DEPARTMENT OF ECOLOGY
State of Washington

Evaluating the Human Health Toxicity of Carcinogenic PAHs (cPAHs) Using Toxicity Equivalency Factors (TEFs)

Implementation Memorandum #10

To: Interested Persons

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Purpose of this Memorandum

This implementation memorandum describes the procedures for evaluating compliance of environmental samples containing carcinogenic polycyclic aromatic hydrocarbon (cPAH) mixtures using toxicity equivalency factors (TEFs) to estimate human health toxicity, as required by WAC 173-340-708(8)(e) in the Model Toxics Control Act (MTCA) rule.

Introduction

WAC 173-340-200 defines cPAHs as the polycyclic aromatic hydrocarbons identified as Group A (known human) or B (probable human) carcinogens by the U.S. Environmental Protection Agency (EPA). For petroleum-contaminated sites, these include at a minimum: benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene. [1]

The Washington State Department of Ecology (Ecology) uses TEFs to evaluate the toxicity and assess the risks for environmental mixtures of dioxins and furans, dioxin-like polychlorinated biphenyls, and cPAHs. The TEF method used in MTCA is based on a concept developed by the

[1] Ecology may also require inclusion of the additional cPAHs in Table 708-3 in WAC 173-340-900 if site testing data or information from other comparable sites or waste types indicates the additional compounds are potentially present at the site. As of the date of this guidance, Ecology has not required inclusion of these additional cPAHs at contaminated sites.

EPA. The method evaluates the toxicity and assesses the risks of a mixture of structurally-related chemicals that cause the same human health effect through the same biological process or "mechanism of action" (in this case, cancer triggered by the cPAH binding to the same molecular receptor in the cell). [2]

A TEF is an estimate of the toxicity of a chemical relative to that of a **reference chemical.** For mixtures of cPAHs, the reference chemical is **benzo(a)pyrene.** Benzo(a)pyrene was chosen as the reference chemical because its toxicity is well characterized. Thus, the TEF for each cPAH is an estimate of that cPAH's toxicity relative to that of benzo(a)pyrene.

The policies and procedures described in this memo for applying TEFs to cPAHs are intended to provide guidance for implementing WAC 173-340-708(8)(e) in the Model Toxics Control Act (MTCA) rule which requires that:

- Mixtures of cPAHs be considered a single hazardous substance when establishing and determining compliance with cleanup levels. This means that a target cancer risk level of one in one million (1×10^{-6}) is used for the whole mixture when calculating cleanup levels under Method B, and one in one hundred thousand (1×10^{-5}) under Method C.
- The TEFs in Table 708-2 (and Table 708-3, if applicable) be used to evaluate the toxicity of these mixtures.
- The physical-chemical properties of individual cPAHs be used when evaluating cross-media impacts such as leaching of cPAHs from soil to groundwater.

Although there are toxicity values available in EPA's IRIS database for some cPAHs, the MTCA rule requires that TEFs be used when determining compliance with cleanup levels for cPAH mixtures. The cPAHs at a minimum that must be analyzed for and included in the calculations, and their respective TEFs, are listed in Table 1.

Table 1. Toxicity equivalency factors (TEFs) for the minimum required carcinogenic polycyclic aromatic hydrocarbons under WAC 173- 340-708(e) (from Table 708-2 in WAC 173-340-900)

CAS Number	cPAH	TEF (Unitless)
50-32-8	Benzo(a)pyrene	1
56-55-3	Benzo(a)anthracene	0.1
205-99-2	Benzo(b)fluoranthene	0.1
207-08-9	Benzo(k)fluoranthene	0.1
218-01-9	Chrysene	0.01
53-70-3	Dibenz(a,h)anthracene	0.1
193-39-5	Indeno(1,2,3-cd)pyrene	0.1

[2] EPA uses the term "Relative Potency Factor" for cPAHs. See: *Development of a Relative Potency Factor (RPF) Approach for Polycyclic Aromatic Hydrocarbon (PAH) Mixtures*, EPA/635/R-08/012A, February, 2010 Review Draft.

