

September 22, 2017

British Columbia Ministry of Environment and Climate Change Strategy
Land Remediation Section
525 Superior Street
Victoria, BC V8V 1T7

**Re: Defining the Contaminant Source Zone
Protocol 2 Groundwater Protection Model**

1.0 INTRODUCTION AND BACKGROUND

The following recommendations were prepared by Core6 Environmental (Core6) for the British Columbia Ministry of Environment and Climate Change Strategy (BCMOE) with funding provided by BCMOE and the Society of Contaminated Sites Approved Professionals of British Columbia (CSAP). It is recognized that any BCMOE protocols or guidance informed by these recommendations, may differ from those provided herein.

The BC Contaminated Sites Regulation (CSR) Schedule 5 matrix soil standards were originally derived in 1996 using the Contaminated Sites Standards Taskgroup (CSST) model. The model was specifically developed to simulate the transport of various organic and inorganic contaminants of concern (COCs) in groundwater towards various receiving environments, for the purpose of protecting four water uses (i.e., drinking water, aquatic life, irrigation water, livestock water). Recently, the standards have been updated using a refined version of the CSST model, now renamed the Omnibus model. In November 2017, it will be possible to calculate site-specific soil standards using the Omnibus model under Protocol 2 (P2) of the CSR. As these models simulate the transport of COCs from a source, and source is not explicitly defined in the CSR or associated protocols or guidance, a definition of “source” is required.

There are three variables (herein referred to as the source dimension variables) that are used to define the size of the source in terms of the horizontal and vertical extent. These variables and the current default values assigned in the CSST and Omnibus models are:

1. The source dimension length (X) – default value = 10 m
2. The source dimension width (Y) – default value = 30 m
3. The source dimension depth (Z) – default value = 3 m

The intent of the P2 model is to allow for a site-specific definition of the source based on actual site characterization data. During completion of a detailed sensitivity analysis of the P2 model, it was observed that the model was relatively sensitive to changes in these source dimension variables. In particular, when modeling organic COCs, the model was determined to be most sensitive to changes to the source depth (Z). This is because the source depth is used to define the thickness of the unsaturated zone and therefore the vertical distance over which unsaturated transport can occur. And in general, small increases in unsaturated zone thickness can result in

relatively large increases in back-calculated site-specific soil standards due to the increased contaminant attenuation that occurs when the unsaturated transport model is active. In general, the individual source dimensions are utilized in one or more of the four sub-models (i.e., soil leachate partitioning model, unsaturated transport model, groundwater mixing model, and saturated transport model) and therefore affect outcomes based on several modeled processes. For example, the source dimension length (X) is used in the groundwater mixing zone model to calculate the dilution factor as well as the mixing zone depth. The source dimension width (Y) is used in the saturated transport model to simulate transverse dispersion. The source dimension depth (Z) is used in the unsaturated transport model when defining the unsaturated zone thickness. Due to the use of these source dimension terms in the various sub-models used in the P2 model, it is critical to have a clear definition of the source term dimensions that are scientifically defensible and easily derived using typical site data, such that site-specific soil standards can be derived.

1.1 Objectives

The primary objective of the work was to develop a simplified approach for defining the source term dimensions at a given contaminated site for use in the Protocol 2 Groundwater Protection Model. This will allow the source term variables to be utilized directly in the P2 model and help facilitate use of the model.

2.0 DEFINITION OF A CONTAMINANT SOURCE

According to the United States Environmental Protection Agency (USEPA 1991), a source or source material is defined as:

“... a material that includes or contains hazardous substances, pollutants or contaminants that act as a reservoir for migration of contamination to groundwater, surface water, to air, or acts as a source for direct exposure”.

Examples of source materials include contaminated soil and debris, pools of non-aqueous phase liquids (NAPLs) submerged beneath groundwater or in fractured bedrock, NAPLs floating on groundwater, and contaminated sediment and sludge. Examples of non-source materials include groundwater, surface water, and residuals resulting from treatment of site materials. The United States National Resource Council (NRC 1994) modified the USEPA (1991) definition to include residual NAPL and inorganic contaminant sources:

“Contaminant source areas include not only typical near-surface sources such as leaking drums, process wastes, and sludges, but also deep subsurface sources such as residual non-aqueous-phase liquids (NAPLs), pools of NAPLs, and metals that have precipitated in mineral phases having low solubility”.

