

Overview of CSST Procedures for the Derivation of Soil Quality Matrix Standards for Contaminated Sites

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January 31, 1996

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Part A

A1. The Contaminated Sites Soil Task Group (CSST) History and Objectives

A1.1 CSST History

The Contaminated Sites Soil Task Group (CSST) was formed in November of 1994 and completed its work in November 1995. Under its terms of reference (BC Ministry of

Environment, Lands and Parks, 1994), CSST was charged with the development of scientifically defensible environmental quality standards to protect human and environmental health from contaminants present in the soil of contaminated sites. The members of CSST represented health and environment experts providing assistance to the BC Ministry of Environment, Lands and Parks in the derivation of appropriate soil quality standards for use in the [Contaminated Sites Regulation](#) (BC Ministry of Environment, Lands and Parks, 1995a). In conducting this work, CSST encouraged open communication between its members and sought advice and support from other knowledgeable professionals. CSST reported regularly to a steering committee composed of representatives from the Ministry of Environment, Lands and Parks, the Ministry of Health and the province's Medical and Environmental Health Officers. (See Appendix A for a listing of CSST members.)

In developing its policy recommendations, CSST started with two documents provided by the CCME's Subcommittee on Environmental Quality Criteria for Contaminated Sites (SEQCCS); "A Protocol for the Derivation of Ecological Effects-based and Human Health-based Soil Quality Criteria for Contaminated Sites" (CCME, 1994a) and "Guidance Manual for Developing Site Specific Soil Quality Remediation Objectives for Contaminated Sites in Canada" (CCME, 1994b). CSST considered all aspects of the CCME's documents, including the stated goals and principles, levels of protection and scope of receptors to which protection is to be accorded as well as specific derivation formulas. In some cases, CSST accepted CCME recommendations while in other cases CSST policy recommendations differ from those of CCME. The rationale behind CSST science policies are recorded in the document, "CSST Policy Decision Summary" (BC Ministry of Environment, Lands and Parks, 1996). The soil quality standard derivation procedures provided herein are based on CSST's science policy decisions as documented in the CSST Policy Decision Summary.

A1.2 CSST Objectives

Recognizing that both scientific and policy considerations must be addressed, CSST's challenge was to derive soil quality standards which serve the following objectives under British Columbia's contaminated sites legislation:

- to determine when a site is considered to be contaminated,
- to determine when remediation has been adequately performed at a site, and
- to control the relocation of contaminated soils.

Developing procedures to derive soil quality standards to address the above objectives formed the basis of the work of CSST.

A2. The CSST Procedures and the CCME National Soil Quality Criteria Protocol

A2.1 Relationship to CCME Protocol

The proposed CCME Protocol was developed by the SEQCCS to provide National criteria for the assessment and remediation of contaminated sites in Canada. The common goal of both

CCME and CSST was to produce scientifically defensible and "transparent" risk-based defined exposure scenario soil quality numbers. CSST accepted the fundamental methodology represented in the CCME Protocol as guidance and developed derivation procedures for soil quality standards using CCME policy as the foundation for its work. However, CSST also recommended adoption of a number of different policies regarding certain aspects of the CCME Protocol, such as the level of protection afforded receptors.

CSST adapted the CCME Protocol because it believed that for many parameters, the CCME Protocol produced both human and ecological health criteria which provided a level of protection which would not be workable within the contaminated site remediation and management program envisioned for British Columbia. CSST was of the opinion that soil quality standards derived from the CCME Protocol would be generally more appropriate for use in the prevention of new contaminated sites than in the remediation of existing sites.

A2.2 Comparison to CCME Protocol

Both the CCME protocol and the CSST procedures emphasize the derivation of standards which reflect acceptable concentrations of contaminants in soil. The alterations made to the CCME Protocol by CSST centre primarily around the levels of protection, the defined exposure scenarios, reasonable critical receptors, and the use of "checks" in derivations. The levels of protection, exposure scenarios and receptors used in the CSST methods reflect policies considered appropriate within the context of contaminated site management in British Columbia. New equations have been added by CSST to address some site specific factors not considered by CCME. In addition, derivation methods in the CSST procedures are often simpler than those proposed by the CCME. This reflects CSST's judgement that some of the CCME procedures use default assumptions of questionable scientific veracity or are overly complex.

The derivation of soil criteria in the CCME protocol to protect groundwater for use as drinking water has been expanded by CSST to also address the protection of aquatic life, irrigation and livestock watering. CSST also considered the possibility of deriving standards to address potential "physical hazards" and organoleptic concerns posed by some contaminants.

As a result, CSST developed procedures to derive standards to address concerns relating to objectionable odours associated with some contaminants. Standards relating to other physical hazards (i.e. explosivity, flammability) are more appropriately addressed and evaluated through reference to the Special Waste Regulation.

As a result of the incorporation of mechanisms to account for common site specific factors, the soil quality standards derived under the CSST protocol are designed to be both flexible and easy to use' BC Environment has opted to present all derived soil quality standards as discrete components of substance specific "matrices" which contain human, environmental and "other" protective standards.

A3. CSST Procedures for the Derivation of British Columbia Soil Quality Standards for Contaminated Sites

A3.1 Summary of CSST Methods

This overview of CSST Procedures provides the basic concepts and methods employed by CSST in developing soil quality matrix standards. The derivation procedures as detailed herein provide the basic steps needed to generate risk-based soil remediation standards for the defined exposure scenarios presented. In this summary, the general rationale, methodology and equations used by CSST to derive the soil quality standards is outlined and referenced.

A3.1.1 Environmental Protection Standards

For the protection of the non-human components of the terrestrial ecosystem, the derivation procedures consider primarily adverse effects from exposure to soil-based contaminants at point-of-contact. Potential exposure pathways, receptor arrays, and exposure scenarios are described for major land uses. As in the CCME procedures, CSST generally believes that derivation of soil contact standards, protective of plants and soil invertebrates, will act to sustain the ecological receptors thought critical to the primary activities associated with the identified land use categories. Additionally, groundwater protection soil quality standards for non-polar and polar organic and heavy metal contaminants are also derived for the protection of aquatic life, irrigation and livestock watering. These indirect exposure routes are evaluated through the application of simplified transport and redistribution models using specified site default characteristics. The models were constructed to protect a wide variety of site specific conditions.

A3.1.2 Human Health Protective Standards

For the protection of human health, derivation procedures for threshold and non-threshold toxicants are differentiated. Receptors and exposure periods are chosen to be generally representative of each land use scenario. Also provided is CSST's procedure to derive soil standards to protect groundwater for use as drinking water.

A3.2 Limitations of CSST Methodology

CSST's methodology does not generally attempt to account for the important factor of contaminant depth in the soil. This issue is a management consideration which is addressed in the [Contaminated Sites Regulation](#) (BC Ministry of Environment, Lands and Parks, 1995a).

The defined exposure scenarios used to develop the soil quality standards are necessarily limited in scope and do not cover the full spectrum of the types of sites, environments and organism-site interactions that can exist. For example, the effects of exposure to mixtures of chemicals cannot be addressed, as the bulk of toxicological data are concerned with the effects of isolated chemicals. However, it is believed, on the basis of professional judgement and the scientific literature on contaminated site exposures, that the defined exposure scenarios used by CSST can address the majority of hazardous and potentially hazardous exposures likely to occur.

It is also recognised that each chemical will offer specific characteristics that cannot be adequately documented in this summary. These substance specific characteristics have been identified and discussed in supporting substance assessment documents produced by the CCME.

In addition, it is recognized that new data will come to light as the science of toxicology and soil contaminant exposure develops.

A3.3 Land Use Based Differential Protection

Toxicological effects-based soil quality standards were derived according to broad land use categories. These are: Agricultural, Residential/Urban Parkland, Commercial and Industrial land uses. For provincial regulatory purposes, the Residential/Urban Parkland group was separated to give two discrete land use categories. Standards were derived to protect human and key ecological receptors that sustain 'normal' activities carried out on these lands. Specific land use scenarios were defined for each category based on the representative "normal" activities carried out on these lands. Sensitivity to contamination varies among the land uses, reflecting CSST's policy decisions made regarding the differential level of protection to be accorded to the ecological or human health components. Thus, Agricultural and Residential/Urban Parkland land uses are accorded a greater level of protection from contamination than Commercial or Industrial land uses. This differential protection was deemed necessary to sustain the specified land use activities. It should be noted however, that the land use scenario envisioned for each category may not always occur on a site-specific basis.

A3.3.1 Land Use Definitions

The definition of each land use must be broad enough to be generally representative of the likely conditions encountered. However, the definition provided for each land use also acts to "bound" or limit the receptors and exposure pathways considered in the derivation of soil quality standards for that land use. CSST's definitions of the four land use categories are provided below:

Agricultural: land where the primary activity is related to food production, such as using the land for growing crops and producing livestock. This also includes lands categorised as agricultural that provide habitat for resident and transitory wildlife and native flora (e.g. transition zones).

Residential / Urban Parkland: lands where the primary activity is occupation of the land for residency and lands used for the purpose of recreational activity. This also includes parkland and residential lands used by wildlife, such as buffer zones between areas of residences, but does not include "wildlands" such as national or provincial parks.

Commercial: lands where the primary activity is related to commercial operations (e.g. shopping mall) and occupancy is not for residential or manufacturing purposes. This does not include operations where the growing of food is the primary activity.

