ATLANTIC PIRI
PARTNERSHIP IN RBCA IMPLEMENTATION

ATLANTIC RBCA (Risk-Based Corrective Action)

Version 3

Ecological Screening Protocol for Petroleum Impacted Sites in Atlantic Canada

Scientific Rationale

Scientific Rationale to support the Adoption/Development of Tier 1 Ecological Screening Levels for Soil, Surface Water, Groundwater and Sediment

July 2012

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1.0 INTRODUCTION

1.1 Background

This document provides a summary of the scientific rationale and approach used in the development of ecological screening levels for petroleum hydrocarbons in soil, groundwater, surface water and sediment. In many cases, the approach relied on the combined application of empirical toxicity data, predictive models and criteria derived by other jurisdictions. As these sources evolve, it is anticipated that the toxicity benchmarks will be revisited and revised where necessary.

1.2 Consideration of Other Environmental Quality Benchmarks

It is acknowledged that some jurisdictions within Canada have developed soil quality guidelines for pathways other than direct ecological soil contact. Such pathways were not considered in this protocol if corresponding values for petroleum hydrocarbon parameters were not available (e.g. nutrient/energy cycling pathway). Similarly, pathways were not considered if they were considered outside the scope of this protocol (i.e., soil quality guidelines that protect aquatic life, protection of livestock and wildlife water for drinking, protection of irrigation water, management limits). If a site assessment indicates the need for soil benchmarks for these pathways, users of this protocol are encouraged to review the soil quality benchmarks documentation from CCME (2008), Alberta Environment (2010), and British Columbia Ministry of the Environment matrix numerical soil standards to determine if suitable benchmarks exist for BTEX and petroleum hydrocarbons. For example, if the site assessment indicates that livestock are drinking water at the site, it should be noted that CCME (2008) derived a livestock watering guideline for petroleum hydrocarbon fractions that is based on the toxicity of whole crude oil to cattle and such guidelines should be consulted.

In most situations regarding the potential or actual petroleum hydrocarbon contamination of groundwater or surface water, it is strongly preferred that these media be sampled and analyzed directly during site assessment activities. In the rare situation where this is not possible, a soil quality benchmark that is protective of groundwater and/or surface water receptors may be derived using the methodology provided within CCME (2006), the ecological water screening benchmarks reported herein, and relevant site-specific soil and groundwater parameters, if/where available.

2.0 SOIL ECOLOGICAL SCREENING LEVELS

2.1 Protective of Plants and Soil Invertebrates (all land uses)

Soil screening levels appropriate for the assessment of potential impacts of benzene, toluene, ethylbenzene xylenes and petroleum hydrocarbons to terrestrial plants and soil invertebrate receptors were available from CCME's Environmental Quality Guidelines (CEQG) (CCME, updated 2010) and the CCME's Canada Wide Standard for Petroleum Hydrocarbons (CCME, 2008). For benzene, ethylbenzene, toluene and xylenes (BTEX), the CCME values were adopted. For the petroleum hydrocarbons, this protocol has adopted the CWS F1 – F4 fractions which are a departure from the standard gasoline, diesel/#2 and #6 oil/lube products described in Atlantic RBCA. However, the conversion between the RBCA and CWS fractions has been made easy with the reporting format outlined in the Atlantic RBCA Guidelines for Laboratories, Tier I and Tier II Petroleum Hydrocarbon Methods (APIRI, 2010). This reporting format allows for the combination of the various reported TPH fractions to be read as the RBCA fractions (eg. "gasoline") or the CWS fractions (e.g. F1). A comparison of the Atlantic RBCA fraction and CWS fraction is presented in **Table 1**. Please note that CWS approach does not have a "total petroleum hydrocarbon (TPH)" value so the site professional must compare each fraction with the appropriate screening level to determine if there are any exceedences (i.e., the analytical results will generate and F1, F2 and F3 value, each of which must be compared to the corresponding F1, F2 and F3 screening levels in Tables 1a and 1b. If any one of the fractions exceeds its respective screening level, then the response to the question in the protocol "Do site characterization data indicate the presence of PHC in site surface soil (depth < 1.5 m) above the appropriate screening levels in Tables 1a and 1b?" would be "yes".

The soil screening levels are summarized in **Table 1a**. Values for both coarse-grain and fine-grain soils were adopted. In order to use Table 1a, the site professional must ensure the analytical data are in the F1-F4 format and then the data can be compared directly to the screening levels in the table.

Table 1 Atlantic RBCA Fractions and CWS

Atlantic RBCA Tier I Fractions	CWS Fractions
>C6-C10	F1: C6-C10
>C10-C16	F2: C10-C16
>C16-C21	F3: C16-C34
>C21-C32	F4: C34-C50 *
Modified TPH (equals all TPH less BTEX)	

*Typically, Atlantic PIRI lab protocol does not include the analysis of beyond C32 (ie. F4). If the sample chromatogram indicates the possible presence of material in this range, as indicated by the failure to return to baseline at C32, additional analysis may be required to capture these values.

Table 1a Tier 1 Soil Ecological Screening Levels for the Protection of Plants and Soil Invertebrates; Direct Soil Contact (mg/kg dry weight)

Land Use	Soil Grain Type	Substance							
		Benzene	**Toluene**	**Ethyl Benzene**	**Xylenes**	**F1** C6-C10	**F2** C10-C16	**F3** C16-C34	**F4** C34-C50 *
Agricultural	Coarse	31	75	55	95	210	150	300	2800
	Fine	60	110	120	65	210	150	1300	5600
Residential	Coarse	31	75	55	95	210	150	300	2800
	Fine	60	110	120	65	210	150	1300	5600
Commercial	Coarse	180	250	300	350	320	260	1700	3300
	Fine	310	330	430	230	320	260	2500	6600
Industrial	Coarse	180	250	300	350	320	260	1700	3300
	Fine	310	330	430	230	320	260	2500	6600

Notes:

1) All benchmarks in Table 1a are for surface soils. All benchmarks are adopted directly from CCME and CCME (2008).
2) CWS fractions F1-F4 vary from the Atlantic RBCA Tier I reporting fractions, however, soil data obtained from laboratories in Atlantic Canada can be combined to be reported as the CWS fractions and compared directly to these the values in this table (Atlantic PIRI, 2010).
3) Unless vegetation or soil invertebrate presence below 1.5 m can be demonstrated, these benchmarks apply to the top 1.5 m of the soil profile.
4) Typically, Atlantic PIRI lab protocol does not include the analysis of beyond C32 (ie. F4). If the sample chromatogram indicates the possible presence of material in this range, as indicated by the failure to return to baseline at C32, additional analysis may be required to capture these values.

2.2 Protective of Wildlife and Livestock (agricultural lands)

The CCME has developed livestock and/or wildlife soil and food ingestion soil quality guidelines for BTEX for the agricultural land use category. Alberta Environment (2010) has developed livestock and/or wildlife soil and food ingestion soil quality guidelines for BTEX and F1, F2, F3, and F4 for the agricultural and natural areas land use categories.

The CCME guidelines for BTEX were developed according to the CCME (1996) Protocol. CCME did not develop this type of guideline for the petroleum hydrocarbon fractions as it was cited that there were insufficient data to enable a satisfactory assessment of the soil and food ingestion exposure pathway, and also noted that the bioaccumulation and/or biomagnification of petroleum hydrocarbons into livestock and wildlife food items was unlikely to be significant. CCME (2008) also noted that it is unlikely that this exposure pathway would drive risk management decisions at petroleum contaminated sites.

The derivation of the Alberta Environment guidelines occurred as follows (taken from Alberta Environment, 2010): Soil ingestion guidelines were calculated for BTEX and petroleum hydrocarbon fractions F1 to F4. Both petroleum hydrocarbons and BTEX are not considered to bioaccumulate in potential food items, thus the guideline derivation only considered soil ingestion of these substances. The following equation was used to calculate the soil ingestion guideline for BTEX and petroleum hydrocarbons. Livestock guidelines were calculated using receptor parameters for a cow, while wildlife guidelines were calculated using receptor parameters for a meadow vole. Alberta Environment (2010) states that wildlife soil ingestion guidelines calculated using the meadow vole are expected to be protective for the majority of wildlife species.

$$SRG_{SI-L/W} = \frac{0.75 \times DTED \times BW_{L/W}}{SIR_{L/W} \times BF}$$

Where:
SRGSI-L/W = soil remediation guideline for soil ingestion - livestock or wildlife (mg/kg);
0.75 = allocation factor (dimensionless);
DTED = daily threshold effect dose (mg/kg-bw/day);
BWL/W = body weight - livestock or wildlife (kg);
SIRL/W = soil ingestion rate - livestock or wildlife (kg/day); and,
BF = bioavailability factor (1.0; assumed).

Table 1b presents the livestock and wildlife soil and food ingestion soil quality guidelines for BTEX and petroleum hydrocarbon fractions that were developed by the CCME and Alberta Environment. For the final Tier 1 values presented in the Ecological Screening Protocol, the Alberta Environment criteria were selected over the CCME values as Alberta Environment includes both BTEX and TPH criteria and also were issued more recently (2010). To simplify the final table, the wildlife values were selected as the final screening levels because they were more conservative than the livestock values and therefore protective of both types of receptors. As with **Table 1a**, the site professional must ensure the analytical data are in the F1-F4 format and then the data can be compared directly to the screening levels in the table.

Table 1b Tier 1 Soil Ecological Screening Levels for the Protection of Wildlife (mammals and birds) and Livestock; Soil & Food Ingestion Soil Quality Benchmarks; mg/kg dry weight

Land Use	**Substance**							
	Benzene	**Toluene**	**Ethyl Benzene**	**Xylenes**	**F1** C6-C10	**F2** C10-C16	**F3** C16-C34	**F4** C34-C50 *
Agricultural[a]	25 (CCME) 44 (AENV, livestock) 18 (AENV, wildlife)	1400 (CCME) 2500 (AENV, livestock) 980 (AENV wildlife)	910 (CCME) 1600 (AENV, livestock) 640 (AENV, wildlife)	3700 (CCME) 6600 (AENV, livestock) 2600 (AENV, wildlife)	NGA[b] (CCME) 27000 (AENV, livestock) 11,000 (AENV, wildlife)	NGA[b] (CCME) 25000 (AENV, livestock) 9800 (AENV wildlife)	NGA[b] (CCME) 30000 (AENV, livestock) 16000 (AENV, wildlife)	NGA[b] (CCME) 21000 (AENV, livestock) 8400 (AENV, wildlife)

Notes:

1) All benchmarks in Table 1b are for both fine and coarse grained surface soils.
2) All benchmarks are taken directly from CCME (2007, Update 7.1), CCME (2008) and Alberta Environment (AENV) (2010).
3) AENV fractions F1-F4 vary from the Atlantic RBCA Tier I reporting fractions, however, soil data obtained from laboratories in Atlantic Canada can be combined to reported as the CWS fractions and compared directly to these the values in this table (APIRI, 2010).
4) NGA = no guideline available.

a Livestock and/or wildlife soil and food ingestion soil quality guidelines only exist for the agricultural land use category from CCME, and from only the natural areas and agricultural land use categories from Alberta Environment (the values are the same for both of these land use categories).

* Typically, Atlantic PIRI lab protocol does not include the analyses of the fractions greater than C32 (ie., F4) unless GC/MS chromatogram has not returned to baseline which would suggest the heavier fractions are present. If the chromatographs indicate that fractions greater than C32 are present, additional analyses are run to capture these fractions

3.0 GROUNDWATER ECOLOGICAL SCREENING LEVELS FOR THE PROTECTION OF PLANTS AND INVERTEBRATES IN DIRECT CONTACT WITH SHALLOW GROUNDWATER

Groundwater benchmarks for the protection of plants and invertebrates via direct contact were adopted directly from Alberta Environment (2010) and are summarized in **Table 2**. The direct contact pathway between groundwater and soil-borne organisms is applicable whenever groundwater is present within 3 m of the ground surface, as prescribed in the Alberta Environment guidance document. It applies to all land uses, and is based on the corresponding soil benchmark.

Non-polar organic compounds can partition between soil organic carbon, pore water, and pore vapour, and this partitioning can be estimated based on well-established partitioning equations. The benchmark guideline for this exposure pathway for these chemicals is calculated from existing ecological soil contact soil remediation guidelines using standard assumptions for the partitioning of the contaminant between soil and pore water. Separate guidelines are calculated for coarse and fine soils, using the following equation:

$$GWRG_{DC} = SRG_{DC} \frac{\rho_b}{\theta_w + \left(K_{oc} \times f_{oc} \times \rho_b\right) + \left(H' \times \theta_a\right)}$$

Where:

GWRGDC = groundwater benchmark protective of direct contact with plants and soil invertebrates in areas of shallow groundwater (mg/L);
SRGDC = soil benchmark protective of direct contact with plants and soil invertebrates (mg/kg);
ρ_b = dry soil bulk density (g/cm3);
θ_w = moisture-filled porosity (dimensionless)
= total porosity for saturated soils;
K_{oc} = organic carbon partition coefficient (L/kg);
f_{oc} = fraction of organic carbon (g/g);
H′ = dimensionless Henry’s Law Constant (dimensionless); and,
θ_a = vapour-filled porosity (dimensionless) = zero for saturated soils.

The default values of the various parameters used in the Alberta Environment derivation were:

ρ_b = 1.4 (fine soil), 1.7 (coarse soil);
θ_w = total porosity in saturated soils = 0. 47 (fine soil), 0.36 (coarse soil);
K_{oc} = chemical-specific;
f_{oc} = 0.005;
H' = chemical-specific; and,
θ_a = 0 for saturated soils.

These default parameters are similar to those used in the Atlantic RBCA Tool Kit and User Guidance. Specifically, Atlantic RBCA uses total soil porosities of 0.47 (fine soil) and 0.36 (coarse soil). Both Alberta and Atlantic RBCA use f_{oc} = 0.005 for shallow soils.

While there are screening levels for F1 and F2, Alberta Environment (2010) does not derive a value for F3 or F4, due to their low water solubility.

The resulting numbers are given in **Table 2**.

