

# Protocol 28 “2016 Standards Derivation Methods”

## Chapter 4. Derivation of Soil to Groundwater Protection Matrix Soil Quality Standards

### 4.1 Definitions

The following words, acronyms and expressions used in this document are defined in [Procedure 8, “Definitions and Acronyms for Contaminated Sites”](#).

aquatic life water use	matrix numerical soil standard
conceptual site model	ministry
contaminated site	numerical water standards
drinking water use	point of compliance
high water mark	receiving environment
irrigation water use	receptor
livestock water use	Regulation
	site-specific numerical standard

### 4.2 Introduction

Groundwater is a valuable resource. It is a source of recharge to our streams, rivers and lakes, and is a source of water for drinking, irrigation and livestock. The discharge and use of groundwater can affect the health of humans and the environment. In consequence, as part of the initial development of the soil standards in the Regulation in the mid-1990’s, the ministry developed a model, as approved by the Contaminated Sites Soil Taskgroup (CSST), the “CSST model”, to derive soil to groundwater protective standards for the protection of drinking, aquatic life, irrigation and livestock water uses [1].

Since the initial development of the CSST model, there have been changes to the science and policies underlying the model as well as use of other models/procedures for derivation of soil-groundwater protective standards by other jurisdictions. Thus, it was deemed necessary to update the CSST model to more current day procedures and methods by incorporation of advances related to the science of modelling contaminant transport in soil and water and to ensure consistency in the use of the model, or model elements, between the various ministry protocols and technical guidance. This was done as part of the Stage 10 amendments to the Regulation [2]. The updated model, hereafter, “Groundwater Protection Model, GPM, or model” is described herein.

### 4.3 Groundwater Protection Model

The Groundwater Protection Model is used for the calculation of the groundwater protective matrix numerical soil standards in Schedule 3.1-Part1 of the Regulation. The matrix numerical soil standards provide for the protection of human health and the environment. The matrix standards are based on eight land uses with eight site-specific factors. Application of individual site-specific factors varies by land use. The overall land uses and site-specific factors are shown in Appendix 4A, Table 4A-1.

As based on Table 4A-1, the model is specifically used for the calculation of matrix numerical soil standards for the following four site-specific factors:

- groundwater used for drinking water;
- groundwater flow to surface water (freshwater or marine) used by aquatic life;
- groundwater used for livestock watering; and,
- groundwater used for irrigation.

The soil standards derived using the model are to ensure that the substance concentrations in groundwater (groundwater concentrations) discharging and in contact with a receptor are less than or equal to the substance specific numerical water standard for the water use associated with the respective receptor. For ease of calculation and representation, a point of compliance is used as a surrogate for a receptor. Thus, allowable groundwater concentrations at the point of compliance are based on the respective drinking, aquatic life (freshwater and marine), livestock watering or irrigation water use standards presented in Schedule 3.2 of the Regulation. Applicable water uses are determined in accordance with [Protocol 21, "Water Use Determinations"](#).

The model is used in a backward calculation mode to calculate matrix numerical soil standards that are protective of the respective water uses. This process involves specification of the applicable numerical water standards at a point of compliance with subsequent backward calculation of the allowable substance concentrations in soil (soil concentrations) at a source area.

The model includes both organic and inorganic substances. The original model in 1996 (CSST model) was developed for select non-polar organic substances and inorganic substances and included one ionizing organic substance (pentachlorophenol). The original model was based on 16 substances deemed most commonly found at contaminated sites. The substance list was subsequently expanded to 22 substances in

2002. The current number of substances in Schedule 3.1-Part 1 is 38<sup>1</sup>. In general, the substances selected for inclusion in the model are based on frequency of occurrence at contaminated sites and availability of human and environmental health toxicological information. The current list of substances in the model is presented in Table 4A-2, Appendix 4A.

## 4.4 Model Details

### 4.4.1 Framework

The model framework consists of four components to simulate the fate and transport of a substance from soil to groundwater and the subsequent fate and transport of the substance in groundwater to a point of compliance. The four components are integrated and include both physical and chemical mechanisms. The components are as follows:

- leachate generation in the unsaturated zone via substance partitioning between soil, soil pore air, and soil pore water (leachate generation);
- leachate fate and transport through the unsaturated zone (leachate transport);
- leachate mixing with groundwater at the water table (leachate mixing); and,
- substance fate and transport through the saturated zone to a point of compliance (solute transport).

The model is a hybrid of other models provided in literature. The leachate generation and leachate mixing components are drawn from the US Environment Protection Agency (USEPA) "Soil Screening Guidance" (SSG) [3]. The leachate transport component is based on a one-dimensional steady-state analytical solution for contaminant fate and transport in the unsaturated zone modified from Kool *et al.*, 1994 [4]. The groundwater transport component is based on a two-dimensional steady-state analytical solution for contaminant fate and transport in the saturated zone modified from Domenico, 1987 [5].

The representativeness of the model for the purposes of calculating soil-groundwater protective standards is achieved by the following elements:

- the major transport processes are represented;
- the major variables affecting each of the transport components are included and can be modified;

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<sup>1</sup> Not including polychlorinated biphenyls, total [PCBs] and polychlorinated dioxins and furans, total [PCDDs and PCDFs] for which soil standards are not calculated using the GPM as water use standards are not available for these substances.

- 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 site-specific data; and,
- the model is scientifically based and defensible.

#### **4.4.2 Conceptual Site Model**

##### **4.4.2.1 Overview**

The model is formulated on a conceptual site model of a contaminated site (see Figure 4B-1, Appendix 4B). The conceptual site model consists of a source of contamination in the unsaturated zone with prescribed dimensions (length, width and depth). Infiltration of precipitation through the contamination source results in leachate generation by partitioning of contaminant mass between soil, soil pore water and soil pore air.

The second component of the model involves leachate migration through the unsaturated zone to the water table. Flow is steady-state and one-dimensional (vertical) in the unsaturated zone. Attenuation mechanisms that are active for unsaturated zone transport include sorption and biological degradation (biodegradation) but only for organic substances. Note that, although included in the model, the unsaturated zone transport component is not invoked in the calculation of the Schedule 3.1-Part 1 matrix numerical soil standards. This is done by setting the source depth equal to the water table depth in the model.

The third component of the model involves mixing of leachate and groundwater at the water table. Mixing is based on a simple water balance model between leachate infiltration and groundwater flux. Mixing is calculated to occur to a mixing thickness in the saturated zone. No attenuation processes are active in the mixing component. However, the net effect of mixing is dilution of leachate by groundwater. Dilution as a result of mixing is calculated as a dilution factor.

The final component of the model consists of migration of a solute in groundwater to the point of compliance. Flow is steady-state and two-dimensional (longitudinal and transverse to groundwater flow) in the saturated zone. Attenuation mechanisms that are active for saturated zone transport include dispersion and, for organic substances, sorption and biodegradation.

The point of compliance for drinking water, livestock watering and irrigation water uses is a water well in the saturated zone. The point of compliance for aquatic life water use is 10 m from the high water mark of an aquatic receiving environment consistent with [Technical Guidance 15, "Concentration Limits for the Protection of Aquatic Receiving Environments"](#). For the purpose of calculating matrix numerical soil standards, the points of compliance are assumed to be present 10 m laterally downgradient of the soil source.

#### **4.4.2.2 Site Conditions/Defaults**

The matrix numerical soil standards protective of groundwater are derived using model parameters typical of the climatic conditions of the lower Fraser River/Vancouver area and assumed soil/hydrogeological characteristics typical of those found within the Fraser River sands of the Fraser River delta area in BC. Other assumptions include source dimensions, transport distance (distance from source to point of compliance), and receiving environment water hardness.

The assumed/default model values are summarized as follows and are also provided in Table 4C-1, Appendix 4C.

#### **Source Dimensions/Transport Characteristics**

- The source dimensions are a source length of 10 m (longitudinal to groundwater flow), source width of 30 m (transverse to groundwater flow), and source depth of 3 m. The assumed source dimensions represent a contaminated soil volume of 900 m<sup>3</sup>.
- The transport distance is assumed to be 10 m for all site-specific factors (water uses).

