Canadian Council of Ministers of the Environment

CANADA-WIDE STANDARD

for

PETROLEUM HYDROCARBONS (PHC) IN SOIL

Technical Supplement

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Overview of this Technical Supplement

The PHC CWS is a 3-tiered, risk-based remedial standard developed for four generic land uses – agricultural, residential/parkland, commercial and industrial. This technical supplement has been prepared to describe the scientific and socio-economic basis of the standard and guide its appropriate application to PHC contaminated sites in Canada.

The risk-based nature of the PHC CWS means that, for each land use, all values to be protected (life forms or *receptors*, ecosystem properties) are explicitly documented as well as the contaminants considered within PHCs and the pathways by which PHCs can affect these values. This approach provides great flexibility, it allows assessment and management of different variations within a land use and even extension of the standard to other land use categories (e.g., wildlands). The vision, or *exposure scenario*, attached to each land use is the heart of the PHC CWS.

Agricultural lands: where the primary land use is growing crops or tending livestock. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. Agricultural land may also include a farm residence.

Residential/Parkland: where the primary activity is residential or recreational activity. The ecologically-based approach assumes parkland is used as a buffer between areas of residency, but this does not include wild lands such as national or provincial parks, other than campground areas.

Commercial: where the primary activity is commercial (e.g., shopping mall) and there is free access to all members of the public, including children. The use may include, for example, commercial day-care centres. It does not include operations where food is grown.

Industrial: where the primary activity involves the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy.

Section 1 describes the scientific approach, data sources, and specific assumptions made regarding receptors and their interactions with a site under the exposure scenario applicable to each land use. Section 2 describes how the environmental management objectives underpinning the Tier 1 levels can be achieved cost-effectively through the phased acquisition and application of site-specific information in Tiers 2 and 3. Section 3 describes the principal benefits and costs of the PHC CWS as applied at Tier 1. Section 4 provides a summary of the analytical method supporting the PHC CWS.

Summary of Key Changes Since 2001

When the PHC CWS was implemented in 2001, a commitment was made to review new scientific information and experience with implementation, and update the standard after 5 years. Based on input from stakeholders 3 advisory subgroups were struck to report back to CCME and recommend changes to the Standard. Subgroup reports are provided under separate cover (CCME 2006 b,c,d). Based on the recommendations of three advisory subgroups, the following key changes were made to the PHC CWS:

- The human soil ingestion and dermal contact pathways were combined, consistent with the current protocol (CCME 2006a).
- Modifications were made to several fate and transport model parameters to reflect current science.
- Ecological soil contact values were updated based on further toxicity testing and field studies conducted since the PHC CWS was implemented.
- Subsoil tables were removed from most of the Canada Wide Standard reports due to differences in implementation between jurisdictions and concerns regarding the approach taken. In their place, management limits were developed that have explicitly stated considerations that were previously incorporated into the subsoil ecological guidelines. Subsoil tables were included in the technical supplement to maintain consistency with the 2001 Canada Wide Standards.
- Consistent with the 2001 Canada Wide Standards, surface terrestrial ecological criteria will continue to apply for all sites between 0 and 1.5 meters below ground level. For depths greater than 3 meters below ground level, a management limit was developed that may be applied in place of the surface ecological soil criteria. Due to jurisdictional differences in interpreting requirements for management practices, no guidance is given for depths between 1.5 and 3 meters below ground surface. Guidance for application of the criteria may be developed by the jurisdiction for these depths.

Section 1: Development of Tier 1 Generic Soil Quality Levels

Approach for PHCs

Tier 1 levels for each land use are derived through a systematic evaluation of all pathways of exposure that apply to the receptors of concern identified under that land use. A detailed account of this process as applied to development of soil quality guidelines is presented in CCME (1996a, 2006a). Below is a condensed description of the process as applied to development of the Tier 1 PHC CWS. Emphasis is used in areas where changes were made to processes and/or decisions presented in CCME (2006a). A summary of the receptor/pathway combinations considered under each land use in the PHC CWS is presented in Table 1. Each combination is discussed further in the appropriate section of this Technical Supplement. Gaps in the environmental fate and effects literature meant that not all receptor/pathway combinations could be explicitly addressed.

Table 1: Land-uses, key receptors and exposure pathways.

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

* wildlife dermal contact and ingestion data may be particularly important for PHCs (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

** indoor inhalation pertains to a farm residence.

Tier 1 levels in the PHC CWS are presented as an integration of the above pathway/receptor combinations – only the governing pathway is presented. In application, users will gather information on relevant pathways and will frequently require information on the pathways that do not normally govern at Tier 1. Tier 1 information on these pathways is presented in the technical guidance accompanying this standard (CCME 2007a, 2007b).

In addition to the toxic risks addressed by the receptor/pathway analyses, certain other management considerations apply. These include:

- Free phase formation;
- Exposure of workers in trenches to PHC vapours;
- Fire and explosive hazards;

- Effects on buried infrastructure; and,
- Aesthetic considerations.

Whereas the primary focus in PHC CWS standard development is prevention of toxic effects to the receptors in Table 1, in certain situations these pathways may be of little immediate concern and PHC management is driven by these management considerations and other policy factors.

Human Health Levels

Protocol Summary

Petroleum hydrocarbons are grouped by physico-chemical properties into four fractions based on the equivalent carbon number of the chain lengths. Group toxicological and physico-chemical properties are used to estimate concentrations of PHCs in soil that would not lead to an exposure exceeding a hazard index of 1, multiplied by a soil allocation factor to account for exposure from other contaminated media at the site, along 3 major exposure pathways – inhalation of vapours, direct contact with contaminated soil (dermal contact and incidental ingestion of soil) and ingestion of cross-contaminated groundwater. The same pathways and same exposure equations are used for all land uses, however, exposure duration and frequency vary between land uses and only an adult's exposure is considered for the industrial land use. Representative values are used for most parameters and characteristics which, when combined with inherent conservatism built into toxicity reference values, exposure scenarios and models, gives a protective and practical result. There are insufficient data to evaluate PHC exposure through the food chain. The few data available indicate that plant uptake of PHCs and subsequent exposure at higher trophic levels is not a concern.

Toxicological Basis

Exposure to PHCs leads to a variety of results depending upon the particular compounds or mixtures involved, intensity, frequency and duration of exposure, and exposure pathway. While certain PHCs are confirmed human carcinogens (e.g., benzene, benzo(a)pyrene), these are exceptional and, where present at a site, they are dealt with as separate issues using compound-specific guidelines or risk assessments. Most PHCs are understood to act as threshold toxins, eliciting general narcosis symptoms.

