g.*, containing play equipment, picnic area or other such attributes that encourage frequent use by children).

A further proposed subdivision of the high density residential land use is an apartment that includes an underground parking garage, or above-grade parking garage, that is open to outdoor air and is below the entire portion of the building containing dwelling units. An open-air parkade is defined as a storey of the building where at least 25% of the total area of its perimeter walls is open to the outdoors in a manner that will provide cross ventilation to the entire storey.

For high density land use with a children's playground or garden, the residential land use standards would apply to the entire site, unless the children's playground and garden can be considered separately from the remaining site area through subdivision or other administrative tool. Consideration should also be given to whether the above exclusionary factors (*e.g.*, children's playground, gardens) warrant a notification on the certificate of compliance or other administrative procedure.

The definition of high density apartments and condominiums explicitly excludes townhouses or "garden apartments" defined as typically two-storey dwelling units with enclosed gardens that are specific to a dwelling unit (*i.e.*, not common space), except when townhouses are integrally connected to an apartment as part of a integrated multi-building development.

10.2 Soil - Human Health (Intake of Contaminated Soil)

For the purposes of development of high density residential soil standards for intake of contaminated soil, it is recommended that an exposure term (ET) of 0.5 be utilized. Currently, at residential and parkland sites, CSST procedures employ an ET of 1, while for commercial sites a value of 0.33 is used. Thus, the value recommended for high density residential sites is between the commercial and residential/parkland values. The high density standards developed using this ET would apply to common areas that include landscaped grass areas, ornamental gardens and walking paths on soils that are not used for play purposes. An ET of 0.5 suggests that such play activities would occur at a rate of about 50% of typical residential sites.

10.3 Soil - Ecological Health (Toxicity to Soil Invertebrates and Plants)

Modification of the CSST protocol to derive new standards for the protection of soil invertebrates and plants is not recommended. Instead, the existing commercial standards for the protection of soil invertebrates and plants are proposed for the high density residential land use. This recommendation is based on the similarity between high density residential land use and commercial land uses in terms of its utilization by soil invertebrates and plants:

- **Consideration of exposure pathway based on size of undeveloped area**: CSR Protocol 13 and the MoE Procedure “Definitions and Acronyms for Contaminated Sites” define “potential terrestrial habitat” as land that “contains over 50 m^2 (where residential land use applies at the site) and over 1,000 m^2 (where commercial or industrial land use applies at the site) of contiguous undeveloped land.” High density sites are considered likely to have between 50 m^2 and 1,000 m^2 of contiguous undeveloped land and therefore, terrestrial ecological receptors require some level of protection from soil contamination. Protection of soil invertebrates and plants is also a mandatory standard irrespective of land use.
- **Consideration of level of protection based on nature of receptors:** Vegetation at most high density residential land use sites is considered likely to be maintained (*e.g.*, ornamental gardens, sidewalks, hedges, planter boxes and lawns). Non-maintained, natural vegetation is likely limited in spatial extent, in part, because high density sites will tend to exist in a landscape dominated by human influences. The types of soil invertebrates and plants likely present at a high density site is considered similar to the ecological community present at commercial sites, and therefore, the level of protection afforded by the commercial standards is likely adequate for high density sites as well.

The presence of a garden used for human consumption would result in residential land use standards being applied, except if the garden use met the definition in Section 10.1. A small number of high density land use sites may include a land parcel of special ecological value including setbacks required under the B.C. Riparian Areas Regulation (RAR) that would warrant a subdivision or other mechanism(s) to afford a higher level of protection for this land parcel.

10.4 Soil Vapour – Human Health

The development of high density residential vapour standards evaluated the ET for apartment residents and parking garage users and attendants. Moreover, preliminary modeling was undertaken to estimate vapour attenuation factors between indoor air and soil vapour for apartment dwelling units and enclosed parking garages.

For the vapour intrusion pathway, the potential exposure to human receptors was considered for apartments and parking garages. The proposed ETs for these scenarios are 1.0 for apartment residents and 0.125 for parking garage users and attendants. For comparison, an ET of 0.33 is incorporated in the CSR Schedule 11 Vapour Standards for commercial land use.

A preliminary modeling study was completed using the Johnson and Ettinger model to estimate vapour attenuation factors for a first-floor apartment dwelling for an apartment without a parking garage, and for a below-grade parking garage. Using subsurface input parameter values consistent with BC MoE Technical Guidance 4, and building-related parameters representative of an apartment, there was little difference between the attenuation factors calculated for an apartment dwelling and detached house, and thus little basis for different attenuation factors for an apartment scenario compared to current TG4 attenuation factors for residential land use. For a parking garage scenario, the estimated median attenuation factor for the parking garage airspace is approximately 50X less than the current TG4 residential attenuation factor, for the scenario considered (1 m distance from building to soil vapour).

For an apartment without a parking garage, it is recommended that the current TG4 attenuation factors for residential land use be adopted for the high density residential scenario (three-storey or greater apartment).