Industrial: lands where the primary activity involves the production, manufacture or construction of goods

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Part B

B1. The Derivation of Environmental Protective Matrix Soil Quality Standards

B1.1 Introduction

CSST developed derivation procedures for the following six discrete Environmental Protective matrix standards:

1. Toxicity to soil invertebrates and plants
2. Livestock ingesting soil and fodder
3. Major microbial functional impairment
4. Groundwater flow to surface water used by aquatic life
5. Groundwater used for livestock watering
6. Groundwater used for irrigation watering

The derivation procedures for each of these discrete standards is detailed below.

B2. Derivation of Toxicity to Soil Invertebrates and Plants Standard

B2.1 General Considerations

The "Toxicity to soil invertebrates and plants" standard represents the primary soil standard for the protection of ecological health. This standard represents a "mandatory" matrix standard which is required to be applied at every site.

In deriving substance "Toxicity to soil invertebrates and plants" standards for the protection of ecological health, CSST focused its attention primarily on the effects of chemical stressors to the biotic component of the terrestrial ecosystem. The ecological effects-based "Toxicity to soil invertebrates and plants" standard (SQS_{EE}) was derived through the use of sensitive measurement endpoint data from key receptors which are considered to act as predictive sentinel species. Primary acceptable endpoints for SQS_{EE} derivation include mortality, reproduction and growth. CSST considered the complete set of such endpoint measurements as given in draft unpublished CCME Ecological Health Substance Assessment documents as the raw data from which to derive the SQS_{EE} matrix standards.

B2.1.1 Ecological Receptors and Exposure Pathways

In determining the critical ecological receptors and exposure pathways for use in deriving environmental protection matrix standards, CSST believed that the selected receptors should reflect the important characteristics of the ecosystem for each land use and should be compatible with the system attributes. Thus, although the level of protection provided is less rigorous for industrial and commercial sites, CSST believed that even these lands should be able to support a reasonable level of ecological function (i.e. at least be able to grow unsupplemented grass). The paucity of ecological effects information available for terrestrial organisms required that selection of ecological receptors be focused only on those receptors considered key to the maintenance of land use activities.

Similar data limitations restricted the pathways of soil exposure that could be considered for these receptors. Possible direct exposure pathways considered were:

1. Direct Soil Contact - by microbes, soil invertebrates and plants
2. Food Ingestion- by livestock eating contaminated plants
3. Soil Ingestion- by livestock eating soil

Ultimately, CSST decided to focus on direct soil contact as the appropriate exposure pathway to derive the primary ecological health protective standard. This choice was thought appropriate as these organisms may receive the greatest threat from contaminated soil. Consequently, this pathway is considered in all land uses and is used to calculate the "toxicity to soil invertebrates and plants" standard. Due to the lack of data regarding dermal contact with contaminated soil by other organisms, it is assumed that the level of protection provided for soil dependent species will also be generally adequate for the protection of livestock and wildlife. This assumption holds except in the case where explicit evidence to the contrary exists.

In addition to the above direct exposure pathways, CSST acknowledged the need to protect against indirect contamination of ground water which may affect aquatic life or transfer contamination to water used for irrigation or livestock watering. Table 1 summarizes the receptors and exposure pathways considered for each land use.

Table 1. Ecological Receptors and Exposure Pathways Considered for Specific Land-use Categories in the Derivation of Ecological Effects Soil Quality Standards

Land Use	Receptors	Direct Exposure Pathways	Indirect Exposure Pathways
Agricultural	- soil nutrient cycling processes (microbes) - crops/plants - soil invertebrates - livestock	- direct soil contact - soil and fodder ingestion by livestock	- transfer of contaminant to groundwater affecting: 1. aquatic life 2. livestock 3. plants
Residential / Urban Parkland	- plants - soil invertebrates	- direct soil contact	- transfer of contaminant to groundwater affecting: 1. aquatic life

			2. plants
Commercial	- plants - soil invertebrates	- direct soil contact	- transfer of contaminant to groundwater affecting: 1. aquatic life
Industrial	- plants - soil invertebrates	- direct soil contact	- transfer of contaminant to groundwater affecting: 1. aquatic life

B2.1.2 Details

"Toxicity to soil invertebrates and plants" soil quality standards were calculated for all land uses to protect plants and soil dependent invertebrates from the adverse effects of direct contact with contaminants in soil. As described below, both LC20 and EC50-NL values were estimated for each substance. For Agricultural, Residential and Urban Parkland uses, the concentration corresponding to the more stringent of the LC20 and the EC50-NL values was chosen as the appropriate "Toxicity to soil invertebrates and plants" soil quality matrix standard. For Commercial and Industrial land uses, the concentration representing the less stringent of the LC20 and the EC50-NL values was chosen as the appropriate "Toxicity to soil invertebrates and plants" matrix standard.

The "Toxicity to soil invertebrates and plants" standard is derived according to the five step procedure below:

1. Consider all appropriate invertebrate and plant toxicity data from CCME "Substance Assessment" documents
2. Separate data into discrete lethal and non-lethal effect distributions
3. Calculate median effects concentrations for lethal and non-lethal distributions
4. Fit linear regression lines to lethal and non-lethal median distributions. If lethal or non-lethal regression correlation coefficient < 0.25 use "Empirical Exception" rule¹.
5. Determine regression intercepts for EC50-NL and LC20 and apply appropriate level of protection rule for:
 - o A/R/P - lesser of EC50-NL or LC20
 - o C/I - greater of EC50-NL or LC20

¹ "Empirical Exception" rule: Estimate EC50-NL and/or LC20 via empirical extrapolation from median effects distributions.

B2.2 Site-specific Factors for Agricultural Land

CSST recognized that in some circumstances the "Toxicity to soil invertebrates and plants" standard derived above might not adequately protect livestock raised on remediated agricultural sites. In consequence, CSST developed the procedure detailed below to derive a "Livestock ingesting soil and fodder" standard. This standard is applicable to agricultural land use only.

B2.2.1 Livestock Ingesting Soil and Fodder Standard

Wherever sufficient livestock toxicity data was available, a "Livestock ingesting soil and fodder" standard was derived to ensure that remediated agricultural sites would not pose health risks for domestic livestock directly ingesting soil and foraging on vegetation grown on these sites. Livestock exposures to both contaminated soil and plants grown in contaminated soil are assessed through this site specific factor. Where data indicated a particular or unique species sensitivity to the contaminant in question, the standard was derived using parameters relevant to that species, otherwise cattle were generally assumed as the default receptor of concern.

B2.2.2 Details

The CSST "Livestock ingesting soil and fodder" standard derivation procedure is detailed below (Exhibit 1).

Exhibit 1 - Derivation of Livestock Ingesting Soil and Fodder Standard (Cs)

$$C_s = \frac{TRV \times BW}{[(Bv \times IR_f) + IR_s] \times AB \times ED \times AUF}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
C _s	= Livestock ingesting soil and fodder standard	
TRV	= toxicity reference value	chemical specific ¹
BW	= receptor body weight (kg)	600 ²
BV	= soil to plant transfer coefficient for vegetative tissue	chemical specific ³
IR _f	= food ingestion rate (kg/d) or 0.687 x BW ^{0.651}	13.5 ²
IR _s	= soil ingestion rate (kg/d) or 0.083 x DMIR	1.5 ²
AB	= bioavailability	1.0 (i.e. 100%)
ED	= duration of exposure	1.0 ⁴ (i.e. 365d/yr)
AUF	= area use function:	1.0 ⁵ (i.e. 100%)

ratio of affected area

range

DMIR = dry matter intake rate (kg/d) 15²

1 = see [Exhibit 2](#)

2 = default value for cattle

3 = point estimate from Oak Ridge National Laboratory, ORNL, 1984

4 = ED is climate specific because the duration of exposure to the contaminant is dependent to a variable extent on the climate of the given region

5 = AUF is area specific since the receptors may not occupy the entire given area and the contaminant might not be uniformly distributed throughout the given area

The substance toxicity reference values (TRV) of Exhibit 1 are calculated as detailed in Exhibit 2 and are generally derived using the lower bound of the estimated high dietary concentration range for the contaminant as reported in Puls (1994).

Exhibit 2 - Calculation of Toxicity Reference Value (TRV) for Use in Derivation of CSST Livestock Ingesting Soil and Fodder Standard

$$\text{TRV} = \frac{\text{CD} \times \text{IR}_f}{\text{BW}}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
TRV	= toxicity reference value	
CD	= lower bound of the high dietary concentration (mg/kg)	chemical specific
<u>IR_f</u>	= fodder ingestion rate (kg/d)	13.5 ¹
BW	= body weight (kg)	600 ¹

1 = default value for cattle

The estimated TRVs represent dosages where frank adverse effects to the receptor are not expected to occur. Calculated copper and lead livestock soil quality standards based on this approach resulted in soil standard concentrations at or below reported background levels. To remedy this, the upper bound of the high dietary range was used to derive "Livestock ingesting soil and fodder" matrix standards for these two contaminants (Macfarlane, 1995a).

The CSST "Livestock ingesting soil and fodder" standard derivation procedure is generally consistent with a similar procedure presented in the CCME Protocol (CCME 1994a). However, CSST has modified the CCME method to make use of the dietary toxicity data available for livestock species documented in Puls (1994). In addition, the CSST procedure considers the potential exposure of a receptor via ingestion of both contaminated soil (IRS) and contaminated fodder (IRf) at a site. Estimates of contaminant uptake by plants (fodder) were derived using the soil-to-plant transfer coefficients for the vegetative portion of plants (BV) referenced in the 1984 Oak Ridge National Laboratory report "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture" (ORNL, 1984).