The toxicology of PHCs was extensively reviewed by the US Total Petroleum Hydrocarbons Working Group (TPHCWG), which was formed by the US Department of Defense in the mid-1990s. The TPHCWG defined 14 aromatic and aliphatic sub-fractions of PHCs based on similar physico-chemical properties. Different oral reference doses (RfDs) and inhalation reference concentrations (RfCs) are presented for each aliphatic or aromatic subfraction in the TPHCWG system. These RfDs and RfCs were re-evaluated as part of the 5-year technical review of the PHC CWS. The PHC CWS uses these TPHCWG sub-fractions and further groups them into the four practical fractions -- F1: nC6-nC10, F2: >nC10-nC16, F3: >nC16-nC34, F4: >nC34. Within a TPHCWG sub-fraction the balance between aromatic and aliphatic constituents is assumed to be 20/80 based on an analysis of some representative hydrocarbon products. These analyses were also used to determine appropriate proportions of different carbon ranges within a PHC CWS fraction. Toxicological information for each TPHCWG subfraction is combined with the information on the expected mass of each subfraction to produce a toxicological benchmark for each PHC CWS fraction.

Documented background exposure that Canadians experience is considered in the development of the Tier 1 levels. A review of literature indicated no general information on the occurrence of PHC fractions F2, F3 or F4 in air, water or food. This is likely due to their low volatility and water solubility. Data were available on F1 components indicating that only inhalation exposures are routinely significant. Inclusion of these data reduced the effective RfC for volatile aliphatics by 0.5 to 2% and for volatile aromatics by 20%.

<u>Derivation of Tier 1 Levels</u>

Exposure equations for each pathway are re-arranged to solve for the soil concentration delivering an exposure equivalent to the appropriate allocation of the RfC or RfD (fractions 2, 3 and 4) or "residual" RfC/RfD adjusted for background exposure unrelated to PHC contamination of soil. After all pathways have been assessed the governing value is brought forward for the Tier 1 look-up table.

Direct soil contact (soil ingestion and dermal contact) values are calculated using a general exposure equation presented in CCME (2006a, 2007a). This are defined independent of soil texture.

Inhalation exposure Tier 1 levels are based on an implementation of the Johnson and Ettinger (1991) model for intrusion of vapours into an enclosed space (building). Default buildings are, for residential land use, a single family dwelling with basement or slab-on-grade construction and, for commercial and industrial land uses, a slab-on-grade construction. Coarse and fine textured soils, defined as having a median grain size of >75 μm or < 75 μm respectively, are presented as separate cases because vapour transport for the former is dominated by advection as opposed to diffusion for fine soils. Equation 21 of the Johnson and Ettinger paper is used to calculate an attenuation factor for both the coarse-textured and fine-textured cases, using appropriate soil properties as summarized in CCME (2007a), and this is coupled to the relevant RfC to back-calculate an acceptable soil concentration. Critical soil variables include distance from the contamination to the building foundation, set to 30 cm to reflect common backfilling practice, and soil organic carbon content, set to 0.5% to reflect average sub-soil conditions in Canada. Both of these are adjustable in Tier 2 (see CCME, 2007b). Where contamination exists within 30 cm of a building, the proponent must carry out a Tier 2 or 3 assessment. Details regarding transport, building characteristics and exposure are provided in CCME (2007a).

Potential human exposure to PHCs from ingestion of water is addressed by defining the downgradient boundary of a PHC contaminated site as the point of compliance for groundwater potability. Again, soil textures are separated because of differing transport characteristics. Details regarding the groundwater model, site characteristics, hydrological regimes and compliance benchmarks are provided in CCME (2006a, 2007a). The model includes a dynamic advective-dispersive component, which may be used at higher Tiers to address offsite management of PHC-contaminated groundwater.

Ecological Levels

<u>Protection Goals</u>

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 1 levels for ecological receptors focuses on the effects of PHCs on the biotic components of a terrestrial ecosystem. Specifically, it evaluates the potential for adverse effects to occur from exposures to soil-based PHCs at the point-of-contact or by indirect means (e.g., soil to groundwater pathways or food chain transfer). Additional detail is provided below on how these protection goals were achieved for the different exposure pathways considered.

Ecological Soil Contact – Plants and Terrestrial Invertebrates

The derivation of Tier 1 levels for ecological receptors for soil contact is based on toxicological data for vascular plants and soil invertebrates. Toxicological data were commissioned for the 2000 PHC CWS. Since that time, additional research on the toxicity of PHC fractions to plants and soil invertebrates has been completed. Available data include laboratory and field ecotoxicity studies. Endpoints examined in laboratory studies included chronic and sub-chronic responses (e.g., root elongation, shoot growth, and invertebrate reproduction) as well as acute and lethal responses (e.g., seed germination and invertebrate survival). Field studies focused on chronic endpoints such as plant biomass, and levels of invertebrate populations.

The overall approach adopted for the derivation of Tier 1 guidelines for PHCs in soils for the protection of the ecological soil contact pathway was to use the weight of evidence methodology in the latest CCME (2006a) protocol where possible, but to modify these procedures where required, while remaining consistent with the overall goals of CCME (2006a). This approach was necessary to make the best possible use of the disparate types of ecotoxicological information that were available. The CCME (2006a) weight of evidence method is based on using the 25^{th} percentile of a distribution of $IC/EC/LC_{25}$ data for agricultural and residential/parkland use, and the 50^{th} percentile of this same distribution for commercial/industrial land use. This approach represents a departure from that used in the 2001 PHC CWS, where guideline derivation was based on a distribution of $IC/EC/LC_{50}$ values.

Scientific literature indicates that the toxicity of PHCs in soils can be affected by soil texture. Where data were sufficient, coarse and fine soils were considered separately, and distinct guidelines developed for each texture if justified. Soil contact guideline values for PHC fraction F1 were developed based on available ecotoxicological data for F1 and Mogas (motor gasoline). The Mogas dataset was more extensive, but less applicable, since Mogas, although primarily F1, contains a proportion of F2. Accordingly, the F1 data were used in preference, and the Mogas data were only used where F1 data were not available. The guidelines were developed in a manner consistent with the CCME (2006a) protocol as noted in the preceding paragraph. The available data did not support developing separate guidelines for coarse and fine soils, and the same guideline value is used for both textures.