#### **Soil/Hydrogeological Characteristics**

- The soil type is representative of a fine to medium grained sand unit with the following properties:
  - total porosity is 36% and 11.9% of the pore volume is water filled in the unsaturated zone (the calculated air-filled porosity is 24.1% in the unsaturated zone);
  - effective porosity is 25% in the saturated zone;
  - bulk density is 1.7 g/cm<sup>3</sup>;
  - organic content (fraction of organic carbon) is 0.5%;
  - hydraulic conductivity is 3E-05 m/s and the hydraulic gradient is 0.8%;
  - depth to the water table is 3 m;
  - thickness of the unconfined aquifer is 5 m; and
  - soil pH and water pH (of the aquifer) are 6.5.

### **Meteorological Characteristics**

- The precipitation rate is 1,000 mm/year and the runoff plus surface evapotranspiration rate is 450 mm/year. The calculated infiltration rate is 550 mm/year.
- The number of days of frozen ground is zero.

### **Receiving Environment**

- The water hardness at the receiving environment is 200 mg/L CaCO<sub>3</sub>.

#### **4.4.3 Fate and Transport**

Flow in the model is assumed to be essentially one dimensional with incorporation of attenuation processes affecting contaminant movement. Attenuation includes both physical and chemical mechanisms. Physical mechanisms include dilution (mixing) and dispersion. Chemical mechanisms include partitioning (adsorption/desorption) and biodegradation (organic substances only).

Partitioning within the model is dependent on the substance type. For non-polar organic substances, partitioning is a function of the organic carbon partitioning coefficient of the substance and the amount of organic carbon in the soil. For weakly-ionizing organic substances (e.g., pentachlorophenol), partitioning is additionally influenced by soil pH. Values for organic carbon partitioning coefficients have been compiled from literature. A value for the fraction of organic carbon in soil is based on the assumed soil type.

Partitioning of inorganics is considerably more complex, being additionally dependent on factors such as soil pH, sorption to clays, presence of organic matter and iron oxides, oxidation/reduction conditions, major ion chemistry and the chemical form of the inorganic substance. As a simplification, a distribution coefficient, calculated as a function of pH, is used for partitioning of inorganic substances in the model. Values for the distribution coefficient have been compiled from the USEPA Soil Screening Guidance [3] and literature.

#### **4.4.4 Assumptions**

Model assumptions are based on the fate and transport components and analytical solutions incorporated in the model. Assumptions include:

- the soil is physically and chemically homogeneous;
- the contaminant is not present as a free product phase (i.e., a non-aqueous phase liquid);
- the source concentration in soil is constant;

- partitioning at the source between the air, water and solid phases of the soil is linear and in equilibrium;
- the maximum substance concentration in leachate (leachate concentration) is equivalent to a percentage of the theoretical solubility limit of the substance in water under the defined site conditions;
- the moisture content and infiltration rate are uniform throughout the unsaturated zone;
- flow in the unsaturated zone is assumed to be one-dimensional and downward only, with dispersion, retardation and biodegradation (first-order decay);
- partitioning of solutes in the leachate between the water and solid phases of the unsaturated zone soils is linear and in equilibrium;
- mixing of leachate with groundwater is assumed to occur through mixing of leachate and groundwater mass fluxes;
- the groundwater aquifer is unconfined;
- flow in the saturated zone 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 and biodegradation (first-order decay);
- partitioning of solutes in the groundwater between the water and solid phases of the saturated zone soils is linear and in equilibrium;
- dispersion is assumed to occur in the longitudinal and horizontal transverse directions only (vertical dispersion is ignored);
- diffusion is not considered, and,
- dilution by groundwater recharge downgradient of the source is not included.

#### **4.4.5 Equations**

The mathematical equations for each of the four model components are presented in Appendix 4D as Exhibits 4D-1 through 4D-5. The component equations are presented in the order of calculation in the model, i.e., equations proceed from the point of compliance to calculation of the soil concentration/soil matrix standard in the source area.

The equations are identified as follows:

- solute transport in the saturated zone is presented in Exhibit 4D-1;
- leachate/groundwater mixing equations are presented in Exhibits 4D-2 and 4D-3;
- leachate transport in the unsaturated zone is presented in Exhibit 4D-4; and
- soil/leachate partitioning is presented in Exhibit 4D-5.

A summary of all terms used in the model is presented in Exhibit 4D-6.

Substance properties for all substances in the model are presented in Tables 4E-1 through 4E-4, Appendix 4E and include:

- analytical method detection limits;
- solubility limit;
- dimensionless Henry's Law constant;
- distribution coefficient;
- organic carbon partitioning coefficient; and
- biodegradation half-life (unsaturated and saturated zone values).

Background substance concentrations in soil (background concentration in soil), as applicable, are provided in Table 4E-5, Appendix 4E.

The numerical water standards used in the model as point of compliance groundwater concentrations are provided in Table 4F-1, Appendix 4F. The numerical water standards are drawn from Schedule 3.2 of the Regulation in force at the time of approval of this protocol.

## **4.5.0 Derivation of Soil to Groundwater Protection Standards**

### **4.5.1 Methodology**

The model spreadsheet used for calculating matrix numerical soil standards is provided as part of [Technical Guidance 13, "Groundwater Protection Model"](#). The model is based on the equations provided in section 4.4.5. Description of the methodology for calculating individual matrix soil standards is provided below.

#### **4.5.1.1 General Sequence**

The general calculation methodology for an individual substance is summarized in Flowchart 4G-1 provided in Appendix 4G. Based on the flowchart, calculation begins at the point of compliance with assignment of the applicable water use standard for the selected site-specific factor. Calculation ends with a calculated soil concentration protective of the specific water use standard assigned at the point of compliance.

The calculated soil concentration is then compared to background concentrations in soil, as applicable, and analytical method detection limits in soil. If less than either, the soil concentration is adjusted upwards to the respective value. The adjusted value is then rounded (as per CSST rounding rule) and becomes the calculated soil standard for the respective site-specific factor.

#### **4.5.1.2 Partitioning Considerations**

Organic carbon partitioning coefficient and distribution coefficient isotherms ( $K_{oc}$  vs pH and  $K_d$  vs pH, respectively) are provided in the model for weakly ionizing organic



substances (pentachlorophenol) and select inorganic substances (arsenic, beryllium, cadmium, chromium(hexavalent), chromium(trivalent), copper, lead, nickel, selenium and zinc), respectively. For these substances, the partitioning value is dependent on the soil pH. To accommodate this dependency, matrix numerical soil standards for these substances (excluding chromium) were calculated for a range of soil pH values for which partitioning values are available. For chromium (hexavalent and trivalent), matrix numerical soil standards were calculated at a soil pH of 6.5 only to minimize the complexity of the matrix in the Regulation that includes both substances.

The pH range selected is for soil pH of 5 to 8 in one-half pH increments. For each increment, the mid-point pH value is identified, rounded up, and the corresponding partitioning value is selected. For pH < 5, a pH value of 5.0 is used. For pH > 8, a pH value of 8.0 is used. Where the calculated standards for an increment do not change significantly from the preceding value, the increments are collapsed to minimize repetition of similar standards. Where a range is collapsed, the calculated standard for the lowest pH range of similar standards is used as the matrix numerical soil standard<sup>2</sup>.

Note that as the soil pH value changes, the water pH value used in the model is changed similarly. This influences the numerical water standard selected for pentachlorophenol as described in section 4.5.1.3.

#### **4.5.1.3 Water Use Standard Selection Considerations**

The numerical water standards used at the point of compliance are selected from Schedule 3.2 of the Regulation. Considerations related to water use standard selection are described as follows.

For aquatic life water use, where the water use standards vary by water hardness, the water use standard selected is based on a default water hardness value of 200 mg/L CaCO<sub>3</sub>.

Specific to zinc, the water use standard selected for irrigation water use is dependent on the soil pH. Thus, as the soil pH values change for the increments presented for zinc in Schedule 3.1-Part 1, the irrigation water use standard selected as the groundwater concentration at the point of compliance also changes. The specific irrigation water use standard/soil pH relationship is found in Schedule 3.2 of the Regulation.