Given that the purpose of the P2 model is to calculate site-specific soil standards that are protective of the four water uses (i.e., DW, AW, IW, LW), the source definition should recognize the ability of a source to impact the groundwater quality at a contaminated site. Accordingly, the proposed definition of a source for application of the P2 includes the following:

- Presence and extent of measurable LNAPL in a groundwater monitoring well, as defined in CSR Protocol 16;
- Presence of residual NAPL in soil, where residual NAPL is defined as the NAPL saturation level where a continuous NAPL becomes discontinuous and immobilized by capillary forces (USEPA, 1995); and

- Presence of relatively soluble organic solids, inorganic debris, waste materials and/or inorganic precipitates/sorbed phase inorganics that can dissolve or desorb into porewater or leachate, resulting in a dissolved-phase contaminant plume.

Using the above definition of a source it is possible to define a methodology for characterizing and defining the source term dimensions at a contaminated site for use in P2. Due to the variability in chemical behaviour of different contaminants and their mobility in the subsurface, the approach used to define the dimensions of the source term will be different for different types of contamination. Specifically, the method to define the source dimensions for petroleum hydrocarbon (PHC) contamination at a site will be different than that for inorganic contamination at a site or for a site impacted by chlorinated solvents and/or other less commonly encountered COCs such as pesticides.

3.0 RECOMMENDED APPROACH

3.1 Petroleum Hydrocarbon Sources

For the purposes of this technical memorandum, PHCs are defined as substances that are comprised of a multicomponent mixture of hydrocarbon compounds such as: gasoline, diesel, heating oil, and other fuel or non-fuel petroleum based oils. PHC release sites that are comprised of one or two PHC compounds e.g. toluene or benzene that may be encountered at for example a chemical manufacturing plant or a drug manufacturing site would not be considered a PHC contaminated source. Defining the source term variables for non-PHC sources, including inorganic substances are provided in subsequent sections of this memorandum.

Using the definitions of source outlined above as well as relevant CSR Protocols, it is recommended that the source term dimensions for PHCs be defined based on:

- The horizontal and vertical extent of NAPL as defined in CSR Protocol 16, and
- The horizontal and vertical extent residual NAPL in soil.

PHC 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 well defined in Protocol 16 for both LNAPL and DNAPL, and the definitions and described methods within the Protocol can be used to define the area of extent and depth to which the LNAPL/DNAPL occurs.

Defining the horizontal and vertical extent of residual NAPL in soil is somewhat more complicated. As residual saturation levels can vary significantly (e.g., less than 1% to greater than 20%), it is difficult to define the extent of a PHC source by measuring the residual saturation of NAPL in soil. Furthermore, BC laboratories are not accustomed to analyzing soil samples to quantify the residual NAPL saturation. It is therefore recommended that soil concentrations of key petroleum hydrocarbon COCs be used as surrogates to define the source dimension variables.

There are published methods to approximate the potential presence of NAPL in soil using standard chemical analyses of organic substances. These methods can be used to estimate the critical soil concentrations at which point residual NAPL is assumed present, and critical soil concentrations under which residual saturation levels are exceeded and NAPL may become mobile. These analytical methods utilize chemical analyses of PHCs in soil, and are described in USEPA (1996), Feenstra *et al.* (1991), and API (2000). In API (2000), ranges of residual PHC saturation levels based on soil concentrations for different NAPL sources (e.g., gasoline) were defined and provided. For gasoline, for example, residual saturation levels were defined by Total Petroleum Hydrocarbon (TPH) concentrations in soil ranging from 100 mg/kg to over 80,000 mg/kg, depending on the actual residual NAPL content in the soil.