Soil contact guideline values for PHC fraction F2 were developed based on available ecotoxicological data for F2. As with the guideline derivation for F1, the guidelines were developed in a manner consistent with the CCME (2006a) protocol. The same guideline values apply to coarse and fine soils, since the available data did not support separate derivations.

A different approach was required and employed in the analysis of the available F3 data. A range of field and laboratory studies were available. Data from all the studies were carefully considered. However, the greatest weight was placed on the results of the field studies, based on i) the greater relevance of the field studies to actual ecological and agricultural situations; ii) the larger number of species considered in the field studies, and in particular, the larger number of invertebrate species, which have been shown to be often more sensitive to F3 than plants; and, iii) uncertainty with the measured exposure concentrations of F3 in some of the laboratory studies. The methodology used to develop guidelines from the field study results involved developing a distribution of the response of each species and endpoint relative to controls. Then if the 25th percentile (agricultural and residential/parkland use) or the 50th percentile (commercial or industrial land use) of the distribution showed a decrease of less than 25% relative to controls, the exposure concentration of F3 in the soils of the field study was deemed to show an effect level which was consistent with the protection goals of the CCME (2006a) protocol. Separate field studies were available for coarse and fine soils, and analysis of these datasets showed that separate guidelines for F3 in coarse and fine soils were required.

Although it was agreed that this method was generally more reflective of actual response used, some concern was raised particularly related to the response of earthworms in freshly contaminated soils and the potential for the data to reflect some amount of weathering. Please see CCME (2007c) for more information.

Soil contact guideline values for PHC fraction F4 were developed in the 2001 PHC CWS for coarse and fine soil based on ecotoxicity testing with whole crude oil. Since that time, ecotoxicological data have become available for F4. The new F4 data were analyzed using the CCME (2006a) protocol, but the results were not significantly different from those previously obtained, and the existing F4 guideline values are retained in the current document.

Exposure via Groundwater – Aquatic Life and Livestock Watering

Concentrations of PHCs in soil that would not be expected to pose a threat to ecological/ agricultural receptors via ground water exposure pathways were estimated by modeling transport from soil via groundwater to a downgradient discharge point. The default downgradient distance to the discharge point used to calculate Tier 1 guidelines was 10 m for aquatic life. It was assumed that in most cases the distance from contaminated soil to the nearest surface water body would be greater than 10 m, and further, that this distance for a particular site would be unlikely to change dramatically in the future. Sites with contamination closer than 10 m to a surface water body would require a site-specific approach. The default downgradient distance for livestock watering was 0 m, based on the assumption that a livestock watering well or dugout could potentially be constructed at any location in the future.

The toxicological approach for the protection of aquatic life guidelines was based on a large number of studies that reported a generalized narcosis endpoint that was linked to the body residue of hydrocarbon compounds in aquatic invertebrates. This dataset was used to estimate threshold values for PHC fractions in water. The toxicological basis for the livestock watering guideline was available data on the toxicity of whole crude oil to cattle.

Soil and Food Ingestion Exposure – Livestock and Wildlife

Exposure of livestock and wildlife to contaminants through ingestion of contaminated soil and via food chain-mediated exposure is part of the exposure scenario considered in the latest CCME (2006a) protocol. However, a guideline value was not calculated in the 2001 PHC CWS based on insufficient available data to make a satisfactory assessment of this exposure pathway, and the assumption that the bioconcentration/biomagnification of PHCs into livestock and wildlife food items was unlikely to be significant. New data to refine the evaluation of the guidelines for this exposure pathway have not emerged since 2001, and no guideline was calculated for this exposure pathway in the current document. It is still considered unlikely that this exposure pathway would control risk management decisions at PHC contaminated sites.

Management Limits

In addition to the chronic toxicity of PHC to human and ecological receptors, various effects of PHC contamination are also considered. These effects include:

- Free phase formation;
- Exposure of workers in trenches to PHC vapours;
- Fire and explosive hazards;
- Effects on buried infrastructure; and,
- Aesthetic considerations.

These potential effects, combined with technological factors, were used to derive 'management limits' for PHC fractions, which are considered to apply at all soil depths and are not adjustable at Tier 2.

Integration of Ecological, Human Health and Management Levels

Tabular Tier 1 levels in the PHC CWS present the lower of the values generated for human health protection, ecological protection and the management levels, such that all are protected when Tier 1 levels are applied. Detailed results for all potential receptor/pathway combinations are presented for fine and coarse textured soils in Tables 2 and 3 below. Tier 2 and 3 approaches are expected to focus on the governing condition for a particular fraction.

In contrast to the 2001 criteria, the subsoil criteria have now been removed from the Tier 1 tables. In their place, a soil management factor is added to the Tier 1 table. At depths greater than 3 meters, it is expected that the ecological surface soil criteria will no longer be relevant but that the management factors will still apply to site cleanup.

Table 2

Tier 1 levels (mg/kg soil) for PHCs for fine-grained surface soils

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Protection of GW for Livestock Watering[3]	4200	10 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	210	150	1300	5600
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk	NC	NC	NC	NC
	Management Limit[5]	800	1000	3500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	210	150	1300	5600
	Produce	NC	NC	NC	NC
	Management Limit[5]	800	1000	3500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	19 000	10 000	23 000	RES
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	320	260	2500	6600
	Offsite Migration	NA	NA	19 000	RES
	Management Limit[5]	800	1000	5000	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	320	260	2500	6600
	Offsite Migration	NA	NA	19,000	RES
	Management Limit[5]	800	1000	5000	10 000

NA = Not applicable. Calculated value exceeds 1,000,000 mg/kg or pathway excluded.
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.

1 = Assumes site is underlain by groundwater of potable quality in sufficient yield (K of 10^{-4} cm/sec or greater).
2 = Assumes surface water body at 10 m from site.
3 = Generally applicable for this land use as related to use of dugouts and wells for supply of livestock water.
4= For depths between 0 and 1.5 meters below ground level, the terrestrial ecological pathway must be applied. A management limit has been developed for PHC that must be applied at all depths if the ecological pathway is removed. CCME does not specify for depths between 1.5 and 3 meters bgl.
5= Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects

Table 3

Tier 1 levels (mg/kg soil) for PHCs for coarse-grained surface soils.