B2.3 Derivation of Major Microbial Functional Impairment Soil Quality Standard

As a matter of policy, CSST decided to ensure additional protection for microbial functional processes in agricultural soils. In consequence, CSST has recommended simple adoption of the CCME "major microbial function check" criterion as the "Major microbial functional impairment" standard. The reader is referred to the CCME Protocol document (see pages 40-56 and Appendix A of that document) for details of the derivation procedure (CCME, 1994a). Where sufficient data exists, Environment Canada has calculated microbial protective criteria for inclusion in CCME substance assessment documents.

B2.4 Environmental Soil Quality Standards for the Protection of Groundwater

CSST recognized that groundwater is a valuable resource. Groundwater is a source of recharge to our streams, rivers and lakes, and is a source of drinking water and irrigation water. The discharge and use of groundwater can affect the health of humans and aquatic life, and influence the aesthetic quality of the environment. In consequence, CSST developed procedures to derive soil-groundwater protective standards for the protection of drinking water, livestock watering, irrigation watering and use by aquatic life.

B2.4.1 General Considerations

Matrix soil standards for the protection of groundwater were derived using a groundwater transport model approved by CSST. This model simulates the movement of a contaminant from the soil to the groundwater, and the subsequent movement of the contaminant in the groundwater to a receptor. Contaminant transport is modelled through four chemical/ physical components, including: contaminant partitioning between soil, soil pore air, and soil pore water; contaminant leachate movement and attenuation through the unsaturated soil zone; contaminant leachate mixing with the groundwater, and contaminant movement and attenuation through the saturated groundwater zone to a receptor.

CSST considered many of the groundwater models available, including that described in the CCME protocol (CCME, 1994a; CCME, 1995a). Ultimately however, CSST recommended the use of a relatively simple model proposed by BC Environment.

B2.4.2 Details

BC Environment, with the assistance of Golder Associates Ltd., compiled a model in which flow is assumed to be essentially one dimensional, while still incorporating the major transport and attenuation processes affecting contaminant movement. The draft "Soil Screening Guidance, 1994" produced by the US Environment Protection Agency was used as the framework to develop the model (EPA, 1994). The mathematical code for the saturated groundwater transport is based on work by Domenico and Robbins, (Domenico and Robbins, 1984). Model assumptions however, are based on work by BC Environment.

BC Environment recommended its four component model because:

- the major transport processes are represented,
- the major variables affecting each of the transport components are included, can be identified, and can be modified,
- physical and chemical affects are considered,
- model assumptions and criteria derivations are "transparent,"
- the model can be calibrated,
- the model performs with reasonable accuracy using a small set of input parameters,
- the accuracy and reliability of the model increases as site specific information increases,
- the model can be used with assumed site characteristics or use site specific data, and
- the model is scientifically based and defensible.

The BC Environment Transport Model as approved by CSST has been used to develop soil matrix standards for the protection of groundwater for both organic and inorganic contaminants. The model best simulates the transport of non-polar organic contaminants, and with modifications the model is used to simulate the transport of weakly ionizing substances. Metal transport modelling must be augmented by using an equilibrium geochemical speciation model, such as MINTEQ2.

In all transport models, the proportionment or partitioning of a chemical between soil, soil pore air, and soil pore water is critical. In the CSST approved model, the partitioning for non-polar organic contaminants is primarily a function of the organic carbon coefficient of the contaminant and the amount of organic carbon in the soil. For weakly ionizing substances, such as pentachlorophenols, partitioning in the model is additionally influenced by the pH of the soil. Partitioning of inorganics is considerably more complex, being additionally dependent on factors such as pH, sorption to clays, organic matter, iron oxides, oxidation/reduction conditions, major ion chemistry and the chemical form of the metal. This model uses distribution coefficients (K_d) calculated as a function of pH, and as a function of an idealised soil with assigned physical and chemical characteristics. For inorganic contaminants modelling flexibility is limited in that distribution coefficients are only allowed to vary with respect to changes in soil pH. Soil pH, however, is only one of many geochemical parameters that actually can affect and change the distribution coefficient.

Attenuation within the model is essentially confined to adsorption-desorption reactions (partitioning), dilution (mixing between contaminated leachate and groundwater, biological degradation (for organics only) and dispersion.

The transport model derives soil concentration standards to ensure that the contaminant concentrations in the groundwater discharging and in contact with a receptor are less than or equal to established substance specific water quality criteria for the receptor (i.e. aquatic life) or water use (i.e. irrigation watering, livestock watering or drinking water) of concern. Thus, allowable concentrations in the groundwater at the point of contact with a receptor are based on either the aquatic life criteria, or for irrigation and livestock water uses, the respective irrigation or livestock watering criteria, presented in the CCME "Interim Canadian Environmental Quality Criteria for Contaminated Sites" (CCME, 1991), or "Canadian Water Quality Guidelines" (CCME, 1995b) and/or BC Environment's "Approved and Working Criteria for Water Quality" (BC Ministry of Environment, Lands and Parks, 1995b). Soil standards to protect groundwater for use as drinking water are based on the drinking water criteria presented in "Guidelines for Canadian Drinking Water Quality" (Health Canada, 1993) and/or "Approved and Working Criteria for Water Quality" (BC Ministry of Environment, Lands and Parks, 1995b) documents.

The Groundwater Protection Transport Model is based on assumptions generally typical of the climatic conditions of the lower Fraser River/ Vancouver area of British Columbia, and assumed groundwater characteristics typical of those found within the Fraser River sands of the Fraser River delta area. Other assumptions include:

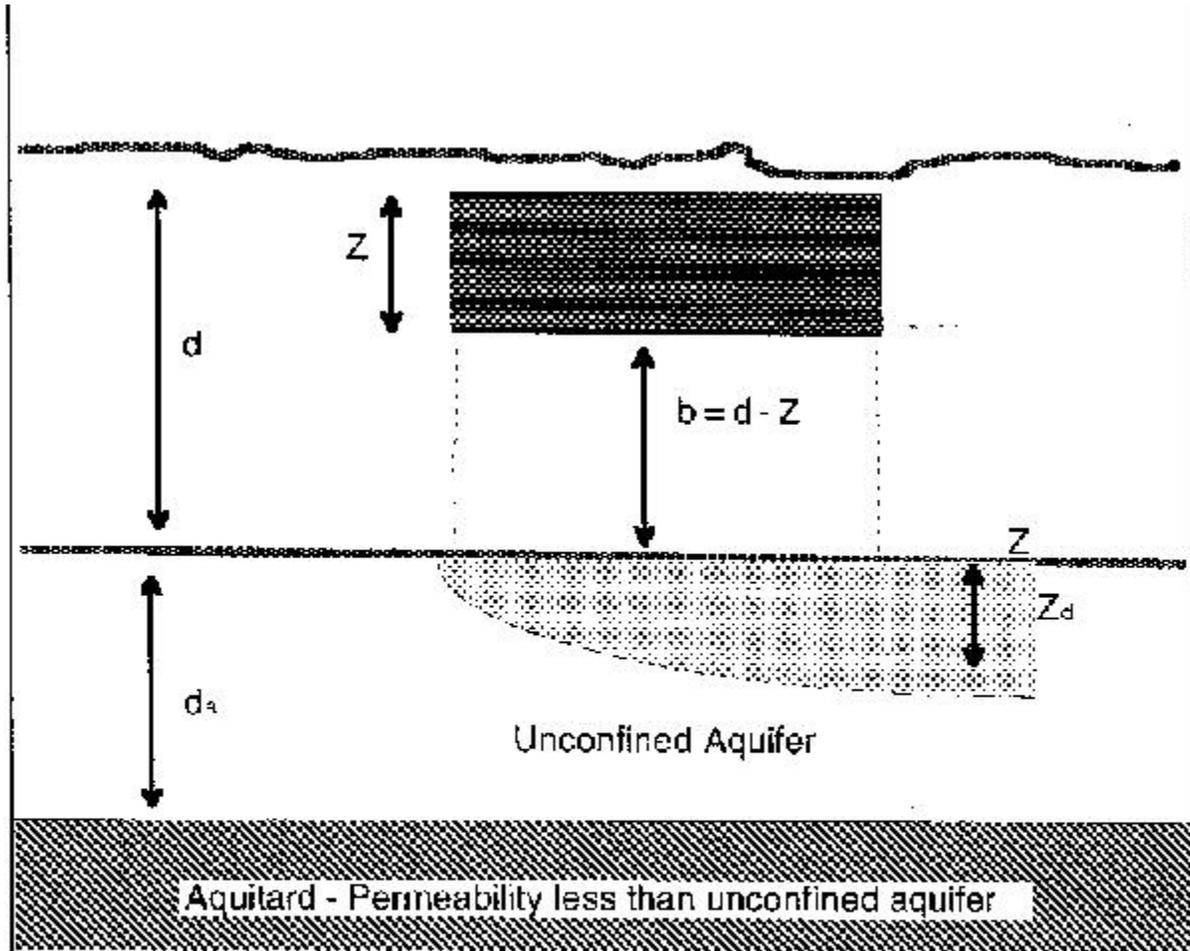
- the site is medium sized (between 1500 m² and 12000 m²),
- the total volume of contaminated soil is less than 450 cubic metres (5m x 30 m x 3 m),
- the depth to groundwater is not more than three (3) metres,
- the distance to the receptor is at least 10 metres,
- the soil is physically and chemically homogeneous,
- the organic content of the soil is at least 0.6 percent,
- the moisture content is uniform throughout the unsaturated zone,
- the porosity of the soil is 30 percent, and 10 percent of the pore volume is water filled,
- the infiltration rate is uniform throughout the unsaturated zone,
- flow in the unsaturated zone is assumed to be one dimensional and downward only, with dispersion, retardation and biological degradation,
- the contaminant is not present as a free product phase (i.e. a non-aqueous phase liquid),
- the maximum concentration in the leachate is equivalent to the solubility limit of the chemical in water under the defined site conditions,
- the groundwater aquifer is unconfined,
- the groundwater flow is uniform and steady,
- co-solubility and oxidation/reduction effects are not considered,
- attenuation in the saturated zone is assumed to be one dimensional with respect to retardation, dispersion and biodegradation,
- dispersion is assumed to occur in the longitudinal and horizontal transverse directions only, and diffusion is not considered,
- mixing of the leachate with the groundwater is assumed to occur through mixing of leachate and groundwater mass fluxes, and
- dilution by groundwater recharge down gradient of the source is not included.

