Method B and C Target Cleanup Goals and Adjustment for Additive Risk and Hazard

Supporting Material for Cleanup Levels and Risk Calculation (CLARC)

Toxics Cleanup Program

Washington State Department of Ecology
Olympia, Washington

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Related Information

- Cleanup and Risk Calculation (CLARC) workbook[1]

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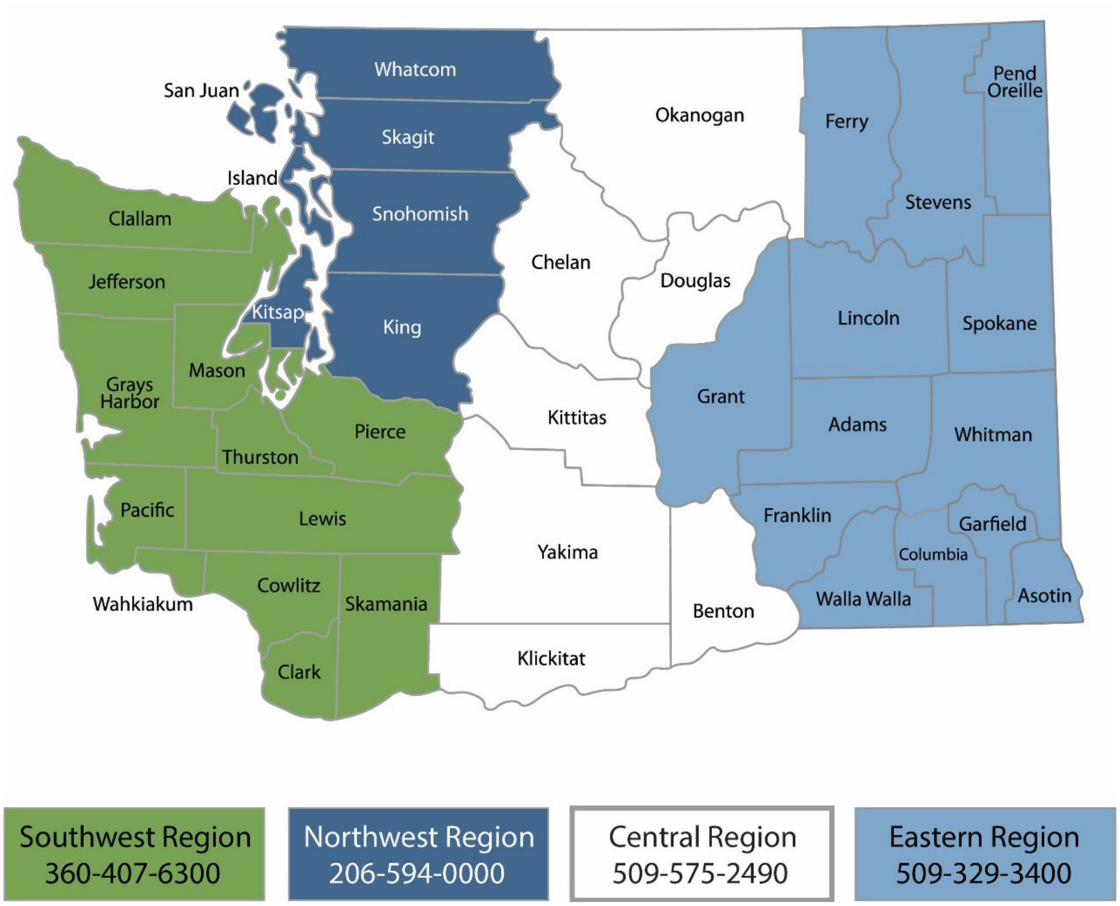
[1] https://www.ecology.wa.gov/regulations-permits/guidance-technical-assistance/contamination-cleanup-tools/clarc

Department of Ecology's Regional Offices

Counties served



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Chapter 1: Summary

Human health risk-based cleanup levels under the Model Toxics Control Act (MTCA) are based on prescribed target excess cancer risk and noncancer hazard goals, both for individual hazardous substances and for combined (additive[2]) impacts. Target risk-based goals (cancer and noncancer) under MTCA for Methods B and C are detailed below.