For an apartment with an enclosed or open garage below the entire footprint of the building with dwellings, it is recommended that the current TG4 attenuation factors for residential land use be reduced by a factor of 50X, with these attenuation factors applicable to the parking garage and dwelling units. It is noted that the 50X reduction factor for dwelling units above a parkade is conservative, but further analysis and modeling would be required to determine to what extent this factor could be further increased.

10.5 Implications of High Density Residential Protocol for Standards

In order to evaluate the potential implications of the recommended protocol on matrix soil standards, the current residential and commercial soil standards are compared to the proposed high density soil standards in Table 10.

Table 10: Implications of Recommended High Density Residential Matrix Soil Standards

Substance	Intake Contaminated Soil			Toxicity to Soil Invertebrates & Plants		Soil Leaching		
	Residential (μg/g)	Approximate HDR (μg/g)	Commercial (μg/g)	Residential (μg/g)	HDR (Commercial) (μg/g)	Groundwater flow to surface water (freshwater)[1] (μg/g)	Groundwater flow to surface water (marine)[1] (μg/g)	Groundwater used for drinking water (μg/g)
Arsenic	100	200	300	50	100	20	25	15
Barium	6500	13000	20000	1000	1500	3500	1500	400
Benzene	1000	2000	4000	70	150	10	2.5	0.04
Benzo(a)pyrene	5	10	15	1	10	NS	NS	NS
Cadmium	3 or 35[2]	70	100	70	500	2 to 150[3]	2 to 200[3]	1.5 to 1000[3]
Chloride	>1000	>1000	>1000	350	2500	550	550	90
Chromium	100	200	300	300	700	60 to 65	60 to 95	60
Copper	15000	30000	50000	150	250	90 to 30,000[3]	90 to 30,000[3]	250 to 350,000[3]
Dichloro-diphenyl-trichloroethane (DDT)	15	30	50	10	15	NS	NS	NS
Ethylbenzene	3500	7000	10000	1	20	6000	7000	7
Ethylene Glycol	65000	130000	200000	5500	20000	1500	1500	NS
Lead	500	1000	1000	1000	2000	150 to 40,000[3]	150 to 40,000[3]	100 to 4000[3]
Mercury (inorganic)	15	30	40	100	150	NS	NS	NS
Pentachlorophenol	100	200	300	20	50	0.35 to 300,000[3]	0.35 to 300,000[3]	1 to 750,000[3]
Polychlorinated Biphenyls (PCBs)	5	10	15	5	50	NS	NS	NS
Polychlorinated Dioxins and Furans (PCDDs and PCDFs)	0.00035	0.0007	0.001	0.001	0.0025	NS	NS	NS
Sodium Ion (Na+)	>1000	>1000	>1000	200	1000	NS	NS	15000
Tetrachloroethylene (PERC)	1000	2000	3500	5	50	5	5	NS
Toluene	40000	80000	100000	1.5	25	350	40	2.5
Trichloroethylene (TCE)	200	400	600	5	50	0.65	0.65	0.015
Xylene	65000	130000	200000	5	50	NS	NS	20
Zinc	10000	20000	30000	450	600	150 to 3000[3]	150 to 35,000[3]	150 to 15,000[3]

Notes:
1. Groundwater flow to surface water used by aquatic life.
2. Standard is 35 ug/g if no vegetable consumption.
3. pH dependent.

When the implications of the changes in matrix soil standards are evaluated independently without consideration of other potential pathways, the following changes to the CSR Schedule 5 matrix soil standards would result:

- The high density soil standard for human health intake of contaminated soil would generally be 2X greater than the residential standard[6]; and
- The high density soil standard for toxicity to soil invertebrates and plants would be 1.3X (zinc) to 20X (ethylbenzene) greater than the residential standard.

When soil standards for groundwater used for drinking water and protection of human health are considered, for many Schedule 5 substances, the standard for the drinking water pathway will be lower than the proposed high density residential soil standard, although for several substances, the comparison will depend on the pH of the groundwater. Substances where the high density standard could potentially result in lower soil standards when the drinking water pathway applies are cadmium, copper, lead, sodium, pentachlorophenol and zinc. Substances where drinking water standards will be the driver are arsenic, barium, benzene, chloride, chromium, ethylbenzene, toluene, trichloroethylene and xylenes.

When soil standards for groundwater flow to surface water and protection of aquatic life is considered, there are similar considerations as for the drinking water pathway. Substances where the high density standard could potentially result in lower soil standards when the aquatic life pathway applies are cadmium, copper, ethylbenzene, lead, pentachlorophenol, toluene and zinc. Substances where aquatic life standards will be the driver are arsenic, barium, benzene, chloride, chromium, ethylene glycol and trichloroethylene.

For the soil vapour intrusion pathway, the implication of a high density residential standard is soil vapour attenuation factors that are 50X lower for an apartment with parking garage below the entire footprint of the dwelling units compared to the current residential scenario.

[6] The 2X factor is approximate and should be confirmed by BC MoE.

11.0 CLOSURE

We trust the information contained in this report is sufficient for your present needs. Should you have any additional questions regarding this project, please do not hesitate to contact the undersigned at 604-296-4200.