Table 2 Tier 1 Groundwater Ecological Screening Levels for Plant and Invertebrate Direct Contact with Shallow Groundwater (mg/L)

Land Use	Soil Grain Type	Substance					
		Benzene	Toluene	Ethyl Benzene	Xylenes	F1 C6-C10	F2 C10-C16
Agricultural	Coarse	61	59	20	31	7.1	1.8
	Fine	100	82	42	21	6.5	1.8
Residential/ Parkland	Coarse	61	59	20	31	7.1	1.8
	Fine	100	82	42	21	6.5	1.8
Commercial	Coarse	350	200	110	120	11	3.1
	Fine	540	240	150	74	9.9	3.1
Industrial	Coarse	350	200	110	120	11	3.1
	Fine	540	240	150	74	9.9	3.1

Source: Alberta Environment (2010).

1) Benchmarks are applicable only if groundwater is present within 3 metres of ground surface.
2) Alberta Environment fractions vary from the Atlantic RBCA Tier I reporting fractions, however, soil data obtained from laboratories in Atlantic Canada can be combined to reported as the CWS fractions and compared directly to these the values in this table (Atlantic PIRI, 2010).
3) There is no benchmark for F3 or F4 as this fraction is considered insufficiently soluble to migrate to groundwater from soil.

4.0 GROUNDWATER AND SURFACE WATER BENCHMARKS TO PROTECT AQUATIC LIFE

4.1 Laboratory Reporting Detection Limit Considerations for Water Analyses

A survey of two commercial environmental analytical labs in Atlantic Canada has determined that the reportable detection limits (RDL) for petroleum hydrocarbons in water using the Atlantic PIRI method are typically as follows:

- Benzene, toluene, ethylbenzene: 0.001 mg/L
- Xylenes: 0.002 mg/L
- >C6-C10 (minus BTEX): 0.01 mg/L
- >C10-C16: 0.05 mg/L
- >C16-C21 : 0.05 mg/L
- >C21-C32: 0.1 mg/L
- Modified TPH (equals all TPH less BTEX) : 0.1 mg/L

These RDLs are similar to the U.S. EPA's Practical Quantification Limits (PQL), which are considered to be the lowest practical limit at which an analyte's concentration can be quantified.

To avoid problems with false positives during use of this protocol, no Tier 1 screening benchmarks were set below these RDLs.

4.2 Surface Water Benchmarks

The development of guidelines for petroleum hydrocarbons that were protective of aquatic life reflected a chronic endpoint. The intent was to provide a concentration below which no deleterious effects would be expected to the receiving aquatic habitat over an extended period of time. A chronic HC_5 (concentration considered to have no deleterious effects to less than 5% of the aquatic species) represented a suitable endpoint. Given the paucity of data for petroleum hydrocarbons that was available to develop an HC5, the PETROTOX model (Version 3.04) was used to calculate values for the petroleum hydrocarbons of interest. The details of the PETROTOX model, along with guidance for its use, are provided in the PETROTOX User's Guide (Version 1.03 and subsequently Versions 3.01 and 3.06). A brief summary is presented here.

PETROTOX is a Quantitative Structure Activity Relationship (QSAR) model designed to mimic the conduct of an aquatic toxicity test that would be used to investigate the petroleum hydrocarbon product loading or concentration of petroleum hydrocarbon fractions responsible for eliciting either acute or chronic effects on an aquatic organism.

One of the advantages of this model is its ability to integrate the detailed fractionation analysis of the petroleum hydrocarbon mixture into the calculation. For the water quality standards developed in this protocol, the default Atlantic RBCA composition of gasoline, diesel/#2 and #6 oil/lube was applied. **Table 3** compares the composition of the respective petroleum products and CWS fractions.

Table 3 Comparison of Detailed Aliphatic and Aromatic Fractions between RBCA Gasoline, Diesel/#2 and #6 Oil/lube with CWS Fractions F1-F3

Aliphatic and Aromatic Subfractions	Atlantic RBCA			CCME CWS		
	Gasoline	Diesel/#2	#6 Oil/lube	F1 C6-C10	F2 C10-C16	F3 C16-C34
Aliph>C05-C06	0.27	-	-	-	-	-
Aliph>C06-C08	0.27	-	-	0.55	-	-
Aliph>C08-C10	0.16	0.05	0.01	0.36	-	-
Aliph>C10-C12	0.12	0.19	0.05	-	0.36	-
Aliph>C12-C16	-	0.26	0.17	-	0.44	-
Aliph>C16-C21	-	0.17	0.26	-	-	0.56
Aliph>C21-C34	-	0.03	0.32	-	-	0.24
Arom>C07-C08	-	-	-	-	-	-
Arom>C08-C10	0.06	-	-	0.09	-	-
Arom>C10-C12	0.12	0.06	0.01	-	0.09	-
Arom>C12-C16	-	0.12	0.03	-	0.11	-
Arom>C16-C21	-	0.09	0.07	-	-	0.14
Arom>C21-C34	-	0.02	0.08	-	-	0.06

Source: Atlantic RBCA User Guidance, Ver 3

The complex nature of petroleum hydrocarbon mixtures is accommodated by the PETROTOX model by making the following assumptions:

- All petroleum hydrocarbons exert their effect on aquatic organisms via a non-polar narcotic mode of toxic action
- Narcotic effects occur at a predicted body burden
- The effect of a mixture of petroleum hydrocarbons is equal to the sum of the effects of its contributing constituents (i.e., the toxicity is additive)

The QSAR model takes advantage of the relationships that have been established between the non-polar narcotic mode of toxic action displayed by hydrocarbons, and their properties such as boiling point, water solubility, and the octanol-water partition coefficient (K_{OW}). PETROTOX employs a properties database developed by CONCAWE that contains physical/chemical data and the modelled toxicity for 1457 hydrocarbon structures that are potentially found in petroleum products. There are 42 distinct species of aquatic organisms, ranging from algae to fish, represented in the toxicity data set.

In order to calculate the toxicity of a petroleum hydrocarbon mixture, each fraction within the mixture or hydrocarbon block is assigned a boiling point range (refer to **Table 4**). Based on this range, the CONCAWE database is queried, and matches assigned in order to identify the associated water solubility, and the K_{OW}. PETROTOX uses these characteristics to generate an average Probable No-Effect Concentration (PNEC) for each hydrocarbon block using the Target Lipid Model (TLM) with the application of an acute/chronic ratio (ACR) of 4.47. ACRs were defined as the acute LC_{50} (or EC_{50}) [i.e. mortality, immobilization] divided by the chronic NOEL (or EC10) [i.e. survival, growth, reproduction effect endpoints]. For example, to define an ACR for Daphnia, the measured 48-hr EC_{50} was divided by the 21-day chronic NOEL (using the most sensitive chronic effect endpoint). Within PETROTOX, ACRs have been compiled across a wide range of species and petroleum hydrocarbon classes. The uncertainty in this empirical distribution of ACRs is then propagated through the PNEC calculation in order to ensure the acute to chronic extrapolation is protective of 95% of the species. As a check that this calculation procedure delivers adequate protection across organisms for chronic effects, the PNEC predictions were compared to a large database of reliable, measured chronic NOECs and it was confirmed that 95% of the NOECs fell above the respective PNECs.

In order to accommodate site-specific data quantifying the concentration of petroleum hydrocarbons in groundwater or surface water, toxicity benchmarks were calculated that focused on the water accommodated fraction (WAF) of the petroleum hydrocarbons. The default output for PETROTOX reports the final chronic or acute values based on product loading, which may or may not be appropriate for environmental applications based on the solubility, volatility and other partitioning behaviour of the product fractions. Only that portion of the petroleum hydrocarbon mixture that is dissolved in the water will be available to the aquatic test species and thus contribute to the toxicity. Thus, for those fractions that are volatile, with the majority partitioning to the headspace, or for those that are relatively insoluble, with the majority associated with the un-dissolved free-phase, the WAF will be only a small proportion of the product loading, and the toxicity endpoint based on product loading would not be synonymous to the WAF.

The calculation of the toxicity endpoint based on the WAF was accomplished by considering only the concentration of each petroleum hydrocarbon block dissolved within the water phase as reported in the output of the PETROTOX model. Since the overall composition of the parent mixture affects both the solubility and toxicity of the individual petroleum hydrocarbon blocks due to Raoult's law, the specific toxicity values were calculated using the following:

$$(\text{Toxicity Benchmark})_a = (\text{Water Accommodated Fraction})_a \,/\, (\text{Toxic Unit})_a$$

The water accommodated fraction for each petroleum hydrocarbon block “a” was taken from the water phase as reported in the model output. The respective toxic units associated with each block were also derived from the PETROTOX output. The model was run using a zero-headspace test system and an infinite loading scenario. The latter approach was applied to more closely reproduce an environmental situation where mobile or residual LNAPL acts as the contaminant source and is in direct contact with groundwater or surface water. The zero-headspace was incorporated to eliminate the loss of volatiles within the WAF to the air phase, which would potentially bias the output. A sample of the model inputs and subsequent calculations is provided in Section 6.

The PETROTOX model provides the option of calculating both acute LC_{50} and chronic NOEL toxicity benchmarks for petroleum hydrocarbon substances or mixtures to a variety of aquatic species including algae, invertebrates and fish. However, as will be seen later in this Appendix, the derivations for groundwater and sediment also consider an HC_{50} for chronic toxicity endpoints, and an LC_{50} (rainbow trout) for the acute endpoint.

In order to identify these three endpoints, chronic NOELs and acute LC_{50}s for the petroleum hydrocarbon fractions were calculated for each of the 42 aquatic species listed in the PETROTOX model. These toxicity values were ranked and used to develop a species sensitivity curve. The organism displaying a chronic sensitivity at the 5th percentile was determined to be the alga, *Chlamydomonas reinhardtii* and at the 50th percentile was a fish, golden ide (*Leucisus idus melanotus*). The LC_{50} was represented by rainbow trout (*Oncorhynchus mykiss*). In addition to being relatively sensitive, occupying a position on the curve just below the 20th percentile, rainbow trout have been commonly used in bioassays to assess the potential toxicity of industrial effluents and as such, provide a useful point of reference. The ratio between the chronic HC_{50} and the chronic HC_5 was approximately 4.3; between the 96-hour LC_{50} and the chronic HC_5 it was 8.3.

A summary of resulting WAF benchmarks for each of the petroleum fractions is provided in **Table 4**.

Table 2 PETROTOX Derived Aquatic Toxicity Benchmarks for PHC Fractions and BTEX (mg/L)

TPH Fraction	**Boiling Point Range(^{o}C)**	**Chronic HC_5 *C. reinhardtii* (mg/L)**	**Chronic HC_{50} *L. idus melanotus* (mg/L)**	**Acute LC_{50} *O. mykiss* (mg/L)**
Aliphatic				
$C_5 – C_6$	33.8-68.2	2.35	10.4	20.2
C_6 - C_8	68.2-127.5	0.36	1.6	3.1
$C_{>8}$ - C_{10}	127.5-178.4	0.033	0.15	0.28
$C_{>10}$ - C_{12}	178.4-221.8	0.0034	***>0.034***	***>0.034***
$C_{>12}$ - C_{16}	221.8-292.3	***>0.00076***	***>0.00076***	***>0.00076***
$C_{>16}$ - C_{21}	292.3-361.0	***>0.000002***	***>0.000002***	***>0.000002***
$C_{>21}$ - C_{34}	361.0-483.0	***>0.000002***	***>0.000002***	***>0.000002***
Aromatic				
Benzene	77.8	2.1	9.1	17.5 (4.6)
Toluene	117.6	0.77	3.35	6.4 (4.2)
Ethyl Benzene	139.7	0.32	1.39	2.7 (5.5)
Xylenes	139.7-143.6	0.33	1.43	2.75
$C_5 – C_6$	33.8-68.2	na	na	na
C_6 - C_8	68.2-127.5	see BTEX	see BTEX	see BTEX
$C_{>8}$ - C_{10}	127.5-178.4	0.70	3.1	6.0
$C_{>10}$ - C_{12}	178.4-221.8	0.23	1.0	2.0
$C_{>12}$ - C_{16}	221.8-292.3	0.05	0.22	0.43
$C_{>16}$ - C_{21}	292.3-361.0	0.011	***>0.0136***	***>0.0136***
$C_{>21}$ - C_{34}	361.0-483.0	***>0.000134***	***>0.000134***	***>0.000134***

Note: Bolded and italicised values preceded by a ">" symbol indicate that the predicted benchmarks were at a concentration that exceeded the predicted water solubility. In these cases, the dissolved concentration necessary to elicit the toxic endpoint would not be achievable and thus the benchmark was listed as a value greater than the solubility limit. Values in brackets for Benzene, Toluene and Ethylbenzene represent laboratory-generated acute toxicity values reported by the CCME (2001) for salmonid species, and were generally in good agreement with the values derived from PETROTOX.

F3 and F4 fractions are not considered as they are well established as not being sufficiently soluble, such that movement via dissolution in groundwater is not likely to be an operable exposure pathway to aquatic receptors (OMOE, 2011; CCME, 2008)

As previously discussed, PETROTOX calculates species specific acute and chronic toxicity values for petroleum products such as gasoline, diesel/#2 or #6 oil/lube that are based on product loading. In order to calculate the chronic HC_5, the chronic HC_{50} and the 96-hour LC_{50} based on the WAFs representative of these products, the respective toxicity endpoints for each subfraction associated with the petroleum hydrocarbon product composition was summed using the following equation:

$$QG_{PHC} = 1/ [\Sigma (MF_{subfraction\ a} / QG_{subfraction\ a})]$$

Where:

QG_{PHC} = the final acute or chronic water quality benchmark in (mg/L).
$MF_{subfraction\ j}$ = the mass fraction of each sub-fraction within the WAF.
$QG_{subfraction\ j}$ = the acute or chronic toxicity benchmark for each sub-fraction in (mg/L).

A sample calculation of the modelling input for PETROTOX, the output file and subsequent calculations is provided in Section 6. As with the individual fractions, the toxicity values were ranked and used to develop a species sensitivity curve. The organism displaying a chronic sensitivity at the 5th percentile was *C. reinhardtii* and at the 50th percentile was *L. idus melanotus*. **Figure 1** illustrates the acute and chronic sensitivity curves for each of the petroleum products.