Refer to Schematic drawing 1 for a typical transverse section through a contaminated source.

The mathematical equations for each of the four model components are presented below in Exhibits 3, 4, 5, 6 and 7. The soil/leachate partitioning component is presented in [Exhibit 3](#). The flow component in the unsaturated soil zone is presented in [Exhibit 4](#). The mixing of unsaturated and saturated zone waters is presented in Exhibit 5. The flow component in the saturated groundwater zone is presented in Exhibit 6. Conditions relating to the contaminant concentration in the saturated groundwater zone are provided in [Exhibit 7](#). Exhibit 8 provides definitions for parameters, and corresponding default values, used in modelling to produce matrix soil groundwater protective standards.

For each of the chemicals for which matrix soil-groundwater protection standards have been derived, the chemical characteristics used in the model are presented in [Appendix B](#). Chemical characteristics provided include solubility, organic:water and other distribution coefficients, biological degradation rates, and Henry's Law constants.

Schematic Drawing 1 - Transverse Section of Contaminated Source in Various Layers of Soil



Z = thickness of contaminated source
 d = depth from ground surface to uncontaminated groundwater surface
 b = thickness of the unsaturated zone
 d_a = thickness of unconfined groundwater aquifer
 Z_d = thickness of mixing zone

Exhibit 3 - Soil/Leachate Partitioning Model

$$C_s = C_L \{ Kd + (n_u + H'n_a) \}$$

Pb

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
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C _S	= soil concentration at source (mg/kg)	
C _L	= leachate concentration at source (mg/L)	calculated value
Kd	= distribution coefficient for a chemical (cm ³ /g)	chemical/physical specific ¹
n _u	= water filled porosity (dimensionless)	0.1
H'	= dimensionless Henry's Law constant for the chemical	H x 42.3 ²
H	= Henry's Law constant (atm-m ³ /mol)	chemical specific
NA	= air filled porosity (dimensionless): NA = n - n _u .	0.2
Pb	= dry bulk density of soil (g/cm ³)	1.75 ³

¹ = see Appendix B

² = where 42.3 is a units conversion factor for 15°C

³ = based on "Fraser River sand" characteristics

Exhibit 4 - Unsaturated Groundwater Zone

$$C_z = C_L \exp \left[\frac{b}{n_u} \left\{ 1 + \left(\frac{4n_u L_{US}}{V_U} \right)^{1/2} \right\} \right]$$

$$v_u = \frac{I}{n_u R_u}; R_u = 1 + \frac{Pb}{n_u} \times Kd$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
C _Z	= chemical concentration of the leachate at the watertable (mg/L)	
C _L	= leachate concentration at the source (mg/L)	calculated value

b	= thickness of the unsaturated zone (m): $b=d-Z$	0
d	= depth from surface to uncontaminated groundwater surface (m)	3
Z	= depth of contaminated soil (m)	3
α_u	dispersivity in the unsaturated zone (m)	0.1 x b
LUS	decay constant for chemical (seconds ⁻¹) in unsaturated zone:	calculated value
	$L_{US} = \frac{0.691}{t_{1/2US}} \times (e^{-0.07 \times d}) \times 1 - (D_{1/2US})$	365
$t_{1/2US}$	= chemical half-life in unsaturated zone	chemical specific ¹
$D_{1/2US}$	= frost free days	365
V_u	= average linear leachate velocity (m/s)	calculated value
I	= infiltration rate (m/yr): $= P - (RO + EV)$	0.55
P	= precipitation rate (m/yr)	1
(RO + EV)	= sum of runoff rate (RO) + surface evapotranspiration rate (EV) (m/yr)	0.45
n_u	= water-filled porosity (dimensionless)	0.1
RU	= retardation factor in unsaturated zone (dimensionless)	calculated value
P_b	= dry bulk density of soil (kg/L)	1.75 ²
Kd	= distribution coefficient for a chemical (cm ³ /g): for organics - $K_d = K_{oc} \times f_{oc}$ for metals - K_d = function of soil organic carbon, pH, redox conditions, iron oxide content, cation exchange capacity, and major ion chemistry	chemical specific ¹
Koc	= organic carbon partitioning coefficient (cm ³ /g)	chemical specific ¹
foc	= weight fraction of organic carbon in soil (dimensionless)	0.006

¹ = see [Appendix B](#)

² = based on "Fraser River sand" characteristics

Exhibit 5 - Mixing Zone Unsaturated/Saturated

$$CZ = C_{gw} \left\{ 1 + \frac{(Zd \times V)}{I \times X} \right\}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
CZ	= chemical concentration of the leachate at the water table (mg/L)	
C _{gw}	= chemical concentration in the groundwater calculated value at source (mg/L)	calculated value
Z _d	= average thickness of mixing zone (m)	0.5 ¹
V	= Darcy velocity in groundwater (m/year)	12.6
I	= infiltration rate (m/s)	2 x 10 ⁻⁸
X	= length of contaminated soils (m) for point source	5

¹= Z_d is a function of mixing zone depths available due to dispersion/diffusion and due to infiltration and underground flow rates. See Exhibit 6.

Exhibit 6 - Calculation of Average Thickness of Mixing Zone, Z_d

$$Zd = r + s$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
Z _d	= average thickness of mixing zone (m)	
r	= mixing depth available due to dispersion and diffusion (m): r = 0.01 x X	calculated value
X	= length of contaminated soils (m)	5

s	= mixing depth available due to infiltration rate and groundwater flow rate (m): $s = da \{ 1 - e^{-[2.178 \times (X \times 1)/V \times da]} \}$	calculated value
DA	= unconfined groundwater aquifer (m) (used to calculate Zd)	5
I	= infiltration rate (m/yr): $I = P - (RO + EV)$	0.55
P	= precipitation rate (m/yr)	1
(RO + EV)	= sum of runoff rate (R0) + surface evapotranspiration rate (EV) (m/yr)	0.45
V	= Darcy velocity (m/vr)	12.6

¹ = Zd is a function of mixing zone depths available due to dispersion / diffusion and due to infiltration and underground flow rates. See Exhibit 6.

Exhibit 7 - Saturated Groundwater Zone

$$C_w(x,y,z,t) = \frac{C_{gw} \exp\left\{-\frac{x}{2\sqrt{Kt}} \left[1 + \sqrt{1 + \frac{4Ls}{Kt}}\right]\right\} \operatorname{erfc}\left[\frac{x - n t(1 + \frac{4Ls}{Kt})}{2\sqrt{Kt}}\right]}{4\sqrt{Kt} \operatorname{erf}\left[\frac{y+Y/2}{2\sqrt{Kt}}\right] - \operatorname{erf}\left[\frac{y-Y/2}{2\sqrt{Kt}}\right]}$$

$$\operatorname{erf}\left[\frac{y+Y/2}{2\sqrt{Kt}}\right] - \operatorname{erf}\left[\frac{y-Y/2}{2\sqrt{Kt}}\right]$$

$$2\sqrt{Kt} \operatorname{erf}\left[\frac{y+Y/2}{2\sqrt{Kt}}\right] - 2\sqrt{Kt} \operatorname{erf}\left[\frac{y-Y/2}{2\sqrt{Kt}}\right]$$

$$V = Ki; \quad n = \frac{V}{Rf}; \quad Rf = 1 + \frac{PbKd}{n}; \quad Kd = Kocfoc$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
C _w	= chemical concentration in groundwater flow at receptor (mg/L)	applicable water quality standard
x	= distance to source (m)	10

x,y,z	= Cartesian coordinates that coincide with principle directions of the dispersivity tensor (m)	x is site specific
t	= time since contaminant release (years)	100
C _{gw}	= chemical concentration in the groundwater at source (mg/L)	calculated value
α _x , α _y , α _z	= principle values of the dispersivity tensor (m): α _x = 0.1 α _y = 0.1	calculated values
LS	= decay constant (seconds ⁻¹) in saturated zone: LS. = $0.691 \times (e^{-0.07 \times d})$	chemical / depth specific
	$t/2S$	
d	= depth from surface to uncontaminated groundwater surface (m)	3
t _{1/2s}	= decay (biodegradation) half-life (s)	chemical specific ¹
v	= velocity of the contaminant (m/s)	$v = V / nRf$
V	= Darcy velocity or specific discharge (m/yr): $V = Ki$	12.6
K	= hydraulic conductivity (m/s): $K = V/i$	calculated value
I	= groundwater gradient (dimensionless): $i = V/K$	calculated value
n	= porosity of contaminated soil	0.3
n _e	= effective porosity (dimensionless)	0.2
Y	= source's width (m), perpendicular to groundwater flow	30
R _f	= Retardation factor (dimensionless)	calculated value
P _b	= bulk density of soil (g/cm ³)	1.75
K _d	= distribution coefficient for chemical and chemical/soil (cm ³ /g) K _d = K _{oc} × f _{oc}	chemical / soil specific ¹
K _{oc}	= distribution coefficient for chemicals between organic carbon and water (cm ³ /g)	chemical specific ¹
f _{oc}	= weight fraction of organic carbon in soil (dimensionless)	0.006