Using TEFs to Evaluate the Human Health Toxicity of cPAH Mixtures

To evaluate the human health toxicity of a cPAH mixture, the chemical concentrations of the cPAHs in the mixture are converted to an equivalent concentration of benzo(a)pyrene. This calculation can be expressed mathematically, below. This formula applies to any medium, but is used most commonly for soil and groundwater samples. For notation purposes, the result is referred here as the "total toxic equivalent concentration" or "Total TEQ."

Total TEQ = $\sum C_n * TEF_n$

Where:

Total TEQ	=	Total Toxic Equivalent Concentration of a cPAH mixture [3]
Cn	=	Concentration of the individual cPAH in the mixture
TEFn	=	Toxicity equivalency factor for the individual cPAH in the mixture

The following steps describe how to determine the Total TEQ for a mixture of cPAHs in a sample, and how to use this value to evaluate compliance (see Examples 1 and 2):

1. Analyze the sample to determine the concentration of each cPAH.
2. Multiply each cPAH concentration in the sample by its corresponding TEF from Table 1, above. This provides a toxic equivalent concentration (TEQ) for each cPAH.
3. Add the products in step 2 to obtain the Total TEQ for the sample.
4. Either look up or calculate a cleanup level for benzo(a)pyrene for the medium of concern (e.g. groundwater or soil). [4]
5. To evaluate compliance, compare the Total TEQ for the sample with the applicable cleanup level for benzo(a)pyrene for the medium being sampled (e.g. soil or groundwater).

Evaluating the Potential for cPAH Mixtures in Soil to Impact Groundwater

When evaluating the potential for cPAH mixtures in soil to impact groundwater, the MTCA rule requires that the physical and chemical properties of individual carcinogenic cPAHs be considered (WAC 173-340-708(8)(e)(iv)). This adds complexity to the above calculation

[3] EPA calls this the "Total Toxicity Equivalence".

[4] Either use a) the Method A cleanup level in Table 720-1 for groundwater, and Tables 740-1 or 745-1 for soil (as appropriate); or b) determine cleanup levels using the equations in MTCA sections 720, 740, or 745. See Ecology's CLARC tables for pre-calculated Method B and C concentrations for groundwater. Because MTCA requires that the soil ingestion AND dermal pathways be evaluated for petroleum mixtures, the soil direct contact value for cPAHs must be calculated using Equations 740-5 (for unrestricted land use) or 745-5 (for industrial land use). These values are not in CLARC and must be calculated using the equations. See Tables 6 and 7 for the results of these calculations using default assumptions.

because both the toxicity and mobility of the individual cPAHs must be considered when determining compliance. There are three ways this can be done:

1. Use the MTCATPH spreadsheet to derive a soil concentration protective of groundwater.
2. Calculate a simplified total "toxic mobility equivalent concentration" that considers both the TEF (for toxicity) and the organic carbon-water partitioning coefficient (Koc) (for mobility) of each cPAH.
3. Use other methods authorized by WAC 173-340-747, such as using a different leaching model or conducting an empirical demonstration. [5]

This approach is typically needed for soil samples at sites with cleanup levels based on industrial land use *because concentrations derived that are protective for the direct contact exposure pathway for industrial land use may not be low enough to be protective of groundwater.*

Method 1: Using the MTCATPH Spreadsheet

To evaluate the potential for cPAH mixtures in soil to cause unacceptable risks in groundwater using the MTCATPH spreadsheet, enter the cPAH data into the spreadsheet and a value of zero for the petroleum fractions and other petroleum compounds. Use the spreadsheet to evaluate if the sample will cause the groundwater to exceed the level of risk acceptable under MTCA. The spreadsheet already factors in the TEFs and relative mobility of the individual cPAHs.

The output from the spreadsheet will be a statement as to whether the sample "passes" (is protective of groundwater) or "fails" (is not protective). Another function on the spreadsheet can be used to back-calculate a soil concentration for the cPAH mixture that would be protective of groundwater.