GOLDER ASSOCIATES LTD.

Audrey Wagenaar, M.Sc.
Associate, Senior Environmental Scientist

Ian Hers, Ph.D., P.Eng.
Principal, Senior Specialist Engineer

AW/IH/asd

\\bur1-s-filesrv2\final\2010\1436\10-1436-0123\rep 0524_11 high density soil standards - final.docx

12.0 REFERENCES

ASHRAE Standard 62.1 2007. Ventilation for acceptable indoor air quality.

ASHRAE Standard 62.2 2007. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings (ANSI Approved).

British Columbia Ministry of Environment (BC MOE). 1996. *Overview of CSST procedures for the derivation of soil quality matrix standards for contaminated sites*. Prepared by Risk Assessment Unit, Environmental Protection Department, BC Environment. January 31, 1996. Includes CSST Policy Decision Summary.

British Columbia Building Code. 2006. Housing and Construction Standards, BC Ministry of Public Safety and Solicitor General.

British Columbia Ministry of Environment (BC MOE). 2008. Protocol 13. *Screening Level Risk Assessment*. Available on-line at:

http://www.env.gov.bc.ca/epd/remediation/policy_procedure_protocol/protocols/pdf/protocol_13.pdf

British Columbia Ministry of Environment (BC MOE). 2010a. *Contaminated Sites Regulation (CSR)*. BC Reg. 375/96, O.C. 1480/96 [includes amendments up to B.C. Reg. 286/2010, October 4, 2010]). Available on-line at: http://www.env.gov.bc.ca/epd/remediation/leg_regs/csr.htm

British Columbia Ministry of Environment (BC MOE). 2010b. *Technical Guidance on Contaminated Sites. Technical Guidance 4 – Vapour Investigation and Remediation*. Version 1. September 2010. Available on-line at: http://www.env.gov.bc.ca/epd/remediation/guidance/technical/pdf/tg04.pdf

British Columbia Ministry of Environment (BC MOE). 2011. *Procedure 8 – Definitions and Acronyms for Contaminated Sites*. Available on-line at: http://www.env.gov.bc.ca/epd/remediation/policy_procedure_protocol/procedure/pdf/proc-08-cs-definitions-V1-1.pdf

Canadian Council of Ministers of the Environment (CCME). 1994a. "*A Protocol for the Derivation of Ecological Effects-Based and Human Health-Based Soil Quality Criteria for Contaminated Sites*". Available on-line at: http://www.ccme.ca/assets/pdf/sg_protocol_1332_e.pdf

Canada Mortgage and Housing Corporation (CMHC). 2005. *Assessment of Suite Compartmentalization and Depressurization in New High-Rise Residential Buildings*. Technical series 05-112. October.

CCME. 1994b. "*Guidance Manual for Developing Site Specific Soil Quality Remediation Objectives for Contaminated Sites in Canada*". Available on-line at: http://www.ccme.ca/assets/pdf/pn_1197_e.pdf

CCME. 2006. *A Protocol for the Derivation of Environmental and Soil Quality Guidelines*. Winnipeg, Manitoba. Available on-line at: http://www.ccme.ca/assets/pdf/sg_protocol_1332_e.pdf

City Farmer, 2008. *Urban Agriculture Opportunities for Southeast False Creek*. http://www.cityfarmer.info/2008/03/09/urban-agriculture-in-southeast-false-creek-sefc-the-olympic-village-vancouver-bc/. Accessed January 11, 2011.

City of Vancouver. 1992. *High-density housing for families with children guidelines*. Land Use and Development Policies and Guidelines.

City of Vancouver. 2009. *Urban agriculture guidelines for the private realm.* Land Use and Development Policies and Guidelines.

Commonwealth of Australia. 2001. *Exposure Scenarios and Exposure Settings.* Commonwealth of Australia. ISBN 0 7308 5661 5.

Davis, S. and Mirick, D.K. 2006. *Soil ingestion in children and adults in the same family*. J Expo Sci Environ Epidemiol. 16:63-75.

Fellin, P. and R. Otson. 1996. *The Effectiveness of Selected Materials in Moderation of Indoor VOC Levels.* In Volatile Organic Compounds in the Environment, ASTM STP 1261, W. Wang, J. Schnoor, and J. Doi, Eds., American Society for Testing and Materials, 1996, pp. 135-146.

Figley, D.A. A Guide for Estimating Indoor Concentrations of Soil Gas Pollutants in Houses. Prepared for CMHC, 1997.

Golder, 2003. *Safe Housing for Lightly Contaminated Lands Research Project – Pacific Place Study Results*. Report submitted to Canada Mortgage and Housing Corporation (CMHC), November.

Golder Associates, 2010. *BC MoE Technical Guidance Vapour Intrusion Computer Model – User's Guide and Supporting Information*. Report submitted to Science Advisory Board for Contaminated Sites, October 6.