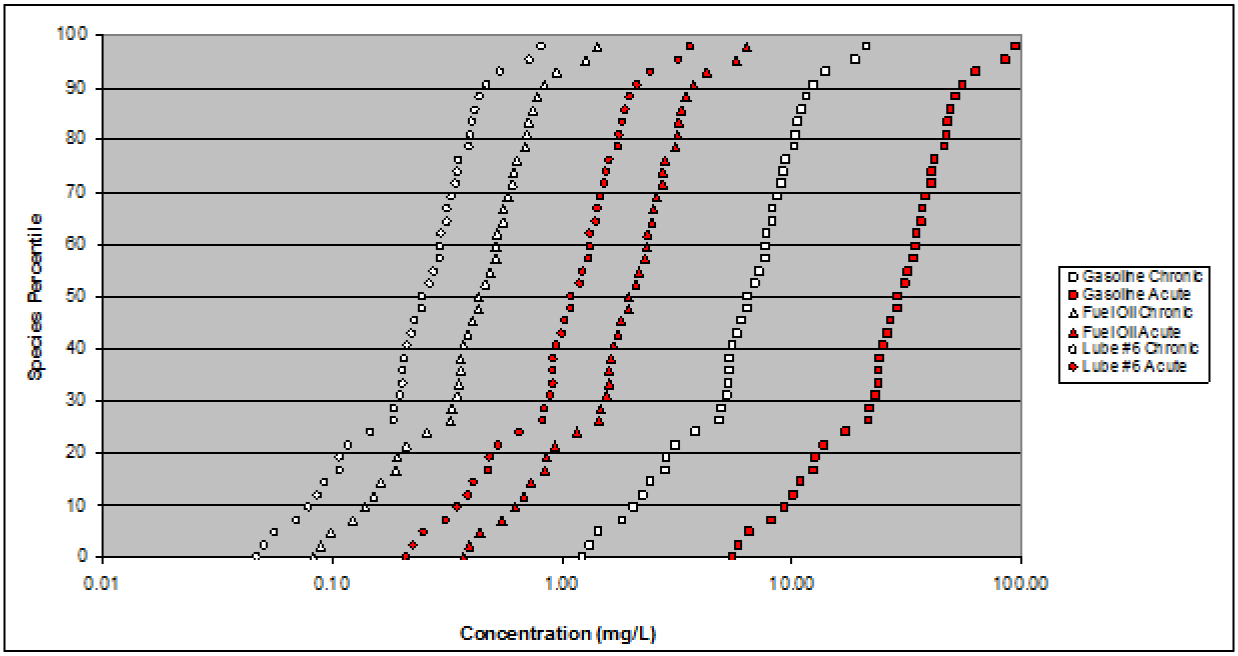


Figure 1 Aquatic species sensitivity curves for both acute and chronic endpoints to petroleum hydrocarbons

Table 5 provides a summary of the petroleum product toxicity values based on the WAF. As with the fraction specific toxicity benchmarks, those for the petroleum products focused on the chronic HC_5 from *C. reinhardtii*, the chronic HC_{50} from *L. idus melanotus*, and the 96-hour LC_{50} for *O. mykiss*.

Table 3 PETROTOX Derived Aquatic Toxicity Benchmarks for Petroleum Products (mg/L)

PHC Product	Surface Water Benchmarks for Modified TPH (mg/L)		
	Chronic HC_5 ***C. reinhardtii***	**Chronic HC_{50}** ***L. idus melanotus***	**Acute LC_{50}** ***O. mykiss***
Gasoline	1.46	6.46	12.52
Diesel/#2	0.098	0.43	0.84
Lube Oil	0.056	0.25	0.48

The recommended Tier 1 surface water benchmarks for BTEX and the petroleum products are taken from the Chronic HC_5 values in **Tables 4** and **5**, with due consideration for the RDLs reported in Section 4.1. However, only the benchmark for #6 oil/lube is driven by RDL considerations and was set at the RDL of 0.1 mg/L. The final values are presented in **Table 3** of the Ecological Screening Protocol (Appendix 2 of Atlantic RBCA Version 3 User Guidance) and **Table 6b**.

It is also important to note that these benchmarks apply equally to both freshwater and marine/estuarine environments. Data from DiToro (2000) have shown that species from these ecosystems display similar sensitivities to petroleum hydrocarbon exposure.

4.3 Groundwater Benchmarks

A number of provincial jurisdictions have developed groundwater criteria for the protection of down-gradient aquatic habitats that consider the potential for contaminants to migrate via groundwater to these ecosystems. In most cases, these criteria are based on ambient surface water criteria adjusted to consider attenuation within the groundwater, or dilution within the groundwater/surface water interface area. Both of these characteristics can vary significantly depending on the nature of the contaminated site and the receiving surface water.

It has been considered reasonable and relatively conservative in some jurisdictions to assume that the groundwater quality will be attenuated and/or diluted by 10-fold prior to, or during contact with the surface water. This approach essentially involves applying a factor of 10 to the respective surface water quality benchmarks in order to calculate groundwater quality benchmarks that would be protective of down gradient aquatic habitat. There may or may not be distance criteria applied in relation to the application of this 10-fold factor.

A precedent for a 10-fold factor exists within the British Columbia Contaminated Site Regulations (Schedule 6) and within the Ontario Ministry of the Environment. Outside of Canada, the Massachusetts Department of Environmental Protection has used such a

10-fold factor since 1990 in the aquatic components of their Massachusetts Contingency Plan. In Ontario, the OMOE (2011) notes the following with respect to this dilution assumption.

- OMOE assumes dilution by surface water in a mixing zone as it is the ecological receptors in the water column which are the considered the most sensitive and require protection, and therefore determine the acceptable surface water concentration. OMOE acknowledges that dilution will occur when groundwater discharges to surface water and has chosen a conservative, order of magnitude dilution factor of 10.

- The use of 10 times dilution in surface water assures that acute toxicity should not occur before dilution since a 10x acute-to-chronic factor is used in deriving the aquatic toxicity value (i.e, the aquatic protection value or APV) and is therefore consistent with other OMOE policies.

- However, this 10x factor does not equate to allowing the entire stream flow to dilute the incoming groundwater plume.

BC MOE (2009) states that the aquatic life standards in Schedule 6 of the Contaminated Sites Regulation apply to both groundwater and surface water prior to its discharge into an aquatic receiving environment, and assume a minimum 1:10 dilution is available. The 1:10 dilution assumption is based on the premise that impacted water on a site will be diluted 10-fold by the time it reaches a surface water receiving environment.

A report prepared for Nova Scotia Environment by Stantec and Intrinsik (2011) recommended a 10-fold factor (attenuation factor) that is applied to surface water quality benchmarks to derive groundwater quality standards for the protection of freshwater and marine aquatic life. The report recommended these groundwater standards be used for screening groundwater quality at locations greater than 10 metres from a freshwater or marine water body. It was also recommended that freshwater or marine water quality guidelines should be applied directly (or unadjusted) when evaluating groundwater quality at locations within 10 metres of a freshwater or marine surface water body. This recommendation is also made here for sites being evaluated under the Atlantic RBCA process. Similar policies and practices regarding the assessment of groundwater at contaminated sites currently exist within Ontario, Alberta and British Columbia. Adding to these recommendations, Atlantic PIRI has further developed this concept of groundwater screening levels so that they have been adjusted for distance to receiving environment, beyond the 10 metre zone.

Another approach to consider involves use of the guidance within the Fisheries Act. Section 36 of the Fisheries Act prohibits the deposit of a deleterious substance to water that is inhabited by fish. Section 34 of the Act defines the release of a "deleterious substance" as, in part:

> "any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water."

The application of this definition has generally involved the use of the rainbow trout 96-hour acute toxicity test with the critical endpoint being the LC_{50} (concentration that is lethal to 50% of the test organisms). Groundwater may be considered a discharge where it seeps into, and first makes contact with a surface water body. If the approach taken for other discharges is applied to groundwater, the quality of this water at the point of discharge, and without the benefit of dilution, needs to be such that it is not deleterious to fish. Therefore, alternate groundwater quality benchmarks could be based on the appropriate fish LC_{50} that is available for each of the substances of interest (i.e., benzene, toluene, ethylbenzene, xylenes, gasoline, diesel/#2 and #6 oil/lube). Available fish LC_{50} values for these substances are listed in **Table 4.**

A summary of the groundwater quality benchmarks resulting from the two approaches described above is provided in **Table 6a**. The recommended Tier 1 groundwater benchmarks for BTEX and petroleum hydrocarbons are the lower of the two values presented in **Table 6b**. The screening benchmarks in Table 6b represent default values that apply to groundwater that is as close as 10 meters from a freshwater or marine habitat. Where more detailed delineation of groundwater contamination and site conditions are available, **Table 6c** provides screening benchmarks that have been adjusted to account for the soil type and distance to the aquatic habitat. The Domenico (1987) analytical solute transport model was used to account for attenuation between the groundwater source zone and the downgradient point of compliance (POC) located 10 from the aquatic receptor. The analytical solution includes three dispersive components (i.e., lateral, transverse, and vertical spreading of plume), with the addition of a constant advective velocity, and a kinetic term that allows for first-order reaction and retardation. The use of the transient Domenico (1987) model with no biodegradation is consistent with the transient solution provided in the Atlantic RBCA Toolkit, v.3.22.

The solution considers that if no restriction was placed on the modeling, the ESLs in groundwater could be based on potential impacts at the POC from 10,000 or more years in the future. Since source-depletion and biodegradation are not considered in the development of the ESLs, both of which are important processes for petroleum hydrocarbons in particular, the default travel time was set at a relatively large number (100 years). Similar transport restrictions have been used by CCME (2006) and Ontario Ministry of Environment (2011). One hundred years is considered acceptable as the vast majority of sites meeting the ESLs would have aerobic degradation, a finite source, and much more dispersion/diffusion than is assumed in the generic setting.

Table 4a Groundwater Quality Screening Benchmarks for Petroleum Hydrocarbons (mg/L)

Substance		**Groundwater Benchmarks (mg/L)**	
		Based on 10 x Chronic HC_5 (*C. reinhardtii*)	**Based on Acute LC_{50} *O. mykiss***
Benzene		21	4.6 [a]
Toluene		7.7	4.2 [a]
Ethylbenzene		3.2	5.5 [a]
Xylenes		3.3	2.75
Modified TPH	Gasoline	14.6	12.5
	Diesel/#2	0.98	0.84
	#6 oil/lube	0.56	0.48

a) CCME Canadian Water Quality Guidelines for the Protection of Aquatic Life, 1999..

Notes:

The recommended Tier 1 groundwater screening levels for BTEX and petroleum hydrocarbons in Table 6b are the lower of the two values presented in this table

Table 6b Tier 1 Surface Water and Groundwater Ecological Screening Levels for the Protection of Freshwater and Marine Aquatic Life (mg/L)

Water Type	**Substance**						
	Benzene	**Toluene**	**Ethyl Benzene**	**Xylenes**	**Modified TPH**		
					Gas	**Diesel/ #2**	**#6 oil/lube**
Surface Water	2.1	0.77	0.32	0.33	1.5	0.10	0.10[b]
Groundwater[a]	4.6	4.2	3.2	2.8	13	0.84	0.48

Source: PETROTOX Ver 3.06

b) Groundwater screening levels can be used for evaluating groundwater quality at locations greater than 10 metres from a freshwater or marine water body. It is recommended that surface water screening levels should be applied directly (or unadjusted) when evaluating groundwater quality at locations within 10 metres of a freshwater or marine surface water body.

c) This screening level set to the RDL for #6/lube oil (actual modelled screening level = 0.06 mg/L)

Table 6c **Tier 1 Groundwater Ecological Screening Levels for the Protection of Freshwater and Marine Aquatic Life (mg/L), adjusted for distance to receiving aquatic environment and soil type**

Distance to Surface Water	**Benzene (mg/L)**		**Toluene (mg/L)**		**Ethyl benzene (mg/L)**		**Xylenes (mg/L)**		**Gasoline (mg/L)**		**Diesel (mg/L)**		**Lube Oil (mg/L)**	
(m)	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
10	4.6		4.2		3.2		2.8		13		0.84		0.48	
20	5	4.6	4.6	4.2	3.5	3.2	3	2.8	13	13	0.85	4.5	1.3	18
30	7.6	4.8	6.9	4.4	5.3	3.4	4.6	2.9	13	14	1.3	24	2.2	113
40	12	5.6	11	5.1	8.0	3.9	7	3.4	15	37	2.9	178	4.9	1070
50	17	6.7	15	6.1	11	4.7	10	4.1	22	86	6	>sol	22	>sol
60	22	8.1	20	7.4	15	5.6	14	5.5	37	495	14	>sol	56	>sol
70	29	9.7	26	8.8	20	7.5	17	7.5	55	>sol	21	>sol	85	>sol
80	36	11	33	10	25	9.9	22	11	75	>sol	28	>sol	117	>sol
90	43	13	39	14	30	13	26	18	92	>sol	39	>sol	161	>sol
100	51	16	47	17	36	20	31	30	114	>sol	85	>sol	511	>sol
110	59	19	54	21	41	28	36	49	139	>sol	207	>sol	1243	>sol
120	68	23	62	27	47	45	42	92	171	>sol	333	>sol	1996	>sol
130	77	29	71	35	54	76	47	>sol	207	>sol	436	>sol	2615	>sol
140	87	44	79	69	60	130	53	>sol	467	>sol	>sol	>sol	>sol	>sol
150	97	45	88	70	67	>sol	59	>sol	750	>sol	>sol	>sol	>sol	>sol
200	150	250	140	>sol	100	>sol	91	>sol	>sol	>sol	>sol	>sol	>sol	>sol
Solubility (SOL) a	1,780		515		150		160		TDB		TDB		TDB	

Source: PETROTOX Ver 3.06

Note: SOL is the groundwater concentration representing the solubility limit for the compound. Beyond this point, a separate, non-aqueous phase liquid layer will begin to form. Above SOL concentrations, NAPL will form and will initially be non-mobile, but at higher concentrations will be subject to gravitational forces, be measurable and become mobile (Atlantic PIRI, 2012)

4.4 BTEX Surface Water and Groundwater Benchmark Comparisons

Tables 7 to 9 present comparisons of the recommended Eco RBCA surface water and groundwater screening levels for BTEX, to selected freshwater and marine surface water and groundwater quality benchmarks from other jurisdictions in North America and Europe. These comparisons are made as a number of jurisdictions have existing water quality benchmarks for BTEX (much more so than for petroleum hydrocarbons), and there is a higher degree of uncertainty regarding application of the underlying theory of the target lipid narcosis model to BTEX (as was conducted with the PETROTOX model), than there is to petroleum hydrocarbon fractions. Another reason for conducting these comparisons is that the use of the PETROTOX model in developing water quality benchmarks for BTEX is a relatively novel approach in North America. Thus, there is interest in determining how the outcomes of this derivation method compare to benchmarks that were developed using more traditional methods. While these comparisons function as a limited check mechanism on the PETROTOX-derived values for BTEX, it should be recognized that no formal detailed ground truthing or validation of the PETROTOX-derived values against empirical aquatic toxicity data for BTEX has been conducted at this time.