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Protection of GW for Livestock Watering[2]	5300	14 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	210	150	300	2800
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk	NC	NC	NC	NC
	Management Limit[4]	700	1000	2500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	12 000	6800	15 000	21 000
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	210	150	300	2800
	Produce	NC	NC	NC	NC
	Management Limit[4]	700	1000	2500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	19 000	10 000	23 000	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	320	260	1700	3300
	Offsite Migration	NA	NA	4300	RES
	Management Limit[4]	700	1000	3500	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	320	260	1700	3300
	Offsite Migration	NA	NA	4300	RES
	Management Limit[4]	700	1000	3500	10 000

NA = Not applicable
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
1 = Assumes surface water body at 10 m from site.
2 = Includes use of dugouts and wells for supply of livestock water.
3 = For depths between 0 and 1.5 meters below ground level, the terrestrial ecological pathway must be applied. A management limit has been developed for PHC that must be applied at all depths if the ecological pathway is removed. CCME does not specify for depths between 1.5 and 3 meters bgl.
4= Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects
[a] This value was revised from 1800 mg/kg to the correct value of 970 kg/mg on June 25, 2012
[b] This value was revised from 600 mg/kg to the correct value of 380 mg/kg on June 25, 2012

Table 4

Tier 1 levels (mg/kg soil) for PHCs for fine-grained subsoils*.

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Protection of GW for Livestock Watering[3]	4200	10 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	NA	NA	NA	NA
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk	NC	NC	NC	NC
	Management Limit[5]	800	1000	3500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	NA
	Vapour Inhalation (indoor, basement)	710	3600	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	610	3100	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	NA	NA	NA	NA
	Produce	NC	NC	NC	NC
	Management Limit[5]	800	1000	3500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	RES
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	NA	NA	NA	NA
	Offsite Migration	NA	NA	19 000	NA
	Management Limit[5]	800	1000	5000	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	NA
	Vapour Inhalation (indoor)	4600	23 000	NA	NA
	Protection of Potable GW[1]	170	230	NA	NA
	Protection of GW for Aquatic Life[2]	RES	RES	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[4]	NA	NA	NA	NA
	Offsite Migration	NA	NA	19,000	NA
	Management Limit[5]	800	1000	5000	10 000

* = Subsoil criteria is reflective of decisions made for a minimum of 3 meters BGL. Jurisdictions may choose to apply conditions regarding interpretation of the subsoil tables.
NA = Not applicable. Calculated value exceeds 1,000,000 mg/kg or pathway excluded.
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
1 = Assumes site is underlain by groundwater of potable quality in sufficient yield (K of 10^{-4} cm/sec or greater).
2 = Assumes surface water body at 10 m from site.
3 = Generally applicable for this land use as related to use of dugouts and wells for supply of livestock water.

4= For depths between 0 and 1.5 meters below ground level, the terrestrial ecological pathway must be applied. A management limit has been developed for PHC that must be applied at all depths if the ecological pathway is removed. CCME does not specify for depths between 1.5 and 3 meters bgl.

5= Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects

Table 5 - Tier 1 levels (mg/kg soil) for PHCs for coarse-grained subsoils.

Land Use	Exposure Pathways	F1 (C6-C10)	F2 (>C10-C16)	F3 (>C16-C34)	F4 (>C34)
Agricultural	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970	380	NA	NA
	Protection of GW for Livestock Watering[2]	5300	14 000	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	NA	NA	NA	NA
	Eco Soil Ingestion	NC	NC	NC	NC
	Produce, Meat and Milk	NC	NC	NC	NC
	Management Limit[4]	700	1000	2500	10 000
Residential	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	NA
	Vapour Inhalation (indoor, basement)	40	190	NA	NA
	Vapour Inhalation (indoor, slab-on-grade)	30	150	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	NA	NA	NA	NA
	Produce	NC	NC	NC	NC
	Management Limit[4]	700	1000	2500	10 000
Commercial	Direct Contact (Ingestion + Dermal Contact)	NA	NA	NA	NA
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	NA	NA	NA	NA
	Offsite Migration	NA	NA	4300	RES
	Management Limit[4]	700	1000	3500	10 000
Industrial	Direct Contact (Ingestion + Dermal Contact)	RES	RES	RES	RES
	Vapour Inhalation (indoor)	320	1700	NA	NA
	Protection of Potable GW	240	320	NA	NA
	Protection of GW for Aquatic Life[1]	970[a]	380[b]	NA	NA
	Nutrient Cycling	NC	NC	NC	NC
	Eco Soil Contact[3]	N/A	N/A	N/A	N/A
	Offsite Migration	NA	NA	4300	RES
	Management Limit[4]	700	1000	3500	10 000

* = Subsoil criteria is reflective of decisions made for a minimum of 3 meters BGL. Jurisdictions may choose to apply conditions regarding interpretation of the subsoil tables.
NA = Not applicable
RES = Residual PHC formation. Calculated value exceeds 30,000 mg/kg and solubility limit for PHC fraction.
NC = Not calculated. Insufficient data to allow derivation.
1 = Assumes surface water body at 10 m from site.
2 = Includes use of dugouts and wells for supply of livestock water.
3 = For depths between 0 and 1.5 meters below ground level, the terrestrial ecological pathway must be applied. A management limit has been developed for PHC that must be applied at all depths if the ecological pathway is removed. CCME does not specify for depths between 1.5 and 3 meters bgl.
4= Includes additional considerations such as free phase formation, explosive hazards, and buried infrastructure effects
[a] This value was revised from 1800 mg/kg to the correct value of 970 kg/mg on March 21, 2012.
[b] This value was revised from 600 mg/kg to the correct value of 380 mg/kg on March 21, 2012.

Section 2: Tiered Framework for Assessment and Management of PHCs at Contaminated Sites.

The framework is based on a synthesis of the ASTM (1995) and CCME (2006a) 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 and/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. Equally important to application of the PHC CWS is the recommendation of an approach for the analysis of PHC contamination in soil that is consistent with, and supports application of the ambient soil quality levels.

Though the intent of the CWS is to promote a consistent, high level of protection for human health and the environment as a result of site remediation, in both Tiers 2 and 3, decisions may be taken in calculating a site-specific level that are so specific to a site (e.g. distance to a building), that even minor changes to the specified land use (i.e., a re-located, expanded or additional home on a residentially zoned site) may alter the protection afforded by the recommended ambient soil quality level. Only for stable characteristics of a site (such as depth to groundwater) that will not change with changes to land use, or when the Tier 1 levels are used, should the recommended ambient soil quality level be considered as protective for that site *unconditionally*. Otherwise, *conditions* may be attached to site management (e.g., monitoring, limits to site use, use of groundwater). In situations where engineered or institutional controls are used to manage risks to acceptable levels, closure may also be conditional (i.e., monitoring may be required).

Site Characterization

The goal of site characterization is to adequately describe site conditions in order to address assessment and management options.