Gusdorf, J. and Hamlin, T. 1995. *Indoor Air Quality and Ventilation Rates in R-2000 Houses.* Buildings Group, Residential Programs, Energy Technology Branch. *Call-up No. 23440-95-1037*. Energy Technology Branch, CANMET, Department of Natural Resources Canada, Ottawa, Ontario (43 pg).

Hawley, J.K. 1985. *Assessment of health risk from exposure to contaminated soil*. Risk Anal. 5(4):289-302.

Haysom and Reardon, 1998. *Current approaches for mechanical ventilation of houses*. Construction Technology Update No. 15. National Research Council of Canada (NRC).

Health Canada. 2009. *Federal Contaminated Site Risk Assessment in Canada – Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA)*. Environmental Health Assessment Services, Safe Environments Programme, Health Canada, Ottawa, Ontario.

Hers, I., Zapf-Gilje, R., Li, L., and Atwater, J. 2001. *The use of indoor air measurements to evaluate intrusion of subsurface VOC vapors into buildings*. Air & Waste Management Association. 51: 1318-1331.

Holland Barr Planning Group, 2007. *Designing Urban Agriculture Opportunities for Southeast False Creek.* Report prepared for the City of Vancouver. October.

Johnson, P.C. and R. Ettinger. 1991. *Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapours into Buildings*. Environ. Sci. Technol. 25 (8):1445-1452.

Johnson, P.C. 2005. *Identification of application-specific critical inputs for the 1991 Johnson and Ettinger vapor intrusion algorithm*. Groundwater Monitoring & Remediation, 25(1): 63-78.

Kalamess, T., J. Kurnitski, J. Jokisalo, L.Eskola, K. Jokiranta and J. Vinha. 2010. *Measured and simulated air pressure conditions in Finnish residential buildings.* Building Serv. Eng. Res. Technol. doi:10.1177/0143624410363655.

Krarti, M. and A. Ayari. 2005. *Ventilation for Enclosed Parking Spaces*. ASHRAE Journal, February.

Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S. and Raizenne, M.E. 2002. *It's about time: A comparison of Canadian and American time-activity patterns*. J Expo Anal Environ Epidemiol 12: 427-432.

Leech, J.A., Wilby, K., McMullen, E. and Laporte, K. 1997. *The Canadian human activity pattern survey: report of methods and population surveyed*. *Chron Dis Can* 17: 118-123.

Lencar, C. and Dr. Ray Copes. 2009. *Progress Report on the Sampling Activities for the Child Activities Pattern Survey to be used on the Potential Pathways of Exposure from Contaminated Soil to Residents of Multi-unit Apartment Buildings*. Prepared for British Columbia Ministry of Environment.

Lsitburek, J.W. 2005. Understanding Air Barriers. ASHRAE Journal, July.

National Building Code of Canada. 2005. Institute for Research In Construction (IRC), National Research Council of Canada.

NEPC. 1999a. *National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B(7b) Exposure settings and exposure scenarios*. National Environment Protection Council, Adelaide.

NEPC. 1999b. *National Environmental Protection (Assessment of Site Contamination) Measure (1999)*.National Environment Protection Council, Adelaide.

NEPC. 1999c. *National Environment Protection (Assessment of Site Contamination) Measure 1999,Schedule B(7a) Guideline on Health-Based Investigation Levels*. National Environment Protection Council, Adelaide.

NEPC. 1999d. *National Environment Protection (Assessment of Site Contamination) Measure 1999,Schedule B(4) Guideline on Health Risk Assessment Methodology*. National Environment Protection Council, Adelaide.

National Institute for Public Health and the Environment **(**RIVM). 2009. *Soil Remediation Circular 2009,* The Netherlands**.**

New Zealand Ministry for the Environment (NZMfE). 2010. *Draft Methodology for Deriving Soil Guideline Values Protective of Human Health.* Wellington: Ministry for the Environment. February 2010.

Olson DA, RL Corsi**.** 2001**.** *Characterizing exposure to chemicals from soil vapor intrusion using a two-compartment model*. Atmos Environ 35:4201–4209.

Ontario Ministry of Environment (MOE), 2009. *Modified Generic Risk Assessment Spreadsheet*. October.

Özkaynak, H., Xue, J., Zartarian, V.G., Glen, G., Smith, L. 2011. *Modeled Estimates of Soil and Dust Ingestion Rates for Children*. Risk Analysis Vol. 31(4), 562-608.

Proskiw, G. and Phillips, G. 2008. *An examination of air pressure and air movement patterns in multi-unit residential buildings*. Building Enclosure Science and Technology Conference, Minneapolis.

Richards, C. 2005. Retrofitting a Multi-Unit Residential Building to Reduced Purchased Energy by a Factor of 10. MSc. Candidate Presentation, University of Saskatchewan. December 1.

Richardson, G.M. and O'Connor Associates Environmental Inc. 1997. *Compendium of Canadian Human Exposure Factors for Risk Assessment*. O'Connor Associates Environmental Inc., Ottawa, Ontario.

