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Site-Specific Numerical Soil Standards Model Parameters

This document provides guidance to qualified professionals for determining site-specific model parameters for use in deriving site-specific numerical soil standards (SSSs) under Protocol 2 "Site-Specific Numerical Soil Standards".

Site-specific model parameters are used in the ministry's Groundwater Protection Model (GPM) to derive SSSs for the site-specific factors protective of groundwater use. The GPM is applied in the Modified GPM method to derive SSS(s) and in the Leachate Test method to calculate the modelled leachate concentration.

Specific guidance on how to run the ministry's GPM can be found in Technical Guidance 13, "Groundwater Model". Specific guidance on model parameters can be found in Protocol 28 "2016 Standards Derivation Methods", Chapter 4, Derivation of Soil to Groundwater Protection Matrix Soil Quality Standards.

1.0 Groundwater Protection Model

The ministry's GPM is used in the "SSS Model Type" to back-calculate either a SSS (under the Modified GPM method) or a modelled leachate concentration (under the Leachate Test method) that is protective of the applicable water use in the shallowest unconfined aquifer. A schematic illustrating the GPM is found in Appendix 1.

The GPM takes into account four different model processes from source to point of compliance: (1) soil–leachate partitioning at the source, (2) unsaturated transport of leachate to the groundwater table, (3) mixing at the groundwater table, and (4) saturated transport to the point of compliance. A conceptual model illustrating the four processes is found in Appendix 2.

The model parameters used in the GPM can be divided into four major categories: (1) source dimensions, (2) infiltration, (3) hydrogeology, and (4) physical/chemical properties. Available model parameters and their use in the four GPM model processes are listed in Appendix 3.

2.0 Parameter sensitivity

A parameter sensitivity analysis was completed to define and prioritize a list of model parameters that are considered most sensitive to the calculated SSSs under Protocol 2 [1]. This analysis provides a focused assessment on which model parameters may be considered for potential modification when deriving SSSs on a site.

Parameter sensitivity varies for each matrix substance and will specifically vary for organic and inorganic substances. The most important difference is that only organic matrix substances will degrade in the unsaturated zone, whereas inorganic matrix substances are unaffected by unsaturated transport. A detailed review of the sensitivity analysis is found in [1].

Based on the relative change in SSSs derived from the GPM, the model parameters were ranked from highest to lowest sensitivity for organic and inorganic substances, Table 1.

Table 1. Ranking of model parameter sensitivity

Sensitivity	Organics	Inorganics
Highest	Depth to water	Soil pH
	Infiltration	Infiltration
	Source depth	Partitioning coefficient (K_d)
	Fraction of organic carbon (f_{oc}) and partitioning coefficient (K_{oc})	Distance to point of compliance
	Distance to point of compliance	Hydraulic conductivity and gradient
Lowest	Half-life	

Due to the significant attenuation of degradable organic substances in the unsaturated zone, the GPM is highly sensitive to parameters used to calculate unsaturated zone attenuation (i.e. depth to water table, source depth, sorption and half-life). The infiltration rate, which is used to calculate the dilution factor when leachate mixes at the groundwater table, is also a sensitive parameter for both organic and inorganic substances. Source dimensions influence both the unsaturated zone thickness relevant for organics and the transport distance to point of compliance and, thus, are also sensitive parameters. Remaining hydrogeological parameters like porosity, bulk density, hydraulic conductivity, gradient, and pH_{water} are less sensitive model parameters in the GPM.

3.0 Site-specific model parameters

SSSs are derived using the Modified GPM method by substituting the model default parameters with site-specific values. As per Protocol 2, parameters related to source dimensions, infiltration and hydrogeology can be modified within the acceptable parameter ranges provided in Table 2 of the protocol. The methods provided for modifying model parameters include using look-up regional data, literature data or site-specific data determined by site investigations (Protocol 2, Table 1).

Based on the sensitivity of model parameters, decisions can be made regarding which default parameters to modify with site-specific values. One strategy for modifying model parameters is to start by modifying the infiltration rate using data from the look-up table in Protocol 2, Appendix 1. If further modification is sought, the hydrogeological parameters can be modified using either literature values (an option for selected parameters only, see section 3.2) or site-specific data obtained during site investigations. Finally, depth to water table and/or transport distance to point of compliance can be modified. This step requires site-specific data to determine the source dimensions.