Specific to pentachlorophenol, the water use standard selected for aquatic life water use is dependent on the water pH and water temperature. Regarding temperature, the

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<sup>2</sup> For example, if similar soil standards are calculated for pH ranges of 7.0 - 7.5, 7.5 - 8.0 and >8.0, then the calculated value for the pH range of 7.0 - 7.5 is used as the soil standard instead of recalculation of the standard at a pH = 7.0. The net effect is that the soil standard is calculated at a pH = 7.3 (midpoint of 7.0 - 7.5 range) instead of pH=7.0.

matrix numerical soil standards for pentachlorophenol are all based on a temperature  $\geq 20$  °C. Regarding water pH, as noted in section 4.5.1.2, the water pH value varies similarly to the soil pH. Thus, the aquatic life water use standard selected as the groundwater concentration at the point of compliance changes as the soil/water pH changes. The specific aquatic life water use standard/water pH/temperature relationship is found in Schedule 3.2 and further described in [Technical Guidance 9 “Chlorophenol Aquatic Life Water Quality Standards”](#).

#### **4.5.1.4 Example Soil Standards Calculations**

Example matrix numerical soil standards calculations for zinc (groundwater used for irrigation water) and pentachlorophenol (groundwater flow to surface water used by aquatic life) are provided in Tables 4H-1 and 4H-2, Appendix 4H, respectively.

#### **4.5.2 Constraints**

Certain constraints are incorporated into the model. These are summarized as follows.

##### **Solubility Limit**

A solubility limit value for organic substances is used in the model. The limit value used is 50% of the theoretical solubility of the substance. This is to minimize the potential for calculation of soil standards at soil concentrations approaching the presence of nonaqueous phase liquids.

##### **Inorganic Substances**

For inorganic substances, where calculated soil concentrations exceed 1,000,000  $\mu\text{g/g}$  (i.e., 100% substance), the corresponding soil standard is reported as  $>1,000$   $\text{mg/g}$ .

##### **Dilution Factor**

The dilution factor is calculated as part of mixing of leachate and groundwater (Exhibit 4D-2, Appendix 4D). The calculated dilution factor is 3.3 based on model defaults. Although not invoked as part of calculation of the matrix numerical soil standards, a constraint is incorporated into the model to limit the dilution factor to a value of 1 where the contamination source extends into the water table. This constraint may be realized as part of calculations done for site-specific numerical soil standards under [Protocol 2 “Site-Specific Numerical Soil Standards”](#).

##### **Mixing Zone Thickness**

The mixing zone thickness is calculated as part of mixing of leachate and groundwater (Exhibit 4D-2, Appendix 4D). For calculating matrix numerical soil standards, a mixing zone thickness of 1.7 m is calculated based on model defaults. Although not invoked in calculating matrix numerical soil standards, a constraint is incorporated into the model to limit the mixing zone thickness to a thickness no greater than the aquifer thickness.

This constraint may be realized as part of calculations done for site-specific numerical soil standards under Protocol 2.

#### **4.5.3 Standards Not Calculated/Provided**

Soil standards are not calculated or provided for all pathways for the following substances in Schedule 3.1-Part 1:

- anthracene;
- benzo(a)pyrene;
- dichlorodiphenyltrichloroethane, total [DDT];
- fluoranthene;
- mercury;
- tetrachloroethylene; and,
- trichloroethylene.

Soil standards are not provided for anthracene, benzo(a)pyrene, and fluoranthene as it is predicted, using the GPM, that the applicable water use standards for the substances will not be exceeded at the point of compliance. For mercury, soil standards are not calculated due to insufficient acceptable scientific data (soil water distribution coefficient) to permit calculation. Similarly, an appropriate soil to groundwater fate/transport model is not considered available for DDT to predict the subsurface fate and transport of complex mixtures and therefore soil standards are not calculated.

Regarding tetrachloroethylene and trichloroethylene, soil standards are not provided for the groundwater used for drinking water (DW) pathway and the groundwater used for livestock watering (LW) pathway (trichloroethylene only). Although it is possible to calculate soil standards for these substances/pathways, the calculated soil standards are below analytical method detection limits and are otherwise problematic for use within the regulatory regime. Other factors considered in the decision not to set soil standards for the groundwater to drinking water and livestock watering pathways are:

- tetrachloroethylene and trichloroethylene can be difficult to identify and characterize in site soil investigations due to complex subsurface transport processes (e.g., DNAPL; transport through fissures/fractures/rootlets and along low permeability layers); and
- due to the volatile and soluble nature of tetrachloroethylene and trichloroethylene, the primary and preponderant exposure pathways of concern for these substances are the vapour and water pathways. Therefore, regulatory reliance on the application of the respective vapour and water quality standards for tetrachloroethylene and trichloroethylene is considered adequate to provide effective protection from soil to groundwater mediated exposures to humans and livestock.

A tabular summary of the substances/pathways for which matrix numerical soil standards are not calculated/provided is included as Table 4I-1, Appendix 4I.

#### 4.6.0 References

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**Revision history**

Approved Date	Effective Date	Document Version	Notes
	November 2017	1.0	

**APPENDIX 4A**

**Table 4A-1  
Schedule 3.1-Part 1  
Site-specific Factors by Land Use**

**Table 4A-2  
Schedule 3.1-Part 1 Substances**

**Table 4A-1**  
**Schedule 3.1-Part 1**  
**Site-specific Factors by Land Use**

COLUMN 1	COLUMN 2	COLUMN 3	COLUMN 4	COLUMN 5	COLUMN 6	COLUMN 7	COLUMN 8	COLUMN 9
Site-specific Factor	Wildlands (Natural) (WL <sub>N</sub> )	Wildlands (Reverted) (WL <sub>R</sub> )	Agricultural (AL)	Urban Park (PL)	Residential (Low Density) (RL <sub>LD</sub> )	Residential (High Density) (RL <sub>HD</sub> )	Commercial (CL)	Industrial (IL)
<b>HUMAN HEALTH PROTECTION</b>								
Intake of contaminated soil								
Groundwater used for drinking water								
<b>ENVIRONMENTAL PROTECTION</b>								
Toxicity to soil invertebrates and plants								
Livestock ingesting soil and fodder								
Major microbial functional impairment								
Groundwater flow to surface water (freshwater or marine) used by aquatic life								
Groundwater used for livestock watering								
Groundwater used for irrigation								

\* shaded cell indicates that site-specific factor applies for the particular land use.

**Table 4A-2**

**Schedule 3.1-Part 1 Substances**

Organic Substances		Inorganic Substances	
Substance	Chemical Abstract Service # (CAS)	Substance	Chemical Abstract Service # (CAS)
anthracene	120-12-7	arsenic	7440-38-2
benzene	71-43-2	barium	7440-39-3
benzo(a)pyrene	50-32-8	beryllium	7440-41-7
dichlorodiphenyltrichloroethane, total [DDT]	n/a	cadmium	7440-43-9
diisopropanolamine [DIPA]	110-97-4	chloride ion	16887-00-6
ethylbenzene	100-41-4	chromium, hexavalent and trivalent	18540-29-9 and 16065-83-1
ethylene glycol	107-21-1	cobalt	7440-48-4
fluoranthene	206-44-0	copper	7440-50-8
methanol	67-56-1	cyanide	57-12-5
naphthalene	91-20-3	lead	7439-92-1
nonylphenol and nonylphenol ethoxylates	84852-15-3	manganese	7439-96-5
pentachlorophenol [PCP]	87-86-5	mercury	7439-97-6
perfluorooctane sulfonate [PFOS]	1763-23-1	molybdenum	7439-98-7
phenol	108-95-2	nickel	7440-02-0
sulfolane	126-33-0	selenium	7782-49-2
tetrachloroethylene	127-18-4	sodium ion	17341-25-2
toluene	108-88-3	uranium	7440-61-1
trichloroethylene	79-01-6	vanadium	7440-62-2
xylene, total	1330-20-7	zinc	7440-66-6