Note: Above simplified solution based on the assumptions that there is no vertical dispersion,

and effective molecular diffusion is relatively negligible,

Therefore

$$DX = \alpha_x v_x \text{ and } DY = \alpha_y v_y$$

$$DX = \text{longitudinal mechanical dispersion coefficient (m}^2/\text{s)} \alpha_x v_x + D^*$$

$$DY = \text{lateral mechanical dispersion coefficient (m}^2/\text{s)} \alpha_y v_y + D^*$$

¹ = see [Appendix B](#)

Exhibit 8 - Default Groundwater Model Parameters

$$Zd = r + s$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
S	= maximum solubility	chemical specific ¹
n	= total porosity (dimensionless)	0.3
nu	= water filled porosity	0.1
NA	= air filled porosity (dimensionless): NA = n - nu	calculated value 0.2
Pb	= dry bulk density of soil (g/cm ³)	1.75
H	= Henry's Law constant	chemical specific ¹
H'	= dimensionless Henry's Law constant	chemical specific ¹
α_x	= dispersivity in unsaturated zone	0.1 x b
foc	= fraction of organic carbon in soil	0.006
V	= Darcy velocity in saturated zone (m/yr)	12.6
Zd	= thickness of mixing zone (m)	0.5
Kd	= distribution coefficient for a chemical (cm ³ /g)	chemical specific ¹
Koc	= organic carbon partitioning coefficient (cm ³ /g)	chemical specific ¹
α_x	= dispersivity in x-direction	$\alpha_x = 0.1x$

α_y	= dispersivity in y-direction	$\alpha_y = 0.1 \alpha_x$
d	= unconfined groundwater aquifer (m)	5
b	= thickness of the unsaturated zone note: $b = d - Z$	0
d	= depth from surface to uncontaminated groundwater surface (m)	3
x	= distance from source to receptor (m)	10
NE	= effective porosity (dimensionless)	0.2
$t_{1/2US}$	= decay (biodegradation) half-life at unsaturated sites	chemical specific ¹
$t_{1/2S}$	= decay (biodegradation) half-life at saturated sites	chemical specific ¹
I	= infiltration rate (m/yr) Note: $I = P - (RO + EV)$	0.55 (1 - 0.45)
P	= precipitation rate (m/yr)	1
(RO-EV)	= runoff rate plus surface evapotranspiration rate (m/yr)	0.45
X	= source dimension length (m)	5
Y	= source dimension width (m)	30
Z	= source dimension thickness (m)	3
$D_{1/2US}$	= frost free days	365

¹ =reference values provided in [Appendix B](#)

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Part C Human Health Protective Standards

C1. Derivation of Human Health Based Soil Quality Standards (SQS_{HH})

C1.1 Introduction

CSST has developed derivation procedures for two human health protection soil quality matrix standards:

1. Intake of contaminated soil, and
2. Groundwater used for drinking water.

The derivation of the "Groundwater used for drinking water" soil standard has been detailed in section B2.4 above. Procedures to derive the "Intake of contaminated soil" standard are provided below.

C1.2 General Considerations

The derivation of the "Intake of contaminated soil" quality standard involved four basic components: determination of a critical human reference dose representative of a defined acceptable toxicological hazard or risk posed by a chemical,

- definition of appropriate critical human receptors for the specified land uses,
- development of defined exposure scenarios for the specific land uses, and
- integration of exposure scenarios and toxicity information with CSST policy decisions to calculate soil quality standards.

The "Intake of contaminated soil" human health soil quality standard is intended to ensure that human exposure to a contaminant resulting from the ingestion of contaminated soil would not exceed a specified level of acceptable hazard or risk established by CSST. Consequently, soil quality standards were developed by considering exposure to contamination through the direct soil ingestion pathway. Other potential exposure pathways such as the inhalation of dust or vapours and the consumption of contaminated vegetables, milk and meat produced on contaminated soils were also considered by CSST.

In the case of dermal exposure, sufficient data to derive standards is lacking. In the case of exposures to dust or vapours and milk and meat produced on contaminated sites, CSST was of the opinion that either the models or default parameters used to estimate such exposures lacked sufficient scientific validation. Thus, these additional indirect human exposure pathways were excluded from standard derivation procedures.

However, for most non-volatile substances direct ingestion of soil contaminants was believed to be the quantitatively most significant human exposure pathway of concern for use in deriving human health protective standards. In addition, CSST believed that for some contaminants, empirical information linking soil contaminant exposure with health outcomes might exist. Consequently, CSST contracted a study with independent health experts to review such information. The results of that study were used to adjust, where necessary and scientifically defensible, substance "Intake of contaminated soil" standards derived on the basis of toxicological models (see section C3 below).

C1.3 Threshold and Non-threshold Contaminants

Environmental contaminants were classified with respect to their potential carcinogenicity and mutagenicity based on the quantity, quality and nature of the available toxicological and epidemiological studies. Health Canada (1992) separates substances into two broad categories, non-threshold and threshold contaminants using this information. Non-threshold contaminants, such as carcinogens or germ cell mutagens are those for which it is assumed that there is some probability of harm to human health at any level of exposure. Consequently for such substances, it is not possible to determine a dose below which adverse effects may not occur. Threshold substances are those for which a level may be set below which no adverse effects are expected to be produced. The critical endpoints usually considered for deriving reference doses for threshold substances are either NOAEL (No Observed Adverse Effect Level) or LOAEL (Lowest Observed Adverse Effect Level) based.

For threshold and non-threshold contaminants a "reference dose" has been determined. This is the Tolerable Daily Intake (TDI) for threshold substances and the Risk Specific Dose (RsD) for non-threshold substances. For a threshold substance, exposure less than the TDI should pose essentially a negligible probability of incidence of an adverse effect in the population. For a non-threshold substance, the RsD used by CSST corresponds to an expected excess lifetime cancer incidence of 1×10^{-5} (i.e. 1 in 100,000).

C2. Level of Protection, Receptors and Pathways

C2.1 Levels of Protection for the Protection of Human Health

For the purpose of deriving the "Intake of contaminated soil" quality standards to protect human health, CSST determined that contaminated site related risks arising from human exposure to non-threshold carcinogenic substances should not exceed a risk level of 1×10^{-5} . The matrix standard derived for such substances, therefore reflects this level of risk.

In order to derive matrix soil quality standards for threshold contaminants, it was necessary to ascribe some allowable proportion of the total exposure to contaminants present at a site to the soil medium. Considering the five sources to which people are exposed (i.e. air, water, soil, food and consumer products) CSST recommended that 20% of the total TDI for threshold contaminants be allotted to soil.

CCME recommended that the Estimated Daily Intake (EDI) for a particular contaminant due to normal background exposure (i.e. not including exposure which may occur at a contaminated site) also be accounted for in deriving soil quality criteria to protect human health (CCME, 1994a; CCME, 1995a). CCME reasons that as we are constantly exposed to this background contamination, risks posed by a contaminated site should be determined in addition to the background exposure. Thus, CCME soil criteria are calculated in consideration of the background soil exposure as well as the soil allocation (20%) of tolerable daily intake. CSST recognized the potential impact of normal background (i.e. EDI) exposures. However, since estimation of generic EDIs is both difficult and of questionable relevance for any specific site, CSST recommended that the CCME methodology incorporating background EDIs not be

followed. Rather, CSST believed that a simple 20% apportionment of the TDI to soil would ensure an adequate level of protection. CSST also noted that incorporation of consideration of background EDIs in the CCME methodology often resulted in the derivation of soil quality values which typically approximate or, on occasion, are actually less than that of the usual background soil concentration of ubiquitous substances. As noted in section E1 below, the proposed [Contaminated Sites Regulation](#), as a matter of policy, does not force clean up of contaminated site soil concentrations to less than local background levels.

C2.2 Choice of Exposure Pathways and Receptors for Land Uses

For the purposes of deriving intake of contaminated soil standards, CSST assumed a chronic human exposure scenario (i.e. lifetime exposure to a remediated site). This assumption acts to overestimate actual exposure and helps ensure that no site usage limitations will exist within a defined land use.

The choice of sensitive receptors was linked to land use considerations and was primarily dependent on the ages of the human receptors reasonably expected to be associated with those land uses. Studies have indicated that children are likely to ingest much larger quantities of soil and have greater general exposure to soil contaminants than adults. These factors, as well as lower average body weights for younger individuals, create a broad range of receptor characteristics which might be considered in derivation of soil quality standards (Table 2).