This spreadsheet and instructions for its use can be found at:
http://www.ecy.wa.gov/programs/tcp/tools/toolmain.html

Method 2: Calculating a Total Toxic Mobility Equivalent Concentration

Another method that can be used to evaluate the potential for cPAH mixtures in soil to impact groundwater is to convert the cPAH mixture to an equivalent concentration of benzo(a)pyrene that accounts for both the toxicity and mobility of the individual cPAH compounds relative to benzo(a)pyrene.

Under this method, the mobility of a cPAH relative to benzo(a)pyrene can be approximated by dividing the Koc for benzo(a)pyrene by the Koc for the cPAH of interest. This "relative mobility factor" can then be used to assess the mobility of individual cPAHs and cPAH mixtures. Relative mobility factors for the cPAHs that must be analyzed for and included in the calculation

[5] These methods are beyond the scope of this memo. Ecology is currently preparing separate guidance on empirical demonstrations.

are presented in Table 3.

The calculation to convert the chemical concentrations in a cPAH mixture to an equivalent concentration of benzo(a)pyrene that factors in both the toxicity and leaching mobility of the individual cPAHs can be expressed mathematically as follows. For notation purposes, the result is referred here as the "total toxic mobility equivalent concentration" or "Total TMEQ."

Total TMEQ = $\sum C_n * TEF_n * RMF_n$

Where:

Total TMEQ	=	Total Toxic Mobility Equivalent Concentration
C_n	=	Concentration of the individual cPAH in the mixture
TEF_n	=	Toxic equivalency factor for the individual cPAH in the mixture (from Table 1)
RMF_n	=	Relative mobility factor for the individual cPAH in the mixture (from Table 2)

Table 2. Relative mobility factors for the minimum required carcinogenic polycyclic aromatic hydrocarbons under WAC 173- 340-708(e)

CAS #	cPAH	Koc [6]	Relative Mobility Factor
50-32-8	Benzo(a)pyrene	968,774	1.00
56-55-3	Benzo(a)anthracene	357,537	2.71
205-99-2	Benzo(b) fluoranthene	1,230,000	0.79
207-08-9	Benzo(k) fluoranthene	1,230,000	0.79
218-01-9	Chrysene	398,000	2.43
53-70-3	Dibenz(a,h)anthracene	1,789,101	0.54
207-08-9	Indeno(1,2,3-cd)pyrene	3,470,000	0.28

Koc = Organic carbon – water partitioning coefficient

Relative mobility factor = Benzo(a)pyrene Koc / cPAH Koc

The following steps describe how to determine the Total TMEQ for mixtures of cPAHs, and how to use this value to evaluate compliance (see Examples 3, 4, and 5):

1. Analyze the sample to determine the concentration of each cPAH.
2. Multiply each cPAH concentration in the sample by its corresponding TEF from Table 1 (above) and its corresponding relative mobility factor from Table 2 (above). This calculates a toxic mobility equivalent concentration (TMEQ) for each cPAH.
3. Add the products in Step 2 to obtain the Total TMEQ for the cPAH mixture.
4. Either look up or calculate a cleanup level for benzo(a)pyrene that is protective of

[6] Source: Koc's for benzo(a)pyrene, benzo(a)anthracene and dibenzo(a,h)anthracene are from Table 747-1 in WAC 173-340-920; the remainder are from the MTCATPH 11 workbook.

groundwater through the leaching pathway. [7]

5. To evaluate compliance for the sample, compare the Total TMEQ for the cPAH mixture with the soil concentration protective of groundwater for benzo(a)pyrene.

How to Handle Non-Detected Values in Total TEQ and Total TMEQ Calculations

The cleanup levels for cPAHs are quite low. This may require using sensitive analytical methods such as EPA Method 8270 SIM to minimize the number of non-detected values. However, even with this method, there may be several non-detected values in samples at a site. If so, use the following as guidance for handling these non-detected values in these calculations.