Where site-specific conditions warrant modification outside the parameter ranges provided, the rationale and supporting data must be provided in an application for a Director's decision.

Although a variety of approaches are possible, one approach for modifying parameters is shown in the flowchart of Appendix 4.

Parameter categories are discussed in detail below.

3.1 Infiltration

Infiltration is a moderately sensitive parameter when deriving SSSs for both organic and

inorganic matrix substances. A water balance approach defines the infiltration rate, I, where the amount of infiltration into the ground is defined as the difference between the precipitation, P, in the form of rainfall and snowfall and the sum of the evapotranspiration, ET, and surface water runoff, RO. The following expression summarizes the infiltration equation:

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

Look-up infiltration data has been derived for the province [2]. The look-up table and figure in Protocol 2, Appendix 1 provides infiltration rates for available urban centres.

The following method is recommended in determining which infiltration rate to use on a site:

- If the site is located within a 20 km radius of a listed urban centre, use the infiltration rate listed for that centre.
- If the site is located outside a 20 km radius and in between two listed urban centres, and does not cross an infiltration contour on the infiltration figure, use the infiltration rate for the urban centre closest to the site. An average of the two infiltration rates can be calculated in situations where the site is located equidistant from the two stations.
- If the site is located at a horizontal distance greater than the 20 km radius from a listed urban centre and one or more infiltration rate contours are crossed, use an infiltration rate corresponding to the closest infiltration rate contour to the site.
- If the site is located between two contour intervals, the infiltration rate can be estimated to the nearest 100 mm/year. For example, the town of Sechelt, which is located midway between the 800 mm/year and 600 mm/year contours, would be considered to have an annual infiltration rate of 700 mm/yr.

If a site-specific infiltration rate (e.g. using on-site infiltrometer test) is to be used, an application for a Director's decision can be made.

3.2 Hydrogeology

Hydrogeological parameters can be modified in the GPM by a qualified hydrogeologist to reflect site-specific conditions.

The less sensitive hydrogeological parameters, including total porosity, effective porosity, dry bulk density and pH of groundwater, can be modified using sourced literature values or actual site-specific values. When deriving SSS for pentachlorophenol [PCP] for the site-specific factor protective of aquatic life, site-specific data is required to modify pH_{water}.

Site-specific hydrogeological parameter values are determined through in-situ field investigations. Technical guidance on site investigations can be found in Technical Guidance 8 "Groundwater Investigation and Characterization". Further, Technical Guidance 6 "Assessment of Hydraulic Properties for Water Use Determinations" provides additional guidance for assessing aquifer properties.

Laboratory analyses of representative soil samples are required to determine site-specific values for pH of soil, dry bulk density, ρ_b, and fraction of organic carbon, f_{oc}. Technical Guidance 1 "Site Characterization and Confirmation Testing" provides guidance on how to conduct soil sampling to determine a representative soil sample. The selection of pH for running the GPM is described in Protocol 28 "2016 Standards Derivation Methods", Chapter 4, Derivation of Soil to Groundwater Protection

Matrix Soil Quality Standards.

Field investigations are required to determine the hydraulic conductivity, K, and the hydraulic gradient, i. Similarly, site-specific aquifer thickness, d_a, can be determined if desired, however the parameter is not a sensitive parameter in the GPM. Since saturated transport in the GPM is simulated in the shallowest unconfined groundwater flow system, the hydraulic conductivity, gradient, and thickness should be measured and represent conditions in the unconfined flow system. For sites where there are perched water tables or where the hydraulic conductivity, gradient and aquifer thickness cannot be determined, the default model parameter values will need to be used.

The depth to water table, d, is a sensitive model parameter for organic substances. The distance to water table can only be modified from its default value of 3 m (i.e. no unsaturated zone) if site-specific source dimensions are determined as described in Protocol 2, Section 5.1.1.

The transport distance to the point of compliance, x, is a sensitive model parameter for both organic and inorganic substances. The transport distance can only be modified from its default value of 10 m if the site-specific source dimensions are determined and groundwater meets the requirements described in Protocol 2, Section 5.1.3.

3.3 Source dimensions

The horizontal and vertical extent of the source dimensions are defined by the length, X, width, Y, and depth, Z. Due to the variability in chemical behaviour and mobility of different contaminants in the subsurface, the approach used to define the dimensions of the source is different for different types of contamination. Specifically, the method used to define the dimensions of a petroleum hydrocarbon contamination source is different than that used to define an inorganic or chlorinated hydrocarbon contamination source.