Web addresses for links are in the endnotes on the last page of this guidance.

- **Carcinogens** – Carcinogens include any substance or agent that may produce cancer in humans. Individual and additive risk-based goals for carcinogens include the following:
    - **Individual** – The human health excess cancer risk level for individual carcinogens shall not exceed an excess risk of one in a million (1×10^{-6}) under Method B (*see* WAC 173-340-705[i] (2)(c)(ii)), and one in one hundred thousand (1×10^{-5}) under Method C (*see* WAC 173-340-706[ii] (2)(c)(ii)).

      These excess cancer risk levels may also be expressed as 1E-06 or 1E-05. This form of scientific notation (e.g., 1E-06) is used throughout the rest of the document. Further detail on the expression of excess cancer risk is presented in Chapter 3.
    - **Additive** – Under both Method B and C, the total excess cancer risk from multiple chemicals and/or exposure pathways may not exceed 1E-05 (*see* WAC 173-340-705(4) and WAC 173-340-706(4)).
- **Noncarcinogens** – Noncarcinogens include those hazardous substances that may produce acute or chronic noncancer toxic effects on human health. Individual and additive hazard goals for noncarcinogens include the following:
    - **Individual** – Under both Method B and C, cleanup levels for noncarcinogens may not exceed a hazard quotient (HQ) one (1) (*see* WAC 173-340-705(2)(c)(i) and WAC 173-340-706(2)(c)(i)).
    - **Additive** – Under Methods B and C, the total noncancer effects from multiple chemicals and/or exposure pathways may not exceed a hazard index (HI)[3] of 1 (*see* WAC 173-340-705(4) and WAC 173-340-706(4)).

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[2] Method A cleanup levels do not consider additive cancer risk or noncancer hazard (Method A sites involve only a few hazardous substances; e.g., 10 or fewer), whereas adjustments for these are required under Methods B and C. Note that if a Method A cleanup level is being used under Method B, the Method A value may need to be adjusted downward to account for additive cancer risk and/or noncancer hazard.

[3] "Hazard Index" or HI means the sum of two or more hazard quotients (HQs) for multiple hazardous substances and/or multiple exposure pathways.

- **Adjustments** – Cleanup levels for individual hazardous substances established under Methods B and C (and human health risk-based remediation levels[4]) shall be adjusted downward to take into account exposure to multiple hazardous substances and/or exposure pathways (*see* WAC 173-340-708[iii] (5) and (6)). This adjustment needs to be made only if, without this adjustment, the noncancer HI would exceed 1, or the total excess cancer risk would exceed 1E-05.

  WAC 173-340-708(5)(c) and (d) says that for the purposes of establishing cleanup levels under Methods B and C, exposure to multiple hazardous substances may be apportioned between hazardous substances in any combination as long as the total excess cancer risk does not exceed 1E-05 and noncancer hazards (i.e., HI) do not exceed 1. For example, this provision means that when adjusting for additive cancer risk under Method B, you can decide to set the cleanup level for some carcinogens at the 1E-06 risk level and for other carcinogens at a lower level, as long as the total risk doesn't exceed 1E-05. This same line of thought applies to adjusting noncancer HQ to meet an HI of 1.

Important: Risk assessment results may be presented to one significant figure when evaluating compliance with additive cancer risk and noncancer hazard (i.e., HI) goals (*see* Chapter 3). Also, cancer risk and noncancer HQ associated with cleanup levels set at natural background or the practical quantitation limit (PQL) can be zeroed out (i.e., not included in the additive risk calculation) when evaluating compliance with additive cancer risk and noncancer hazard (i.e., HI) goals. Including these when evaluating additive impacts from multiple chemicals could result in cleanup levels below natural background or PQL, which is not allowed under the rule (*see* WAC 173-340-705[i] (6)).