If an analytical method with detection limits acceptable to Ecology has been used, and one or more of the cPAHs has never been detected in any sample at the site, then a value of zero may be assigned to the concentration of that cPAH for these calculations.

If a cPAH is not detected in a sample but has been detected at the site, there are a variety of methods that can be used to enable these calculations. The easiest method is to assign a value of one-half the detection limit (or one-half the reporting limit, if the detection limit is not provided) to that cPAH when conducting these calculations. However, for data sets with a large number of nondetects (e.g., greater than 50 percent), this may skew the calculations. In this case, consider consulting with a statistician on alternative methods for handling nondetects. [8]

Examples Illustrating These Calculations

The following examples illustrate these calculations.

Example 1: Evaluating Compliance with Method A Unrestricted Land Use Soil Cleanup Levels

Consider a residential site where the soil is contaminated with a mixture of cPAHs and the soil cleanup level is based on Method A for unrestricted land use. Based on this scenario, use the following steps to evaluate whether the cPAH concentrations in a soil sample exceed the Method A soil cleanup level for cPAH mixtures. Measured soil concentrations and calculations referred to in the following steps are presented in Table 3, below.

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[7] Lookup value in Ecology's CLARC tables for a soil concentration of benzo(a)pyrene that is protective of groundwater, or calculate a site-specific concentration using equation 747-1 or the MTCASGL spreadsheet (3 phase model).

[8] See also EPA's statistical guidance for handling non-detects. For example, see EPA's statistical guidance (Pro UCL) http://www.epa.gov/osp/hstl/tsc/software.htm and EPA Region 3 *Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments.* http://www.epa.gov/reg3hwmd/risk/human/info/guide3.htm

Step 1: Analyze the soil sample to determine the concentration of each cPAH (column 2 in Table 3).

Step 2: For each cPAH identified in the sample, multiply the cPAH concentration by its corresponding TEF (column 3 in Table 3) to obtain a TEQ for that cPAH (column 4 in Table 3).

Step 3: Add the results from Step 2 to obtain the Total TEQ for the cPAH mixture in the sample (0.093 mg/kg in this example).

Step 4: Look up the Method A soil cleanup level for unrestricted land use for benzo(a)pyrene in Table 740-1 (0.1 mg/kg).

Step 5: To evaluate compliance for the sample, compare the Total TEQ for the cPAH mixture (0.093 mg/kg) to the Method A soil cleanup level for benzo(a)pyrene (0.1 mg/kg).

Conclusion: The Total TEQ for the cPAHs in this soil sample (0.093 mg/kg) does not exceed the Method A cleanup level for benzo(a)pyrene (0.1 mg/kg). Therefore, the cleanup level for the cPAH mixture has been met for this particular soil sample. Note that the Total TEQ is substantially less than the total cPAH concentration of 1.56 mg/kg if TEFs were not used, and thus results in a potential savings in cleanup cost.

Table 3. TEQ calculation for evaluating compliance with a Method A unrestricted land use soil cleanup level (Example 1)

cPAH	Measured Soil Concentration (mg/kg)	Toxicity Equivalency Factor (TEF, Unitless) (1)	Toxic Equivalent Concentration (TEQ, mg/kg) (2)
Benzo(a)pyrene	0.01	1.00	0.01
Benzo(a)anthracene	0.15	0.10	0.015
Benzo(b)fluoranthene	0.20	0.10	0.02
Benzo(k)fluoranthene	0.10	0.10	0.01
Chrysene	0.80	0.01	0.008
Dibenz(a,h)anthracene	0.20	0.10	0.02
Indeno(1,2,3-cd)pyrene	0.10	0.10	0.01
Sum	**1.56**	--	**0.093 = Total TEQ**
Method A Soil Cleanup Level for Unrestricted Land Use (Table 740-1)			**0.1 mg/kg**

(1) From Table 1.
(2) TEQ = cPAH concentration * TEQ

Example 2: Evaluating Compliance with Method A Groundwater Cleanup Levels

Consider a cleanup site where the groundwater is contaminated with a mixture of cPAHs and the groundwater cleanup level is based on Method A. Based on this scenario, use the following steps to evaluate whether the cPAH concentrations in a groundwater sample exceed the Method A soil cleanup level for cPAH mixtures. Measured groundwater concentrations and calculations referred to in the following steps are presented in Table 4, below.

