Canadian Council of Ministers of the Environment

Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale Supporting Technical Document

Executive Summary

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1.1 Synopsis

The Canada-Wide Standard for Petroleum Hydrocarbons in Soil (PHC CWS) was developed by the Canadian Council of Ministers of the Environment (CCME) under the Harmonization Sub-Agreement on Standards. The PHC CWS was endorsed by Ministers of Environment (with the exception of Quebec) in May 2001. A commitment was made to review additional scientific, technical and economic analysis to reduce information gaps and uncertainties after 5 years; the present version of the PHC CWS includes modifications and updates resulting from that review.

The PHC CWS is a 3-tiered remedial standard for soil and subsoil protective of human and environmental health under four generic land uses – agriculture, residential/parkland, commercial and industrial. The purpose of this document is to provide an overview of the land use-based framework for the PHC CWS and the detailed scientific rationale in support of the derivation of the Tier 1 values. These values form the numerical basis of the PHC CWS and reflect the risk management and environmental quality goals of the standard as determined by CCME in consideration of scientific, technical and socio-economic factors and the substantive input of stakeholders.

1.2 Background

Petroleum hydrocarbons (PHC) describe a mixture of organic compounds found in or derived from geological substances such as oil, bitumen and coal. Petroleum products released to the environment, such as gasoline, crude oil and jet fuel, typically contain hundreds to thousands of compounds in varying proportions.
PHC in the environment are a concern for a number of reasons. First, their reduced nature and volatility pose a fire/explosion hazard. Second, most PHC constituents are toxic to some degree. Third, lighter hydrocarbons are mobile and can be a problem at considerable distances from their point of release due to transport in ground, water or air. Fourth, larger and branched chain hydrocarbons are persistent in the environment. Fifth, PHC may create aesthetic problems such as offensive odour, taste or appearance in environmental media. Finally, under some conditions PHC can degrade soil quality by interfering with water retention and transmission, and with nutrient supplies.

Because PHC composition at a release site is a function of the source (e.g., gasoline vs. crude oil), site factors (e.g., soil texture, climate), time since release, and management, the effects noted above occur to varying degrees. Knowledge of the distribution and abundance of PHC types is necessary for accurate assessment and management response. However, most Canadian regulatory approaches and guidelines in the late 1990s did not consistently address this assessment requirement and also differed widely in other important ways, including the analytical methods required or accepted, scientific basis for assessment, and risk management objectives. This meant that PHC contaminated sites were not consistently evaluated and managed, and that results were reported in a widely differing array of parameters and formats. This condition is unsatisfactory and made more serious by the scope of the PHC problem. Throughout Canada, many tens of thousands of PHC release sites exist, and environmental liabilities have been estimated in the $10 billion range. Consistent, science-based assessment tools are needed to protect the environment and control costs. The PHC CWS was developed to address this need.

1.3 Framework for PHC CWS

The PHC CWS framework is based on a synthesis of the ASTM (1995) and CCME (1996, 2006) frameworks for the assessment and management of contaminated sites, and incorporates at successive tiers: (1) the application of generic (national) Tier 1 levels that are protective of human health and the environment, (2) site-specific adjustments to the Tier 1 levels to calculate Tier 2 levels that accommodate unique site characteristics, and (3) Tier 3 levels that are developed from a site-specific ecological or human health risk assessment, when assumptions inherent in the Tier 1 values are not appropriate for a site. The level of protection afforded, and the associated underlying guiding principles, are preserved throughout this tiered process. The tiered approach essentially represents increasing levels of precision in a site assessment through consideration of more specific site characteristics. Details on the phased acquisition of site information to support a sound PHC management decision are presented in a separate User Guidance document.