A general overview of procedures for adjusting cleanup levels to comply with additive cancer risk and noncancer HI goals specified in MTCA is provided below. See Chapter 5 for detailed instruction (with practical examples) on adjusting cleanup levels including those that are based on applicable state and federal laws.

1.1 Adjusting cleanup levels for carcinogens

Under Method B, if there are multiple carcinogens present and the total site risk exceeds 1E-05, then the cleanup level for one or more individual carcinogens will have to be adjusted downward so that the total cancer risk from all carcinogens does not exceed 1E-05 (rounded to one significant figure). **Under Method C**, a downward adjustment is required for at least one individual carcinogen if there are two or more cleanup levels (CULs) set at a 1E-05 cancer risk. It

[4] "Remediation level (REL)" means a concentration (or other method of identification) of a hazardous substance in soil, water, air, or sediment above which a particular cleanup action component will be required as part of a cleanup action at a site (*see* https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-355; WAC 173-340-708(5)(a)).

is important to note that sites must meet the target cancer risk goals for both individual hazardous substances (i.e., cleanup level set at a 1E-06 risk under Method B) and for combined (additive) impacts. As such, cleanup levels for individual chemicals cannot be upwardly adjusted to equal the additive risk goal of 1E-05.

Under Method B, if 15 carcinogens are present, each at their respective cancer-based cleanup level (i.e., 1E-06 risk), an adjustment to cleanup levels is necessary as the total risk exceeds 1E-05 (i.e., 1E-06 × 15 = 1.5E-05). A total risk of 1.5E-05 is rounded to 2E-05 at one significant figure. In this case, a downward adjustment needs to be made to one or more cleanup levels so that the total risk does not exceed 1E-05 at one significant figure. As an example, follow the steps below if you want to downward adjust the cleanup levels for 4 of the 15 carcinogens[5] to meet the target additive risk goal of 1E-05 at one significant figure.

Step 1. Assign the acceptable individual risk level of 1E-06 to all 15 carcinogens. This results in a total risk of 1.5E-05 (i.e., 1E-06 × 15).

Step 2. Take the total risk of 1.5E-05 generated from the 15 carcinogens and subtract the allowable total risk of 1E-05 at one significant figure (i.e., 1.5E-05 – 1.49E-05[6]). This results in a balance of 1E-07 that may be distributed evenly among the four carcinogens targeted for downward cleanup level adjustment (i.e., 1E-07 ÷ 4 = 2.5E-08).

Step 3. Downward adjust the target risk level for the four carcinogens by subtracting 2.5E-08 from the acceptable individual chemical risk level of 1E-06 (i.e., 1E-06 – 2.5E-08). This results in a target risk level of 9.75E-07. This risk level is used for the four carcinogens targeted for downward cleanup level (CUL) adjustment, and 1E-06 is applied to the rest (i.e., [9.75E-07 × 4] + [1E-06 × 11] = 1.49E-05).

Step 4. Downward adjustment of CULs to a risk of 9.75E-07 for the four carcinogens may be calculated from their Method B risk-based cancer CUL (based on a 1E-06 risk level) by setting up and solving for "CUL_{adj}" in the proportion relationship shown below.

$$\frac{Method\ B\ CUL_{cancer}}{\text{1E-06}} = \frac{\boldsymbol{CUL_{adj}}}{\text{9.75E-07}}\quad or\quad \boldsymbol{CUL_{adj}} = \frac{Method\ B\ CUL_{cancer} \times (\text{9.75E-07})}{\text{1E-06}}$$

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[5] If you wanted to distribute the excess risk balance evenly among all 15 of the carcinogens, you would divide the allowable total risk of 1E-05 at one significant figure (i.e., 1.49E-05) by 15. This results in a target risk level of 9.93E-07 for each carcinogen. This risk level would then be used rather than the default of 1E-06 to derive CULs for the 15 carcinogens (i.e., 9.93E-07 × 15 = 1.49E-05) under Method B. Then follow Step 4 to calculate the adjusted CULs. **Note**, it's less common to distribute risk evenly for groundwater CULs because some are based on applicable state and federal law such as a maximum contaminant level (MCL). For example, in this scenario we would not upward adjust an MCL-based CUL if the risk at its MCL is lower than 9.93E-07.