The minimum data requirements for a PHC CWS assessment include:

- site description (location, size, etc.)
- land use - historical, existing, intended, and potential land uses at the site and surrounding the site, including presence/absence of critical wildlife habitat
- proximity of the site to surface water and drinking water supplies (presence and nature of any nearby aquatic or marine habitat)
- depth to groundwater (measured or inferred from records)
- human receptors
- ecological receptors
- primary exposure pathways
- stratigraphy and properties of surficial materials (especially soil texture)
- depth to contamination and distances to points of exposure/compliance

- built environment – presence and types of buildings, utility corridors and conduits
- contamination characterization and delineation (including presence or suspected presence of NAPL) as needed for comparison with Tier 1 PHC ambient soil quality levels and soil quality guidelines for other contaminants of concern. Guidance on analytical methods appropriate for the application of the PHC standard is provided in CCME (2001).

Tier 1 Assessment and Management

Information collected as described above is evaluated to decide whether the site broadly fits any of the four land use categories. If it does not adequately match any of the land uses nor any hybrid thereof, it should be addressed at Tier 3.

Assuming the site is suitable for generic assessment, concentrations of the relevant PHC fractions are determined and compared to the appropriate look-up Tier 1 levels to identify any exceedances. It is critical that the core site characterization data have been collected or the site investigator may enter the lookup tables in a way that leads to management error. For example, Tier 1 levels are available for coarse and fine textured materials. In the absence of soil texture information, it is possible to under-manage contamination by applying Tier 1 values for fine textured sites to a coarse textured site, or over-manage contamination by applying Tier 1 values for coarse textured sites to a fine textured site. In this instance, it is to the proponent's advantage to have textural information because, in its absence, the regulator may insist on the use of the more sensitive default.

If no exceedances are found in Tier 1 assessment, investigation ceases and the site can be declared compliant with the PHC CWS. Conversely, if exceedances are found two options exist. First, the site may be remediated to eliminate exceedances. Alternatively, additional site information may be collected to refine the estimate of exposure and risk in a Tier 2 assessment. This may lead to a conclusion that less aggressive management – including, possibly, "no further action" – is required on the site. Which option is selected will depend on a number of factors including the concentrations and extent of PHC contamination, limiting pathways applicable, physical characteristics of the site, availability and cost of technology, and needs for liability reduction.

In general, it is the proponent's responsibility to identify and respond to any site or receptor factors that could unduly accentuate exposure or risk beyond that envisioned in the Tier 1 exposure scenario; the presence of these factors generally leads to a requirement for a Tier 2 or Tier 3 assessment. These factors may include (but are not limited to):

- contamination within 30 cm of a building foundation;
- contamination within 10 m of a surface water body;
- hydraulic conductivity significantly greater than 10^{-5} m/s;
- contamination within fractured bedrock;
- ecological receptors of high sensitivity or socio-economic value; or,
- greater than normal frequency of human or ecological exposure.

Tier 2 Assessment and Management

Reasonably conservative assumptions are made in Tier 1 regarding site, receptor and contaminant factors to ensure that remediation to these levels will meet environmental management objectives. At individual sites, it is often advantageous to replace default assumptions with actual data concerning certain influential parameters. Tier 2 assessment describes such procedures. In addition, there are opportunities to reduce reliance on models by replacing model predictions by point-of-exposure or near-point-of-exposure measurements.

Technical options at Tier 2 are not unlimited. Approved Tier 2 procedures must meet several criteria; they must:

1. Be based on factors influencing exposure that can be measured and verified.
    - Assessments must not be encumbered by technical information regarding factors that have little influence on management outcome
    - Alterations to parameters and assumptions must be made using data that can be relatively easily measured and confirmed as necessary
2. Support clear land and water use decision making
    - It must be clear what any adjustments mean in terms of the future management of the site
    - The objective is retention or recovery of the maximum range of land and water use options – where options are constrained, this must be made clear to stakeholders
3. Maintain clarity and simplicity in the assessment
    - Stakeholders, including regulators, require that Tier 2 assessments can be reviewed and approved without heavy resource investments. For non-regulatory stakeholders this means faster turnaround on reviews and more efficient land transactions

Taken together, these criteria mean that Tier 2 procedures applicable to *human health protection* will focus on relatively stable aspects of the site and contaminants and how these influence exposure along “secondary pathways” where transport of PHC is involved (primarily inhalation exposures and ingestion of contaminated groundwater). *Characteristics of receptors such as body weight, breathing rate, time spent on site etc. are not candidates for Tier 2 modification because they can be neither predicted nor controlled in a generic way. Modification of exposure characteristics (e.g. time spent on site) would normally lead to site restrictions and on-going risk management responsibilities, and may not be approved by regulatory authorities at Tier 2.*

Application of the above criteria to ecological protection indicate that secondary exposure pathways (e.g., transport of PHC to an adjacent surface water body) can be addressed as well as factors that influence the bioavailability of PHC to soil dwelling organisms. *As is the case in human health protection, modifications to exposure scenarios that require changes to the behaviour, distribution or abundance of ecological receptors are not supported in Tier 2. Such proposals generally result in land use limitations and on-going risk management responsibilities. Where necessary, these are best accommodated at Tier 3.*

The following section describes the major data sources relevant to Tier 2 and outlines their application in Tier 2 site management. Note that no continuous adjustment procedures are available for pathway/receptor combinations where professional judgement has been used to incorporate qualitative or semi-quantitative factors or information (e.g. the management levels). For example, no adjustments are available for direct contact by ecological receptors. The alternative in this case is the replication of the bioassay suite used in developing the Tier 1 standards with site soils and relevant representatives of the organism groups, which is normally considered to be a Tier 3 procedure.