Based on a review of the API (2000) study for different petroleum hydrocarbon sources, it seems reasonable that a PHC source could be defined using the CSR adopted carbon fractions for volatile hydrocarbons (VH) and extractable petroleum hydrocarbons (EPH). Analysis of these two carbon fractions capture the PHC carbon ranges: C_{6-10} and C_{10-19}/C_{19-32} , respectively. Accordingly, a straightforward approach to defining the source term variables would be to characterize the soil quality at a site via analysis of VH_s and EPH_s ¹, and set threshold VH_s and EPH_s concentrations that would be used to define a residual contaminant source. Accordingly, the source dimension variables at a PHC-contaminated site would be defined by any of the following soil concentrations:

- VH_s ₆₋₁₀ concentration greater than 100 mg/kg
- EPH_s ₁₀₋₁₉ concentration of 1000 mg/kg
- EPH_s ₁₉₋₃₂ concentration of 1000 mg/kg

Note that these concentration levels (i.e., $VH_s = 100$ mg/kg) are consistent with the lower end concentration range cited in API (2000) for gasoline type contamination (i.e., TPH = 100 to 80,000 mg/kg). It is implied that at sites where NAPL is not present and VH_s and EPH_s concentrations in soil beneath an adequately characterized area of potential environmental concern (APEC) or area of environmental concern (AEC) are present at concentrations less above defined threshold VH_s and EPH_s concentrations, then there is not a substantial enough source (i.e., insufficient contaminant mass), to cause groundwater contamination for PHC related COCs. If it is also confirmed through sampling of groundwater immediately beneath and downgradient of the APEC/AEC that no PHC related COCs are present in groundwater at concentrations greater than the applicable water uses, then this would provide an additional line of evidence that no PHC source is present at the APEC/AEC. Under this scenario, groundwater/contaminant transport modeling would not be necessary as there is limited potential for groundwater to be impacted in the future, and hence limited potential for impacted groundwater to reach a given receptor in the future. Accordingly, derivation of the site-specific soil standards using the P2 model would not be necessary, and only the Schedule 5 Contaminated Soil and Toxicity to Soil Invertebrates and Plants matrix soil standards would apply to the site.

3.1.1 Summary and Recommended Approach

The following approach is recommended when defining the horizontal and vertical dimensions of a PHC contaminant source:

- If NAPL is identified at the site as described in CSR Protocol 16, the source dimension variables will be defined as the horizontal and vertical extent of NAPL; or
- If NAPL is not identified at the site as described in CSR Protocol 16, the source dimension variables will be defined by the horizontal and vertical extent of VH_s and EPH_s in soil that is reported to be at concentrations greater than threshold source concentrations of 100 mg/kg and 1000 mg/kg, respectively; or
- In situations where both NAPL is present and VH_s and EPH_s concentrations are greater than the respective source threshold concentrations, the source dimension variables will be defined by the greater of the horizontal and vertical extent of either the NAPL or VH_s/EPH_s concentrations in soil, or combined region of the two to define the full extent of the PHC source.

No PHC source is considered present at sites that meet all of the following conditions:

- No NAPL has been identified as defined in CSR Protocol 16;

¹ Use and analysis of VH and EPH is recommended as the results do not subtract the contribution of the BTEX (benzene, toluene, ethylbenzene, and xylenes) and PAH (polycyclic aromatic hydrocarbon) fractions, as is the case with VPH (volatile petroleum hydrocarbons) and LEPH/HEPH (light and heavy extractable petroleum hydrocarbons).

- Soil VH_s and EPH_s concentrations at a properly characterized site (i.e., in accordance with CSR Technical Guidance 10 and 11) within a given APEC/AEC are less than 100 mg/kg and 1000 mg/kg, respectively;
- Groundwater has been sampled directly below and immediately downgradient of the suspected source (APEC/AEC) for the appropriate potential contaminants of concern (PCOCs), and individual PCOC concentrations are less than the CSR Schedule 6 standards for the applicable water uses. It must also be demonstrated that the suspected contaminant source has been present for an adequate duration such that if contamination has been released, sufficient time has elapsed for it to reach groundwater. For the purposes of Protocol 2, it must be demonstrated that groundwater has been sampled for the appropriate PCOCs/COCs a minimum of 5 years (unpaved sites) and 10 years (paved sites) subsequent to the date that the suspected contaminant source was present/active at the site. Alternatively, practitioners can calculate a site-specific suitable timeframe using the instructions below; and
- It can be demonstrated that the APEC/AEC contaminant source is a multi-component hydrocarbon mixture such as gasoline, diesel, heating oil, or other petroleum based oil.