[6] A risk of 1.49E-05 is equal to 1E-05 at one significant figure.

As an example **under Method C**, let's say there are four carcinogens at the site for which cleanup levels need to be established. The level of risk for individual contaminants is 1E-05. However, no single carcinogen can be set at a 1E-05 level because the others must be allocated some risk. Therefore, some adjustment needs to be made to all four carcinogens. Follow the steps below if you want to set cleanup levels based on different risk levels for these four carcinogens. For example, you may want to set higher cleanup levels for two of the carcinogens based on a 60% total contribution to the overall risk[7].

Step 1. Multiply the total acceptable risk of 1E-05 at one significant figure (i.e., 1.49E-05) by 60% (60% × 1.49E-05 = 8.94E-06), and then by 40% (40% × 1.49E-05 = 5.96E-06).

Step 2. Divide the risk apportionments of 8.94E-06 (based on 60%) and 5.96E-06 (based on 40%) each by two. This results in individual risks of 4.47E-06 (i.e., 8.94E-06 ÷ 2) that may be assigned to two of the carcinogens, and individual risks of 2.98E-06 (i.e., 5.96E-06 ÷ 2) for the other two. The total risk for all four carcinogens is 1.49E-05 or 1E-05 at one significant figure.

Step 3. Downward adjustment of the CULs to individual risks of 4.47E-06 and 2.98E-06 may be calculated from their Method C risk-based cancer CUL (based on a 1E-05 risk level) by setting up and solving for "CUL_{adj}" in the proportion relationship shown below. The formula below is set up to calculate the "CUL_{adj}" based on a risk of 4.47E-06. However, the same formula may be used to calculate the "CUL_{adj}" for the lower risk level (just replace 4.47E-06 with 2.98E-06).

$$\frac{Method\ C\ CUL_{cancer}}{\text{1E-05}} = \frac{\boldsymbol{CUL_{adj}}}{\text{4.47E-06}} \quad or \quad \boldsymbol{CUL_{adj}} = \frac{Method\ C\ CUL_{cancer} \times (\text{4.47E-06})}{\text{1E-05}}$$

Note: The need to adjust cancer-based cleanup levels as shown in the example above is not expected to be very common since it requires 15 or more carcinogenic chemicals of concern (COCs) that are driving the human direct contact pathway. As an example, at most MTCA sites, soil cleanup levels include concentrations that are protective of groundwater beneficial use (e.g., soil leaching levels protective of potable groundwater). Cleanup levels based on soil leaching are commonly much lower than human direct contact levels. If soil leaching levels are applied as the cleanup level to estimate risk from human direct contact, the total risk for soil contact is not likely to exceed 1E-05.

[7] If you wanted to distribute the excess risk balance evenly among the four the carcinogens, you would simply divide the allowable total risk of 1E-05 at one significant figure (i.e., 1.49E-05) by four. This results in a target risk level of 3.73E-06. This risk level would then be used rather than the default of 1E-05 to derive CULs for the four carcinogens (i.e., 3.73E-06 × 4 = 1.49E-05) under Method C. Then follow Step 3 to calculate the adjusted CULs.