DATA-BASED TECHNICAL PROCEDURES

The following procedures may be applied without invoking conditions on land and water use. Details of these procedures are provided in CCME (2007b).

a) Off-site movement of dust (Industrial Land Use only).
   Tier 1 levels for surface soils at industrial sites are supported by an erosion/ deposition check to protect any adjacent, sensitive lands. If no such surrounding land exists, the check may be removed.
b) Fraction of organic carbon in soils.
   The fraction of organic carbon in soil is determined by chemical analysis and this result is inserted in the partitioning model used by the vapour and solute transport models.
c) Depth/Distance to contamination.
   This distance is important in determining soil concentrations of F1 and F2 that will be protective against intrusion of vapours into enclosed spaces. The information is gathered through depth sampling and analysis in routine site assessments. The vapour intrusion pathway can be excluded for distances greater than 30 m unless there are precluding factors such as a low permeability surface or significant preferential migration pathways between the source and receptor location; however, excluding this pathway on the basis of distance may require land use restrictions.
d) Hydraulic conductivity and gradient.
   These parameters influence lateral movement of PHC in groundwater. The default parameters in the mixing/dilution model can be replaced by measures or estimates from the site.
e) Hydrological recharge.
   This parameter affects degree of dilution of leachate in groundwater and has been calculated to be protective in the general Canadian environment. Low precipitation, high evapotranspiration regions will have more favourable dilutions. The recharge rate may be calculated based on local data on precipitation, evapotranspiration and runoff.
f) Horizontal distance from contamination source to downgradient surface water body.
   This distance is specified as a default in the groundwater model and may be replaced by site data.
g) Exposure point observations on soil air and groundwater.
   In Tier 1, potential indoor exposure is based on modeled attenuation of vapours from a proximal soil source area. If information is available on actual vapour concentrations in the soil pore space beneath the building, a simpler dilution relationship can be used to calculate potential indoor exposure. Such measurements must be supported by evidence that the vapour concentrations measured will not increase in future. Similarly, screening calculations using a simple dilution model are performed in Tier 1 to estimate groundwater-protective soil concentrations. Observations on groundwater at the site are

a better form of information provided that there is evidence that concentrations measured will not increase with time. Further information on the use of soil vapour and groundwater measurements is presented in the User Guidance (CCME, 2007b).

h) Actual proportion of TPHCWG sub-fractions by mass as per site specific analytical results (%).
The 80/20 assumption for aliphatics/aromatics can be replaced by specific information. Also, the balance among carbon chain-length sub-fractions can be altered.

i) Depth to groundwater and source dimensions.
The model describing PHC movement from soil to groundwater to a point of exposure includes the depth separation between a contaminated soil source and groundwater. The default assumption is that contaminated soil extends to an unconfined aquifer. Distance separation and dimensions of the source can be modified by site-specific measurements.

It is critical that adequate data are obtained to support any Tier 2 modifications. Further information on data requirements and appropriate methods for determining model parameters is included in the User Guidance (CCME, 2007b).

Other procedures may be acceptable at Tier 2 depending on jurisdiction. Additional candidate procedures may be constrained in application by any combination of:

- too technically complex to be considered at Tier 2 (appropriate for Tier 3);
- adjustment alters risk management objectives and requires off-site risk management; or,
- adjustment mechanism not yet fully proven or demonstrated.

Some procedures that may be supported at Tier 2 but are potentially affected by the above practical constraints include:

a) Volatiles in soil gas via application of Raoult's Law
Information on PHC concentrations in all fractions present may be used to estimate more realistic partitioning of volatile PHC among soil solids, soil moisture, soil air and PHC residuals. The analytical characterization must be conducted in the zone of maximum contamination. Recalculated vapour phase concentrations are inserted into the vapour transport model.

b) Point of compliance for groundwater protection outside property boundary
Dynamic advective-dispersive groundwater transport models and monitoring are used to support management of a PHC plume originating on one site and extending to another. The downgradient property owner must agree to forego relevant uses of the groundwater while this condition persists.

In general, site-specific information is useful in creating "headroom" for a proponent when it bears on the governing pathway. Site specific data on non-limiting pathways can promote understanding but does not alter the management outcome.

Tier 2 management may or may not carry on-going risk management considerations that place responsibilities on parties for monitoring, care and control and may require engineered and/or institutional controls. Whether such measures are necessary depends on a number of factors as discussed below.

Tier 3: Site-specific Risk Assessment

In some cases, an Ecological Risk Assessment (ERA) and/or human health risk assessment (HHRA) may be warranted. Risk assessment is an important process for evaluating and predicting the existing and potential impact of toxic substances and other perturbations on the ecosystem and its components (i.e., species, populations, communities), including human health.

When compared to applying environmental quality guidelines, risk assessment is a more complex and involved method for establishing site-specific remediation objectives. Different descriptions of contaminant fate, behaviour and exposure may be involved. All models must be calibrated and validated for the particular site. Site-specific risk assessment may be appropriate when, for example, guidelines-based objectives (i.e., Tier 1 and 2 levels that have been modified to account for site-specific factors) are not relevant for the specified uses of the site, where guidelines-based objectives do not seem appropriate given the site-specific conditions, where significant or sensitive receptors of concern have been identified, or where there is significant public concern.

Several risk assessment frameworks have been developed in Canada (e.g., CCME 1996b; Health Canada, 2006; BC MELP 1993, 1998) that are relevant for the assessment and management of petroleum contaminated sites. These frameworks share several common elements, including problem formulation/receptor characterization, exposure and hazard/toxicity assessment, and risk characterization.

The Canadian framework for ecological risk assessment (CCME 1996b) provides a consistent basis for approaching this potentially complex process. The framework provides guidance on deciding when an ERA should be conducted through a series of questions and triggers. Further, it describes key steps and considerations in planning and implementing an ERA, from defining initial goals and objectives and choosing appropriate measurement and assessment endpoints, to reporting the results of an ERA.

The vast majority of site-specific risk assessments are conducted as a consequence of technical or socio-economic barriers to complete remediation. This means that the risk management proposed usually involves exposure management through engineered controls, institutional controls or both. Such controls are necessary when contaminated site stakeholders (owners, operators, adjacent landowners) must alter their actions or commit not to undertake certain future actions in order to prevent exposure (e.g., installation and maintenance of vapour barriers, non-use of groundwater).

Confirmation Testing

Once a Tier 1, Tier 2 or Tier 3 approach has been selected and soil PHC contamination levels have been agreed to, analytical information must be supplied to show that these concentrations have been achieved.

Section 3: Socio-economic Analysis

2001

The *Socio-economic Analysis of Canada-wide Standard for Petroleum Hydrocarbons in Soil* was undertaken with the understanding that Tier 1 standards will be implemented and that they will be protective of human and environmental health. The socio-economic analysis is a cost analysis for implementing the standards that assumes all PHC contaminated sites, irrespective of scale and severity of contamination are remediated to Tier 1 levels. In practice, larger and more severely contaminated sites are often addressed at Tiers 2 and 3.