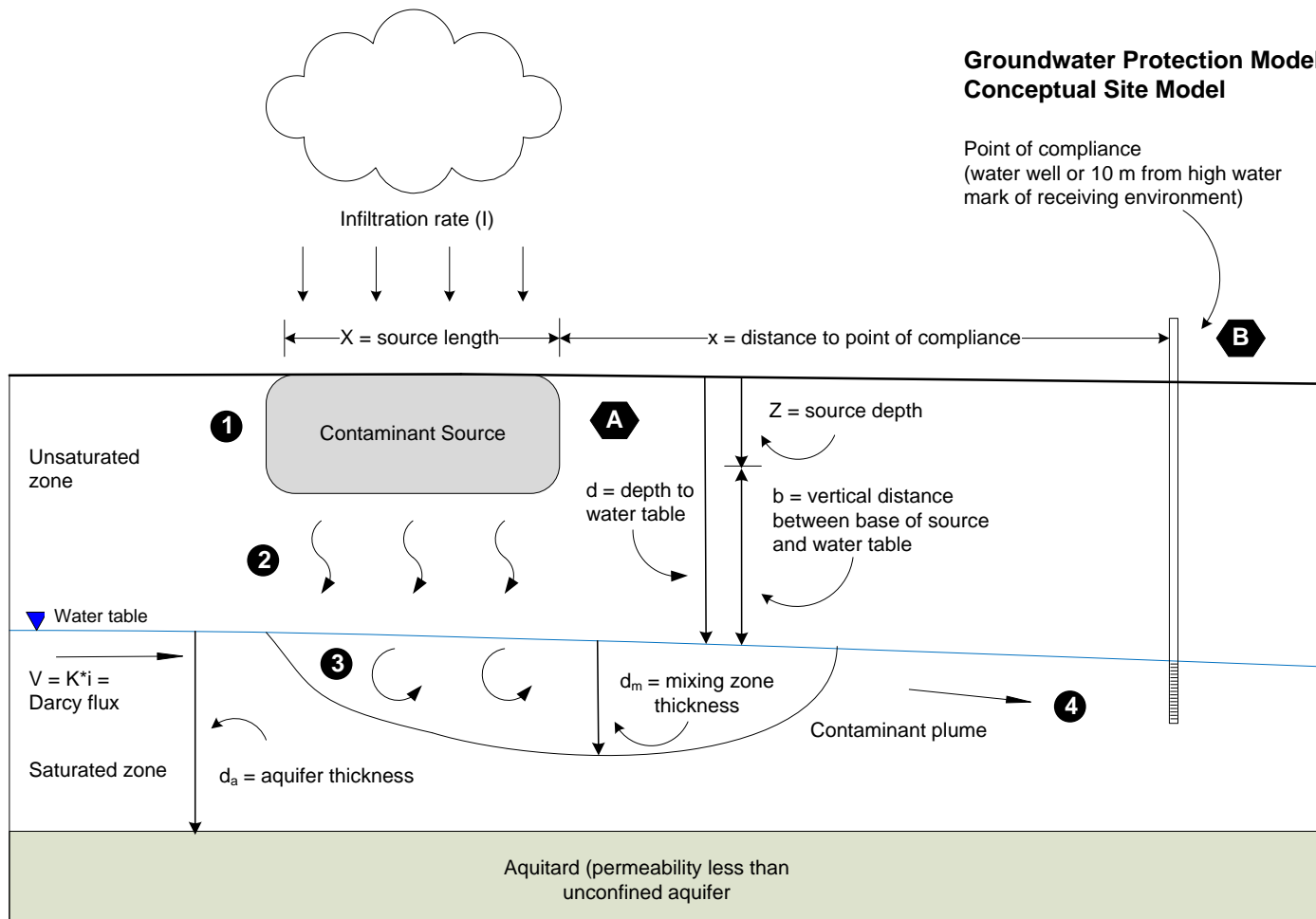
Note:

Not included in Table 4A-2: Polychlorinated biphenyls, total [PCBs] and polychlorinated dioxins and furans, total [PCDDs and PCDFs].



## **APPENDIX 4B**

### **Conceptual Site Model**



#### LEGEND

- |   |  |
|---|--|
| <b>1</b> Leachate concentration due to partitioning             | <b>A</b> Soil concentration at source ( $C_s$ )              |
| <b>2</b> Unsaturated zone contaminant fate and transport        | <b>B</b> Water use standard at point of compliance ( $C_x$ ) |
| <b>3</b> Mixing of leachate and groundwater flux at water table |  |
| <b>4</b> Saturated zone contaminant fate and transport          |  |

Schematic only.  
Not to scale.

## APPENDIX 4C

### Model Default Site Conditions/Characteristics

**Table 4C-1**

**Model Default Site Conditions/Characteristics**

Category	Parameter	Symbol	Unit	Default value
Source Dimensions/ Transport	Source length	X	m	10
	Source width	Y	m	30
	Source depth	Z	m	3
	Distance to point of compliance	x	m	10
Meteorology	Precipitation rate	P	mm/yr	1,000
	Runoff + Evapotranspiration rate	RO+EV	mm/yr	450
	Infiltration rate	I	mm/yr	550
	Number of days of frozen ground	D <sub>fr</sub>	-	0
Soil/ Hydrogeology	Total porosity	n	-	0.36
	Water-filled porosity	n <sub>w</sub>	-	0.119
	Air-filled porosity	n <sub>a</sub>	-	0.241
	Effective porosity	n <sub>e</sub>	-	0.25
	Dry bulk density of soil	ρ <sub>b</sub>	g/cm <sup>3</sup>	1.7
	Fraction of organic carbon	f <sub>oc</sub>	-	0.005
	Hydraulic conductivity	K	m/s	3E-05
	Hydraulic gradient	i	m/m	0.008
	Depth to water table	d	m	3
	Aquifer thickness	d <sub>a</sub>	m	5
	pH of soil	pH <sub>soil</sub>	-	6.5
pH of groundwater	pH <sub>water</sub>	-	6.5	
Receiving Environment	Water hardness	H	mg/L as CaCO <sub>3</sub>	200

## APPENDIX 4D

### Model Component Equations

**Exhibit 4D-1**  
**Solute transport in the saturated zone**

2D saturated transient analytical transport solution from Domenico, 1987 [5]:

$$C(x, y, t) = \frac{C_{gw}}{4} \exp \left\{ \frac{x}{2\partial_x} \left[ 1 - \left( 1 + \frac{4\lambda_s \partial_x}{v'} \right)^{1/2} \right] \right\} \operatorname{erfc} \left[ \frac{x - v't \left( 1 + \frac{4\lambda_s \partial_x}{v'} \right)^{1/2}}{2(\partial_x v't)^{1/2}} \right] \\ * \left\{ \operatorname{erf} \left[ \frac{\left( y + \frac{Y}{2} \right)}{2(\partial_y x)^{1/2}} \right] - \operatorname{erf} \left[ \frac{\left( y - \frac{Y}{2} \right)}{2(\partial_y x)^{1/2}} \right] \right\}$$

$$\partial_x = 0.1x \text{ and } \partial_y = 0.1\partial_x$$

$$\lambda_s = \frac{\ln 2}{t_{1/2s}} \text{ where } \ln 2 = 0.6931$$

$$R_f = 1 + \frac{\rho_b}{n} K_d \text{ where } K_d = K_{oc} f_{oc}$$

$$V = K i$$

$$v = \frac{V}{n_e} = \frac{K i}{n_e}$$

$$v' = \frac{v}{R_f}$$

At steady-state conditions ( $t=\infty$ ), consolidating terms, and for maximum groundwater concentrations along the plume centreline ( $y=0$ ),  $C(x,y,t)$  reduces to:

$$C_x = C_{gw} \exp \left\{ \frac{x}{2\partial_x} \left[ 1 - \left( 1 + \frac{4\lambda_s \partial_x}{v'} \right)^{1/2} \right] \right\} \operatorname{erf} \left[ \frac{Y}{4(\partial_y x)^{1/2}} \right]$$

Solving for  $C_{gw}$ :

$$C_{gw} = \frac{C_x}{\exp \left\{ \frac{x}{2\partial_x} \left[ 1 - \left( 1 + \frac{4\lambda_s \partial_x}{v'} \right)^{1/2} \right] \right\} \operatorname{erf} \left[ \frac{Y}{4(\partial_y x)^{1/2}} \right]}$$

or

$$C_{gw} = \frac{C_x}{\exp \left\{ \frac{x}{2\partial_x} \left[ 1 - \left( 1 + \frac{4\lambda_s \partial_x R_f}{v} \right)^{1/2} \right] \right\} \operatorname{erf} \left[ \frac{Y}{4(\partial_y x)^{1/2}} \right]}$$