1.2 Adjusting cleanup levels for noncarcinogenic effects

The same general approach may be used for cleanup levels based on noncarcinogenic effects, except that the noncancer hazard must be apportioned among the contaminants to meet the additive HI goal of 1. Under Methods B and C, downward adjustment is required to the noncancer-based cleanup levels (which are set at an HQ of 1) if there are **two or more** chemicals of concern (COCs) that elicit a similar type of toxic response (e.g., affect the same target organ). However, the first step in evaluating noncarcinogenic effects is to calculate the HI across all COCs (sometimes referred to as the unsegregated HI). If the HI across all COCs is less than or equal to 1 (at one significant figure), no further evaluation is needed. In cases where the HI exceeds 1, MTCA allows noncancer HQs from multiple chemicals to be segregated by similar type of toxic response (see WAC 173-340-708[iii] (5)(b)). Segregation of noncancer hazards by similar type of toxic response can be complex and assistance from a toxicologist is recommended. This is discussed in more detail in Chapter 5: Adjusting Cleanup Levels.

As an example, if six COCs with similar types of noncancer effects are present, each at their respective noncancer-based cleanup level (i.e., HQ of 1), adjustments for additive effects would be necessary as the HI would be greater than 1. In this case, a downward adjustment needs to be made to the cleanup levels so that the HI does not exceed 1 at one significant figure (i.e., 1.49). Follow the steps below if you want to set cleanup levels based on different HQ levels for these six chemicals. For example, you may want to set higher cleanup levels for three of the noncarcinogens based on a 65% total contribution to the HI[8].

Step 1. Multiply the acceptable HI of 1 at one significant figure (i.e., 1.49) by 65% (65% × 1.49 = 0.969), and then by 35% (35% × 1.49 = 0.522).

Step 2. Divide the HI apportionments of 0.969 (based on 65%) and 0.522 (based on 35%) each by three. This results in individual HQs of 0.323 (i.e., 0.969 ÷ 3) that may be assigned to three of the noncarcinogens, and individual HQs of 0.174 (i.e., 0.522 ÷ 3) for the other three. The HI from all six noncarcinogens is 1.49 or 1 at one significant figure.

Step 3. You can calculate downward adjustment of the CULs to individual HQs of 0.323 and 0.174 from their Method B or C noncancer-based CUL (based on a HQ of 1) by setting up and solving for "CUL_{adj}" in the proportion relationship shown below. The formula is set up to calculate the "CUL_{adj}" based on a HQ of 0.323. The same formula may be used to calculate the "CUL_{adj}" for the lower HQ (just replace 0.323 with 0.174).

$$\frac{Method\ B\ or\ C\ CUL_{noncancer}}{\text{HQ (1)}} = \frac{\boldsymbol{CUL_{adj}}}{0.323}\ \ or\ \ \boldsymbol{CUL_{adj}} = \frac{Method\ B\ or\ C\ CUL_{noncancer} \times (0.323)}{\text{HQ (1)}}$$

[8] If you want to distribute the HI evenly among the six noncarcinogens, divide the allowable total HI of 1 at one significant figure (i.e., 1.49) by six. This results in a HQ of 0.248. You then use this HQ rather than the default of 1 to derive CULs for the six noncarcinogens (i.e., 0.248 × 6 = 1.49). Follow Step 3 to calculate the adjusted CULs. Similar to the discussion in Footnote 5 for carcinogens, in this scenario, we would not upward adjust an MCL-based CUL if the HQ at its MCL is lower than 0.248.

Chapter 2: Accounting for Multiple Pathways of Exposure

According to Ecology's 2001 Concise Explanatory Statement[iv] (CES; Ecology, 2001)[9], adjustments to cleanup levels based on additive impacts from all possible exposure pathways is not normally considered at most sites beyond what is already included in the MTCA standard equations that reflect reasonable maximum exposure (RME)[10]. It's noted that concurrent exposure has been accounted for in some of the MTCA RME equations. Also, concurrent exposure is sometimes reflected in the applicable state and federal laws which can also be referred to as Applicable or Relevant and Appropriate Requirements (ARARs). Some examples of concurrent exposure are provided below.