1.4 Approach to Development of Tier 1 Levels

The PHC CWS Tier 1 levels were developed using risk assessment and risk management techniques. In this approach, the primary environmental and human health values to be protected are identified, an analysis of how these values could be affected by PHC contamination is undertaken, and benchmark concentrations or levels of PHC in soil are calculated to provide an environmentally acceptable endpoint. The primary task is to develop an exposure scenario for each land use that adequately captures the receptors of concern and the pathways by which these can be exposed by PHC contamination in soil or subsoil. A summary of the receptor/pathway combinations addressed under each land use in the PHC CWS is presented in Table E1. Each combination is discussed further in the appropriate section of this Technical Supplement. Tabular Tier 1 levels (see Chapter 5) are calculated for pathway/receptor combinations wherever the pathway is deemed applicable and sufficient data are available to support the derivation.

Table E1: Land-uses, key receptors and exposure pathways.

Exposure Pathway	Agriculture	Residential/ Parkland	Commercial	Industrial
Soil Contact	Nutrient cycling Soil invertebrates Crops (plants) Human (toddler)	Nutrient cycling Invertebrates Plants Human (toddler)	Nutrient cycling Invertebrates Plants Human (toddler)	Nutrient cycling Invertebrates Plants Human (adult)
Soil Ingestion	Herbivores Human (toddler)	(wildlife)* Human (toddler)	(wildlife)* Human (toddler)	(wildlife)* Human (adult)
Groundwater/ Surface Water	Aquatic Life/ Livestock Watering Human (toddler)	Aquatic Life Human (toddler)	Aquatic Life Human (toddler)	Aquatic Life Human (adult)
Vapour Inhalation (humans only)	Toddler, indoor	Toddler, indoor	Toddler, indoor	Adult, indoor
Produce, meat and milk produced on site (humans only)	Toddler**	Toddler** (produce only)		
Off-site migration of Soil/Dust				Human/Eco

* wildlife dermal contact and ingestion data may be particularly important for PHC (e.g., oiling of feathers, etc., although this should be addressed with an initial assessment of the presence of non-aqueous phase liquids - NAPL), but there are unlikely to be sufficient data to develop guidelines that address this exposure pathway

** in most cases PHC are not expected to bioaccumulate to high concentrations in produce, meat or milk, though some polycyclic aromatic hydrocarbons (PAH) may bioaccumulate to a limited extent; the available data are currently insufficient to evaluate this pathway on a generic basis

To address the diversity of PHC contamination types, including various crudes and product admixtures, PHC are considered in four broad physico-chemical fractions synthesized from the sub-fractions defined by the US Total Petroleum Hydrocarbons Criteria Working Group. The fractions are defined in equivalent carbon numbers as follows:

F1: C6 to C10
F2: >C10 to C16
F3: >C16 to C34
F4: C34+

Aliphatic and aromatic sub-fractions are handled separately in the human health assessment.

Whereas the primary focus in PHC CWS standard development is prevention of toxic effects from F1-F4 on the receptors listed in Table E1, in certain situations these pathways may be of little immediate concern and PHC management is governed by other factors including:

- ignition hazard
- odour and appearance
- effects on buried infrastructure
- formation of non-aqueous phase liquids (NAPL)
- socio-economics and technological capabilities

Such factors are considered at the Tier 1 level in the management levels described below.

1.5 Human Health Protection

Direct contact with contaminated soil, including inadvertent ingestion of soil and dermal contact with soil, can be a significant pathway of human exposure to contaminated soil. Studies indicate that children ingest much greater amounts of soil and dust each day than adults, primarily due to greater hand-to-mouth activity and a greater time spent playing outdoors and on the floor. In the PHC CWS toddlers were assumed to ingest four times the amount of soil as an adult, consistent with Health Canada (2004) recommendations. Tier 1 levels were calculated using an algorithm adapted from CCME (2006a).

Ingestion of cross-contaminated groundwater is addressed through use of the analytical groundwater model from CCME (2006a). It is conservatively assumed that the PHC contamination is underlain by an unconfined aquifer, that a potable well is located at the downgradient boundary of the site, and that the potable well could be a person's sole source of drinking water. At the Tier 1 level, this pathway, where applicable, may govern remedial response for F1 and F2 on sites with fine-textured soils, and F1 only on coarse-textured soils with a commercial or industrial land use.