$C_{gw}$  = groundwater concentration below source ( $\mu\text{g/L}$ )

$C_x$  = water use standard at point of compliance ( $\mu\text{g/L}$ )

$x$  = distance to point of compliance (default value 10 m)

$\partial_x$  = longitudinal dispersivity (m)

$\partial_y$  = transverse dispersivity (m)

$\lambda_s$  = biodegradation rate in saturated zone ( $\text{days}^{-1} * 365 \text{ days/yr}$ )

$t_{1/2s}$  = half-life in saturated zone (days)

$R_f$  = retardation factor in saturated zone

$\rho_b$  = dry bulk density of soil (default value  $1.7 \text{ g/cm}^3$ )

$n$  = total porosity (default value 0.36)

$K_d$  = distribution coefficient (L/kg)

$K_{oc}$  = organic carbon partitioning coefficient (L/kg)

$f_{oc}$  = fraction of organic carbon (default value 0.5%)

$v'$  = retarded average linear groundwater velocity in saturated zone (m/yr)

$v$  = average linear groundwater velocity in saturated zone (m/yr)

$V$  = Darcy flux or specific discharge (m/yr)

$n_e$  = effective porosity (default value 0.25)

$K$  = hydraulic conductivity ( $\text{m/s} * 3.154\text{E}+07 \text{ s/yr}$ )

$i$  = hydraulic gradient

$Y$  = source width (m)

**Exhibit 4D-2**  
**Leachate/groundwater mixing**

From EPA SSG [3]:

$$C_z = C_{gw} * DF$$

$$DF = 1 + \left( \frac{d_m V}{X I} \right)$$

Note: DF = 1 if source extends into water table

$$I = P - (RO + EV)$$

$C_z$  = leachate concentration at water table ( $\mu\text{g/L}$ )

$C_{gw}$  = groundwater concentration below source ( $\mu\text{g/L}$ )

DF = dilution factor

$d_m$  = mixing zone thickness (m)(Exhibit D-3)

X = source length (m)

I = infiltration rate (m/yr)

P = precipitation rate (m/yr)

RO+EV = runoff plus evapotranspiration rate (m/yr)

**Exhibit 4D-3**  
**Leachate/groundwater mixing - mixing zone thickness**

From EPA SSG [3]:

$$d_m = r + s = 0.1X + d_a \left[ 1 - \exp \left( - \frac{XI}{Vd_a} \right) \right]$$

$$r = 0.1X$$

$$s = d_a \left[ 1 - \exp \left( - \frac{XI}{Vd_a} \right) \right]$$

Note:  $d_m$  constrained to  $\leq d_a$

$d_m$  = mixing zone thickness (m)

r = depth of mixing due to vertical dispersivity (m)

s = depth of mixing due to downward velocity of infiltrating water (m)

$d_a$  = aquifer thickness (m)



**Exhibit 4D-4**  
**Leachate transport in the unsaturated zone**

Unsaturated zone transport as modified from Kool *et al.*, 1994 [4]:

$$C_L = \frac{C_z}{\exp \left[ \frac{b}{2\partial_u} \left( 1 - \left( 1 + \frac{4\lambda_u \partial_u R_u}{v_u} \right)^{1/2} \right) \right]}$$

$$b = d - Z$$

$$\partial_u = 0.1b$$

$$\lambda_u = \frac{\ln 2}{t_{1/2u}} \left( 1 - \frac{D_{fr}}{365} \right) \text{ where } \ln 2 = 0.6931$$

$$R_u = 1 + \frac{\rho_b}{n_w} K_d$$

$$v_u = \frac{I}{n_w}$$

- $C_L$  = leachate concentration at source ( $\mu\text{g/L}$ )
- $C_z$  = leachate concentration at water table ( $\mu\text{g/L}$ )
- $b$  = vertical distance between base of source and water table (m)
- $d$  = depth to water table (m)
- $Z$  = source depth (m)
- $\partial_u$  = dispersivity in unsaturated zone (m)
- $\lambda_u$  = biodegradation rate in unsaturated zone ( $\text{days}^{-1} \cdot 365 \text{ days/yr}$ )
- $t_{1/2u}$  = half-life in unsaturated zone (days)
- $D_{fr}$  = number of days of frozen ground
- $R_u$  = retardation factor in unsaturated zone
- $n_w$  = water filled porosity (default value 0.119)
- $v_u$  = leachate velocity in unsaturated zone (m/yr)

**Exhibit 4D-5**  
**Soil/leachate partitioning**

From EPA SSG [3]:

$$C_s = \frac{C_L \left[ K_d + \left( \frac{n_w + H'n_a}{\rho_b} \right) \right]}{1000}$$

$$n_a = n - n_w$$

$C_s$  = soil concentration at source ( $\mu\text{g/g}$ )

$C_L$  = leachate concentration at source ( $\mu\text{g/L}$ )

$n_a$  = air filled porosity (default value 0.241)

$H'$  = dimensionless Henry's law constant

1000 = conversion factor (1000  $\mu\text{g/mg}$ )

**Exhibit 4D-6  
Summary of model terms**

Category	Parameter	Symbol	Unit	Default value
Source Dimensions/ Transport	Source length	X	m	10
	Source width	Y	m	30
	Source depth	Z	m	3
	Distance to point of compliance	x	m	10
Meteorology	Precipitation rate	P	mm/yr	1,000
	Runoff + Evapotranspiration rate	RO+EV	mm/yr	450
	Infiltration rate	I	mm/yr	550
	Number of days of frozen ground	D <sub>fr</sub>	-	0
Soil/ Hydrogeology	Total porosity	n	-	0.36
	Water-filled porosity	n <sub>w</sub>	-	0.119
	Air-filled porosity	n <sub>a</sub>	-	0.241
	Effective porosity	n <sub>e</sub>	-	0.25
	Dry bulk density of soil	ρ <sub>b</sub>	g/cm <sup>3</sup>	1.7
	Fraction of organic carbon	f <sub>oc</sub>	-	0.005
	Hydraulic conductivity	K	m/s	3E-05
	Hydraulic gradient	i	m/m	0.008
	Depth to water table	d	m	3
	Aquifer thickness	d <sub>a</sub>	m	5
	pH of soil	pH <sub>soil</sub>	-	6.5
	pH of groundwater	pH <sub>water</sub>	-	6.5
Substance	Half-life in unsaturated zone	t <sub>1/2u</sub>	days	
	Half-life in saturated zone	t <sub>1/2s</sub>	days	
	Organic carbon partitioning coefficient	K <sub>oc</sub>	L/kg	
	Distribution coefficient	K <sub>d</sub>	L/kg	
	Dimensionless Henry's law constant	H'	-	
	Solubility limit (based on substance theoretical solubility)	S	µg/L	
Calculated	Vertical distance between base of source and water table	b	m	
	Mixing zone thickness	d <sub>m</sub>	m	
	Dilution factor	DF	-	
	Leachate velocity in unsaturated zone	v <sub>u</sub>	m/yr	
	Darcy flux or specific discharge	V	m/yr	
	Average linear groundwater velocity in saturated zone	v	m/yr	
	Retardation factor in unsaturated zone	R <sub>u</sub>	-	
	Retardation factor in saturated zone	R <sub>f</sub>	-	
	Dispersivity in unsaturated zone	∂ <sub>u</sub>	m	
	Longitudinal dispersivity	∂ <sub>x</sub>	m	
	Transverse dispersivity	∂ <sub>y</sub>	m	
	Biodegradation rate in unsaturated zone	λ <sub>u</sub>	yr <sup>-1</sup>	
Biodegradation rate in saturated zone	λ <sub>s</sub>	yr <sup>-1</sup>		

**Exhibit 4D-6  
Summary of model terms (cont'd)**

<b>Category</b>	<b>Parameter</b>	<b>Symbol</b>	<b>Unit</b>	<b>Default value</b>
Receiving Environment	Water hardness	H	mg/L as CaCO <sub>3</sub>	200
Soil/Groundwater Concentrations	Water use standard at point of compliance	C <sub>x</sub>	µg/L	
	Groundwater concentration below source	C <sub>gw</sub>	µg/L	
	Leachate concentration at water table	C <sub>z</sub>	µg/L	
	Leachate concentration at source	C <sub>L</sub>	µg/L	
	Soil concentration at source	C <sub>s</sub>	µg/g	
	Background concentration in soil	C <sub>b</sub>	µg/g	
	Analytical method detection limit	C <sub>dl</sub>	µg/g	
	Soil standard (adjusted for detection limit, background concentration, and rounding)	C <sub>c</sub>	µg/g	