Science Advisory Board for Contaminated Sites in British Columbia (SABCS). 2009a. *Review of CSST (1996) Soil Matrix Derivation Approach and Related Policy Decisions Volume I: SABCS Review and Recommendations for Revision of the CSST(1996) Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites*. Prepared for British Columbia Ministry of Environment. November 2009.

Science Advisory Board for Contaminated Sites in British Columbia (SABCS). 2009b. *Review of CSST (1996) Soil Matrix Derivation Approach and Related Policy Decisions Volume II: SABCS Review and Recommendations for Revision of the CSST (1996) Policy Decision Summary*. Prepared for British Columbia Ministry of Environment. November 2009.

Science Advisory Board for Contaminated Sites in British Columbia (SABCS). 2008. *Detailed Ecological Risk Assessment (DERA) in British Columbia Technical Guidance*. Prepared by Golder Associates Ltd. Available on-line at: http://www.sabcs.chem.uvic.ca/DERA2008.pdf

SenterNovem, 2007. Know the quality of your soil or aquatic sediment: clarifying the risks. Rep. No. 3BODM0704. September 1.

Stanek, E.J. III and Calabrese, E.J. 2000. *Daily soil ingestion estimates for children at a Superfund site*. Risk Anal. 20(5):627-35.

Stanek, E.J. III, Calabrese, E.J. and Zorn, M. 2001. *Soil ingestion distributions for Monte Carlo risk assessment in children*. Human and Ecological Risk Assessment. 7(2):357-368.

Stanek, E.J., III, Calabrese, E.J., Barnes, R., and Pekow, P. 1997. *Soil ingestion in adults–results of a second pilot study*. 36:249-257.

Todoruk, Tiona, Deanna Cottrell, Lindsay Paterson, David Williams, Colm Condon, Ian Hers, Gregg Sutherland, Byron Kirkham, Norm Healy. 2009. *White Paper for Discussion Soil Vapours in Parkades (and Other Non-standard Exposure Scenarios)*. Prepared for Science Advisory Board for Contaminated Sites in British Columbia. September 23, 2009.

UK Environmental Agency. 2009. *Updated Technical Background to the CLEA Model*. Report No. SC050021/SR3. January.

United States Environmental Protection Agency (USEPA). 2009. *Exposure Factors Handbook External Review Draft 2009 Update*. Available on-line at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=209866.

United States Environmental Protection Agency (USEPA). 2008a. *Child-Specific Exposure Factors Handbook*. Report EPA/600/R-06/096F, National Center for Environmental Assessment, Office of Research and Development, US EPA, Washington, DC. 20460.

U.S. EPA (Environmental Protection Agency). 2008b. *U.S. EPA's Vapour Intrusion Database: Preliminary Evaluation of Attenuation Factors.* Office of Solid Waste, Washington DC 20460.

Woods, T. Does Your Building Suck? Tony Woods, President, CanAm Building Envelope Specialists Inc. *www.zerodraftusa.com/doesyour**buildingsuck**.pdf* (Accessed February 11, 2011).

Zhao, B., X. Li, D. Li and J. Yang. 2003. *Revised Air-exchange Efficiency Considering Occupant Distribution in Ventilated Rooms*. J. of *Air & Waste Manage. Assoc.* 53:759-763.

APPENDIX A

Literature Search

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
1	British Columbia Ministry of Environment (BC MOE). 2008. Protocol 13. Screening Level Risk Assessment. Available online at: http://www.env.gov.bc.ca/epd/remediation/policy_procedure_protocol /protocols/pdf/protocol_13.pdf	N	N	Y	Y	N
2	Dutch National Institute for Public Health and the Environment **(RIVM). 2009.** *Soil Remediation Circular 2009*.	N	N	Y	Y	N
3	Lencar, C. and Dr. Ray Copes. 2009. Progress Report on the Sampling Activities for the Child Activities Pattern Survey to be used on the Potential Pathways of Exposure from Contaminated Soil to Residents of Multi-unit Apartment Buildings. Prepared for British Columbia Ministry of Environment.	N	N	Y	N	N
4	New Zealand Ministry for the Environment (NZMfE). 2010. *Draft Methodology for Deriving Soil Guideline Values Protective of Human Health.* Wellington: Ministry for the Environment. February 2010.	N	N	Y	N	N
5	Richardson, G.M. and O'Connor Associates Environmental Inc. 1997. Compendium of Canadian Human Exposure Factors for Risk Assessment. O'Connor Associates Environmental Inc., Ottawa, Ontario.	N	N	Y	N	N
6	Science Advisory Board for Contaminated Sites in British Columbia (SABCS). 2009a. Review of CSST (1996) Soil Matrix Derivation Approach and Related Policy Decisions Volume I: SABCS Review and Recommendations for Revision of the CSST(1996) Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites Prepared for British Columbia Ministry of Environment. November 2009.	N	N	Y	Y	N
7	Science Advisory Board for Contaminated Sites in British Columbia (SABCS). 2009b. Review of CSST (1996) Soil Matrix Derivation Approach and Related Policy Decisions Volume II: SABCS Review and Recommendations for Revision of the CSST (1996) Policy Decision Summary. Prepared for British Columbia Ministry of Environment. November 2009.	N	Y	Y	Y	N