It is evident from the comparisons presented in Tables 7 to 9 that there is considerable variability in the magnitude of the water quality benchmarks for BTEX. This variability is a function of the different approaches and ecological protection goals used by the source agencies to develop these benchmarks, as well as the age of these benchmarks, and the data considered in their development (i.e.., many of the existing benchmarks are based on toxicity data available before the early 1990s).

In considering these tables, it is important to recognize that the ecological protection goals are not the same for all benchmarks that were compiled. The generic water quality benchmarks from CCME, Ontario (the PWQOs), the BC ambient approved water quality guidelines and the EU PNECs are intended to protect all aquatic life, including sensitive organisms and/or life stages, in all types of water bodies, under all foreseeable environmental conditions, including, but not limited to, impacts associated with contaminated sites. For example:

- The OMOE PWQOs are set to be protective of all forms of aquatic life and all aspects of the aquatic life cycles during indefinite exposure to the water (OMOE, 1999).

- CCME water quality guidelines are meant to protect all forms of aquatic life and all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term, from the negative effects of anthropogenically altered parameters or exposures to substances via the water column. In deriving these guidelines, all higher components of the aquatic ecosystem (e.g., algae, macrophytes, invertebrates, and vertebrates (fish, amphibians etc.), and their aquatic life stages are considered, if data are available (CCME, 2007).

- BC MOE approved ambient water quality guidelines are set to provide safe conditions or levels that have province-wide application and are set to protect various water uses, and protect the most sensitive designated water use in a particular body of water.

While these are reasonable and common protection goals for generic benchmarks that are intended to have wide application, these particular benchmarks do not recognize that there can be situations where less stringent ecological protection goals may be reasonable or practical.

Some jurisdictions both within and outside of Canada have recognized that there are situations where it is reasonable to have less stringent ecological protection goals than those afforded by the generic water quality benchmarks. For example, the OMOE (2011) APVs and the BC CSR Schedule 6 values were developed in the context of contaminated site assessment and management, and are less stringent than the PWQOs and ambient water quality guidelines that are also produced by these two Ministries. The OMOE (2011) notes that PWQOs were not used as the basis for the Tables of Site Condition Standards in Ontario because some of the assumptions made in the development of PWQOs are not considered appropriate for the assessment and potential remediation of contaminated brownfield sites. Rather, the APVs are designed to provide a scientifically defensible and reasonably conservative level of protection for most aquatic organisms from the migration of contaminated groundwater to surface water resources (OMOE, 2011). Similar arguments apply to the BC CSR Schedule 6 values versus the BC MOE ambient approved water quality guidelines. Outside of Canada, the ANZECC (2000) trigger values for aquatic ecosystems, which are set to protect 80%, 90%, 95% or 99% of species, also recognize that there are situations where there can be different ecological protection goals for aquatic ecosystems depending on various factors such as water use, land use near the water body, and other ecological stressors known to impact a given body, or result in “disturbed” conditions for resident aquatic biota. These concepts are consistent with Atlantic PIRI Principles 2, 3, and 4 (see Overview Section in main part of protocol).

From an ecological perspective, effects on a few sensitive aquatic species are not generally of concern so long as the function(s) the affected species perform can be accomplished by other species (Reiley et al., 2003). The functions of interest are generally related to energy and nutrient flow (e.g., primary production, controlling abundance of lower trophic level populations and processing of organic detritus). Many aquatic ecosystems exhibit “functional redundancy” (Moore, 1998), which means that multiple species are present to perform each critical function. For example, in most aquatic ecosystems, there are numerous species of phytoplankton, periphyton, zooplankton, macrophytes and fish. The concept of functional redundancy implies that reductions in a few sensitive species are unlikely to impair the overall functions of the aquatic ecosystem. In addition, it is generally established that aquatic systems in unstable environments (such as an urban water body near a contaminated site(s)) are more likely to resist new disturbances (such as petroleum hydrocarbon contamination), than more stable, less disturbed environments. This is especially the case if the new disturbance is similar to past disturbances (e.g., prior release of petroleum hydrocarbons to the water body) (Moore, 1998). A number of studies have shown that the transition from minor (ie., ecologically tolerable) to more severe impacts usually occurs at concentrations greater than the 10th percentile of single species acute or chronic toxicity values (e.g., Giddings et al., 1996; Versteeg et al., 1998).

As water bodies located near contaminated sites are typically impacted or disturbed to varying degrees, irrespective of the impacts from a given site (because of the presence of multiple ecological stressors, human-built infrastructure etc.), it is likely unreasonable to expect that petroleum hydrocarbon contamination should result in no adverse impacts on any species potentially present in the water body. Rather, the protection goals for these types of water bodies should typically allow for moderate impacts, particularly those that are reversible, but avoid the more severe impacts that would lead to adverse impacts on community structure and function. This concept has been employed in other jurisdictions including the United States and Australia, and also served as the part of the conceptual framework for the development of ideal performance standards for agricultural pesticides in Canada (i.e., Cantox Environmental Inc., 2005). Possible exceptions to this general protection goal may be necessary when the sensitive species being potentially impacted are threatened or endangered, are commercially or recreationally important, or have a critical ecological role within the aquatic ecosystem.

Consideration of the above information suggests that the OMOE (2011) APVs and BC MOE CSR Schedule 6 values are the most appropriate points of comparison against the Eco RBCA screening levels as all three sets of values were developed in the context of contaminated site assessment and management, and therefore, should have similar ecological protection goals. The ANZECC trigger values for 90% or 80% protection are also considered reasonable points of comparison against the Eco RBCA values.

Tables 7 **and 8** provide support that that the Atlantic Tier I ecological screening level values show good agreement with OMOE (2011) APVs, and the ANZECC trigger values for 90% and 80% protection. The Atlantic Tier I ecological screening levels are not the highest value in these comparisons for any of the BTEX parameters, with the exception of the benzene marine water quality benchmark (i.e., 2.1 mg/L versus 1.3 mg/L for the ANZECC (2000) 80% protection level marine trigger value).

From the comparisons presented in **Table 9**, the Atlantic Tier I ecological screening levels for groundwater show good agreement with the OMOE (2011) GW-3 values, the BC MOE CSR Schedule 6 values, and are also below most of the interim Federal groundwater benchmarks for fine and coarse-grained soil types.

Given the comparisons and discussion within this section, the Atlantic Tier I ecological screening levels for surface water and groundwater for BTEX are considered to provide a sufficient and reasonable degree of protection to aquatic organisms present in water bodies that are influenced by petroleum-contaminated sites in Atlantic Canada.

Table 5 BTEX Freshwater Surface Water Quality Benchmark Comparisons (mg/L)

	Surface Water Benchmark (mg/L)												
										ANZECC (2000)[i]			
Agency or Source	Atlantic RBCA Tier I screening level	CCME[a]	OMOE PWQOs[b]	Quebec MDDEP[c]	BC MOE Ambient Approved WQG[d]	OMOE (2011) APVs[e]	U.S. EPA National AWQC[f]	EU PNECs[g]	EU REACH PNECs[h]	LOP-99	LOP-95	LOP-90	LOP-80
Parameter													
Benzene	2.1	0.37	0.1	defer to CCME	0.04	0.46	nba	0.08	0.08 and 1.9	0.6	0.95	1.3	2
Toluene	0.77	0.002	0.0008	defer to CCME	0.0005	1.4	nba	0.074	0.68	nba	nba	nba	nba
Ethylbenzene	0.32	0.09	0.008	defer to CCME	0.2	0.181	nba	0.1	0.1	nba	nba	nba	nba
Xylenes	0.33	nba	m: 0.002 o: 0.04 p: 0.03	0.37 (acute) 0.041 (chronic)	0.03	0.33	nba	nba	o and p: 0.042 and 0.25 m: 0.25 total xylenes: 0.33	o: 0.2 m: nba p:0.14	o: 0.35 m: nba p:0.2	o: 0.47 m: nba p:0.25	o: 0.64 m: nba p:0.34

Notes: nba = no benchmark available; PWQO = provincial water quality objective; WQG = water quality guidelines; APV = aquatic protection value; AWQC = ambient water quality criteria; PNEC = predicted no effect concentration; LOP = level of protection (where LOP-99, LOP-95, LOP-90, and LOP-80 correspond to protection levels of 99%, 95%, 90% and 80% of species, respectively).

All water quality benchmark values presented in this table are independent of land use categories. That is, they apply equally to all land use categories.

a) To date, Canadian Council of Ministers of the Environment (CCME) Canadian water quality guidelines for the protection of freshwater aquatic life, for BTEX, have been adopted directly by most Canadian provinces and territories. However, there are exceptions, as reflected in this table (ie., Ontario, British Columbia, Quebec (for xylenes only)). The CCME values are sourced from the Canadian Environmental Quality Guidelines website (http://ceqg-rcqe.ccme.ca/?config=ccme&thesite=ceqg&words=&image.x=13&image.y=5). The CCME factsheets for benzene, toluene, and ethylbenzene are all dated 1999.

b) Ontario Ministry of the Environment Provincial Water Quality Objectives (PWQOs) (OMOE, 1999). The PWQOs are analogous to the CCME water quality guidelines for the protection of freshwater aquatic life in that they are set to be protective of all forms of aquatic life and all aspects of the aquatic life cycles during indefinite exposure to the water. The prefixes: m, o, and p refer to the three xylene isomers (meta, ortho and para). The OMOE did not develop a PWQO for total xylenes. Rather, individual PWQOs were developed for the three xylene isomers.

c) Ministere du Développement durable, de l'Environnement et des Parcs (2011). Critères de qualité de l'eau de surface. Available at : http://www.mddep.gouv.qc.ca/eau/criteres_eau/index.asp. The xylenes benchmarks were adopted from Michigan Department of Environmental Quality (2008).

d) British Columbia Ministry of Environment Approved Water Quality Guidelines. Available at: http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved. Derivation dates are 2007 for benzene, toluene, and xylenes, and 1999 for ethylbenzene.

e) Ontario Ministry of the Environment Aquatic Protection Values, or APVs (OMOE, 2011). The specific basis of the APVs for BTEX is provided in OMOE (2011), but in general, APVs are developed by dividing suitable LC50 or EC50 values for a sensitive species by a 10-fold uncertainty factor. APVs are developed to protect aquatic biota exposed to contaminants from the migration of contaminated groundwater to surface water. Additional details on APV derivation are provided in OMOE(2011).

f) U.S. EPA National Ambient Water Quality Criteria. Available at: http://water.epa.gov/scitech/swguidance/standards/current/index.cfm.

g) European Union (EU) Predicted No-effect Concentrations (PNECs). Details on the derivation of these PNECs are available within EU (2008) for benzene, EU (2007) for ethylbenzene, and EU(2003) for toluene. A PNEC value for xylenes has not been derived by the EU to date. In general, PNECs are obtained by dividing the lowest identified and suitable NOEC by a factor of 10.

h) While the REACH PNEC values are also developed within Europe, they are not regulatory values but rather, have been developed by REACH registrants (typically, these are consortia of industry groups). As such, these PNEC values may not have undergone a detailed quality assurance evaluation or regulatory review. The REACH PNEC values can be obtained at: http://apps.echa.europa.eu/registered/registered-sub.aspx. In some cases, more than one PNEC value has been determined. The prefixes: m, o, and p refer to the three xylene isomers (meta, ortho and para).

i) ANZECC (2000) Trigger Values for Freshwater. Available at: http://www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/anzecc-water-quality-guide-02-pdfs.html. The prefixes: m, o, and p refer to the three xylene isomers (meta, ortho and para). ANZECC did not develop a trigger value for total xylenes.

Table 6 BTEX Marine Surface Water Quality Benchmark Comparisons (mg/L)

Agency or Source	**Surface Water Benchmark (mg/L)**												
	Atlantic RBCA Tier I screening level	**CCME[a]**	**OMOE PWQOs[b]**	**Quebec MDDEP[c]**	**BC MOE Ambient Approved WQG[d]**	**OMOE (2011) APVs[e]**	**U.S. EPA National AWQC[f]**	**EU PNECs[g]**	**EU REACH PNECs[h]**	**ANZECC (2000)[i]**			
										LOP-99	**LOP-95**	**LOP-90**	**LOP-80**
Parameter													
Benzene	2.1	0.11	nba	defer to CCME	0.11 (CCME)	nba	nba	0.08	0.08 and 1.9	0.5	0.7	0.9	1.3
Toluene	0.77	0.215	nba	defer to CCME	nba	nba	nba	0.074	0.68	nba	nba	nba	nba
Ethylbenzene	0.32	0.025	nba	defer to CCME	0.25	nba	nba	0.1	0.1	nba	nba	nba	nba
Xylenes	0.33	nba	nba	nba	nba	nba	nba	nba	o and p: 0.042 and 0.25 m: 0.25 total xylenes: 0.33	nba	nba	nba	nba

Notes: nba = no benchmark available; PWQO = provincial water quality objective; WQG = water quality guidelines; APV = aquatic protection value; AWQC = ambient water quality criteria; PNEC = predicted no effect concentration; LOP = level of protection (where LOP-99, LOP-95, LOP-90, and LOP-80 correspond to protection levels of 99%, 95%, 90% and 80% of species, respectively).