Step 1: Analyze the groundwater sample to determine the concentration of each cPAH (column 2 in Table 4)

Step 2: For each cPAH identified in the sample, multiply the cPAH concentration by its corresponding TEF (column 3 in Table 4) to obtain a TEQ for that cPAH (column 4 in Table 4).

Step 3: Add the results from Step 2 to obtain the Total TEQ for the cPAH mixture in the sample (0.044 ug/liter in this example).

Step 4: Look up the Method A groundwater cleanup level for for benzo(a)pyrene in Table 720-1 (0.1 ug/liter).

Step 5: To evaluate compliance for the sample, compare the Total TEQ for the cPAH mixture (0.044 ug/liter) to the Method A groundwater cleanup level for benzo(a)pyrene (0.1 ug/liter).

Conclusion: The Total TEQ for the cPAHs in this groundwater sample (0.044 ug/liter) does not exceed the Method A groundwater cleanup level for benzo(a)pyrene (0.1 ug/liter). Therefore, the cleanup level for the cPAH mixture has been met for this particular groundwater sample. Note that the Total TEQ is substantially less than the total cPAH concentration of 0.2 ug/liter if TEFs were not used, and thus results in a potential savings in cleanup cost.

Table 4. TEQ calculation for evaluating compliance with a Method A groundwater cleanup level (Example 2)

cPAH	Measured Ground-water Concentration (ug/liter)	Toxicity Equivalency Factor (TEF, Unitless) (1)	Toxic Equivalent Concentration (TEQ, ug/liter) (2)
Benzo(a)pyrene	0.03	1.00	0.03
Benzo(a)anthracene	0.04	0.10	0.004
Benzo(b)fluoranthene	0.03	0.10	0.003
Benzo(k)fluoranthene	0.03	0.10	0.003
Chrysene	0.05	0.01	0.0005
Dibenz(a,h)anthracene	0.01	0.10	0.001
Indeno(1,2,3-cd)pyrene	0.02	0.10	0.002
Sum	**0.2**	**--**	**0.044 = Total TEQ**
Method A Groundwater Cleanup Level (Table 720-1)			**0.1 ug/liter**

(1) From Table 1.
(2) TEQ = cPAH concentration * TEQ

Example 3: Evaluating Compliance with Method A Industrial Land Use Soil Cleanup Levels

Consider an industrial site where the soil is contaminated with a mixture of cPAHs and that soil cleanup level is based on the Method A industrial soil cleanup level. The footnote to the benzo(a)pyrene cleanup level in Table 745-1 indicates this cleanup level is based on protection of groundwater. So, both the toxicity and the mobility of the cPAH mixture must be considered when evaluating compliance with this cleanup level.

Based on this scenario, use the following steps to evaluate whether the cPAH concentrations in a soil sample exceed the Method A industrial soil cleanup level for cPAH mixtures. Measured soil concentrations and calculations referred in the following steps are presented in Table 5, below.

Step 1: Analyze the soil sample to determine the concentration of each cPAH (column 2 in Table 5).

Step 2: For each cPAH identified in the sample, multiply its soil concentration by its corresponding TEF (column 3 in Table 5) and relative mobility factor (column 4 in Table 5) to obtain a TMEQ for that cPAH (column 5 in Table 5).

Step 3: Add the results from Step 2 to obtain the Total TMEQ for the cPAH mixture (0.57 mg/kg in this example).

Step 4: Look up the Method A industrial soil cleanup level for benzo(a)pyrene in Table 745-1 (2.0 mg/kg).

Step 5: To evaluate compliance for the sample, compare the Total TMEQ for the cPAH mixture (0.57 mg/kg) with the Method A industrial soil cleanup level for benzo(a)pyrene (2.0 mg/kg).