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
8	Science Advisory Board for Contaminated Sites in British Columbia (SABCS). 2008. Detailed Ecological Risk Assessment (DERA) in British Columbia Technical Guidance. Prepared by Golder Associates Ltd. Available on-line at: http://www.sabcs.chem.uvic.ca/DERA2008.pdf	N	N	N	Y	N
9	Todoruk, Tiona, Deanna Cottrell, Lindsay Paterson, David Williams, Colm Condon, Ian Hers, Gregg Sutherland, Byron Kirkham, Norm Healy. 2009. White Paper for Discussion Soil Vapours in Parkades (and Other Non-standard Exposure Scenarios). Prepared for Science Advisory Board for Contaminated Sites in British Columbia. September 23, 2009.	N	Y	N	N	Y
10	United States Environmental Protection Agency (USEPA). 2009. Exposure Factors Handbook External Review Draft 2009 Update. Available on-line at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=209866.	N	N	Y	N	N
11	Zhao, B., X. Li, D. Li and J. Yang. 2003. Revised Air-exchange Efficiency Considering Occupant Distribution in Ventilated Rooms. J. of Air & Waste Manage. Assoc. 53:759-763	N	N	N	N	Y
12	Baranowski, A., J. Ferdyn-Grygierek. 2009. Heat demand and air exchange in a multifamily building -- simulation with elements of validation. Building Serv Eng Res Technol. 30: 227	N	N	N	N	Y
13	Bouhamra, W. S., Amal S. Elkilani and Mahmoud Y. Adbul-Raheem. 1998. Predicted and Measured Air Exchange Rates. ASHRAE Journal. 40: 42-45	N	N	N	N	Y
14	Hang, J. A. and Y. G. Li (2010). "Ventilation strategy and air change rates in idealized high-rise compact urban areas." Building and Environment 45(12): 2754-2767.	N	N	N	N	Y
15	He, D., X. W. Fan, et al. (2009). Simulation Study of CO2-based Outdoor Air Rate Control in Public Buildings. ICIEA: 2009 4th IEEE Conference on Industrial Electronics and Applications, Vols 1-6: 3201-3205.	N	N	N	N	Y
16	Lu, T., A. Knuutila, et al. (2010). "A novel methodology for estimating space air change rates and occupant CO2 generation rates from measurements in mechanically-ventilated buildings." Building and Environment 45(5): 1161-1172.	N	N	N	N	Y

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
17	Luther, M. B. (2009). "Ventilation Research on Australian Residential Construction." Architectural Science Review 52(2): 89-98.	N	N	N	N	Y
18	Oie, L., H. Stymne, et al. (1998). "The ventilation rate of 344 Oslo residences." Indoor Air 8(3): 190-196.	N	N	N	N	Y
19	Persily, A., A. Musser, et al. (2010). "Modeled infiltration rate distributions for U.S. housing." Indoor Air 20(6): 473-485.	N	N	N	N	Y
20	Persily, A. K., J. Gorfain, et al. (2006). "Survey of ventilation rates in office buildings." Building Research and Information 34(5): 459-466.	N	N	N	N	Y
21	Tappler, P., F. Twrdik, et al. (2008). "Pilot study for the examination of air change rates in indoor spaces." Gefahrstoffe Reinhaltung Der Luft 68(3): 87-91.	N	N	N	N	Y
22	Teijonsalo, J., J. J. K. Jaakkola, et al. (1996). "The Helsinki office environment study: Air change in mechanically ventilated buildings." Indoor Air-International Journal of Indoor Air Quality and Climate 6(2): 111-117.	N	N	N	N	Y
23	Olson, D. A., and R. L. Corsi. (2002) Fate and Transport of Contaminants in Indoor Air. Soil and Sediment Contamination. 11:583-601	N	Y	N	N	Y
24	Abrahams, P. W. (2002). "Soils: their implications to human health." Science of the Total Environment 291(1-3): 1-32.	Y	N	Y	N	N
25	Ferguson, A. C., R. A. Canales, et al. (2006). "Video methods in the quantification of children's exposures." Journal of Exposure Science and Environmental Epidemiology 16(3): 287-298.	N	N	Y	N	N
26	Hubal, E. A. C., L. S. Sheldon, et al. (2000). "Children's exposure assessment: A review of factors influencing children's exposure, and the data available to characterize and assess that exposure." Environmental Health Perspectives 108(6): 475-486.	N	N	Y	N	N
27	Kerger, B. D., H. W. Leung, et al. (2007). "An adaptable internal dose model for risk assessment of dietary and soil dioxin exposures in young children." Toxicological Sciences 100(1): 224-237.	N	N	Y	N	N
28	Madrid, F., M. Biasioli, et al. (2008). "Availability and bioaccessibility of metals in fine particles of some urban soils." Archives of Environmental Contamination and Toxicology 55(1): 21-32.	N	N	Y	N	N