Table 2. Typical Average Receptor Characteristic Values for the Canadian General Population (sources: Angus Environmental, 1991; Newhook, 1992; MENVIQ, 1992)

Age Classes (years)	Body Weight (Kg)	Air Intake (m³/day)	Water Intake (L/day)	Soil Intake (mg/day)	Skin Surface areas ^{1,2} (m²)
0-0.5	7	2	0.75	20	0.30
0.6-4	13	5	0.8	80	0.26
5-11	7	12	0.9	20	0.41
12-19	57	21	1.3	20	0.43
20+	70	23	1.5	20	0.43

¹ = skin surface areas for different age classes based on: 0-0.5: total body; 0.6-4 and 5-11: head, arms, hands, lower legs; 12-19 and 20+:head, arms, hands.

² = the amount of dirt assumed to be covering skin surfaces for all age classes is 1.0 mg/cm²; taken from EPA (1990), Interim Guidance for Dermal Exposure Assessment.

In considering Table 2, CSST decided that in the case of non-threshold substances, hazard would be assessed using an adult as the critical receptor for all land uses, and exposure was assumed to be continuous over 70 years.

For threshold substances, ideally, exposure would be averaged over, and TDIs measured against, the most sensitive life stages. As such "age-stepping" is a complex procedure for which data are lacking for many substances, CSST decided to derive standards for scenarios (eg. Agricultural, Residential/Urban Parkland, and Commercial) in which the 0.6-4 year old child was assumed to be both the critical receptor and the critical age class. CSST recognized that for some specific chemicals, different receptors and age classes than those assumed may be more appropriate.

The land use defined exposure scenarios envisioned by CSST in deriving human health protective standards are outlined in Table 3.

Table 3. CSST Human Health Land-use Defined Exposure Scenarios

	Agricultural	Residential / Urban Parkland	Commercial
Defined Land Use Scenario	- a multi-functional farm with a family living on-site - children are present - groundwater is used for drinking water	- single family home with a backyard - children are present - groundwater may be used as drinking water	- urban commercial property - children have access to property - groundwater may be used as drinking water
Sensitive Receptor	- child (threshold contaminants) - adult (non-threshold contaminants)	- child (threshold contaminants) - adult (non-threshold contaminants)	- child (threshold contaminants) - adult (non-threshold contaminants)
Exposure Period	See Table 4	See Table 4	See Table 4
Direct Soil Exposure Pathways	- soil ingestion	- soil ingestion	- soil ingestion
Indirect Soil Exposure Pathways	- ingestion of groundwater as drinking water	- ingestion of groundwater as drinking water	- ingestion of groundwater as drinking water

No land use defined exposure scenario for Industrial land is provided in Table 3. CSST recognized that issues relating to soil quality for human health protection on industrial sites is the mandate and responsibility of the Workers' Compensation Board of British Columbia.

Consequently, Industrial "Intake of contaminated soil" standards have not been derived by CSST.

C3. Derivation Equations for Intake of Contaminated Soil Standards

The equations detailed below were used to derive toxicological risk based soil quality standards for direct ingestion of contaminants in soil. A "Real World Clinical Health Experience" review was conducted for CSST by the University of British Columbia, Department of Health Care and Epidemiology to determine the extent of correlation between exposure to arsenic, benzene, cadmium, chromium and lead in soil and "real world" adverse health outcomes (Jin and Teschke, 1995).

Based on the review results presented in the UBC final report (Jin and Teschke, 1995), Ministry of Health members of CSST were able to provide rationales to justify the "adjustment" of toxicological-derived intake of contaminated soil standards for arsenic, cadmium and lead.

C3.1 Intake of Contaminated Soil Standards

The equations used to derive "Intake of contaminated soil" standards for threshold and non-threshold substances are presented below.

C3.1.1 Derivation of Intake of Contaminated Soil Standards for Threshold Substances

The general theoretical equation for calculating preliminary human health soil quality standard (PSQSHH) is shown in Exhibit 9A. This equation is simplified, as described below, to yield the equation in Exhibit 9B which was used by CSST to calculate PSQSHH.

Exhibit 9A - Preliminary Human Health TDI-based "Intake of contaminated soil" Standard (PSQSHH) - Threshold Substances

$$PSQS_{HH} = \frac{[SAF \times TDI] \times BW}{[(AF_I \times IR) + (AF_D \times DR) + (AF_S \times SR)] \times ET}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
PSQS _{HH}	= preliminary human health TDI-based soil quality standard (mg/kg)	
SAF	= soil allocation factor	0.2
TDI	= tolerable daily intake (mg/kg BW-day)	chemical specific
BW	= body weight (kg) child	13

	adult	70
AF _I	= absorption factor for gut (unitless)	1.0
IR	= soil ingestion rate (mg/day)	
	child	80
	adult	20
AF _D	= absorption factor for lung (unitless)	1.0
DR	= soil inhalation rate (kg/day)	0
AF _S	= absorption factor for skin (unitless)	1.0
SR	= soil dermal contact rate (kg/day)	0
ET	= exposure term (unitless) land use	specific ¹

¹ - see [Table 4](#)

The exposure term parameter (ET) of Table 4, is a ratio of the assumed land use defined exposure period versus the maximum possible lifetime exposure period (i.e. 24 hours/day x 7 days/week x 52 weeks/year x 70 years).

Table 4. Exposure Terms for Various Classes of Toxic Substances and Land Uses

Class of Toxic Substance	Receptor	Land Use	Exposure Term (ET)
Non-threshold	Adult	Agricultural, Residential, Urban Parkland	1.0 ¹
		Commercial	0.33 ¹
Threshold	Child	Agricultural, Residential, Urban Parkland	1.0 ¹
		Commercial	0.33 ¹
¹ ET = (24hr/24hr x 7d/7d x 52wk/52wk x 70yr/70yr)			

$$^2 \text{ ET} = (12\text{hr}/24\text{hr} \times 5\text{d}/7\text{d} \times 48\text{wk}/52\text{wk} \times 70\text{yr}/70\text{yr})$$

$$^3 \text{ ET} = (24\text{hr}/24\text{hr} \times 7\text{d}/7\text{d} \times 52\text{wk}/52\text{wk} \times 3.5\text{yr}/3.5\text{yr})$$

$$^4 \text{ ET} = (12\text{hr}/24\text{hr} \times 5\text{d}/7\text{d} \times 48\text{wk}/52\text{wk} \times 3.\text{Syr}/3.\text{Syr})$$

Although the equation provided in Exhibit 9A provides terms to deal with other possible routes of exposure (i.e. inhalation and dermal), currently only the direct soil ingestion route is used to derive standards. Unless verifiable scientific data indicates otherwise, the absorption factor parameter, AFI, is assumed to equal 100%. Consequently, the equation of Exhibit 9A for direct soil ingestion of threshold substances reduces to that of Exhibit 9B.

Exhibit 9B - Simplified Human Health TDI-based "Intake of contaminated soil" Standard (PSQSHH) - Threshold Substances

$$\text{PSQS}_{\text{HH}} = \frac{[\text{SAF} \times \text{TDI}] \times \text{BW}}{(\text{AF}_I \times \text{IR}) \times \text{ET}}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
PSQS _{HH}	= preliminary human health TDI-based soil quality standard (mg/kg)	
SAF	= soil allocation factor	0.2
TDI	= tolerable daily intake (mg/kg BW.day)	chemical specific
BW	= body weight (kg)	
	child	13
	adult	70
AF _I	= absorption factor for gut (unitless)	1.0
IR	= soil ingestion rate (mg/day)	
	child	80
	adult	20
ET	= exposure term (unitless)	land use specific ¹

¹ = see [Table 4](#)

If published Health Canada data for both background EDI and National generic background soil concentrations are available, the following equation (Exhibit 10) is used to derive an additional value, $PSQNH_{H(EDI)}$:

Exhibit 10 - Preliminary Human Health EDI-based "Intake of contaminated soil" Standard ($PSQS_{HH(EDI)}$) - Threshold Substances

$$PSQS_{HH(EDI)} = \frac{(TDI - EDI) \times SAF \times BW + [BSC]}{(AF_1 \times IR) \times ET}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
$PSQS_{HH(EDI)}$	= preliminary human health EDI-based soil quality standard (mg/kg)	
TDI	= tolerable daily intake (mg/kg BW-day)	chemical specific
EDI	= estimated daily intake (mg/kg BW-day)	chemical specific
SAF	= soil allocation factor	0.2
BW	= body weight (kg) child adult	13 70
BSC	= national generic background soil concentration (mg/kg)	chemical specific
AF_1	= absorption factor for gut (unitless)	1.0
IR	=soil ingestion rate (mg/day) child adult	80 20
ET	= exposure term (unitless)	land use speci

It should be noted that for all substances for which matrix standards have been calculated to date, there are either no published Health Canada EDIs or background soil concentrations which would enable calculation of a $PSQS_{HH(EDI)}$ value using the equation in Exhibit 10.

If a $PSQS_{HH(EDI)}$ value could be calculated it would then be compared with the $PSQS_{HH}$ value calculated from CSST's preferred simplified formula (Exhibit 9B). CSST recommends that the final "Intake of contaminated soil" standard should be based on the "more reasonable" of the two preliminary values derived above.

C3.1.2 Derivation of Intake of Contaminated Soil Standards for Non-threshold Substances

The calculation of RsD-based "Intake of contaminated soil" quality standards for non-threshold substances is similar to that given for threshold substances. The general theoretical equation for calculating this human health soil quality standard SQS_{HH} is shown in Exhibit 11A. This equation is simplified, as described below, to yield the equation in Exhibit 11B which was used by CSST to calculate SQS_{HH} .