## **APPENDIX 4E**

### **Substance Properties**

**Appendix 4E**  
**Table 4E-1 Substance Properties**

**Organics/Inorganics**

<b>Substance</b>	<b>Chemical Abstract Service # (CAS)</b>	<b>Analytical Method Detection Limit<sup>1</sup> (µg/g)</b>	<b>Solubility Limit<sup>2</sup> S (mg/L)</b>	<b>Henry's Law Constant H' (-)</b>	<b>Organic Carbon Partitioning Coefficient K<sub>oc</sub> (L/kg)</b>	<b>Biodegradation Half-life Unsaturated Zone t<sub>1/2u</sub> (days)</b>	<b>Biodegradation Half-life Saturated Zone t<sub>1/2s</sub> (days)</b>
anthracene	120-12-7		0.0217	0.00227	16,400	195	390
benzene	71-43-2		895	0.227	146	195	390
benzo(a)pyrene	50-32-8		8.1E-04	1.87E-05	587,000		
cyanide	57-12-5		47,700	0.989			
dichlorodiphenyltrichloroethane, total [DDT]	n/a		0.00275	3.40E-04	169,000		
diisopropanolamine [DIPA]	110-97-4		430,000	2.92E-09	10		
ethylbenzene	100-41-4		84.5	0.322	446	145	290
ethylene glycol	107-21-1	10	500,000	2.45E-06	1.00	105	210
fluoranthene	206-44-0		0.13	3.62E-04	55,500	115	230
mercury	7439-97-6		0.03	0.467			
methanol	67-56-1		500,000	1.86E-04	1.00	125	250
naphthalene	91-20-3		15.5	0.0180	1,540	175	350
nonylphenol and nonylphenol ethoxylates	84852-15-3		3.175	4.65E-05	25,000 <sup>3</sup>		
pentachlorophenol [PCP]	87-86-5		7	1.00E-06	Table 4E-2	383	767
perfluorooctane sulfonate [PFOS]	1763-23-1		0.025	0.449	71,700		
phenol	108-95-2		41,400	1.36E-05	187	265	530
sulfolane	126-33-0	0.1	500,000	1.98E-04	9.08		
tetrachloroethylene	127-18-4		103	0.724	94.9		
toluene	108-88-3		263	0.271	234	65	130
trichloroethylene	79-01-6		640	0.403	60.7		
xylenes, total	1330-20-7		53	0.271	383	145	290

<sup>1</sup> Analytical method detection limits only listed for those substances with calculated soil standards less than the detection limit.

<sup>2</sup> Solubility limit values represent 50% of substance theoretical solubility.

<sup>3</sup> Koc range provided in TOXNET is 10,000 to 50,000 L/kg. Midpoint value of 25,000 selected.

#### Reference sources:

Theoretical solubility values from SRC PHYSPROP [6]. Data downloaded Nov 2015 by the BC Environment Laboratory Advisory Committee.

Koc and H' substance property values from RAIS [7] except for DIPA and nonylphenol. Data downloaded Feb 22/16.

H' substance property values for DIPA and nonylphenol from SRC PHYSPROP [6]. Data downloaded Feb 23/16.

Koc substance property values for DIPA and nonylphenol from SRC HSDB TOXNET [6]. Data downloaded Feb 23/16.

Half-life biodegradation rates from Axiom [9] or, for Pentachlorophenol, CSST 1996 Derivation Protocol [1]. Unsaturated zone biodegradation rates selected as 50% of saturated zone biodegradation rates.

**Appendix 4E  
Table 4E-2 Substance Properties**

**Organic Carbon Partitioning Coefficient  
Pentachlorophenol CAS#87-86-5**

<b>Soil pH (-)</b>	<b>Organic Carbon Partitioning Coefficient Koc (L/kg)</b>	<b>Soil pH (-)</b>	<b>Organic Carbon Partitioning Coefficient Koc (L/kg)</b>
4.9	9,050	7.0	521
5.0	7,960	7.1	496
5.1	6,930	7.2	476
5.2	5,970	7.3	461
5.3	5,100	7.4	447
5.4	4,320	7.5	437
5.5	3,650	7.6	429
5.6	3,070	7.7	423
5.7	2,580	7.8	418
5.8	2,180	7.9	414
5.9	1,840	8.0	410
6.0	1,560	8.1	408
6.1	1,330	8.2	406
6.2	1,150	8.3	404
6.3	998	8.4	403
6.4	877	8.5	402
6.5	781	8.6	401
6.6	703	8.7	400
6.7	640	8.8	400
6.8	592	8.9	400
6.9	552	9.0	399

Reference source:

PCP Koc values from USEPA SSG [3]. Koc values for pH 8.1 to 9.0 calculated using Equations 72 and 74 and Table 41 of Part 5 of the Technical Background Document.



**Appendix 4E**  
**Table 4E-3 Substance Properties**

**Distribution Coefficients**  
**Inorganics**

<b>Substance</b>	<b>Chemical Abstract Service # (CAS)</b>	<b>Kd (L/kg)</b>	<b>Reference Source</b>
barium	7440-39-3	100	MoE [10]
chloride ion	16887-00-6	0.05	MoE [11]
cobalt	7440-48-4	45	RAIS [7]
cyanide	57-12-5	9.9	USEPA SSG [3]
manganese	7439-96-5	65	RAIS [7]
mercury	7439-97-6	52	RAIS [7]
molybdenum	7439-98-7	20	RAIS [7]
sodium ion	17341-25-2	20	Royal Roads [12]
uranium	7440-61-1	450	RAIS [7]
vanadium	7440-62-2	1,000	USEPA SSG [3]

**Appendix 4E**  
**Table 4E-4 Substance Properties**

**Distribution Coefficients**  
**Inorganics**  
**Soil pH – Kd Isotherms**

Soil pH (-)	Kd (L/kg)					
	arsenic CAS# 7440-38-2	beryllium CAS# 7440-41-7	cadmium CAS# 7440-43-9	chromium hexavalent CAS# 18540-29-9	chromium trivalent CAS# 16065-83-1	copper CAS# 7440-50-8
4.9	25	23	15	31	1,200	39.8
5.0	25	26	17	31	1,900	50.1
5.1	25	28	19	30	3,000	63.1
5.2	26	31	21	29	4,900	79.4
5.3	26	35	23	28	8,100	100
5.4	26	38	25	27	13,000	126
5.5	26	42	27	27	21,000	158
5.6	26	47	29	26	35,000	219
5.7	27	53	31	25	55,000	302
5.8	27	60	33	25	87,000	417
5.9	27	69	35	24	130,000	575
6.0	27	82	37	23	200,000	794
6.1	27	99	40	23	300,000	1,150
6.2	28	120	42	22	420,000	1,660
6.3	28	160	44	22	580,000	2,400
6.4	28	210	48	21	770,000	3,470
6.5	28	280	52	20	990,000	5,010
6.6	28	390	57	20	1,200,000	6,310
6.7	29	550	64	19	1,500,000	7,940
6.8	29	790	75	19	1,800,000	10,000
6.9	29	1,100	91	18	2,100,000	12,600
7.0	29	1,700	110	18	2,500,000	15,800
7.1	29	2,500	150	17	2,800,000	17,800
7.2	30	3,800	200	17	3,100,000	20,000
7.3	30	5,700	280	16	3,400,000	22,400
7.4	30	8,600	400	16	3,700,000	25,100
7.5	30	13,000	590	16	3,900,000	25,100
7.6	31	20,000	870	15	4,100,000	25,100
7.7	31	30,000	1,300	15	4,200,000	25,100
7.8	31	46,000	1,900	14	4,300,000	25,100
7.9	31	69,000	2,900	14	4,300,000	25,100
8.0 to 9.0	31	100,000	4,300	14	4,300,000	25,100
Reference Source	USEPA SSG[3]	USEPA SSG[3]	USEPA SSG[3]	USEPA SSG[3]	USEPA SSG[3]	CSST1996[1]