Table 5. TMEQ Calculation for evaluating compliance with a Method A industrial land use soil cleanup level (Example 3)

cPAH	Measured Soil Concentration (mg/kg)	Toxicity Equivalency Factor (TEF) (Unitless) (1)	Relative Mobility Factor (RMF) (Unitless) (2)	Toxic Mobility Equivalent Concentration (mg/kg) (3)
Benzo(a)pyrene	0.2	1.0	1.00	0.2
Benzo(a)anthracene	0.5	0.1	2.71	0.14
Benzo(b)fluoranthene	0.7	0.1	0.79	0.06
Benzo(k)fluoranthene	0.6	0.1	0.79	0.05
Chrysene	2.2	0.01	2.43	0.05
Dibenz(a,h)anthracene	1.0	0.1	0.54	0.05
Indeno(1,2,3-cd)pyrene	0.8	0.1	0.28	0.02
Sum	**6.0**	--	--	**0.57 = Total TMEQ**
Method A Industrial Land Use Soil Cleanup Level for Benzo(a)pyrene (Table 745-1)				**2.0**

(1) From Table 1.
(2) From Table 2.
(3) TMEQ = cPAH concentration * TEF * RMF

Conclusion: The Total TMEQ for the cPAHs in this soil sample (0.57 mg/kg) does not exceed the Method A industrial soil cleanup level for benzo(a)pyrene (2.0 mg/kg). Therefore, the cleanup level for benzo(a)pyrene has been met for this particular soil sample. Note that the Total TMEQ is substantially less than the total cPAH concentration of 6.0 mg/kg, if TEFs and the relative mobility of the cPAHs were not considered, and thus results in a potential savings in cleanup cost.

Example 4: Evaluating Compliance with Method B Soil Cleanup Levels

When Method B is used to establish a soil cleanup level, it may not always be evident which exposure pathway—direct contact or soil leaching to groundwater—is the controlling exposure pathway for a soil sample (that is, whether a cPAH mixture concentration will be protective for direct contact while not protective for leaching because of differences in mobility among the cPAHs). This example is intended to illustrate one way to conduct this evaluation.

Consider a residential site where the soil is contaminated with a mixture of cPAHs and the soil cleanup level is based on Method B for unrestricted land use. In this example, the soil sample will be checked for compliance with the Method B soil concentrations protective of both the

direct contact and soil leaching to groundwater exposure pathways.

Based on this scenario, use the following steps to evaluate compliance for a soil sample. Measured soil concentrations and calculations referred in the following steps are presented in Table 6, below.

Step 1: Analyze the soil sample to determine the concentration of each cPAH (column 2 in Table 6).

Step 2: For each cPAH identified in the sample, multiply the soil concentration by the applicable TEF (column 3 in Table 6) to obtain a TEQ for that cPAH (column 5 in Table 6).

Step 3: Add the results from step 2 to obtain the Total TEQ for the cPAH mixture (1.22 mg/kg in this example).

Step 4: For each cPAH identified in the sample, multiply the soil concentration by the applicable toxicity equivalency factor (column 3 in Table 6) and relative mobility factor (column 4 in Table 6) to obtain a toxic mobility equivalent concentration for that cPAH (column 6 in Table 6).

Step 5: Add the results from Step 4 to obtain the Total TMEQ for the cPAH mixture (1.45 mg/kg in this example).

Step 6: Calculate a Method B direct contact soil concentration for benzo(a)pyrene using equation 740-5 (0.1 mg/kg).[9]

Step 7: Calculate a Method B soil concentration protective of groundwater for benzo(a)pyrene using equation 747-1 (3-phase model). For this example, the Method B benzo(a)pyrene groundwater cleanup level of 0.12 ug/L was used as the target groundwater concentration for the calculation (which results in a soil concentration of 2.3 mg/kg in this example).