All water quality benchmark values in this table are independent of land use categories. That is, they apply equally to all land use categories.

a) To date, Canadian Council of Ministers of the Environment (CCME) Canadian water quality guidelines for the protection of marine aquatic life, for BTEX, have been adopted directly by most Canadian provinces and territories with a marine coastline. However, there are exceptions, as reflected in this table (ie.,, British Columbia). The CCME values are sourced from the Canadian Environmental Quality Guidelines website (http://ceqg-rcqe.ccme.ca/?config=ccme&thesite=ceqg&words=&image.x=13&image.y=5). The CCME factsheets for benzene, toluene, and ethylbenzene are all dated 1999.

b) Ontario Ministry of the Environment has not derived marine Provincial Water Quality Objectives (PWQOs).

c) Ministere du Développement durable, de l'Environnement et des Parcs (2011). Critères de qualité de l'eau de surface. Available at: http://www.mddep.gouv.qc.ca/eau/criteres_eau/index.asp.

d) British Columbia Ministry of Environment Approved Water Quality Guidelines. Available at: http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html#approved. Adoption date is 2007 for benzene, and the derivation date is 1999 for ethylbenzene.

e) Ontario Ministry of the Environment has not developed marine Aquatic Protection Values.

f) U.S. EPA National Ambient Water Quality Criteria. Available at: http://water.epa.gov/scitech/swguidance/standards/current/index.cfm.

g) European Union (EU) Predicted No-effect Concentrations (PNECs). Details on the derivation of these PNECs are available within EU (2008) for benzene, EU (2007) for ethylbenzene, and EU(2003) for toluene. A PNEC value for xylenes has not been derived by the EU to date. In general, PNECs are obtained by dividing the lowest identified and suitable NOEC by a factor of 10. The EU PNECs apply to both freshwater and saltwater aquatic ecosystems.

h) While the REACH PNEC values are also developed within Europe, they are not regulatory values but rather, have been developed by REACH registrants (typically, these are consortia of industry groups). As such, these PNEC values may not have undergone a detailed quality assurance evaluation or regulatory review. The REACH PNEC values can be obtained at: http://apps.echa.europa.eu/registered/registered-sub.aspx. In some cases, more than one PNEC value has been determined. The prefixes: m, o, and p refer to the three xylene isomers (meta, ortho and para). The EU PNECs apply to both freshwater and saltwater aquatic ecosystems.

i) ANZECC (2000) Trigger Values for Marine Water. Available at: http://www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/anzecc-water-quality-guide-02-pdfs.html.

Table 7 BTEX Groundwater Quality Benchmark Comparisons (mg/L)

Agency or Source	Atlantic RBCA Tier I screening level[a]	OMOE 2011 GW-3 Values[b]	OMOE 2011 GW-3 Values (shallow soil scenario and/or within 30 m of water body)[c]	AENV (2010) Groundwater Remediation Guidelines[d]	Interim Federal Groundwater Benchmarks (freshwater)[e]	Interim Federal Groundwater Benchmarks (marine)[f]	BC MOE CSR Schedule 6[g]
Parameter							
Benzene	4.6	5.8	4.6	33 / 0.69	33 / 0.69	9.8 / 0.2	4 (freshwater) 1 (marine)
Toluene	4.2	18	14	ngr / 0.083	ngr / 0.083	8.9	0.39 (freshwater) 3.3 (marine)
Ethylbenzene	3.2	2.3	1.8	ngr / 41	ngr / 41	11	2 (freshwater) 2.5 (marine)
Xylenes	2.8	4.2	3.3	ngr / 18	ngr / 18	nba	nba

Notes: nba = no benchmark available; ngr = no guideline required.

a) The Atlantic RBCA Tier I screening levels apply to both freshwater and marine receiving environments. The values in the table are the lower of rainbow trout LC50 values or 10 times the Petrotox-derived surface water quality benchmarks.

b) The OMOE (2011) GW-3 values are derived from the freshwater Aquatic Protection Values, and address the potential for environmental impacts to aquatic biota when contaminated groundwater discharges into surface water bodies. Calculation of the GW-3 values involves the Domenico 2-D infinite source hydrodynamic dispersion model and a number of assumptions that include: pathway consists of dissolved contaminants from the soil source zone leaching down to the aquifer, flowing in groundwater, and discharging to surface water through the bottom sediment; 300 years of travel time in the aquifer; no biodegradation; and, 10 times dilution by surface water when groundwater discharges to its receiving environment. With respect to this dilution assumption, OMOE assumes there is dilution by surface water in a mixing zone as it is the ecological receptors in the water column which are considered the most sensitive and require protection, and therefore determine the acceptable surface water concentration. OMOE acknowledges that dilution will occur when groundwater discharges to surface water and has chosen a conservative, order of magnitude dilution factor of 10. The OMOE GW-3 values apply only to freshwater receiving environments. The GW-3 values apply to sites with both coarse and medium to fine grained soil, and apply equally to potable and non-potable groundwater use scenarios. Further details on GW-3 derivation and application are provided in OMOE (2011).

c) The OMOE (2011) also developed GW-3 values for a shallow soil scenario and/or situations where a site is within 30 m of a water body. These GW-3 values are also derived from the freshwater Aquatic Protection Values. Thus, they apply only to freshwater receiving environments. These GW-3 values also apply to sites with both coarse and medium to fine grained soil, and apply equally to potable and non-potable groundwater use scenarios.

d) The Alberta Environment (2010) groundwater remediation guidelines are for freshwater receiving environments only. Values are presented for fine and coarse grained soil situations (i.e., fine / coarse). “ngr” implies that no guideline is required. Alberta Environment (2010) states that a chemical parameter is assigned the “ngr” code if the calculated groundwater remediation guideline is greater than the solubility limit of that parameter, or if the calculated remediation guideline is >1,000,000 mg/L. The guidelines assume there is a minimum lateral separation of 10 m between location where contaminated soil or groundwater is measured and the receptor (i.e., location of surface water body). Details regarding derivation of the groundwater remediation guidelines are provided within Alberta Environment (2010).

e) CCME currently does not develop groundwater quality benchmarks. However, Environment Canada is currently applying interim federal groundwater quality guidelines at federal contaminated sites. For freshwater receiving environments, these interim federal guidelines defer to the Alberta Environment (2010) groundwater remediation guidelines. Values are presented for fine and coarse grained soil situations (i.e., fine / coarse). “ngr” implies that no guideline is required.

f) CCME has not developed groundwater quality benchmarks. However, Environment Canada is currently applying interim federal groundwater quality guidelines at federal contaminated sites. The interim federal groundwater quality guidelines for marine receiving environments were calculated by multiplying the groundwater guideline for the protection of freshwater aquatic life by the ratio of the surface water quality guidelines for marine and freshwater life. CCME freshwater and marine water quality guidelines were used to develop this ratio.

g) British Columbia Ministry of Environment Contaminated Sites Regulation Schedule 6 (BCMOE, 2011). The aquatic life standards in Schedule 6 apply to both groundwater and surface water prior to its discharge into an aquatic receiving environment, and assume a minimum 1:10 dilution is available. The 1:10 dilution assumption is based on the premise that impacted water on a site will be diluted 10-fold by the time it reaches a surface water receiving environment (BC MOE, 2009). The standards for all organic substances are for total (unfiltered) substance concentrations.

5.0 SEDIMENT BENCHMARKS

5.1 Canadian Regulatory Guidance for Contaminated Sediments

There are no existing Canadian sediment quality guidelines for petroleum hydrocarbons. The Canadian Council of Ministers of the Environment (CCME) has developed sediment quality guidelines for the protection of aquatic (freshwater and marine) life for some hydrocarbons (PAHs) however such guidelines have not been developed for petroleum hydrocarbon fractions or products. British Columbia Ministry of the Environment has also derived sediment standards for PAHs using a similar approach to that of CCME but has not yet developed sediment benchmarks for petroleum hydrocarbons.

There is no explicit federal legislation addressing sediment quality, in the way that Section 36 of the Fisheries Act (as summarized in Part 3 of this Appendix) addresses protection of water quality. However, sediments (solid phase) and sediment pore water could be considered fish habitat, given the definition of habitat within the Act. From this, it could be assumed that sediments should not contain petroleum hydrocarbons as a free product, nor should sediments or sediment pore water contain sufficient amounts of dissolved petroleum hydrocarbons to be deleterious to fish.

5.2 Narcosis-Based Models to Derive Sediment Quality Benchmarks

For non-polar organics such as BTEX and petroleum hydrocarbons, a number of groups have used similar non-polar narcosis-based models and the equilibrium partitioning method (EqP) to derive sediment quality benchmarks.

On behalf of the Massachusetts Department of Environmental Protection, Battelle (2007) published benchmarks for petroleum hydrocarbon fractions in sediment, based on the non-polar narcosis model and assuming equilibrium partitioning between petroleum hydrocarbons and sediment organic carbon. These benchmarks, which are intended to protect a sensitive species from chronic effects, can be compared (See **Table 10**) to values previously developed by Verbruggen (2004), and values calculated independently by Jacques Whitford Stantec Limited (unpublished) following the model developed by DiToro and McGrath (2000). All three sets of values are based upon the equilibrium partitioning of TPH fractions between sediment organic carbon (f_{oc}, assumed to be 1% of dry weight) and sediment pore water, and assume a non-polar narcosis mode of action for petroleum hydrocarbons. However, all three sets of benchmarks reference different toxicity databases, and differ in the approach that they take in order to achieve the endpoints that they seek to protect.

Battelle (2007) calculated LC_{50} values for representative chemicals and then used an application factor to convert the mean LC_{50} value to a chronic value representative of a sensitive species. Verbruggen (2004) sought to protect the 50th percentile species from very slight effects (for example, a 10% reduction in body mass). DiToro et al. (2000) developed a toxicity model for petroleum hydrocarbons based on the 5th percentile species in an acute toxicity sensitivity distribution, and then used an application factor to estimate a chronic value. Although the results from the three models may initially appear divergent, these three approaches result in estimated chronic exposure benchmarks for TPH fractions in sediment that are remarkably low in the context of both TPH concentrations frequently measured in urban sediments, and the analytical capabilities of most laboratories.

Table 8 Summary of MADEP (2007), Verbruggen (2004), and JWSL (following DiToro et al., 2000 and DiToro and McGrath, 2000) Effects Benchmarks for TPH (mg/kg dry sediment; normalized to 1% sediment organic carbon)

MADEP (Chronic) based on Batelle 2007		Verbruggen (Chronic)		JWSL (Chronic) based on DiToro 2000		JWSL (Acute) based on DiToro 2000	
Aliphatic		**Aliphatic**		**Aliphatic**		**Aliphatic**	
C5-C8	15.9	C5-C6	1.6	C7-C8	9.8	C7-C8	50
C9-C12	27.2	C7-C8	1.5	C9-C10	14	C9-C10	70
C13-C18	55.4	C9-C10	1.4	C11-C12	18	C11-C12	94
C19-C36	98.8	C11-C12	2.6	C13-C16	26	C13-C16	130
		C13-C16	28	C17-C21	NA[a]	C17-C21	NA[a]
				C22-C34	NA[a]	C22-C34	NA[a]
Aromatic		**Aromatic**		**Aromatic**		**Aromatic**	
C6-C8	5.3	C5-C7	3.9	C6-C8	<10	C6-C8	<50
C9-C12	2.3	C8	4.4	C9-C10	11	C9-C10	58
C13-C16	1.3	C9-C10	4.9	C11-C12	13	C11-C12	64
C16-C36	0.4	C11-C12	5.6	C13-C16	15	C13-C16	76
		C13-C16	6.8	C17-C21	20	C17-C21	100
		C17-C21	8.8	C22-C34	27	C22-C34	140
		C22-C35	20				
Sum of TPH[b]	**206.6**	**Sum of TPH[b]**	**89.5**	**Sum of TPH[b]**	**163.8**	**Sum of TPH[b]**	**832**

Notes:

a The aliphatic TPH fractions heavier than C16 are considered to be insufficiently soluble to cause toxicity.

b In principle, the benchmarks above should be treated individually, and HQ or concentration ratio values summed. However, the sum of the individual fraction benchmark values is presented in these cells for illustrative purposes.

Also using narcosis theory and the EqP method, U.S. EPA (2008) developed sediment quality benchmarks for benzene, ethylbenzene, toluene and m-xylene.

The current Atlantic RBCA Tier I sediment screening levels for petroleum hydrocarbons and BTEX were also developed based on the concepts of narcosis and equilibrium partitioning. Specifically, the acute and chronic surface water toxicity values provided by the PETROTOX model were used to calculate the sediment screening levels. The EqP method was used to express the surface water toxicity values from PETROTOX as bulk sediment values (mg/kg dry weight).

The EqP method is based on the assumption that the toxic component of the sediment borne chemical is that which is associated with the sediment porewater. The concentration of the chemical in the porewater is related to that which is measured in the bulk sediment with the application of the K_{oc} (organic carbon partitioning coefficient) of the contaminant and the f_{oc} (fraction organic carbon) of the sediment. By focusing on the contaminant concentration in the sediment porewater, water quality benchmarks can be applied to assess the potential toxicity of the sediment. The EqP approach is most applicable to organic contaminants, particularly non-polar (or non-ionic) organics (U.S. EPA, 2008).

In its simplest form, the Equilibrium Sediment Criteria (ESC) is related to the final aquatic chronic value (FCV) or final aquatic acute value (FAV) with the following equation:

$$ESC = Kp \times FCV \text{ or } FAV$$

The constant Kp is equal to the product of the compound's K_{oc} and the fraction organic carbon in the sediment. This relationship seems to hold as long as the fraction of organic carbon remains above 0.2%.

Both the chronic and acute endpoints from **Table 4** were applied along with the K_{oc} values from the PETROTOX model in order to calculate chronic and acute sediment quality benchmarks, respectively. The resulting narcosis-based sediment benchmarks are listed in **Table 11**. A sample calculation is provided in Section 6.