Site-specific measurements are required to modify the default source dimensions using the criteria listed in Protocol 2, Section 5.1.1. Site-specific source dimensions are a requirement for sites where the parameters "distance to water table" and "distance to point of compliance" are modified. Further details on source definition are provided below and in the document "Defining the Contaminant Source Zone Protocol 2 Groundwater Model" [3].

Petroleum hydrocarbon source

Petroleum hydrocarbon sources are almost exclusively a consequence of NAPL releases. Partially NAPL-saturated soils and soils with residual NAPL can serve as long-term sources of groundwater contamination. The presence of NAPL at a site is defined in Protocol 16 "Determining the Presence and Mobility of Nonaqueous Phase Liquids and Odorous Substances". The definitions and methods described in the protocol can be used to define the horizontal extent and depth to which the LNAPL/DNAPL occurs.

Defining the horizontal and vertical extent of residual NAPL in soil is somewhat more complicated, since residual saturation levels can vary significantly (e.g., less than 1% to greater than 20%). The recommended approach for defining the extent of residual NAPL is to use soil analytical data for key petroleum hydrocarbon substances as surrogates to define the source dimension variables. Protocol 2 uses $VH_{s6\text{-}10}$, $EPH_{s10\text{-}19}$ and $EPH_{s19\text{-}32}$ as surrogates for residual NAPL in soil.

If non-petroleum hydrocarbon substances are present in addition to a petroleum hydrocarbon

source, site-specific source dimensions for those substances are determined as described below.

Inorganic source definition

For inorganic sources, the source dimensions are defined using the applicable Schedule 3.1 Part 1 matrix soil standard for a given contaminant of concern, COC; or a SSS derived under the Modified GPM method by substituting one or more of the following model parameters in the GPM: infiltration, total porosity, water filled porosity, effective porosity, dry bulk density, fraction of organic carbon, pH of soil, pH of groundwater, hydraulic conductivity, hydraulic gradient, aquifer thickness; or the substance concentrations in regional/ local background soil as defined in Protocol 4 "Establishing Background Concentrations in Soil".

Other COCs

For non-petroleum hydrocarbon volatile organic sources and other COCs, the source dimensions are defined based on the applicable Schedule 3.1 Part 1 matrix soil standards.

3.4 Physical/chemical properties

Model parameters contained within the physical/chemical category are restricted and cannot be modified using the Modified GPM method under Protocol 2. If alternative, scientifically defensible physical/chemical properties are available, a qualified professional can apply to use site-specific values in a Director's decision.

4.0 References

1. Core 6 Environmental. (2017). Results of a Sensitivity Analysis of the Omnibus Groundwater Model.

2. Core 6 Environmental. (2017). Estimation of Regional Infiltration Rates in British Columbia, Protocol 2 Groundwater Model.