Migration of soil PHC vapours through cracks and imperfections in building foundations can lead to human inhalation exposure. This pathway is assessed through application of the vapour intrusion model of Johnson and Ettinger (1991). The vapour inhalation pathway governs remedial response at the Tier 1 level for F1 and F2 on coarse-textured sites with an agricultural or residential/parkland land use.

1.6 Ecological Health Protection

Tier 1 levels are derived to protect key ecological receptors that sustain normal activities on the four previously defined land use categories: agricultural, residential/parkland, commercial and industrial. The derivation of Tier I levels for ecological receptors focuses on the effects of PHC on the biotic component of a terrestrial ecosystem. Specifically, it evaluates the potential for adverse effects to occur from exposures to soil-based PHC at point-of-contact or by indirect means (e.g., soil to groundwater pathways, food chain transfer).

Chronic, sub-chronic, acute and lethal responses of plants and invertebrates relevant to the sustainable functioning of soil under the four land uses are used to derive Tier 1 levels. A "weight of evidence" approach is used to arbitrate among the various data sources. The direct soil contact pathway governs remedial response at the Tier 1 level for F3 and F4 under all land uses, and for F2 under some scenarios.

Concentrations of PHC in soil that would not be expected to pose a threat to aquatic life in nearby streams, rivers and lakes is estimated by modeling transport from soil through groundwater to a default discharge point 10 m downgradient from the PHC contaminated site. A dynamic, advective-dispersive model incorporating first-order biodegradation in the saturated zone (Domenico and Robbins 1985 as adapted by BC Environment and CCME, 2006a) is used for this purpose. Remedial response is not governed by the aquatic life protection pathway at the Tier 1 level. The lateral distance may be varied in Tier 2 up to a maximum of 500 m.

1.7 Integration of Human Health and Ecological Levels and Incorporation of Management Levels

A summary of the risk-based values developed for each pathway/receptor combination in the individual land use categories is presented in Chapter 5. In addition, rationale is provided for certain risk management decisions made in the final integration of human health and ecotoxicological inputs.

In the process of developing these features the Development Committee, and subsequently the Soil Quality Guidelines Task Group, considered several factors that are not easily accommodated in explicit, quantitative exposure and risk estimates. These factors included:

- Capabilities of current and emerging remediation technologies;
- Likelihood of subsoil disturbance and excavation under different scenarios;
- Potential effects of PHC on buried infrastructure;
- Aesthetics;
- Costs of risk reduction measures; and
- Property values and environmental stewardship.

The objective of the integration is development of environmentally protective Tier 1 levels that are practical and attainable with proven remedial technologies. Remediation and conservation of PHC-affected soils is preferred over disposal.

1.8 Analytical Method

A benchmark method for determination of PHC in soil is presented that addresses major sources of variability and uncertainty related to the extraction, purification, quantification and reporting. F1 PHC are isolated though purge and trap procedures followed by gas chromatography with a flame ionization detector (GC-FID). F2 – F4 PHC up to C50 are extracted by a Soxhlet procedure, "cleaned up" on silica gel and determined by GC-FID. C50+ PHC, if present, may be determined gravimetrically or through extended chromatography. Specific chromatographic calibration standards are required.

The analytical method has been tested in round-robin trials and found to drastically reduce variability in results over previous round robins where analytical procedures were not controlled. Performance-based alternatives to the benchmark procedures are permitted.

1.9 Recommendations for Future Research and Development

A number of important gaps in understanding were identified through the development of the PHC CWS and these are summarized in Chapter 7. Key opportunities for research in the immediate future include:

- Toxicity testing of PHC fractions on aquatic receptors;
- Biodegradation rates of volatile PHC in the vadose zone;
- Toxicity assessment of gamma-diketone forming F1 aliphatics;
- Effects of soil PHC on buried infrastructure; and
- Aqueous and vapour-phase partitioning of F1, F2 PHC in the presence of residual F3, F4 PHC.