Step 8: To evaluate whether the sample is in compliance, compare the Total TEQ (Step 3) with the soil cleanup level for direct contact (Step 6), and the Total TMEQ for the cPAH mixture (Step 5) with the soil concentration for the protection of groundwater derived in Step 7.

Conclusion: The total TMEQ for the cPAHs in this soil sample (1.45 mg/kg) does not exceed the Method B soil leaching concentration for benzo(a)pyrene (2.3 mg/kg). Therefore, the cPAH mixture does not pose a threat to groundwater. However, the Total TEQ for the cPAHs in this soil sample (1.22 mg/kg) exceeds the Method B direct contact value (0.1 mg/kg). As a result, the cleanup level for the cPAH mixture should be based on the direct contact exposure pathway, and this soil cleanup level for the cPAH mixture has not been met for this particular soil sample.

[9] Equation 740-5 is required to be used for petroleum mixtures.

Table 6. TEQ and TMEQ Calculations for evaluating compliance with a Method B unrestricted land use soil cleanup level (Example 4)

cPAH	Measured Soil Concentration (mg/kg)	Toxicity Equivalency Factor (TEF) Unitless (1)	Relative Mobility Factor (RMF) Unitless (2)	Toxic Equivalent Concentration (TEQ) mg/kg (3)	Toxic Mobility Equivalent Concentration (TMEQ) mg/kg (4)
Benzo(a)pyrene	0.95	1.0	1.00	0.9500	0.9500
Benzo(a)anthracene	1.45	0.1	2.71	0.1450	0.3930
Benzo(b)fluoranthene	0.66	0.1	0.79	0.0660	0.0521
Benzo(k)fluoranthene	0.08	0.1	0.79	0.0080	0.0063
Chrysene	1.39	0.01	2.43	0.0139	0.0338
Dibenz(a,h)anthracene	0.08	0.1	0.54	0.0080	0.0043
Indeno(1,2,3-cd)pyrene	0.27	0.1	0.28	0.0270	0.0076
Sum	**4.88**	--	--	**1.22**	**1.45**
Method B Benzo(a)pyrene Direct Contact (5)				**0.1** [10]	--
Method B Benzo(a)pyrene Leaching (6)				--	**2.3**

(1) From Table 1.
(2) From Table 2.
(3) TEQ = cPAH concentration * TEF
(4) TMEQ = cPAH concentration * TEF * RMF
(5) From equation 740-5 with equation defaults
(6) From equation 747-1 with equation defaults and using the Method B cleanup level of 0.12 ug/liter as the target groundwater concentration. The Method B cleanup level of 0.12 ug/liter is the drinking water standard for benzo(a)pyrene (0.2 ug/liter) adjusted to a $1X10^{-5}$ risk per WAC 1473-340-720(7)(b).

Example 5: Evaluating Compliance with Method C Soil Cleanup Levels

As with Method B (Example 4), when Method C is used to establish a soil cleanup level, it may not always be evident which exposure pathway—direct contact or soil leaching to groundwater—is the controlling exposure pathway for a soil sample. This example is intended to illustrate one way to conduct this evaluation.

Consider an industrial site where the soil is contaminated with a mixture of cPAHs and the soil cleanup level is based on Method C for industrial land use. In this example, the soil sample will be checked for compliance with the Method C soil concentrations protective of both the direct contact and soil leaching to groundwater exposure pathways.

Based on this scenario, use the following steps to evaluate compliance for a soil sample. Measured soil concentrations and calculations referred in the following steps are presented in Table 7, below.

[10] Note that this value does not address the concern that EPA has determined that cPAHs are more toxic to young children and that a more stringent cancer slope factor should be used for this life stage ("early life exposure"). Ecology is currently evaluating whether to include this consideration under MTCA.

Step 1: Analyze the soil sample to determine the concentration of each cPAH (column 2 in Table 7).

Step 2: For each cPAH identified in the sample, multiply the soil concentration by the applicable TEF (column 3 in Table 7) to obtain a TEQ for that cPAH (column 5 in Table 7).