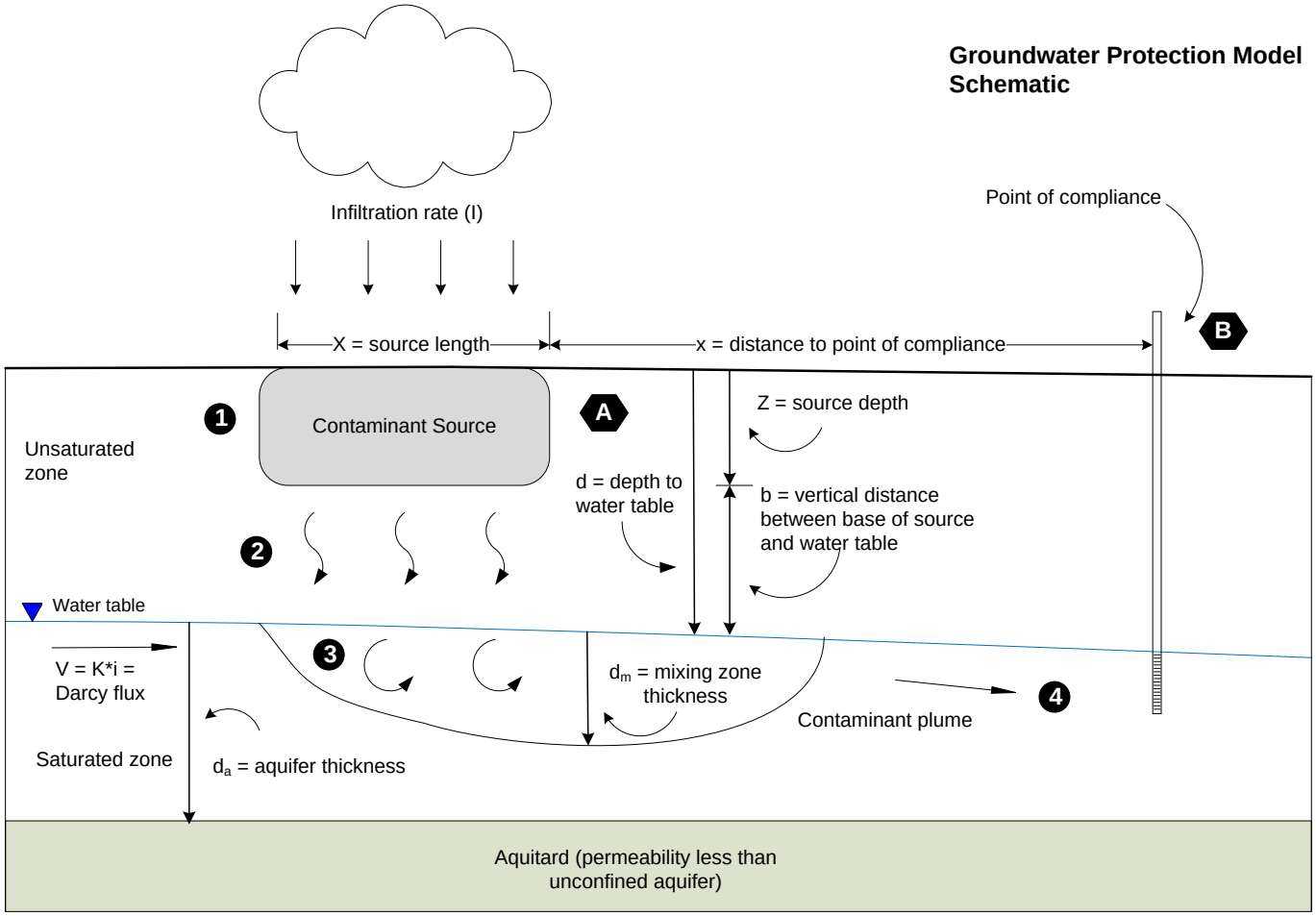
3. Core 6 Environmental (2017). Defining the Contaminant Source Zone, Protocol 2 Groundwater Model.

For more information, please direct inquiries to site@gov.bc.ca.

Revision history

Approved Date	Effective Date	Document Version	Notes
November 1, 2017	November 1, 2017	1.0	Created for the Stage 10 & 11 Amendments to the CSR

Appendix 1 – Schematic of the GPM



LEGEND

1. Leachate concentration due to partitioning
2. Unsaturated zone contaminant fate and transport
3. Mixing of leachate and groundwater flux at water table
4. Saturated zone contaminant fate and transport