Table 9 Chronic and Acute Narcosis-Based Sediment Toxicity Benchmarks (mg/kg dry wt at 1% foc)

	Koc (mg/kg)/(mg/L)	Chronic Sediment Benchmarks - Narcosis (HC_5)	Chronic Sediment Benchmarks – Narcosis (HC_{50})	Acute Sediment Benchmarks - Narcosis (LC_{50} rainbow trout)
Aliphatic				
C_5 – C_6	794	19	83	161
C_6 - C_8	3981	14	64	124
$C_{>8}$ - C_{10}	31623	10.5	46	90
$C_{>10}$ - C_{12}	251189	8.7	*38*	74
$C_{>12}$ - C_{16}	5011872	*>1000*	*>1000*	*>1000*
$C_{>16}$ - C_{21}	630957344	*>1000*	*>1000*	*>1000*
$C_{>21}$ - C_{34}	630957344	*>1000*	*>1000*	*>1000*
Aromatic				
Benzene	59	1.24	5.37	10.3
Toluene	182	1.40	6.10	11.6
Ethyl benzene	363	1.16	5.05	9.80
Xylenes	389	1.28	5.56	10.7
C_5 – C_6	na	na		Na
C_6 - C_8	447	See BTEX		See BTEX
$C_{>8}$ - C_{10}	1585	11.6	49	95
$C_{>10}$ - C_{12}	2512	5.7	25	49
$C_{>12}$ - C_{16}	5012	2.5	11	21
$C_{>16}$ - C_{21}	15849	1.7	8	15
$C_{>21}$ - C_{34}	125893	5.4	24	46

Notes:
>1000 indicates that the sediment benchmark could not be calculated because the solubility of the fraction in water was too low to produce a toxic endpoint to aquatic species.

Note that these are based on a sediment f_{oc} of 0.01. For other values of f_{oc}, the screening levels change proportionally. For example, with f_{oc}= 0.04, the values increase by 4-fold.

Direct comparisons to the sediment screening levels previously presented in Table 7 are somewhat difficult to make due to the differing approaches taken for sourcing the aquatic toxicity data. However, the benchmarks presented in Table 8 are within the same order of magnitude as the corresponding values presented in Table 7. With respect to the BTEX sediment screening levels, there is reasonably good agreement with the narcosis-based benchmarks developed by U.S. EPA (2008) assuming an f_{oc} of 0.01 (i.e., benzene = 6.6 mg/kg dw; toluene = 8.1 mg/kg dw; ethylbenzene = 9.7 mg/kg dw; m-xylene = 9.8 mg/kg dw).

For mixtures of hydrocarbon fractions, such as petroleum products, the response can be predicted with the following algorithm, adapted from the CCME CWS (2008):

$$QG_{PHC} = 1/ [\Sigma (MF_{subfraction\ j} / QG_{subfraction\ j})]$$

Where,

QG_{PHC} = the sediment quality benchmark for gasoline or diesel/#2 or #6 oil/lube (mg/kg dry weight);
$MF_{subfraction\ j}$ = the mass fraction of each sub-fraction within gasoline or diesel/#2 or #6 oil/lube; and,
$QG_{subfraction\ j}$ = the sediment benchmark for each sub-fraction within gasoline or diesel/#2 or #6 oil/lube (mg/kg dry weight).

This approach was applied to the development of sediment toxicity benchmarks for gasoline, diesel/#2, and #6 oil/lube. The PETROTOX model output provides the toxic units (TUs) for each petroleum hydrocarbon block that contributes to the toxicity endpoint. This toxic unit reflects the predicted exposure (predicted concentration of the fraction in the surface water) and the predicted toxicity. Both the acute and chronic benchmark values were back-calculated for each petroleum hydrocarbon block and used to calculate the final sediment toxicity benchmarks listed in **Table 12**. For the final ecological screening levels, the HC5 value was selected for screening “typical” sediment and the HC50 was selected for screening “other” sediment (see definitions in Protocol document). A sample calculation is presented Section 6.

Table 10 Final Sediment Toxicity Benchmarks for Modified TPH by Product – Gasoline, Diesel/#2 Oil, and #6 Oil/Lube (mg/kg dry at 1% foc)

Petroleum Product	Chronic Sediment Benchmarks - Narcosis (HC_5)	Chronic Sediment Benchmarks – Narcosis (HC_{50})	Acute Sediment Benchmarks - Narcosis (LC_{50} rainbow trout)
Gasoline	15.2	67.4	130
Diesel/#2	25.3	112	217
#6 oil/lube	43.3	192	372

As noted in the Table 9, the assumed sediment fraction organic carbon (f_{oc}) was 0.01. For other values of f_{oc}, the benchmarks will change proportionally. For example, with $f_{oc} = 0.04$, the benchmarks increase by 4-fold.

5.3 Non-Narcosis Sediment Benchmarks

Although narcosis is recognized as a major mode of action for petroleum hydrocarbon toxicity in sediment-dwelling organisms, there is also the potential for other toxic effects to occur in sediment. For example, petroleum hydrocarbon presence in sediments may result in such effects as oxygen depletion or physical soiling of organisms. There are no models available to predict these types of effects. Rather, these potential effects are not specific to a given petroleum hydrocarbon fraction or product, but reflect the total amount of petroleum hydrocarbons present. For these types of effects field studies provide the best basis for identifying a sediment benchmark for total petroleum hydrocarbons (TPH).

Based on the weight of evidence from the available field studies (summarized in Section 4.4), the benchmark selected was 500 mg TPH/kg dry weight of sediment. This would be the maximum screening level recommended. For example, if the screening level for individual products are adjusted for foc and the adjusted value exceeds 500 mg/kg, then 500 mg/kg would become the screening level.

5.4 Field Studies on Effects of Petroleum Hydrocarbons in Sediments

Field studies may be based upon gradients of exposure to petroleum hydrocarbons that are present in the environment due to historical spills or ongoing chronic releases, or may be based upon experimental additions of hydrocarbons to test plots or other experimental units.

Nance (1991) studied natural benthic invertebrate assemblages exposed to a gradient of weathered crude oil in New Bayou, Texas, a tidal estuary containing a discharge point for produced water from oil and gas production activities. Local TPH concentrations of more than 10,000 mg/kg were observed in sediments, although most sampling stations had TPH concentrations less than 1000 mg/kg. A sediment TPH concentration of 2500 mg/kg was found to reflect the average value needed to depress population abundance, which was markedly depressed in the vicinity of the produced water outfall, although a zone of stimulated abundance was found both upstream and downstream from the discharge point. Community diversity showed a similar threshold concentration for effects of TPH. Overall, Nance (1991) concluded that areas characterized as within the zone of depression had average sediment TPH concentrations above 2000 mg/kg. Moderate depression effects were observed at TPH concentrations between 2000 and 3500 mg/kg, while major depression effects were observed at those stations that had TPH concentrations above 5000 mg/kg. Nance (1991) estimated that within New Bayou, the zone of stimulation (based upon the abundance of benthic invertebrates) was approximately five times larger than the zone of depression, and that the benthic gain (again based upon abundance of benthic invertebrates) overshadowed the benthic loss by a factor of about 2.2.

Rozas et al. (2000) seasonally sampled fish and benthic invertebrates exposed to weathered TPH originating from spills of gasoline, home heating oil and crude oil present in salt marshes of upper Galveston Bay, Texas. Concentrations of TPH were generally low (approximately 75% of samples contained TPH concentrations <200 mg/kg), although TPH concentrations up to 7833 mg/kg were measured. They found potential relationships between sediment TPH and abundance for very few species of fish or invertebrates. Of 30 abundant taxa examined in fall, only one species (marsh grass shrimp) showed a significant negative relationship with sediment TPH. In contrast, significant positive relationships were found between infaunal densities and TPH concentration for total annelids, total oligochaetes, and Streblospio benedicti. In spring, 33 taxa were examined and significant negative relationships between abundance and sediment TPH concentration were found for four taxa (including two life stages of the brackish grass shrimp, and two species of annelid), and positive relationships were found for one polychaete, the mollusk Geukensia demissa, and total mollusks. It was concluded that background levels (generally <500 mg/kg) of weathered TPH in marsh sediments did not affect habitat use by most estuarine organisms.

Pettigrove and Hoffmann (2005) added synthetic motor oil to clean sediments to simulate hydrocarbon pollution in urban streams, and to study the effects of high molecular weight (>C16) hydrocarbons on benthic invertebrate communities. They found that threshold effects (depressed abundance of sensitive species) began at a concentration of 860 mg/kg, and that TPH concentrations ranging from 1858 to 14,266 mg/kg resulted in a significant reduction in the total numbers of taxa and abundance. Based upon these results, they concluded that low level (860 mg/kg) TPH-polluted sediments might increase the abundance of opportunistic species, whereas TPH concentrations between 860 and 1870 mg/kg are likely to reduce the abundance of TPH pollution-sensitive taxa. TPH concentrations greater than 1870 mg/kg were considered likely to lead to more substantial losses in species presence and abundance. Pettigrove and Hoffmann (2005) also hypothesized that TPH concentrations between 860 and 1870 mg/kg would severely affect predatory organisms that directly or indirectly rely on benthic invertebrates as a source of food. A TPH concentration of 840 mg/kg was proposed by these authors as an interim guideline value to indicate possible ecological impairment.

Anson et al. (2008) furthered the work of Pettigrove and Hoffman (2005) by testing a broader range of petroleum hydrocarbon products under similar conditions. They concluded that the proposed guideline of 840 mg/kg remained valid. Some naturally occurring organic wetland sediments sampled contained substances that resembled TPH, although they did not appear to cause adverse effects on the benthic invertebrate community. Anson et al. (2008) recommended that sediments found to exceed the benchmark value of 840 mg/kg should be further tested to separate potentially benign biogenic sources of hydrocarbons from potentially detrimental anthropogenic TPH.

5.5 Laboratory Reporting Detection Limit Considerations for Sediment Analyses

A survey of two commercial environmental analytical labs in Atlantic Canada has determined that the reporting detection limits (RDL) for petroleum hydrocarbons in sediment using the Atlantic PIRI method are typically as follows:

- Benzene : 0.03 mg/kg
- Toluene: 0.04 mg/kg
- Ethyl Benzene: 0.03 mg/kg
- Xylenes: 0.05 mg/kg
- >C6-C10: 3 mg/kg
- >C10-C16: 15 mg/kg
- >C16-C21 : 15 mg/kg
- >C21-C32: 15 mg/kg
- Modified TPH (equals all TPH less BTEX) : 15 mg/kg

As with the water benchmarks, in order to avoid problems with false positives during use of this protocol, no Tier 1 screening level was set below these RDLs.

5.6 Sediment Toxicity Testing

Although the PETROTOX Model and available field studies provide a reasonable approach for the derivation of sediment quality benchmarks, the paucity of aquatic toxicity data for petroleum hydrocarbon mixtures provides little opportunity to validate the calculated benchmarks. In order to address this data gap, laboratory studies were conducted to determine the toxicity of two petroleum products, #2 Oil (Winter Diesel) and #6 Oil (Bunker C), to two freshwater benthic invertebrates, *Hyalella azteca* and *Chironomus dilutus*. These studies followed standard methods including OECD Method 218 (OECD, 2004), and Environment Canada's Biological Test Methods EPS 1/RM/32 (Environment Canada 1997a) and EPS 1/RM/33 (Environment Canada 1997b). The complete report, including details of the methodology, results and data analysis is provided posted on the Atlantic PIRI website (http://www.atlanticrbca.com/).

For each toxicity test, a formulated sediment was employed. The approximate composition of this sediment is provided in the following table (**Table 13**). In order to achieve the desired concentration of the PHC contaminant, a known weight of pre-conditioned sediment was spiked with the appropriate weight of either #2 or #6 Oil, mixed thoroughly and then aged for an additional 4 weeks as per OECD Method 218 (OECD, 2004).

Table 11 Physical Chemical Characteristics of Formulated Sediment used in PHC Toxicity Testing

Sediment	f_{oc}	% Moisture	% Particle Size			
			Gravel	Sand	Silt	Clay
Formulated	0.03	27	0	72	9	19

Chemical analysis of the prepared, spiked sediment was conducted in order to test for homogeneity of the PHC contamination, and confirmation of the exposure concentrations resulting from the serial dilutions. Replicate samples taken from the prepared sediment showed good agreement with confidence values typically being less then 20% of the mean. It was therefore concluded that the sample mixing and aging provided a suitably homogenous mixture.

Comparisons of nominal and measured TPH concentrations from the exposure concentrations provided a measure of % recovery that ranged from 50 to 100%. The lowest recoveries seemed to be associated with the highest TPH concentrations of the range-finding studies. Recoveries of greater then 100% were noted at the very low TPH concentrations but this was likely the product of limitations with detection and other analytical uncertainties. Within the range of TPH concentrations used for the definitive tests, the measured concentrations of #2 Oil were typically 60 to 85% of the nominal concentration, while with #6 Oil the measure concentration was approximately 67% of nominal. The uncertainty associated with this discrepancy is discussed in the following sections.

A sub-set of the definitive toxicity studies were conducted using both a static exposure (with aeration) approach, and a static-renewal (without aeration) approach. This strategy was employed in order to better understand the effect of these modifiers on the response of the organisms, and the fate of the more volatile components of the #2 Oil being tested. In each case, there was no significant difference in the organism's response or the measured TPH concentrations from samples taken from the exposure chambers at the completion of the exposure time. As a result, all of the dose-response data was used in the subsequent validation of the Petrotox sediment quality benchmarks. A summary of the results from the toxicity tests is provided in the **Tables 14** **and 15**.

The reported LC_{50}s from the toxicity tests were used to represent the acute endpoint. Given the difference between the nominal and measured contaminant concentrations in the exposure chambers, the LC_{50}s were provided based on both in order to illustrate the potential uncertainty (see Table 14). The confidence limits associated with each LC_{50} are provided in brackets. The final column in the table lists the associated acute sediment toxicity benchmarks for the respective PHC, corrected for the higher foc used in the formulated sediments. A comparison of PETROTOX-derived acute sediment benchmarks based on the 5th percentile of the LC_{50}s derived from the toxicity tests shows good agreement. The corrected benchmark for #2 Oil from the PETROTOX model was typically within the range of confidence limits based on the nominal concentrations. It was slightly elevated compared to the LC_{50}s based on the measured PHC concentrations but the greatest difference was only 2-fold. Given the range of uncertainties represented by the confidence limits and the added uncertainty between the nominal and the measured exposure concentrations, this difference was not considered significant. For the #6 Oil, the modelled PETROTOX benchmark showed good agreement with both the LC_{50} expressed with nominal concentrations and the LC_{50} based on measured concentrations.