Step 3: Add the results from Step 2 to obtain the Total TEQ for the cPAH mixture (2.0 mg/kg in this example).

Step 4: For each cPAH identified in the sample, multiply the soil concentration by the applicable toxicity equivalency factor (column 3 in Table 7) and relative mobility factor (column 4 in Table 7) to obtain a TMEQ for that cPAH (column 6 in Table 7).

Step 5: Add the results from Step 4 to obtain the Total TMEQ for the cPAH mixture (2.22 mg/kg in this example).

Step 6: Calculate a Method C direct contact soil concentration for benzo(a)pyrene using equation 745-5 (4.27 mg/kg in this example).

Step 7: Calculate a Method C soil concentration protective of groundwater for benzo(a)pyrene using equation 747-1 (3-phase model). For this example, the Method B benzo(a)pyrene groundwater cleanup level of 0.12 ug/L was used as the target groundwater concentration for the calculation (which results in a soil concentration of 2.3 mg/kg in this example).

Step 8: To evaluate whether the sample is in compliance, compare the Total TEQ (Step 3) with the soil cleanup level for direct contact (Step 6), and the Total TMEQ for the cPAH mixture (Step 5) with the soil concentration protective of groundwater derived in Step 7.

Conclusion: The Total TEQ for the cPAH mixture in this soil sample (2.18 mg/kg) does not exceed the Method C direct contact value (4.3 mg/kg). Therefore, the soil sample is in compliance for the direct contact exposure pathway. However, the Total TMEQ for the cPAH mixture in this soil sample (2.79 mg/kg) exceeds the Method C soil concentration protective of groundwater for benzo(a)pyrene (2.3 mg/kg) and the cPAH mixture poses a threat to groundwater. As a result, the cleanup level for the cPAH mixture should be based on the leaching exposure pathway, and this soil cleanup level for the cPAH mixture has not been met for this particular soil sample.

Note that the Total TMEQ for the cPAH mixture (2.79 mg/kg) exceeds the 3-phase model concentration of 2.3 mg/kg by a small amount. Assuming this sample is representative of the site, this site may be a good candidate for an empirical demonstration to show that the soil is not impacting groundwater.

Table 7. TEQ and TMEQ calculations for evaluating compliance with a Method C industrial land use soil cleanup level (Example 5)

cPAH	Measured Soil Concentration (mg/kg)	Toxicity Equivalency Factor (TEF) Unitless) (1)	Relative Mobility Factor (RMF) Unitless (2)	Toxicity Equivalent Concentration (TEQ) mg/kg (3)	Toxic Mobility Equivalent Concentration (TMEQ) mg/kg (4)
Benzo(a)pyrene	1.59	1.0	1.00	1.5900	1.5900
Benzo(a)anthracene	3.87	0.1	2.71	0.3870	1.0488
Benzo(b)fluoranthene	1.18	0.1	0.79	0.1180	0.0932
Benzo(k)fluoranthene	0.25	0.1	0.79	0. 2500	0.0198
Chrysene	0.71	0.01	2.43	0.0071	0.0173
Dibenz(a,h)anthracene	0.25	0.1	0.54	0.0250	0.0135
Indeno(1,2,3-cd)pyrene	0.25	0.1	0.28	0.0250	
Sum	**8.10**	--	--	**2.18**	**2.79**
Method C Benzo(a)pyrene Direct Contact (5)				**4.3**	--
Method C Benzo(a)pyrene Leaching (6)				--	**2.3**

(1) From Table 1.
(2) From Table 2.
(3) TEQ = cPAH concentration * TEF
(4) TMEQ = cPAH concentration * TEF * RMF
(5) From equation 745-5 with equation defaults
(6) From equation 747-1 with equation defaults and using the Method B cleanup level of 0.12 ug/liter as the target groundwater concentration. The Method B cleanup level of 0.12 ug/liter is the drinking water standard for benzo(a)pyrene (0.2 ug/liter) adjusted to a $1X10^{-5}$ risk per WAC 1473-340-720(7)(b).