The socio-economic analysis was undertaken concurrently with other scientific work done for the PHC Development Committee (DC) and made direct use of the DC's work on human health and ecotoxicity in its consideration of socio-economic impacts. The DC developed recommendations for standards based on that concurrent work and understandings achieved in the socio-economic analysis. Because of this timing the DC provided a set of "seed values" for four categories of land use (agricultural, residential, commercial and industrial), two soil textures (coarse and fine) and conditions that did and did not include protection of groundwater. These were "ball park" estimates of standards that would likely be protective of human and environmental health based on preliminary analyses. Costs of remediating volumes of soil to meet the seed values were estimated assuming common, effective technologies. The socio-economic analysis addressed the matter of how costs and benefits would vary with different levels of protection by considering values that were five times the seed value (i.e. less stringent) and one-fifth the seed value (more stringent). The Development Committee was very clear that the seed values did not have regulatory significance and should not be construed as the most likely set of standards to be recommended to environment Ministers.

The socio-economic analysis considered 11 scenarios of soil contamination to cover most situations pertaining to the upstream, downstream and post-consumer sectors. It examined typical volumes of contamination associated with each scenario. It estimated the costs to remediate those volumes assuming common, effective technologies. The clean up volumes for each scenario were based on the most appropriate combination of land use, soil texture and likely need for groundwater protection for that scenario.

The socio-economic analysis also addressed the potential benefits of implementing a CWS. It did not attempt to economically value health benefits, although it did estimate monetary values for some categories such as reduced agricultural damage and improved land values. Other ecological impacts, such as potential reduction in ability to grow non-agricultural plants or effects on soil fauna that had been scientifically assessed by the DC or Ecological Technical Advisory Group, could not be monetized.

Basic Findings

The analysis confirmed that there is an appreciable difference between costs of remediation to the seed values and to standards more stringent and less stringent than the seed values. The range of costs would be in the order of several billion to a few tens of billions of dollars. Estimated costs to remediate all sites to each of the three levels of protection, for different hypothetical remediation schedules are presented below. The first schedule (clean up all PHC contaminated sites immediately) is unrealistic but sets the context for the other schedules.

	less stringent	seed value	more stringent
All at the present time ($billion)	7.8	15.6	22.8
10% of sites/yr. for 10 yr. ($b)	6.0	12.1	17.6
10%/yr for 5 yr., rest deferred ($b)	4.9	9.7	14.2

Incremental costs of moving from the less stringent case to the seed values and from the seed values to the more stringent case are also shown.

	From less stringent to seed value	From seed value to more stringent
All at present time ($billion)	7.8	7.2
10% of sites/yr. for 10 yr. ($b)	6.1	5.5
10%/yr for 5 yr., rest deferred ($b)	4.8	4.5

The costs were discounted by a public discount rate (5%). The rate at which remediation activity takes place has a large influence on costs.

It was possible to estimate monetary values for some categories of benefits. These included benefits in the areas of: agricultural damage that could be avoided (crop value), increased property value resulting from remediation, blight avoided for some residential sites (effects of PHC contamination on values of adjacent residential sites), and option value of green-field sites (societal preference to clean up a contaminated site rather than developing a previously undeveloped site).

The estimated monetizable benefits are:

	less stringent	seed value	more stringent
All at present time ($billion)	3.4	5.7	9.5
10% of sites/yr. for 10 yr. ($b)	2.7	4.5	7.4
10%/yr for 5 yr., rest deferred ($b)	2.2	3.6	6.0

These monteized benefits do not include health benefits or benefits of ecological protection.

The ratio of monetizable benefits to monetizable costs was approximately 40%, although there was some variation (from 0.37:1 to 0.45:1) depending on the rate of remediation and the stringency of the standard.

It is possible to present monetized costs and benefits according to geographic distribution within Canada.

	% costs	% monetized benefits
West (BC, AB, SK)	70	27
East	23	69
North	5	4

This geographic breakdown does not include human health benefits, which, if included, would be distributed by region in approximately the same proportion as total population.

For most scenarios of contamination that were examined, remediation to any of the three values (seed, less stringent and more stringent) was assumed to be protective of human health. In some instances, however, the margin of safety (based on the work done in the human health component of DC's work) associated with the less stringent values might be considered small. These margins of safety are conservative, and therefore highly likely to be protective of human health, even if small.

These analyses were conducted assuming the Tier 1 values apply to the full depth of contamination. Depending on land use, soil texture, and PHC fraction, the final Tier 1 values recommended by Development Committee vary more or less from the seed values. Generally, Tier 1 levels tend to fall between the seed values and the more stringent case.

It is very important to note that the socio-economic analysis addresses only implementation of Tier 1 levels. Tiers 2 and 3 are normally used for many of the more complex PHC release sites because use of site-specific information at those Tiers can contribute to more informed decision making. Often, application of the site-specific information can result in remediation costs that are reduced from those expected if Tier 1 standards were applied. While the reduction in costs of implementing remediation to Tier 2 or Tier 3 is not quantified at this time (principally because the proportion of sites going to the three levels will depend on stakeholder input and regulatory acceptance), it could be appreciable.

2007 Review

A socio-economic analysis of the revised Canada-wide Standard for Petroleum Hydrocarbons in Soil was undertaken to assess the direct remediation costs and associated social and economic costs and benefits of bringing all PHC contaminated sites into compliance with the Tier 1 standards. The analysis assumes that all PHC contaminated sites, irrespective of scale and severity of contamination would be remediated to Tier 1 levels. In practice, larger and more severely contaminated sites are often addressed at Tiers 2 and 3.

The socio-economic analysis was conducted on the basis of the proposed Tier 1 numerical values established as a result of the 5-year review of the Standard. While qualitative socio-economic factors, such as practical attainability and level of protection of human health and the environment, were considered in the assessment of uncertainties during the development of the revised Tier 1 values, a quantitative analysis was undertaken subsequently to assess the overall costs of complying with the standard, and the financial implications of moving from the original 2000 standard to the revised 2007 values. Social and economic costs and benefits were assessed primarily in a qualitative manner.

A socio-economic analysis was conducted previously in conjunction with development of the original 2000 standard. The results of the present analysis were not compared directly with those of the previous analysis, since different sources of data were used to estimate remediation requirements and costs for PHC contaminated sites. Many of the general socio-economic considerations discussed in the previous analysis remain valid. However, the major goals of the present analysis were to obtain an up-to-date estimate of the overall liability associated with PHC contaminated sites in various industry sectors across Canada, and to assess the effect of the proposed revisions to the numerical standard, in terms of differences in remediation costs, using actual, current site data representative of PHC conditions across a range of facilities and industries.