Table 12 Summary of Acute Toxicity Endpoints from the Sediment Toxicity Studies and the Predicted Toxicities using the PETROTOX Model

Oil Type	Species	Test Type	LC_{50} (mg/kg Modified TPH)		PETROTOX Acute (mg/kg Modified TPH) at foc of 0.03
			Nominal	Measured	
#2 Oil	*H. azteca*	Static	278 (242 to 319)	235 (204 to 270)	336
	H. azteca	Static Renewal	191 (100 to 400)	115 (60 to 240)	
	C. dilutus	Static	301 (239 to 362)	179 (143 to 217)	
#6 Oil	*H. azteca*	Static	633 (451 to 999)	427 (304 to 670)	576

As indicated, the acute toxicity benchmarks from the Petrotox model used the 5th percentile of LC_{50}s from 43 species of aquatic organisms thus focusing on the most sensitive species available. Both *H. azteca* and *C. dilutus* are known to be relatively sensitive to contaminants in the sediment and thus represent suitable test organisms for the development of sediment quality benchmarks but there was no direct relationship between these benthic invertebrates and the 5th percentile species from the PETROTOX model. The excellent agreement between these two endpoints provides good validation of the PETROTOX derived benchmark and strongly supports that it is neither significantly over or under conservative.

To represent the chronic, sublethal endpoint, the reported IC_{25}s were based on biomass used (see Table 15). The IC_{25}s based on growth were unreliable and in many cases could not be appropriately quantified. As with the LC_{50}s, the IC_{25}s were provided based on both the nominal and measured exposure concentrations in order to illustrate the potential uncertainty. The confidence limits associated with each of the IC_{25}s are provided in brackets, with the final column in the table listing the associated chronic sediment toxicity benchmarks from the PETROTOX model (i.e., the 5th percentile of the chronic sensitivity curve). Again, each was corrected for the higher f_{oc} used in the formulated sediments.

Table 13 Summary of Chronic Toxicity Endpoints from the Sediment Toxicity Studies and the Predicted Toxicities using the PETROTOX Model

Oil Type	Species	Test Type	IC_{25} (mg/kg Modified TPH)		PETROTOX Chronic (mg/kg Modified TPH) at f_{oc} of 0.03
			Nominal	Measured	
#2 Oil	*H. azteca*	Static	133 (32 to 172)	113 (27 to 146)	76
	H. azteca	Static Renewal	125 (89 to 212)	74 (53 to 127)	
	C. dilutus	Static	89 (61 to 121)	53 (37 to 73)	
#6 Oil	*H. azteca*	Static	<50 / 200*	<50 / 130*	130

A comparison of the PETROTOX derived chronic sediment benchmarks with the IC_{25}s derived from the toxicity tests, again showed good agreement. The corrected Modified TPH benchmarks for both the #2 and #6 Oil from the PETROTOX model were typically within the range of confidence limits based on the nominal and measured concentrations. It is important to note that for the #6 Oil, the initial IC_{25}s were reported as <50 mg/kg nominal Modified TPH concentration, indicating that the effect on biomass was above the 25% effect level at the lowest exposure concentration. However, as pointed out in the Toxicity Test report, the control biomass of *H. azteca* was unusually high, being almost twice that observed in the other controls despite being left under the same conditions. If the more typical biomass level was applied to results of the #6 Oil chronic toxicity results then the IC_{25} was approximately 200 mg/kg nominal and 130 mg/kg based on the measured TPH concentrations. Again, this was in good agreement with the chronic toxicity benchmark predicted for #6 Oil using the PETROTOX model.

As with the acute endpoints, the excellent agreement provides validation of the PETROTOX-derived benchmarks and strongly supports that it is neither significantly over or under conservative.

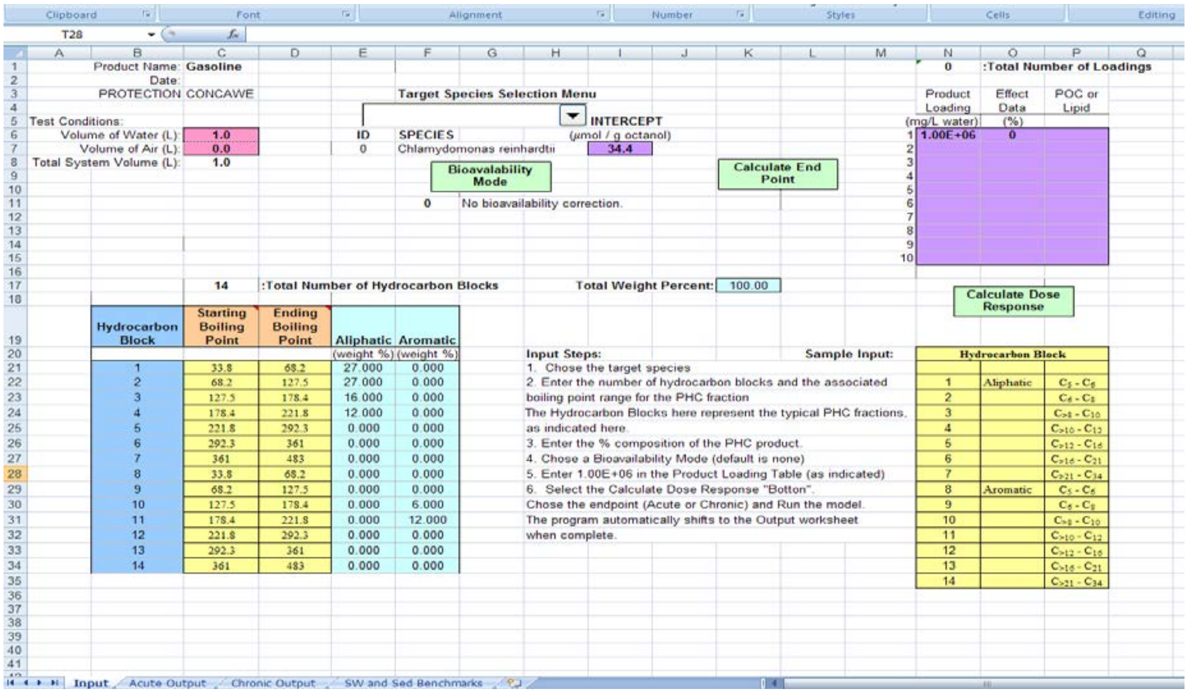
The acute and chronic endpoints from the toxicity tests can also be used to calculate the critical body residues, which provide further validation of the narcosis theory used in the PETROTOX model. Using the Hyalella 14-d LC_{50} mortality of 235 mg/kg dry (based on measured TPH) and the 14-d EC25 biomass of 113 mg/kg dry, an ACR of 2.1 is obtained. For the chironomids, the 10 d-LC_{50} was 179 mg/kg dry while the 10-d EC_{25}

biomass was 53 mg/kg dry with an ACR of 3.4. The acute to chronic ratio is low in both cases and consistent with the target lipid model where ACRs range from 1 to 10 for single hydrocarbons. Given the organic carbon fraction of the sediment was measured to be 0.03 and assuming an average molecular weight of hydrocarbons in #2 fuel oil of 250 g/mol, the chronic EC_{25} for *H. azteca* and *C. dilutus* are 15 and 7 mmol/kg OC. Assuming equilibrium between OC and organism lipid (i.e. mmol/kg OC = mmol/kg lipid) these values provide an estimate of organism body burdens. The target lipid model indicates chronic effects in the range of 5 to 100 mmol/kg lipid and the results from the toxicity test for #2 Oil fall within this range.

If the same calculation is performed on the corrected IC25s from the toxicity tests using #6 Oil a body burden of 14 mmol/kg OC is obtained. Again, this was based on a f_{oc} of 0.03 and an assumed average molecular weight of 300 mg/mol for the heavier product. As with the #2 Oil this agrees with the assumptions of the narcosis theory.

The objective of the sediment toxicity studies using the #2 and #6 Oils were to provide a degree of validation of the PETROTOX-derived sediment benchmarks based on actual dose-response relationships involving benthic organisms exposed to petroleum hydrocarbon products. Insufficient data was collected in order to derive sediment benchmarks based solely on the results of the toxicity tests, as this was not the objective. The lack of toxicity data specific to petroleum hydrocarbon products remains a significant data gap, which contributes a significant amount of uncertainty to both the interpretation of the sediment toxicity tests and the application of the PETROX model. However, the use of the PETROTOX model to predict surface water and sediment quality benchmarks protective of aquatic species represents the best, most available and practical means, and this approach was maintained for the purposes of this protocol. The value of this model and the accuracy of its predictions were further validated by the strong agreement with the associated toxicity endpoints from the sediment toxicity studies.

6.0 SAMPLE CALCULATIONS FOR THE DERIVATION OF ACUTE AND CHRONIC SURFACE WATER AND SEDIMENT BENCHMARKS USING THE PETROTOX MODEL AND AN INFINITE LOADING SCENARIO



Product Name: **Gasoline**
Date:
PROTECTION CONCAWE

Test Conditions:
Volume of Water (L): 1.0
Volume of Air (L): 0.0
Total System Volume (L): 1.0

Target Species Selection Menu

ID	SPECIES	INTERCEPT (µmol / g octanol)
0	Chlamydomonas reinhardtii	34.4

0 No bioavailability correction.

0 :Total Number of Loadings

	Product Loading (mg/L water)	Effect Data (%)	POC or Lipid
1	1.00E+06	0	
2			
3			
4			
5			
6			
7			
8			
9			
10			

14 :Total Number of Hydrocarbon Blocks

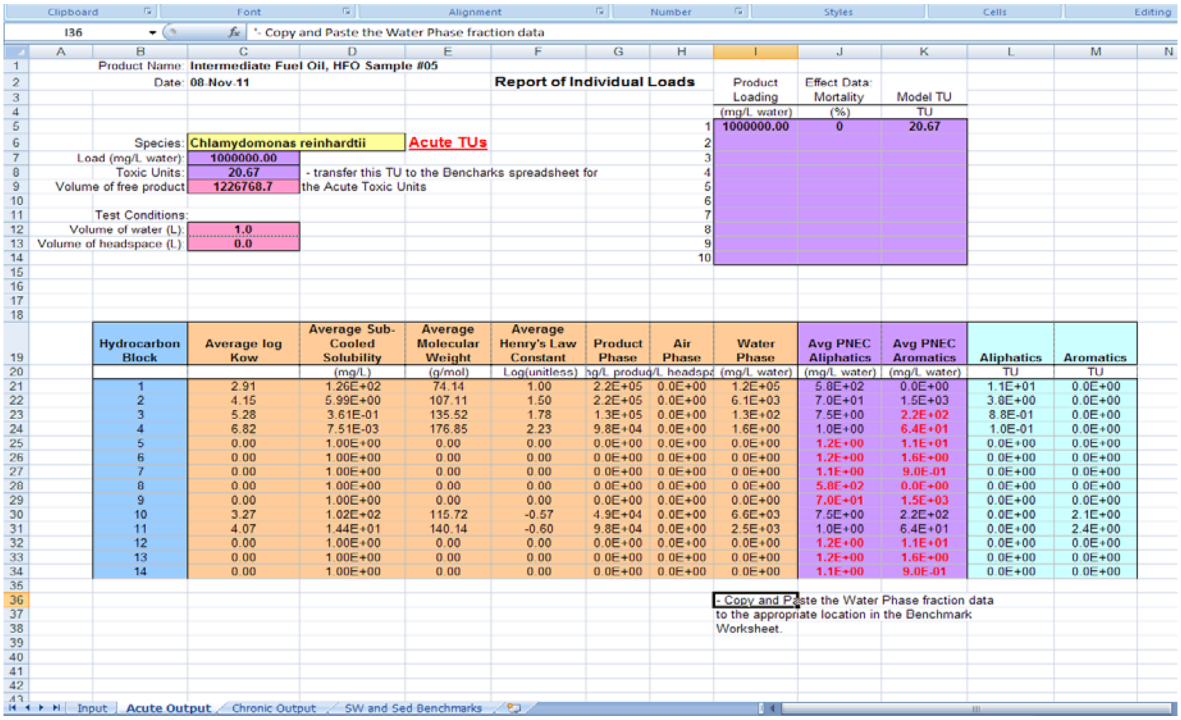
Total Weight Percent: 100.00

Hydrocarbon Block	Starting Boiling Point	Ending Boiling Point	Aliphatic (weight %)	Aromatic (weight %)
1	33.8	68.2	27.000	0.000
2	68.2	127.5	27.000	0.000
3	127.5	178.4	16.000	0.000
4	178.4	221.8	12.000	0.000
5	221.8	292.3	0.000	0.000
6	292.3	361	0.000	0.000
7	361	483	0.000	0.000
8	33.8	68.2	0.000	0.000
9	68.2	127.5	0.000	0.000
10	127.5	178.4	0.000	6.000
11	178.4	221.8	0.000	12.000
12	221.8	292.3	0.000	0.000
13	292.3	361	0.000	0.000
14	361	483	0.000	0.000

Input Steps:
1. Chose the target species
2. Enter the number of hydrocarbon blocks and the associated boiling point range for the PHC fraction
The Hydrocarbon Blocks here represent the typical PHC fractions, as indicated here.
3. Enter the % composition of the PHC product.
4. Chose a Bioavailability Mode (default is none)
5. Enter 1.00E+06 in the Product Loading Table (as indicated)
6. Select the Calculate Dose Response "Botton".
Chose the endpoint (Acute or Chronic) and Run the model.
The program automatically shifts to the Output worksheet when complete.