- **Groundwater** – MTCA standard equations for setting drinking water cleanup levels (WAC 173-340-720[v] Equations 720-1 and -2) consider concurrent exposure to drinking water (via ingestion) and vapors originating from that same water (via inhalation of volatile chemicals during non-ingestion household use such as washing, bathing, showering[11]).
- **Soil** – MTCA standard equations (WAC 173-340-740[vi] Equations 740-3 and 745-3) for setting soil cleanup levels for petroleum mixtures considers concurrent exposure to soil via incidental ingestion and dermal contact. For hazardous substances other than petroleum mixtures, evaluation of concurrent exposure (i.e., ingestion and dermal contact with soil) is only required under modified Method B and C, and only under certain specified circumstances (WAC 173-340-740 (3)(c)(iii)).
- **Surface Water** – In the case of fresh surface water, federal and state water quality standards consider eating fish and consuming water from the same surface water body.

Other than the examples provided above, adjustments to cleanup levels to account for multiple pathways of exposure is not normally done under the current regulation. However, if there is a concern at a site, Ecology can require other additional exposure pathways to be evaluated when establishing cleanup levels and assessing the protectiveness of remedies (e.g., *see* WAC 173-340-740 (1)(c)).[12] Also, cleanup levels and remediation levels based on one pathway should be considered for downward adjustment if the conceptual site model indicates that

[9] A Concise Explanatory Statement (CES) is prepared before a rule is finalized.
[10] RME reflects the highest exposure (based on upper-bound exposure variables such as the 95th percentile) that is reasonably expected to occur at a site under current and potential future site use.
[11] These inhalation exposures due to household uses of water are different from inhalation exposures due to vapor intrusion from the subsurface.
[12] While external radiation dose is not specifically given as an example in WAC 173-340-740(1)(c), if this is a concern at a site, Ecology can require this pathway to be addressed under this provision.

exposure through multiple pathways is likely to occur at a site, and without the adjustment, the total site risk would exceed 1E-05 and the HI would exceed 1 (*see* WAC 173-340-708[iii] (6)(b)).

> **Note**: It's recommended to consult with a toxicologist within Ecology's Toxics Cleanup Program Policy and Technical Support Unit for assistance if it’s determined that cleanup level or remediation level adjustments are necessary to account for multiple pathways of exposure.

Chapter 3:
Significant Figures in Risk Assessment

As explained in the 2001 CES[iv], the requirement for rounding all risk assessment results (e.g., when calculating risk-based cleanup levels) to one significant figure was removed from the MTCA rule (Ecology, 2001). The Science Advisory Board noted that several of the Method A table values are expressed at more than one significant figure which illustrates the impracticability of always rounding to one significant figure. Pre-calculated risk-based Method B and C cleanup levels in Ecology's Cleanup Levels and Risk Calculations (CLARC)[vii] database are rounded to two significant figures[13] which is consistent with United States Environmental Protection Agency's (EPA) Risk Assessment Guidance for Superfund (RAGs) Part B (EPA, 1991). The guidance below should be used when evaluating compliance with risk-based goals identified in MTCA under Methods B and C.

- **Individual Chemicals** – For individual chemicals, compliance is demonstrated by comparing concentrations measured in site media (e.g., soil, groundwater, air) to calculated cancer and noncancer based cleanup levels (using the MTCA equations rounded to two significant figures)[14]. Cancer-based cleanup levels are set at a 1E-06 risk level under Method B, and 1E-05 under Method C. Noncancer-based cleanup levels are set at an HQ of 1. As discussed previously, downward adjustments to cleanup levels may be required to meet additive cancer risk or noncancer hazard (i.e., HI) goals. As such, some cleanup levels may be set at levels lower than the default risk-based goals in MTCA (i.e., 1E-06 for Method B; 1E-05 for Method C).