Exhibit 11A - Derivation of Human Health RsD-based "Intake of contaminated soil" Standard, (SQS_{HH}) - Non-threshold Substances

$$SQS_{HH} = \frac{RsD \times BW}{[(AF_I \times IR) + (AF_D \times DR) + (AF_S \times SR)] \times ET}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
SQS_{HH}	human health RsD-based soil quality standard (mg/kg)	
RSD	= risk specific dose (mg/kg.day)	chemical specific
BW	= body weight (kg)	70
AF_I	= absorption factor for gut (unitless)	1.0
IR	= soil ingestion rate (mg/day)	20
AF_D	= absorption factor for lung (unitless)	1.0
AF_S	= absorption factor for skin (unitless)	1.0
SR	= soil dermal contact rate (kg/day)	0
DR	= soil inhalation rate (kg/day)	0
ET	= exposure term (unitless)	land use specific ¹

¹ = See [Table 4](#)

Again, although the Exhibit 11A equation makes provision for other possible routes of exposure (i.e. inhalation and dermal), currently only direct soil ingestion exposure is considered in deriving SQS_{HH} for non-threshold substances. In accordance with CSST policy, SQS_{HH} is derived using chemical specific RsDs based on a maximal acceptable risk from soil exposure of 1×10^{-5} .

Thus, the equation of Exhibit 11A for direct soil ingestion of nonthreshold substances reduces to that of Exhibit 11B.

Exhibit 11B - Simplified Derivation of Human Health RsD-based "Intake of contaminated soil" Standard, (SQSHH) - Non-threshold Substances

$$SQS_{HH} = \frac{RsD \times BW}{(AF_1 \times IR) \times ET}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
SQS_{HH}	= human health RsD-based soil quality standard (mg/kg)	
RSD	= risk specific dose (mg/kg.day)	chemical specific
BW	= body weight (kg)	70
AF_1	= absorption factor for gut (unitless)	1.0
IR	= soil ingestion rate (mg/day)	20
ET	= exposure term (unitless)	land use specific ¹

¹ = see [Table 4](#)

C3.2 Toxicity from Transfer of Contaminants to Groundwater Used as Drinking Water

As detailed in Part B, a standard was also derived to insure that the calculated "Intake of contaminated soil" standard would not lead to excessive re-distribution of soil contaminant into groundwater used as drinking water. This groundwater protective soil standard was derived using the same groundwater transfer model and equations described in Part B. However in this case, C_W corresponds to either the appropriate substance specific Canadian drinking water guideline (Health Canada, 1993) or the Ministry approved drinking water criteria (BC Ministry of Environment, Lands and Parks, 1995b) for the substance, as detailed in "Procedure to Establish Water Quality Standards used in Contaminated Sites Regulation" (Fox, 1995a). This soil standard to protect groundwater used for drinking water was calculated for all land uses.

Part D

D1. "Other" Soil Quality Standards

CSST recognized that contaminated site matrix soil quality standards should also provide protection against the occurrence of physical hazards (i.e. explosivity or flammability) and objectionable odours. CSST was advised that physical hazards associated with contaminants in soil could be adequately addressed by existing standards which would qualify such soil as a special waste under the Special Waste Regulation. Consequently, the "other" protective "Odour" standard is designed to account only for objectionable odour as an aesthetic concern. The "odour" soil quality standard therefore represents soil contaminant concentrations at which existing guidelines for odour control would not be expected to be exceeded.

D2. Soil Odour Quality Standards

Substance specific soil "Odour" standards have been derived to ensure that volatile contaminants present on site do not give rise to contaminant concentrations in air which exceed reported odour threshold limits.

Substance specific odour threshold limits were obtained from several sources, (Macfarlane, 1995b) and on the advice of CSST, the lowest available substance specific odour threshold limit was used for standard derivation purposes. For Residential sites an exposure duration of one second was used to calculate "soil odour" standards, while an exposure duration of five minutes was assumed for Agricultural, Urban Park and Commercial sites. No soil "Odour" standards were calculated for the Industrial land use category, as standards to protect workers are established under the authority of the Workers' Compensation Board of British Columbia.

The soil "Odour" protective standard derivation equation is given in [Exhibit 12](#).

The soil odour threshold pathway is based on the volatilization of contaminants from the soil surface to a receptor on the site. The derivation uses the equation presented in Exhibit 12 which is based on the methodology outlined in U.S. EPA documents, (EPA, 1990; EPA, 1994) for the evaluation of outdoor inhalation exposure from wind-blown dust and volatiles from surficial contaminated soil. Surficial soil is defined as soil within 0.5 m of the ground surface. (BC Environment is currently evaluating the applicability of other models for evaluating volatility to air where contamination exists at depth.)

The volatilization factor (VF) of [Exhibit 13](#) defines the relationship between concentration of contaminants in soil and volatilized contaminants in air and is based on the Hwang and Falco (1986) model. Substance specific diffusivity coefficients may be calculated using the equation of [Exhibit 14](#). An important premise of the model is that the soil contaminant must be at or below the soil saturation concentration. The soil saturation concentration is derived as described in Exhibit 15 which uses equations from the US EPA's draft Soil Screening Guidance (EPA, 1994).

Exhibit 12 - Odour Protective Standard

$$C_s = VF \times OTL$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
Cs	= soil standard (mg/kg)	chemical specific
OTL	= low odour threshold limit (mg/m ³)	chemical specific
VF	= volatilization factor (m ³ /kg)	calculated value ¹

¹ = see [Exhibit 13](#)

Exhibit 13 - Volatilization and Particulate Emission Factor

Soil-to-Air Volatilization Factor

$$VF (m^3/kg) = \frac{(LS \times V \times DH)}{A} \times \frac{(3.14 \times a \times T)}{(2 \times D_{ei} \times NA \times K_{as} \times 10^{-3} \text{ kg/g})}$$

where:

$$a (cm^2/s) = \frac{(D_{ei} \times NA)}{NA + (\rho\rho)(1-NA)/K_{as}}$$

****note: take the square root of items in red**

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
VF	= volatilization factor (m ³ /kg)	
LS	= length of side of contaminated area (m)	45
V	= wind speed in mixing zone (m/s)	3.33
DH	= diffusion height (m)	
A	= area of contamination (cm ²)	20,500,000
a	= diffusivity	calculated value
T	= exposure intervals (seconds)	land use specific
	Residential	1
	agricultural/ urban parkland/	300

commercial

Dei	= effective diffusivity (cm ² /s):	calculated value
	Dei = DI x (na ^{3.33} /n ²)	
DI	= molecular diffusivity (cm ² /s)	chemical specific ¹
NA	= air-filled soil porosity (unitless)	0.2
n	= total soil porosity (unitless)	0.4
K _{as}	= soil/air partition coefficient (g-soil/cm ³ -air): K _{as} = (H/K _d) x 42.3 ²	calculated value
H	= Henry's law constant (unitless)	chemical specific
K _d	= soil-water distribution coefficient (mg/kg - soil per mg/L - water)	chemical specific
ρ _p	= true soil density or particulate density (g/cm ³)	2.5

¹ = see Exhibit 14;

² = where 42.3 is a units conversion factor for T=15°C

Exhibit 14 - Diffusivity Coefficient (DI)

Calculated using Fuller's method (EPA, 1988)

$$DI = \frac{0.01 T_p^{1.75} \{ [(1/MW_i) + (1/MW_a)] \}}{Pa [3(S V_i) + (S V_a)]^2}$$

***note: take the square root items in red

***note: take the cubed root of items in green

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
DI	= diffusivity coefficient (cm ² /s)	
T _p	= absolute temperature (° K)	288
MW _i	= molecular weight of substance	chemical specific
MW _a	= molecular weight of air	28.8

Pa	= absolute pressure (atm)	1
S _{Vi}	= molecular diffusion volume of substance	chemical specific
S _{VA}	= molecular diffusion volume of air	20.1

¹ = see [Exhibit 13](#)

Exhibit 15 - Determination of Soil Saturation Concentration for a Given Chemical

$$C_{\text{sat}} = \frac{S}{P_b} (K_d P_b + n_u + H' NA)$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
C _{sat}	= soil saturation concentration (mg/kg)	
S	= solubility in water (mg/L-water)	chemical specific
P _b	= soil dry bulk density (kg-soil/L-soil)	1.5
K _d	= soil-water partition coefficient (mg/kg-soil per mg/L-water)	chemical specific
n _u	= water-filled soil porosity (unitless)	0.20
H'	= dimensionless Henry's law constant	H x 42.3'
H	= Henry's law constant	chemical specific
NA	= air-filled soil porosity (unitless)	0.20

¹ = where 42.3 is a units conversion factor for 15°C

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Part E. Ancillary Issues / Details Concerning Derivation Procedures

E1. General Ancillary Issues

In addition to specific adjustments made to some derived standards (e.g. real world adjustment to "Intake of contaminated soil" standards for arsenic, cadmium and lead detailed in section C3

above) several more general adjustments were commonly made to CSST toxicological-derived standards.

E1.1 CSST "Rounding-off" Rule

All soil quality standards derived by CSST methods were subjected to a "rounding-off" rule which states that standards are to be expressed to no more than one significant digit which must always be rounded to either 0 or 5, whichever is closer.

E1.2 CSST "Background" Adjustment

As noted in [Section C2.1](#) above, CSST recognized that, as a matter of policy, site owners should not be expected to clean to soil concentrations below that typical of local background soil concentrations.