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
29	Ruggeri, B. (2009). "Chemicals exposure: Scoring procedure and uncertainty propagation in scenario selection for risk analysis." Chemosphere 77(3): 330-338.	N	N	Y	N	N
30	Sarmiento, B., T. Goyanes, et al. (2005). The use of TPH analytical data to estimate human health risk: practical approaches. Environmental Health Risk III. C. A. Brebbia, V. Popov and D. Fayzieva. 9: 93-102.	N	N	Y	N	N
31	Wong, E. Y., J. H. Shirai, et al. (2000). "Survey of selected activities relevant to exposures to soils." Bulletin of Environmental Contamination and Toxicology 65(4): 443-450.	N	N	Y	N	N
32	Brand E, Otte PF, Lijzen, JPA. 2007. CSOIL 2000; an exposure model for human risk assessment of soil contamination. A model description. RIVM report 711701054/2007. National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands.	N	N	Y	N	N
33	EA. 2009. Updated Technical Background to the CLEA Model. Science Report SC050021/SR3, Environment Agency, Bristol, UK. Retrieved from http://www.environmentagency.gov.uk/subjects/landquality/113813/.	N	N	Y	Y	N
34	EA. 2009. Human Health Toxicological Assessment of Contaminants in Soil. Science Report SC050021/SR2, Environment Agency, Bristol, UK. Retrieved from http://www.environmentagency.gov.uk/subjects/landquality/113813/.	N	N	Y	N	N
35	EA. 2009a. Supplementary Information for the Derivation of SGV for Arsenic. Science Report SC050021, Environment Agency, Bristol, UK.	N	N	Y	N	N
36	EA. 2009b. Supplementary Information for the Derivation of SGV for Cadmium. Science Report SC050021/Technical review cadmium, Environment Agency, Bristol, UK.	N	N	Y	N	N
37	EA. 2009c. Supplementary Information for the Derivation of SGV for Mercury. Science report: SC050021 Environment Agency, Bristol, UK	N	N	Y	N	N
38	NEPC. 1999a. National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B(7b) Exposure settings and exposure scenarios. National Environment Protection Council, Adelaide.	N	N	Y	Y	N

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
39	NEPC. 1999b. National Environment Protection (Assessment of Site Contamination) Measure 1999, Adelaide.	N	N	Y	Y	N
40	NEPC. 1999c. National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B(7a) Guideline on Health-Based Investigation Levels. National Environment Protection Council, Adelaide.	N	N	Y	Y	N
41	NEPC. 1999d. National Environment Protection (Assessment of Site Contamination) Measure 1999, Schedule B(4) Guideline on Health Risk Assessment Methodology. National Environment Protection Council, Adelaide.	N	N	Y	Y	N
42	Golder Associates. 2003. Safe housing for lightly contaminated lands research project - Pacific Place study results. Report to CMHC, Ottawa, Ontario.	N	Y	N	N	Y
43	Shaw, C. Y. 1999. Factors affecting the performance of ventilation systems in large buildings. NRC Construction Technology Update No. 33	N	N	N	N	Y
44	Wilson A. G., G. T. Tamura. 2003. CBD-107. Stack effect and building design. NRC Canadian Building Digest	N	N	N	N	Y
45	Hayes, V., and I. Shapiro-Baruch. 2004. Evaluating ventilation in multifamily buildings. Home Energy Magazine	N	N	N	N	Y
46	CMHC. 2001. Air leakage characteristics, test methods and specifications for large buildings. Technical series 01-123	N	N	N	N	Y
47	CMHC. 2000. Field tests of ventilation systems installed to meet the 1993 OBC and 1995 NBC. Technical series 00-106	N	N	N	N	Y
48	CMHC. 2002. Defining the convective driving force for soil gas intrusion into houses. Technical series 02-114	N	Y	N	N	Y
49	CMHC. 2002. Monitored performance of an innovative multi-unit residential building. Technical series 02-135	N	N	N	N	Y
50	CMHC. 1999. Field testing to characterize suite ventilation in recently constructed mid- and high-rise residential buildings. Technical series 99-118	N	N	N	N	Y
51	CMHC. 2003. Ventilation Systems for Multi-Unit Residential Buildings: Performance Requirements and Alternative Approaches. Technical series 03-121	N	N	N	N	Y