3.1.2 Calculation of Suitable Timeframe of Sampling

To establish a suitable timeframe since contaminant release, practitioners will need to demonstrate the timeframe of the historical presence/operation of the potential source (i.e., APEC/AEC), depth to groundwater, nature of the surface cover, and calculation of vertical groundwater travel time and solute travel time to demonstrate that the contamination would have reached the water table. Vertical groundwater travel times should be estimated using the average linear leachate velocity (unsaturated) that is calculated in the user input interface of the P2 Model once the appropriate site-specific parameters have been inputted into the model. The unsaturated vertical leachate velocities should be calculated for each COC identified in soil and groundwater. The lowest unsaturated vertical leachate velocity should be used to estimate the travel time. The travel time is calculated by dividing the depth to groundwater (metres below ground surface) by the lowest unsaturated vertical leachate velocity (m/yr). The derived travel time must be doubled if the suspected source in question is currently or was historically paved. The following criteria is required to demonstrate that adequate time has elapsed for contamination from a suspected source to reach the groundwater:

- It must be demonstrated that groundwater has been sampled after a period that is greater than or equal to the greatest unsaturated solute travel time (unpaved sites) and twice the travel time (paved sites) subsequent to the date that the suspected contaminant source was present/active at the site; and
- Groundwater must be sampled for appropriate PCOCs/COCs as identified in the Stage 1 and 2 PSI and DSI investigations.

Sites that are demonstrated not to contain a PHC source as defined above are not required to undergo modeling using the P2 groundwater model to calculate site-specific soil standards that are protective the four water uses, and only the Schedule 5 Contaminated Soil and Toxicity to Soil Invertebrates and Plants matrix soil standards apply to the site when characterizing the soil quality. If non PHC COCs are present, defining the source dimension variables for those COCs is required as is utilization of P2 groundwater model to derive site-specific soil standards for those COCs.

3.2 Inorganic Contaminants

Defining a source that is contaminated by inorganic constituents is relatively more complex compared to one contaminated by PHCs. Sources for inorganic contamination include soluble secondary mineral precipitates and/or inorganic fragments/debris that may be present within fill material. In some instances, these solid phase materials can be visually identified; however, their potential to act as a source to

contaminate groundwater is highly dependent on their solubility which is controlled by the geochemistry of the groundwater system. Even at relatively low concentrations (e.g., less than the applicable Schedule 5 soil standards), if suitable geochemical conditions exist or if geochemical conditions change in the future due to alteration of the land use, solubility of these constituents could potentially increase and result in impact to groundwater quality. Therefore, for inorganic contamination it is recommended that the source be defined using the applicable Schedule 5 soil standard for a given COC or the regional/local background soil concentration as defined in Protocol 4.

3.2.2 Summary and Recommended Approach

To define the horizontal and vertical dimensions of an inorganic contaminant source, it is recommended to use the applicable Schedule 3.1 soil standard or Protocol 4 Regional Soil Background concentration to define the source dimension variables.

3.3 Chlorinated Solvents and Other COCs

Similar to inorganic contaminants, there is an increased level of complexity and uncertainty in defining the source dimension variables for chlorinated solvents and other non PHC or inorganic COCs. For these reasons, it is recommended that the source dimension variables be defined based on the applicable Schedule 5 soil standards, or the default source dimension values used in the Omnibus model in consideration that soil standards are not prescribed for all water use pathways for some COCs such as chlorinated organics.

4.0 CLOSURE

We trust this information is sufficient for your needs and requirements, please do not hesitate to contact the undersigned should you have any questions or concerns.

Kind regards,

Core6 Environmental Ltd

ORIGINAL SIGNED

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5.0 REFERENCES

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