Consequently, proposed toxicological-derived CSST soil standards for the following non-anthropogenic pollutants; arsenic, cadmium, copper, lead and zinc were compared to "background" soil concentrations for the Lower Mainland of the Province as detailed in "Changes to Schedule 5 Matrices in Draft 3 of the Contaminated Sites Regulation" (Ward, 1995). As a result, standards for the above parameters were "capped" at contaminant concentrations equivalent to no less than the 90th percentile of the Lower Mainland background soil concentrations. Lower Mainland soil concentrations were used in this procedure, since these soils are generally representative of the soil characteristics assumed in CSST models.

E1.3 Groundwater Standard Adjustments

Where necessary, some soil-groundwater matrix standards were adjusted to incorporate variation relating to differential soil pH, as predicted by the groundwater models used to derive the standards. This effect of variable soil pH to affect modelled contaminant mobility and transport, and hence modify toxicological-derived soil-groundwater protective standards is perhaps most apparent in the standards for pentachlorophenol (PCP).

E1.4 "Detection Limit" Adjustment

CSST noted that it was also necessary to consider contaminant analytical detection limits in establishing soil quality standards. For some of the toxicological-derived soil quality standards calculated for benzene, PCP, and trichloroethylene it was noted that the standards were in fact less than analytical detection limits. Consequently, as detailed in Ward (1995), these soil quality matrix standards were "adjusted" to equal corresponding substance specific analytical detection limits.

E1.5 Derivation of CSST Soil Quality Matrix Standards for Substances for Which No CCME Assessment Documents Will be Generated

CCME is committed to producing Ecological and Human Health Assessment documents for only 15 of the total 18 CSST "Most Commonly Found Contaminants" (BC Ministry of Environment,

Lands and Parks, 1995c). In addition, CCME has no commitment to produce any such documents for the approximately 80 substances remaining in the CCME's "Interim Canadian Environmental Quality Criteria for Contaminated Sites" document (CCME, 1991a). Since the CSST derivation process for soil quality numbers relies on the CCME substance assessment documents for ecological data sets and human health reference values, the lack of requisite assessment documents posed a serious impediment to the generation of soil quality matrix numbers for some substances.

After examining several options to overcome this difficulty, CSST recommended the following courses of action to derive soil quality numbers for substances which lack CCME assessment documents (Fox, 1995b):

For Protection of Human Health:

That BC Environment access requisite human health toxicity reference values from sources other than the CCME, as detailed in the CSST document "Hierarchy of Preferred Sources of Toxicity Reference Values for Use in Calculation of CSST Numbers for Use in Contaminated Sites Regulation" (Fox, 1995c), to calculate soil quality matrix numbers in accordance with CSST recommended procedures.

For Protection of Ecological Health:

That BC Environment use the CCME interim criteria as listed in "Interim Canadian Environmental Quality Criteria for Contaminated Sites" as ecologically protective SQS_{EE} matrix standards (for soil invertebrates and plants) until such time that requisite ecological data sets become available to allow calculation of ecologically protective soil quality numbers in accordance with CSST recommended procedures.

E2. Site-specific Soil Quality Remediation Standards Based on CSST Procedures

The CSST procedures provide a consistent methodology necessary for deriving effects-based soil quality matrix standards under defined exposure scenarios for both ecological and human receptors. Site-specific numerical standards (SSS) can be derived using the equations and procedures detailed herein. Derivation of site specific numerical standards provides an alternative to the matrix standards, to more appropriately reflect site-specific conditions. A protocol detailing SSS derivation procedures is currently under development by BC Environment. This protocol will specify how to use CSST's equations and models to develop site specific numerical standards.

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))))	3
Benzene		0.3	-	-	0.005	1745	83.2	183	365	2.32E-01
Ethylbenzene		0.7	-	-	0.0024	152	1,096.5	114	114	3.67E-01
Toluene		0.3	-	-	0.024	515	302.0	56	105	2.85E-01
Xylenes		-	-	-	0.3	170	389.0	183	183	2.26E-01
Benzo(a)pyrene		0.00001	-	-	0.00001	0.004	891,250	529	1059	1.02E-04
Naphthalene		0.001	-	-	-	32	1,288.2	65	129	2.60E-02
Pyrene		0.00002	-	-	-	0.17	72,443.6	1898	3796	1.04E-03
Pentachlorophenol	<6.9	0.00002	-	0.03	0.03	5000	pH*	383	767	6.01E-04
	6.9 - 7.9	0.0001	-	0.03	0.03	5000	pH*	383	767	6.01E-04
	>7.9	0.0003	-	0.03	0.03	5000	pH*	383	767	6.01E-04
Tetrachloroethylene		0.11	-	-	-	150	158.5	411	821	7.61E-01
Trichloroethylene		0.02	-	0.05	0.05	1070	107	411	821	8.46E-01
PCBs		0.0000001	0.00005	-	-	-	-	-	-	-
Dioxins/Furans		-	-	-	-	-	-	-	-	-
Arsenic (As+3)		0.05	0.1	0.5	0.025	pH*	Kd**	-	-	-
Cadmium (Cd+2)		0.0018	0.01	0.02	0.005	pH*	Kd**	-	-	-
Chromium (Cr+3)		-	-	-	-	pH*		-	-	-
Chromium (Cr+6)		-	-	-	-	pH*	Kd**	-	-	-
Chromium (total)		0.002	0.1	1	0.05	pH*		-	-	-
Copper (Cu+2)		0.008	0.2	0.3	1	pH*	Kd**	-	-	-
Lead (Pb+2)		0.011	0.2	0.1	0.01	pH*		-	-	-
Zinc (Zn+2)		0.03	1.0-5.0	50	5	pH*	Kd**	-	-	-

Rule: t1/2 unsaturated (organics) - Greater of the anaerobic rate high (lowest number of days) and 25% of the anaerobic rate

low (highest number of days). Unless t1/2 unsaturated > t1/2 saturated, then t1/2 unsaturated equals t1/2 saturated.

Rule: t1/2 saturated (organics) - Equals to 50 percent of anaerobic rate low (highest number of days).

*pH dependent

** Kd calculated

Table B-2. Koc and Kd Values for BCE Groundwater Model

pH	Koc PCP	Kd PCP foc=0.006	Kd As(+3)	Kd Cd	Kd Cr(+6)	Kd Cu(+2)	Kd* Pb	Kd Zn (+2)
4.5	20,303	121.82	24.3		35.0			
4.6	18,454	110.73	24.4		34.0			
4.7	16,557	99.34	24.6		33.1			
4.8	14,659	87.95	24.8		32.2			
4.9	12,810	76.84	25.0	0.8	31.4	39.8	*	1.6
5.0	11,055	66.33	25.2	0.9	30.5	50.1	*	1.8
5.1	9,429	56.57	25.4	1.0	29.7	63.1	*	2.0
5.2	7,956	47.73	25.6	1.1	28.9	79.4	*	2.2
5.3	6,648	39.89	25.7	1.3	28.2	100	*	2.5
5.4	5,508	33.05	25.9	1.5	27.4	126	*	3.2
5.5	4,530	27.18	26.1	1.7	26.7	158	*	4.0
5.6	3,703	22.22	26.3	2.0	26.0	219	*	5.0
5.7	3,010	18.06	26.5	2.5	25.3	302	*	6.3
5.8	2,437	14.62	26.7	3.2	24.6	417	*	8.6

5.9	1,965	11.79	26.9	4.0	24.0	575	*	11.7
6.0	1,580	9.482	27.1	5.0	23.3	794	*	15.8
6.1	1,268	7.607	27.3	7.5	22.7	1,148	*	24.0
6.2	1,015	6.090	27.5	11.2	22.1	1,660	*	36.3
6.3	811	4.868	27.7	16.8	21.5	2,399	*	55.0
6.4	648	3.887	27.9	25.1	21.0	3,467	*	83.2
6.5	547	3.100	28.1	36.9	20.4	5,012	*	126
6.6	412	2.470	28.3	54.1	19.9	6,310	*	191
6.7	328	1.967	28.6	79.4	19.3	7,943	*	288
6.8	261	1.566	28.8	117	18.8	10,000	*	437
6.9	208	1.246	29.0	171	18.3	12,589	*	661
7.0	165	0.991	29.2	251	17.8	15,849	*	1,000
7.1	131	0.78	29.4	355	17.4	17,783	*	1,380
7.2	104	0.626	29.6	501	16.9	19,953	*	1,905
7.3	83.0	0.498	29.9	708	16.4	22,387	*	2,630
7.4	65.9	0.396	30.1	972	16.0	25,119	*	3,631
7.5	52.4	0.314	30.3	1,334	15.6	25,119	*	5,012
7.6	41.6	0.250	30.5	1,830	15.2	25,119	*	6,310
7.7	33.1	0.198	30.8	5,512	14.8	25,119	*	7,943
7.8	26.3	0.158	31.0	3,073	14.4	25,119	*	10,000
7.9	20.9	0.125	31.2	3,758	14.0	25,119	*	12,589
8.0	16.6	0.100	31.4	4,597	13.6	25,119	*	15,849
8.1	13.2	0.079	31.7	56,234	13.3			19,953
8.2	10.5	0.063	31.9		12.9			

8.3	8.3	0.050	32.2		12.6			
8.4	6.6	0.040	32.4		12.2			
8.5	5.2	0.031	32.6		11.9			

* Copper Kd values used as surrogates for lead Kd values.