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
52	CMHC. 2005. Assessment of Suite Compartmentalization and Depressurization in New High-Rise Residential Buildings. Technical series 05-112	N	N	N	N	Y
53	ASHRAE Standard 62.1 2007. Ventilation for acceptable indoor air quality.	N	N	N	N	Y
54	Chan, M. Y. and W. K. Chow. 2004. Car park ventilation system: performance evaluation. Building and Environment. 39:635-643	N	N	N	N	Y
55	Krarti M. and A. Ayari. 2001. Ventilation for enclosed parking garages. ASHRAE Journal. pp52-55	N	N	N	N	Y
56	Krarti M., A. Ayari, D. Grot. 1998. Evaluation of fixed and variable rate ventilation system requirements for enclosed parking facilities. ASHRAE Research Project 945-RP	N	N	N	N	Y
57	United States Environmental Protection Agency (USEPA). 1997. Exposure Factors Handbook. Available on-line at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12464#Download	N	N	Y	N	N
58	United States Environmental Protection Agency (USEPA). 2008. Child-Specific Exposure Factors Handbook - Final. Available on-line at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=199243#Download	N	N	Y	N	N
59	New Zealand Ministry for the Environment (NZMfE). 2010. Draft Toxicological Intake Values for Priority Contaminants in Soil. Wellington: Ministry for the Environment. February 2010.	N	N	Y	N	N
60	ASHRAE Standard 62.2 2007. Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings (ANSI Approved).	N	N	N	N	Y
61	British Columbia Building Code. 2006.	N	N	N	N	Y
62	National Building Code of Canada. 2005.	N	N	N	N	Y
63	Haysom and Reardon, 1998. Current approaches for mechanical ventilation of houses. Construction Technology Update No. 15. National Research Council of Canada (NRC).	N	N	N	N	Y
64	Coombes, E., A. P. Jones, et al. (2010). "The relationship of physical activity and overweight to objectively measured green space accessibility and use." Social Science & Medicine 70(6): 816-822.	Y	N	N	N	N

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
65	Godbey, G. C., L. L. Caldwell, et al. (2005). "Contributions of leisure studies and recreation and park management research to the active living agenda." American Journal of Preventive Medicine **28**(2): 150-158.	Y	N	N	N	N
66	Jansson, M. (2010). "Attractive Playgrounds: Some Factors Affecting User Interest and Visiting Patterns." Landscape Research **35**(1): 63-81.	Y	N	N	N	N
67	Jansson, M. and B. Persson (2010). "Playground planning and management: An evaluation of standard-influenced provision through user needs." Urban Forestry & Urban Greening 9(1): 33-42.	Y	N	N	N	N
68	Kaczynski, A. T. and K. A. Henderson (2007). "Environmental correlates of physical activity: A review of evidence about parks and recreation." Leisure Sciences **29**: 315-354.	Y	N	N	N	N
69	McCormack, G. R., M. Rock, et al. (2010). "Characteristics of urban parks associated with park use and physical activity: A review of qualitative research." Health & Place **16**(4): 712-726.	Y	N	N	N	N
70	Kalamees et al. (2010). "Measured and simulated air pressure conditions in Finnish residential buildings." Building Serv. Eng. Res. Technol. doi:10.1177/0143624410363655.	N	N	N	N	Y
71	City of Vancouver (1992). "High-density housing for families with children guidelines." Land Use and Development Policies and Guidelines.	Y	N	N	N	N
72	City of Vancouver (2009). "Urban agriculture guidelines for the private realm." Land Use and Development Policies and Guidelines.	Y	N	N	N	N
73	Proskiw, G. and Phillips, G. 2008. An examination of air pressure and air movement patterns in multi-unit residential buildings. Building Enclosure Science and Technology Conference, Minneapolis.	N	N	N	N	Y
74	Davis, S. and Mirick, D.K. 2006. Soil ingestion in children and adults in the same family. J Expo Sci Environ Epidemiol. 16:63-75.	N	N	Y	N	N
75	Hawley J.K. 1985. Assessment of health risk from exposure to contaminated soil. Risk Anal. 5(4):289-302.	N	N	Y	N	N

Document No.	Reference	General	Vapour Intrusion for High Density Buildings	Human Health - Soil Intake and Dermal Contact	Ecological Pathways	Building HVAC Information
76	Health Canada. 2009. Federal Contaminated Site Risk Assessment in Canada – Part I: Guidance on Human Health Preliminary Quantitative Risk Assessment (PQRA). Environmental Health Assessment Services, Safe Environments Programme, Health Canada, Ottawa, Ontario.	N	N	Y	N	N
77	Stanek, E.J. III and Calabrese, E.J. 2000. Daily soil ingestion estimates for children at a Superfund site. Risk Anal. 20(5):627-35.	N	N	Y	N	N
78	Stanek, E.J. III, Calabrese, E.J. and Zorn, M. 2001. Soil ingestion distributions for Monte Carlo risk assessment in children. Human and Ecological Risk Assessment. 7(2):357-368.	N	N	Y	N	N
79	Stanek, E.J., III, Calabrese, E.J., Barnes, R., and Pekow, P. 1997. Soil ingestion in adults¬-results of a second pilot study. 36:249-257.	N	N	Y	N	N
80	Leech, J.A., Wilby, K., McMullen, E. and Laporte, K. 1997. The Canadian human activity pattern survey: report of methods and population surveyed. Chron Dis Can 17: 118-123.	Y	N	N	N	N
81	Leech, J.A., Nelson, W.C., Burnett, R.T., Aaron, S. and Raizenne, M.E. 2002. It's about time: A comparison of Canadian and American time-activity patterns. J Expo Anal Environ Epidemiol 12: 427-432.	Y	N	N	N	N

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
500 - 4260 Still Creek Drive
Burnaby, British Columbia, V5C 6C6
Canada
T: +1 (604) 296 4200

Golder Associates