**Appendix 4E  
Table 4E-4 Substance Properties**

**Distribution Coefficients  
Inorganics  
Soil pH – Kd Isotherms)(cont'd)**

Soil pH (-)	Kd (L/kg)			
	lead CAS# 7439-92-1	nickel CAS# 7440-02-0	selenium CAS# 7782-49-2	zinc CAS# 7440-66-6
4.9	398	16	18	16
5.0	501	18	17	18
5.1	631	20	16	19
5.2	794	22	15	21
5.3	1,000	24	14	23
5.4	1,260	26	13	25
5.5	1,580	28	12	26
5.6	2,190	30	11	28
5.7	3,020	32	11	30
5.8	4,170	34	9.8	32
5.9	5,750	36	9.2	34
6.0	7,940	38	8.6	36
6.1	11,500	40	8.0	39
6.2	16,600	42	7.5	42
6.3	24,000	45	7.0	44
6.4	34,700	47	6.5	47
6.5	50,100	50	6.1	51
6.6	63,100	54	5.7	54
6.7	79,400	58	5.3	58
6.8	100,000	65	5.0	62
6.9	126,000	74	4.7	68
7.0	158,000	88	4.3	75
7.1	178,000	110	4.1	83
7.2	200,000	140	3.8	95
7.3	224,000	180	3.5	110
7.4	251,000	250	3.3	130
7.5	251,000	350	3.1	160
7.6	251,000	490	2.9	190
7.7	251,000	700	2.7	240
7.8	251,000	990	2.5	310
7.9	251,000	1,400	2.4	400
8.0 to 9.0	251,000	1,900	2.2	530
Reference Source	CSST1996*10[1]	USEPA SSG[3]	USEPA SSG[3]	USEPA SSG[3]

**Appendix 4E  
Table 4E-5 Substance Properties**

**Background Concentrations in Soil (Inorganics)**

<b>Substance</b>	<b>Chemical Abstract Service # (CAS)</b>	<b>Background Concentration in Soil (µg/g)</b>
arsenic	7440-38-2	10
barium	7440-39-3	300
beryllium	7440-41-7	1
cadmium	7440-43-9	1
chromium, hexavalent and trivalent	18540-29-9 and 16065-83-1	60
cobalt	7440-48-4	25
copper	7440-50-8	75
lead	7439-92-1	120
manganese	7439-96-5	2,000
mercury	7439-97-6	0.2
molybdenum	7439-98-7	3
nickel	7440-02-0	70
selenium	7782-49-2	1
vanadium	7440-62-2	100
zinc	7440-66-6	150

Reference source:

[Protocol 28 "2016 Standards Derivation Methods"](#).

## **APPENDIX 4F**

### **Numerical Water Standards**

## Appendix 4F

### Table 4F-1 Numerical Water Standards

Substance	Chemical Abstract Service # (CAS)	Numerical Water Standard (µg/L) (@water pH=6.5 and H=200 mg/L)					
		Drinking Water	Aquatic Life	Aquatic Life (freshwater)	Aquatic Life (marine)	Livestock Watering	Irrigation
anthracene	120-12-7	1,000	1				
arsenic	7440-38-2	10		50	125	25	100
barium	7440-39-3	1,000		10,000	5,000		
benzene	71-43-2	5		400	1,000		
benzo(a)pyrene	50-32-8	0.01	0.1				
beryllium	7440-41-7	8		1.5	1,000	100	100
cadmium	7440-43-9	5		3.5	15	80	5
chloride ion	16887-00-6	250,000		1,500,000		600,000	100,000
chromium, hexavalent	18540-29-9	50		10	15	50	8
chromium, trivalent	16065-83-1	6,000		90	560	50	5
cobalt	7440-48-4	1	40			1,000	50
copper	7440-50-8	1,500		90	20	300	200
cyanide	57-12-5	200		50	10		
dichlorodiphenyltrichloroethane, total [DDT]	n/a	0.45	0.01			30	
diisopropanolamine [DIPA]	110-97-4	3,500	15,000			38,000	39,000
ethylbenzene	100-41-4	140		2,000	2,500		
ethylene glycol	107-21-1	8,000	1,920,000				
fluoranthene	206-44-0	150	2				
lead	7439-92-1	10		110	20	100	200
manganese	7439-96-5	1,500					200
mercury	7439-97-6	1	0.25			2	1
methanol	67-56-1	8,000					
molybdenum	7439-98-7	250	10,000			50	10
naphthalene	91-20-3	80	10				
nickel	7440-02-0	80		1,500	83	1,000	200
nonylphenol and nonylphenol ethoxylates	84852-15-3	45		10	7		
pentachlorophenol [PCP] <sup>1</sup>	87-86-5	60	1.5			30	
perfluorooctane sulfonate [PFOS]	1763-23-1	0.3	60				
phenol	108-95-2	1,000	2,000				
selenium	7782-49-2	10	20			30	20
sodium ion	17341-25-2	200,000					
sulfolane	126-33-0	90	500,000			14,000	8,400
tetrachloroethylene	127-18-4	30	1,100				
toluene	108-88-3	60		5	2,000		
trichloroethylene	79-01-6	5	200			50	
uranium	7440-61-1	20	85			200	10
vanadium	7440-62-2	20				100	100
xylenes, total	1330-20-7	90	300				
zinc <sup>2</sup>	7440-66-6	3,000		1,650	100	2,000	2,000

Reference source: Schedule 3.2 of the Regulation

<sup>1</sup> For aquatic life water use, standard varies with water pH and temperature. Water use standard shown is at water pH = 6.5 and temperature  $\geq 20$  °C. See Schedule 3.2 and Technical Guidance 9 for standards at full range of water pH and temperature.

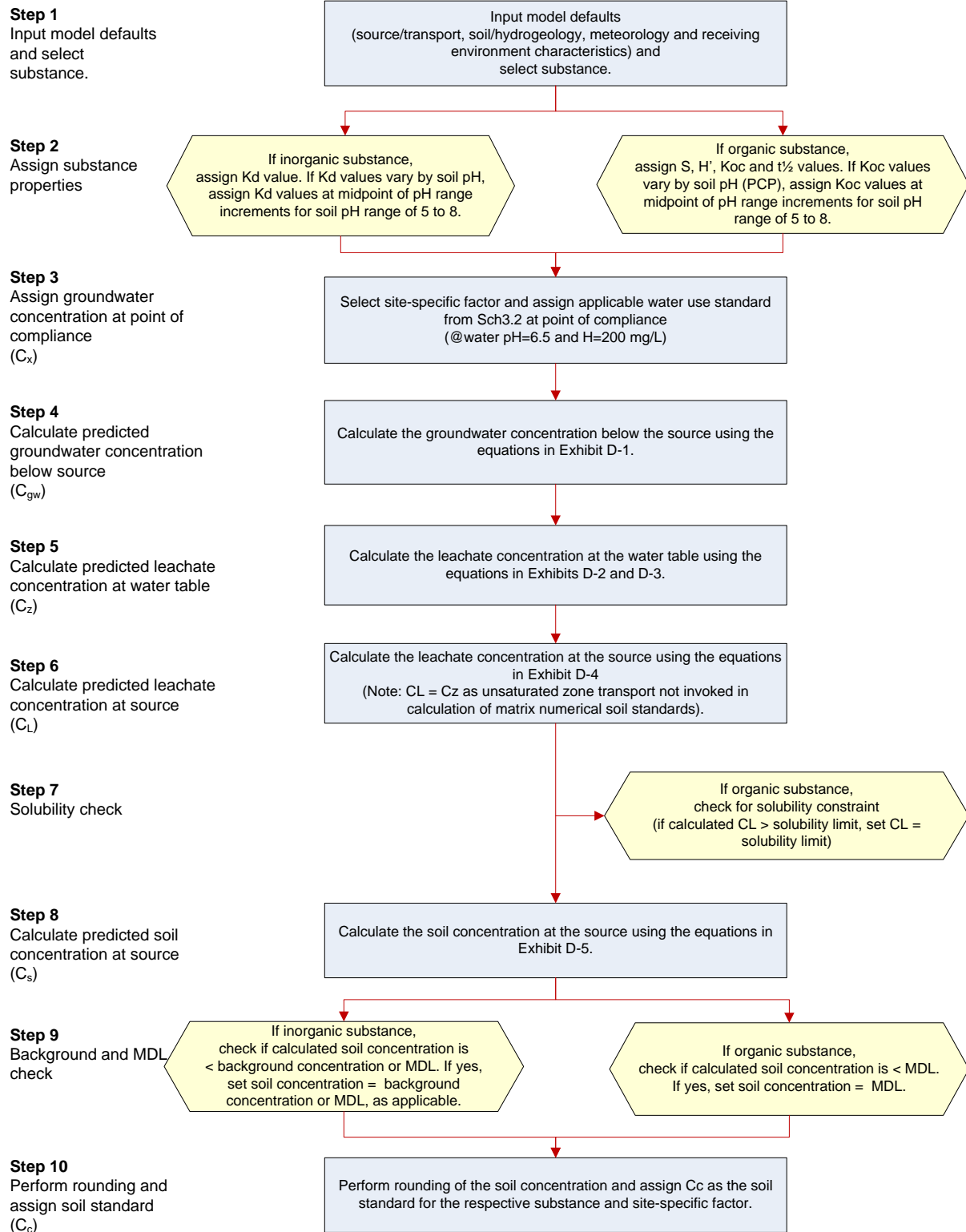
<sup>2</sup> For irrigation water use, standard varies with soil pH. Water use standard shown is at soil pH = 6.5. See Schedule 3.2 for standards at full range of soil pH.