The present analysis was conducted under the direction of the CCME Soil Quality Guidelines Task Group (SQGTG) in consultation with the Canadian Association of Petroleum Producers (CAPP) and the Canadian Petroleum Products Institute (CPPI). A total of 22 unique scenarios were identified, comprising different combinations of facility type, land use, soil texture and groundwater use, that were considered representative of the most common sets of conditions encountered at PHC contaminated sites across Canada. Member companies of CAPP and CPPI were invited to participate by providing data on impacted soil volumes (determined with reference to both the 2000 and proposed 2007 standards), obtained from actual sites conforming to the defined scenarios. Soil data from over 90 sites were used to develop a total of approximately 240 data sets representing the 22 scenarios. These data sets, in combination with industry data on remediation costs, were used to estimate the costs of complying with both the 2000 and 2007 standards under the different scenarios.

By considering the geographic and industry-specific variations in conditions reflected in the different scenarios, remediation requirements and costs were determined regionally for each scenario, and aggregated across the various industry sectors and on a national basis, in order to determine the total cost to remediate presently existing PHC contaminated sites to the 2000 and 2007 standards. The overall remediation costs were compared to remediation industry data to determine the capacity of the industry to perform the work, and the likely timeline over which the work can be completed. The benefits of remediation, not only to the remediation industry, but also to operators, land owners, municipalities and the public, were also considered, primarily in a qualitative manner.

The results of the socio-economic analysis indicate that the effects of the proposed 2007 revisions to the PHC CWS on overall remediation costs for PHC contaminated sites across Canada are relatively small. Total remediation costs for all industries, in constant 2006 dollars, are projected to increase from $40.1 billion to $40.6 billion under the revised standard, an increase of approximately 1.4%. Costs for the remediation of upstream sites comprise approximately 82% of the total, and are projected to increase slightly (1.0%). Remediation costs for downstream sites and other (government, commercial and residential) sites represent 6% and 12% of the total costs, respectively; the respective increases in these costs are forecast to be 2.6% and 3.1%.

The very small increase in costs for upstream sites is attributed to an increase in the F3 criteria and a decrease in the F2 criteria for a number of the soil type, land and water use combinations. This results in a shift of governing fraction from F3 to F2. For downstream sites, the slightly greater increase in costs is due in part to the decrease in F2 criteria as well as a decrease in the F1 values for certain scenarios.

The estimated magnitude of remediation work associated with PHC contaminated sites ($40.6 billion) is projected to exceed the current annual capacity of the remediation industry by more than 57 times. If reasonable growth in the sector is considered, the estimated time to complete remediation of all existing sites is approximately 30 years on a national basis. However, the largest PHC contaminated site liabilities are in the provinces with large upstream oil and gas industries; those provinces also have relatively small remediation industries in comparison with estimated remediation requirements, which may necessitate geographic redistribution of resources in order to meet demand.

Aside from the direct benefits to the remediation industry flowing from the expenditure of remediation costs, the primary tangible or monetizable benefits are the elimination or reduction of operators' balance sheet liabilities associated with contaminated sites and the increase in land values and/or revenues from productive land. The difference in market value between a contaminated site and the same site in an unimpacted or remediated condition is generally considered to be equal to the cost of remediation; the increase in land value in most cases is equal to the cost of remediation. In most cases, therefore, there is no net monetizable benefit to the economy as a whole associated with the remediation of a contaminated site, although the benefit may be transferred between stakeholders. Exceptions to the above apply in situations where the remediation cost exceeds the market value of the property, or in situations where remediation results in an added increase in land value due to the ability to redevelop the land for a more intensive and/or profitable purpose (e.g. low density commercial to high-rise residential).

Due to the neutrality of costs and benefits in most situations, and the difficulty in assessing the exceptions on a generic basis, the net benefits associated with increased land values were considered qualitatively but were not quantified. Other societal benefits include improvements in health and environmental quality, increased enjoyment of the land, elimination or reduction of blight and reduction in contingent liabilities related to the potential for adverse impact. These are generally not considered to be monetizable benefits.

The estimation of overall remediation costs is subject to a number of uncertainties arising from variability in conditions and remediation requirements between sites and across regions, as well variability in remediation unit costs. Those factors contributing significantly to the variability in overall cost include remediation unit costs, particularly for upstream sites, and the estimated soil remediation volumes associated with different scenarios. The variability of some of these factors were characterized on the basis of actual data and used in a probabilistic analysis of total costs.

Section 4: Analysis of Petroleum Hydrocarbons in Soils, CCME Tier 1 Method

An analytical method was developed in conjunction with the Canada-Wide Standard (CWS) for petroleum hydrocarbons in soil (PHCs) for two reasons. The methods previously in use quantify different fractions of PHCs normally found in soil and secondly, an analytical method must be used in a consistent manner to give consistent results. An interlaboratory study conducted at the beginning of the CWS process confirmed this with results varying by factors of 40.

To develop the method an Analytical Methods Technical Advisory Group (AMTAG) was struck consisting of representatives of provincial and federal governments, the petroleum industry and the private laboratory industry. After considerable effort a consensus was reached on a draft method which was pilot tested and then subjected to an interlaboratory study during the summer of 1999. Based on comments from participants in the study and the PHC CWS Development Committee, the method was finalized (CCME 2001).

The method is a mixture of performance-based elements and prescribed procedures. Effort has been expended to ensure that, if applied properly, the method provides results useful for application of the CWS to PHC contaminated sites. Substitution of alternative methods for use in applying the CWS should only occur if a comprehensive statistical comparison has been conducted. No sampling protocol was developed but reference is made to existing CCME, US EPA and ASTM resources.

The method covers hydrocarbon ranges for nC6 to above nC50 as well as percentage moisture. The analytical fractions were chosen to meet the requirements of the CWS. These are nC6 to nC10 (F1), >nC10 to nC16 (F2), >nC16 to nC34 (F3) and >nC34 to nC50(F4). nC50 is probably the highest molecular weight hydrocarbon that can be routinely chromatographed on normal laboratory equipment. In addition a Gravimetric Heavy Hydrocarbon sub method was developed to account for the fraction occurring above nC50. It is recommended that this result be used if it is greater than the nC34 to nC50 fraction.

It was recognized during the interlaboratory study that laboratories performed better if they had had experience with the method. Thus the continuation of ongoing interlaboratory studies is recommended. Initially these would improve user laboratories' knowledge and handling of this complex method. They would help characterize method performance characteristics such as method detection limit, which is presently being assessed in a single laboratory validation study. After the CWS is incorporated into regulations or guidelines, then these studies would become a means of assessing laboratory performance.

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