Sample Input:

Hydrocarbon Block		
1	Aliphatic	C_5 - C_6
2		C_6 - C_8
3		$C_{>8}$ - C_{10}
4		$C_{>10}$ - C_{12}
5		$C_{>12}$ - C_{16}
6		$C_{>16}$ - C_{21}
7		$C_{>21}$ - C_{34}
8	Aromatic	C_5 - C_6
9		C_6 - C_8
10		$C_{>8}$ - C_{10}
11		$C_{>10}$ - C_{12}
12		$C_{>12}$ - C_{16}
13		$C_{>16}$ - C_{21}
14		$C_{>21}$ - C_{34}



'- Copy and Paste the Water Phase fraction data

Product Name: **Intermediate Fuel Oil, HFO Sample #05**
Date: 08-Nov-11

Report of Individual Loads

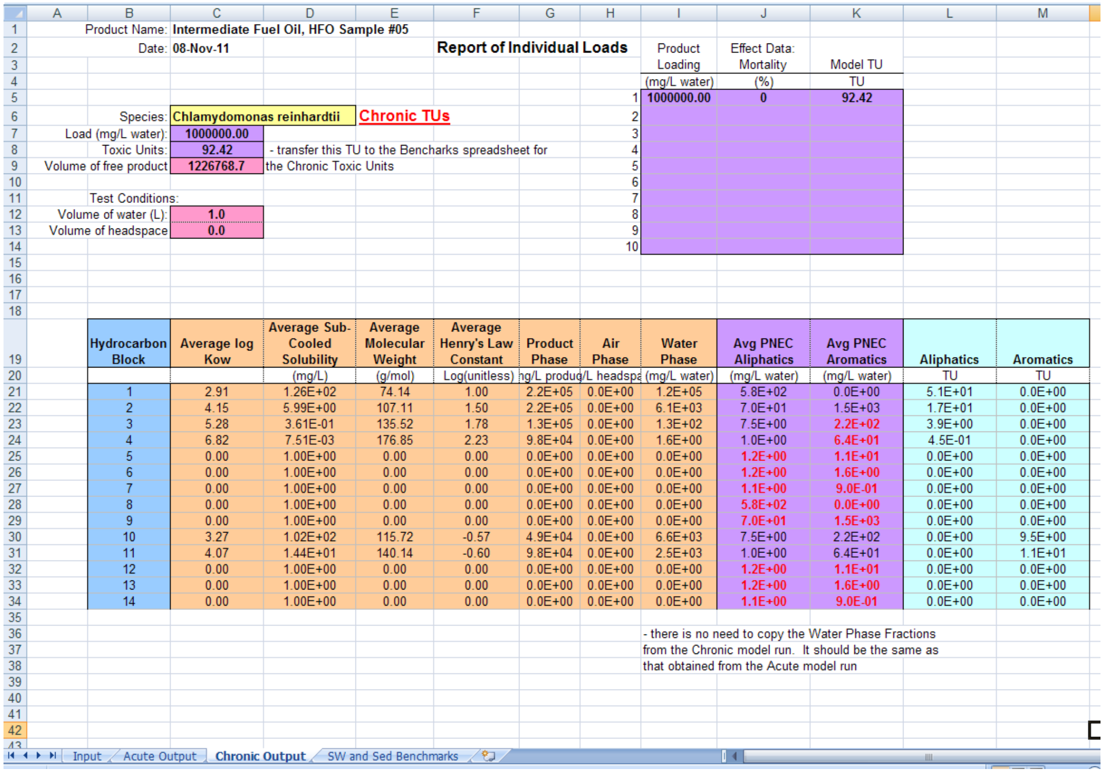
Species: **Chlamydomonas reinhardtii** **Acute TUs**
Load (mg/L water): 1000000.00
Toxic Units: 20.67 - transfer this TU to the Bencharks spreadsheet for the Acute Toxic Units
Volume of free product 1226768.7

Test Conditions:
Volume of water (L): 1.0
Volume of headspace (L): 0.0

	Product Loading (mg/L water)	Effect Data: Mortality (%)	Model TU TU
1	1000000.00	0	20.67
2			
3			
4			
5			
6			
7			
8			
9			
10			

Hydrocarbon Block	Average log Kow	Average Sub-Cooled Solubility (mg/L)	Average Molecular Weight (g/mol)	Average Henry's Law Constant Log(unitless)	Product Phase hg/L produc	Air Phase /L headspa	Water Phase (mg/L water)	Avg PNEC Aliphatics (mg/L water)	Avg PNEC Aromatics (mg/L water)	Aliphatics TU	Aromatics TU
1	2.91	1.26E+02	74.14	1.00	2.2E+05	0.0E+00	1.2E+05	5.8E+02	0.0E+00	1.1E+01	0.0E+00
2	4.15	5.99E+00	107.11	1.50	2.2E+05	0.0E+00	6.1E+03	7.0E+01	1.5E+03	3.8E+00	0.0E+00
3	5.28	3.61E-01	135.52	1.78	1.3E+05	0.0E+00	1.3E+02	7.5E+00	2.2E+02	8.8E-01	0.0E+00
4	6.82	7.51E-03	176.85	2.23	9.8E+04	0.0E+00	1.6E+00	1.0E+00	6.4E+01	1.0E-01	0.0E+00
5	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.1E+01	0.0E+00	0.0E+00
6	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.6E+00	0.0E+00	0.0E+00
7	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.1E+00	9.0E-01	0.0E+00	0.0E+00
8	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	5.8E+02	0.0E+00	0.0E+00	0.0E+00
9	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	7.0E+01	1.5E+03	0.0E+00	0.0E+00
10	3.27	1.02E+02	115.72	-0.57	4.9E+04	0.0E+00	6.6E+03	7.5E+00	2.2E+02	0.0E+00	2.1E+00
11	4.07	1.44E+01	140.14	-0.60	9.8E+04	0.0E+00	2.5E+03	1.0E+00	6.4E+01	0.0E+00	2.4E+00
12	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.1E+01	0.0E+00	0.0E+00
13	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.6E+00	0.0E+00	0.0E+00
14	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.1E+00	9.0E-01	0.0E+00	0.0E+00

- Copy and Paste the Water Phase fraction data to the appropriate location in the Benchmark Worksheet.



Product Name: **Intermediate Fuel Oil, HFO Sample #05**

Date: **08-Nov-11**

Report of Individual Loads

	Product Loading (mg/L water)	Effect Data: Mortality (%)	Model TU TU
1	**1000000.00**	**0**	**92.42**
2			
3			
4			
5			
6			
7			
8			
9			
10			

Species: **Chlamydomonas reinhardtii** **Chronic TUs**

Load (mg/L water): **1000000.00**

Toxic Units: **92.42** - transfer this TU to the Bencharks spreadsheet for the Chronic Toxic Units

Volume of free product **1226768.7**

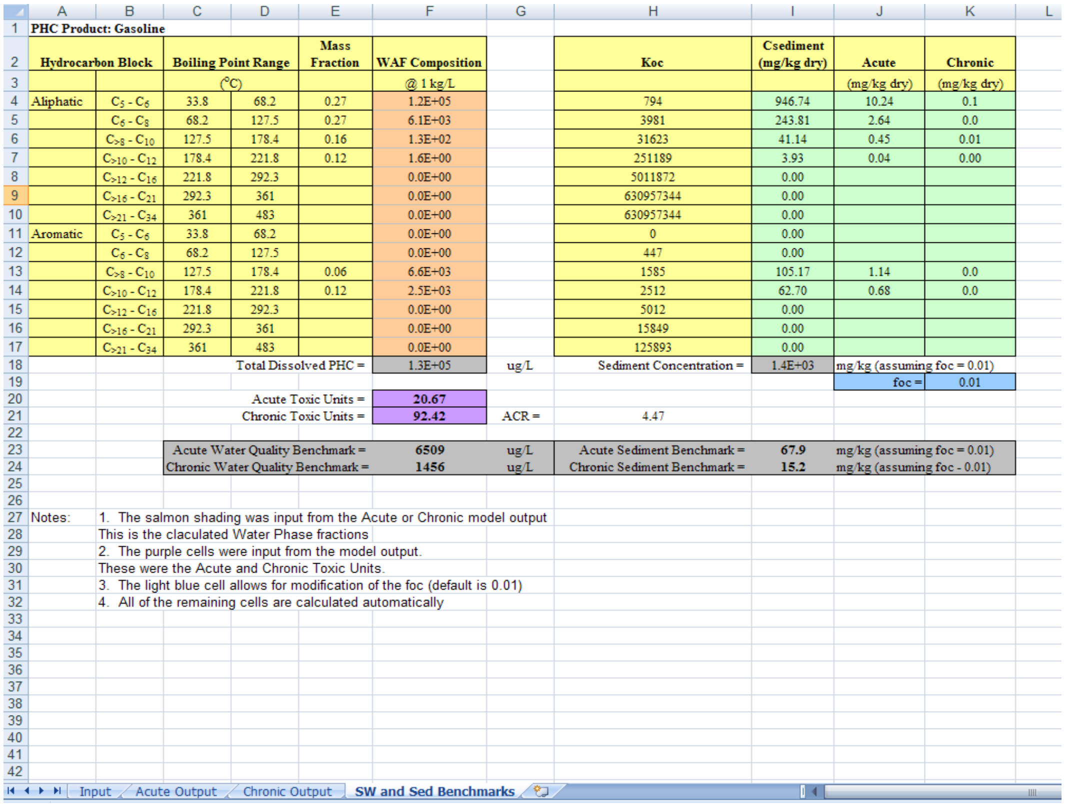
Test Conditions:

Volume of water (L): **1.0**

Volume of headspace **0.0**

Hydrocarbon Block	Average log Kow	Average Sub-Cooled Solubility	Average Molecular Weight	Average Henry's Law Constant	Product Phase	Air Phase	Water Phase	Avg PNEC Aliphatics	Avg PNEC Aromatics	Aliphatics	Aromatics
		(mg/L)	(g/mol)	Log(unitless)	ng/L produc	/L headspa	(mg/L water)	(mg/L water)	(mg/L water)	TU	TU
1	2.91	1.26E+02	74.14	1.00	2.2E+05	0.0E+00	1.2E+05	5.8E+02	0.0E+00	5.1E+01	0.0E+00
2	4.15	5.99E+00	107.11	1.50	2.2E+05	0.0E+00	6.1E+03	7.0E+01	1.5E+03	1.7E+01	0.0E+00
3	5.28	3.61E-01	135.52	1.78	1.3E+05	0.0E+00	1.3E+02	7.5E+00	2.2E+02	3.9E+00	0.0E+00
4	6.82	7.51E-03	176.85	2.23	9.8E+04	0.0E+00	1.6E+00	1.0E+00	6.4E+01	4.5E-01	0.0E+00
5	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.1E+01	0.0E+00	0.0E+00
6	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.6E+00	0.0E+00	0.0E+00
7	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.1E+00	9.0E-01	0.0E+00	0.0E+00
8	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	5.8E+02	0.0E+00	0.0E+00	0.0E+00
9	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	7.0E+01	1.5E+03	0.0E+00	0.0E+00
10	3.27	1.02E+02	115.72	-0.57	4.9E+04	0.0E+00	6.6E+03	7.5E+00	2.2E+02	0.0E+00	9.5E+00
11	4.07	1.44E+01	140.14	-0.60	9.8E+04	0.0E+00	2.5E+03	1.0E+00	6.4E+01	0.0E+00	1.1E+01
12	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.1E+01	0.0E+00	0.0E+00
13	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.2E+00	1.6E+00	0.0E+00	0.0E+00
14	0.00	1.00E+00	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	1.1E+00	9.0E-01	0.0E+00	0.0E+00

- there is no need to copy the Water Phase Fractions from the Chronic model run. It should be the same as that obtained from the Acute model run



PHC Product: Gasoline

Hydrocarbon Block		Boiling Point Range		Mass Fraction	WAF Composition	Koc	Csediment (mg/kg dry)	Acute	Chronic
		(°C)			@ 1 kg/L			(mg/kg dry)	(mg/kg dry)
Aliphatic	C_5 - C_6	33.8	68.2	0.27	1.2E+05	794	946.74	10.24	0.1
	C_6 - C_8	68.2	127.5	0.27	6.1E+03	3981	243.81	2.64	0.0
	$C_{>8}$ - C_{10}	127.5	178.4	0.16	1.3E+02	31623	41.14	0.45	0.01
	$C_{>10}$ - C_{12}	178.4	221.8	0.12	1.6E+00	251189	3.93	0.04	0.00
	$C_{>12}$ - C_{16}	221.8	292.3		0.0E+00	5011872	0.00		
	$C_{>16}$ - C_{21}	292.3	361		0.0E+00	630957344	0.00		
	$C_{>21}$ - C_{34}	361	483		0.0E+00	630957344	0.00		
Aromatic	C_5 - C_6	33.8	68.2		0.0E+00	0	0.00		
	C_6 - C_8	68.2	127.5		0.0E+00	447	0.00		
	$C_{>8}$ - C_{10}	127.5	178.4	0.06	6.6E+03	1585	105.17	1.14	0.0
	$C_{>10}$ - C_{12}	178.4	221.8	0.12	2.5E+03	2512	62.70	0.68	0.0
	$C_{>12}$ - C_{16}	221.8	292.3		0.0E+00	5012	0.00		
	$C_{>16}$ - C_{21}	292.3	361		0.0E+00	15849	0.00		
	$C_{>21}$ - C_{34}	361	483		0.0E+00	125893	0.00		

Total Dissolved PHC = 1.3E+05 ug/L

Sediment Concentration = 1.4E+03 mg/kg (assuming foc = 0.01)

foc = 0.01

Acute Toxic Units = **20.67**

Chronic Toxic Units = **92.42** ACR = 4.47

Acute Water Quality Benchmark = **6509** ug/L

Chronic Water Quality Benchmark = **1456** ug/L

Acute Sediment Benchmark = **67.9** mg/kg (assuming foc = 0.01)

Chronic Sediment Benchmark = **15.2** mg/kg (assuming foc - 0.01)

Notes:

1. The salmon shading was input from the Acute or Chronic model output
This is the claculated Water Phase fractions
2. The purple cells were input from the model output.
These were the Acute and Chronic Toxic Units.
3. The light blue cell allows for modification of the foc (default is 0.01)
4. All of the remaining cells are calculated automatically

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