A. Substance soil concentration at source (C_s)

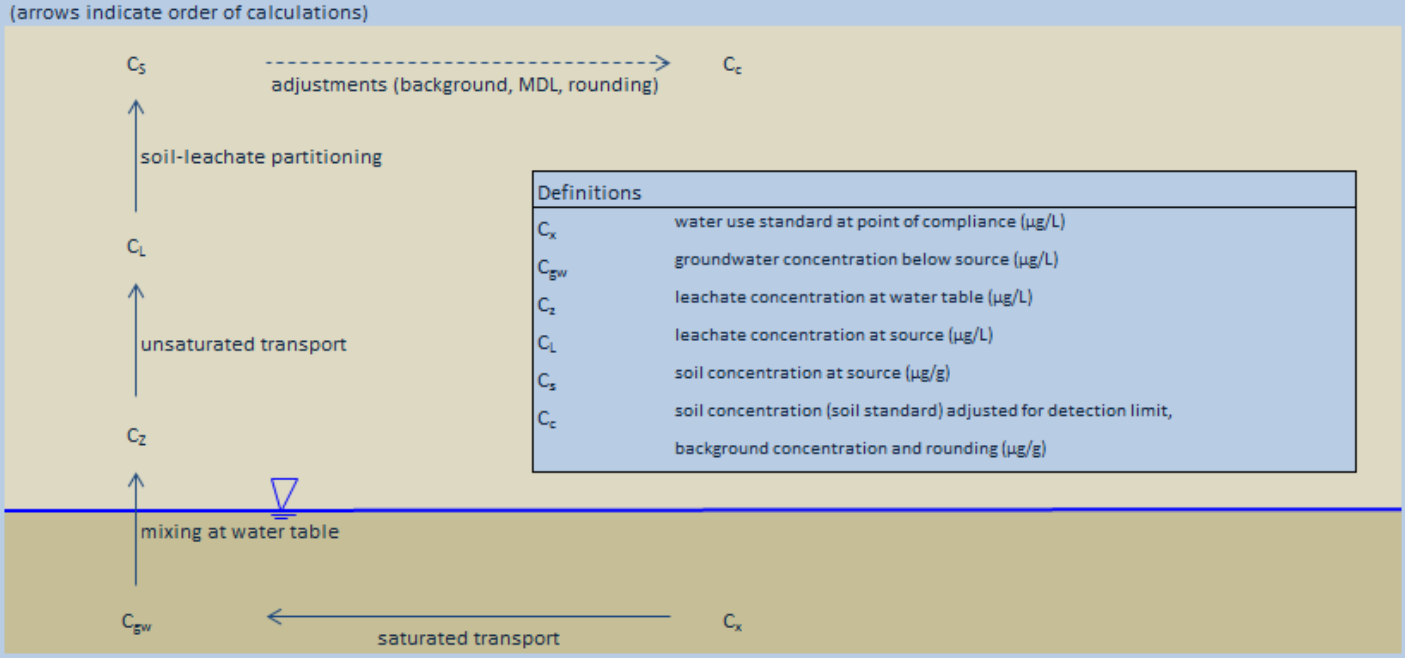
B. Substance groundwater concentration at point of compliance (C_x)

Schematic only.
Not to scale.

Appendix 2 – Conceptual model of the GPM

Conceptual Model

(arrows indicate order of calculations)



Model Type: (•) SSS ( ) SLRA

Run Model | Resize Window

Site-specific Factors	C_x µg/L	C_{gw} µg/L	C_z µg/L	C_L µg/L	C_s µg/g	C_c µg/g
Groundwater used for drinking water	5	12.01	39.71	39.71	0.03	0.035
Groundwater flow to surface water used by aquatic life						
freshwater	400	960.67	3176.80	3176.80	2.64	2.5
marine and/or estuarine	1000	2401.69	7942.00	7942.00	6.61	6.5
any aquatic receiving environment						
Groundwater used for livestock watering						
Groundwater used for irrigation						

Appendix 3 – Active model parameters in the GPM

Category	Parameter	Symbol	Unit	Saturated transport	Mixing	Unsaturated transport	Partitioning
Source dimension	Source length	X	m		X		
	Source width	Y	m	X			
	Source depth	Z	m			X (organic)	
Infiltration	Infiltration	I	m/yr		X	X (organic)	
Hydrogeology	Total porosity	n	-	X			X
	Water filled porosity	n_w	-			X (organic)	X
	Effective porosity	n_e	-	X			
	Fraction of organic carbon	f_{oc}	-	X (organic)		X (organic)	X (organic)
	Hydraulic conductivity	K	m/s	X	X		
	Hydraulic gradient	i	-	X	X		
	Depth to water table	d	m			X (organic)	
	Aquifer thickness	d_a	m		X		
	Dry bulk density	ρ_b	g/cm^3	X		X (organic)	X
	pH of soil	pH_{soil}	pH units	X (PCP)			X (inorganic)
	pH of groundwater	pH_{water}	pH units	X (PCP)			
	Distance to point of compliance	x	m	X			
Physical/ chemical	Half-life	$t_{1/2s}$	days	X (organic)		X (organic)	
	Distribution coefficient	K_{oc}/K_d	L/kg	X		X (organic)	X
	Henry's Law constant	H	-				X
	Number of days frozen	D_{fr}	days/yr			X (organic)	

(organic): This parameter is only active in the GPM when deriving SSS for organic substances
(PCP): This parameter is only active when deriving SSS for pentachlorophenol [PCP]

Appendix 4 – Example of step-wise Modified GPM Method