## APPENDIX 4G

### Soil Standards Calculation Methodology Flowchart



**FIGURE G-1. Matrix Numerical Soil Standards Calculation Flowchart.**  
 (Note: This flowchart is provided for illustrative purposes only. The process description in section 5 takes precedence over this flowchart).



## APPENDIX 4H

### Example Matrix Numerical Soil Standards Calculations

## Appendix 4H

**Table 4H-1 Example Matrix Numerical Soil Standards Calculations**

**Zinc – Groundwater used for irrigation water use**

Soil pH range	Soil pH value used for Kd selection (rounded midpoint value)	Water pH value used for water use standard selection (same as soil pH value)	Kd based on soil pH value (L/kg) (from Table 4E-4, Appendix 4E)	Irrigation water use standard based on water pH value (µg/L) (from Table 4F-1, Appendix 4F @ H=200 mg/L)	Calculated soil standard (before adjustments*)	Calculated soil standard (after adjustments*)	Final matrix numerical soil standard soil pH range (after consolidation of pH ranges)	Final matrix numerical soil standard (after consolidation of pH ranges)
< 5.0	5.0	5.0	18	1,000	59.75	150**		
5.0 - < 5.5	5.3	5.3	23	1,000	76.29	150**		
5.5 - < 6.0	5.8	5.8	32	1,000	106.05	150**	< 6.0	150
6.0 - < 6.5	6.3	6.3	44	2,000	291.47	300	6.0 - < 6.5	300
6.5 - < 7.0	6.8	6.8	62	2,000	410.51	400	6.5 - < 7.0	400
7.0 - < 7.5	7.3	7.3	110	5,000	1,819.92	2,000	7.0 - < 7.5	2,000
7.5 - < 8.0	7.8	7.8	310	5,000	5,126.77	5,000	7.5 - < 8.0	5,000
≥ 8.0	8.0	8.0	530	5,000	8,764.29	9,000	≥ 8.0	9,000

\* adjustments include, as applicable:

background concentration in soil (from Table 4E-5, Appendix 4E);  
analytical method detection limit (from Table 4E-1, Appendix 4E); and,  
rounding (always completed).

\*\* adjusted to background concentration in soil.

## Appendix 4H

### Table 4H-2 Example Matrix Numerical Soil Standards Calculations

**Pentachlorophenol – Groundwater flow to surface water used by aquatic life**

Soil pH range	Soil pH value used for Kd selection (rounded midpoint value)	Water pH value used for water use standard selection (same as soil pH value)	Koc based on soil pH value (L/kg) (from Table 4E-2, Appendix 4E)	Irrigation water use standard based on water pH value (µg/L) (from Technical Guidance 9 @ H=200 mg/L, T≥20°C)	Calculated soil standard (before adjustments*)	Calculated soil standard (after adjustments*)	Final matrix numerical soil standard soil pH range (after consolidation of pH ranges)	Final matrix numerical soil standard (after consolidation of pH ranges)
< 5.0	5.0	5.0	7,960	1	279.09**	300**	< 5.0	300
5.0 - < 5.5	5.3	5.3	5,100	1	159.36	150	5.0 - < 5.5	150
5.5 - < 6.0	5.8	5.8	2,180	1	2.11	2	5.5 - < 6.0	2
6.0 - < 6.5	6.3	6.3	998	1.5	0.23	0.25	6.0 - < 6.5	0.25
6.5 - < 7.0	6.8	6.8	592	2.5	0.1	0.1	≥ 6.5	0.1
7.0 - < 7.5	7.3	7.3	461	3.5	0.088	0.09		
7.5 - < 8.0	7.8	7.8	418	6	0.12	0.1		
≥ 8.0	8.0	8.0	410	6	0.12	0.1		

\* adjustments include, as applicable:

background concentration in soil (none for pentachlorophenol);  
analytical method detection limit (from Table 4E-1, Appendix 4E); and,  
rounding (always completed).

\*\* calculated soil standard is constrained to the solubility limit.

## APPENDIX 4I

**Substances/Pathways for which Matrix Numerical Soil Standards  
are not Calculated/Provided**

## Appendix 4I

**Table 4I-1 Substances/Pathways for which Matrix Numerical Soil Standards are not Calculated/Provided**

Substance	Chemical Abstract Service # (CAS)	Substance Type	Pathway/Site-specific Factor			
			DW	AW	LW	IW
anthracene	120-12-7	organic	NS	NS	NS	NS
arsenic	7440-38-2	inorganic				
barium	7440-39-3	inorganic			NS	NS
benzene	71-43-2	organic			NS	NS
benzo(a)pyrene	50-32-8	organic	NS	NS	NS	NS
beryllium	7440-41-7	inorganic				
cadmium	7440-43-9	inorganic				
chloride ion	16887-00-6	inorganic				
chromium, hexavalent	18540-29-9	inorganic				
chromium, trivalent	16065-83-1	inorganic				
cobalt	7440-48-4	inorganic				
copper	7440-50-8	inorganic				
cyanide	57-12-5	inorganic			NS	NS
dichlorodiphenyltrichloro-ethane, total [DDT]	n/a	organic	NS	NS	NS	NS
diisopropanolamine [DIPA]	110-97-4	organic				
ethylbenzene	100-41-4	organic			NS	NS
ethylene glycol	107-21-1	organic			NS	NS
fluoranthene	206-44-0	organic	NS	NS	NS	NS
lead	7439-92-1	inorganic				
manganese	7439-96-5	inorganic		NS	NS	
mercury	7439-97-6	inorganic	NS	NS	NS	NS
methanol	67-56-1	organic		NS	NS	NS
molybdenum	7439-98-7	inorganic				
naphthalene	91-20-3	organic			NS	NS
nickel	7440-02-0	inorganic				
nonylphenol and nonylphenol ethoxylates	84852-15-3	organic			NS	NS
pentachlorophenol [PCP]	87-86-5	organic				NS
perfluorooctane sulfonate [PFOS]	1763-23-1	organic			NS	NS
phenol	108-95-2	organic			NS	NS
selenium	7782-49-2	inorganic				
sodium ion	17341-25-2	inorganic		NS	NS	NS
sulfolane	126-33-0	organic				
tetrachloroethylene	127-18-4	organic			NS	NS
toluene	108-88-3	organic			NS	NS
trichloroethylene	79-01-6	organic				NS
uranium	7440-61-1	inorganic				
vanadium	7440-62-2	inorganic		NS		
xylenes, total	1330-20-7	organic			NS	NS
zinc	7440-66-6	inorganic				

NS - indicates no soil standard calculated

Yellow cell - indicates soil standard calculated

Blank white cell - indicates no soil standard provided