> **Note**: MTCA uses upper-bound exposure variables (e.g., contact rates, exposure frequency and duration) based on RME to derive risk-based cleanup standards (or site-specific remediation levels) for individual chemicals. Calculation of individual cancer risks and HQs based on exposure concentrations in site media should not be used to determine compliance. For example, if soil concentrations for an individual carcinogen generate a cancer risk of 1.3E-06, one would not round this to one significant figure and conclude that it meets the MTCA Method B risk-based goal of 1E-06. Rather, compliance is determined by comparing site soil concentrations to the Method B cleanup level which is based on a 1E-06 risk level (*see* WAC 173-340-740[vi] (7) for soil compliance monitoring methods).

[13] See the CLARC "What's New & Other Notes" worksheet for additional information on rounding calculated cleanup levels.

[14] Cleanup levels may not always be risk-based. The use of ARARs as the basis for a cleanup level is discussed in section 5.5. Also, some cleanup levels may be established at a natural background level or a practical quantitation limit (*see* 173-340-700[ix] (6)(d); https://app.leg.wa.gov/wac/default.aspx?cite=173-340-700).

- **Additive Cancer Risk or Noncancer Hazard** – Consistent with EPA RAGS Part A (EPA, 1989), risk assessment results may be presented to one significant figure when evaluating compliance with additive cancer risk and noncancer hazard (i.e., HI). It's noted that states in EPA Regions 9 (e.g., California, Hawaii) and 10 (e.g., Alaska, Idaho, Oregon) also allow total risk assessment results to be presented to one significant figure. For example, a total cancer risk of 1.5E-05 or greater is an exceedance of the additive cancer risk-based goal of 1E-05[15]. However, a total cancer risk of 1.49E-05 may be rounded down to 1E-05 and is not an exceedance. Similarly, a noncancer HI of 1.5 or greater is an exceedance of the noncancer hazard based on additive effects, while 1.49 may be rounded down to 1 and is not an exceedance[15].

> **Note**: Under MTCA, forward risk calculations (i.e., calculating cancer risk and HI) are made to evaluate compliance with target additive cancer risk and noncancer hazard thresholds (1E-05 and 1, respectively). These thresholds are presented as one significant figure in MTCA. Rounding the final additive risk and HI calculations to one significant figure aligns with current risk assessment science and is done to reflect the inherent uncertainties in characterizing risk and to not imply a level of precision that is not supported by the underlying data and assumptions used in estimating risks. *Rounding should be applied to the final additive cancer risk and HI results, not to the intermediate calculations*.

- **Notes on Cancer Risk and Noncancer Hazard** – Ecology uses upper-bound exposure variables (e.g., contact rates, exposure frequency and duration) in the MTCA standard equations (to reflect RME conditions) to derive risk-based cleanup standards for individual chemicals to ensure that the quality of cleanup and protection of human health are not compromised. The information provided below provides some perspective on estimates of cancer risk and noncancer hazard.

  - **Cancer Risk** – Cancer potency factors (CPFs; a.k.a., cancer slope factors) are used to estimate cancer risk from exposure to carcinogenic chemicals at a cleanup site. They reflect the upper-bound limit (e.g., 95th percentile of potency) of the cancer potency and thus their use results in a reasonably conservative upper limit to the risk estimate.

    Cancer risk is expressed in terms of lifetime excess cancer risk. This concept assumes that the risk of cancer from a given chemical is in "excess" of the background risk of developing cancer. Note that background cancer risk, which accounts for other sources including genetics and lifestyle choices, can be very significant (e.g., an average of approximately 1 in 3 chances during a lifetime according to the American Cancer

[15] A cancer risk of 1.5E-05 is rounded to 2E-05 at one significant figure. An HI of 1.5 is rounded to 2 at one significant figure.

Society). However, for site cleanup, we only allow excess cancer risk as specified in MTCA (e.g., one in a million under Method B), which adds very little to one's background risk for developing cancer.

- **Noncancer Hazard** – The toxicity criteria used to evaluate potential noncarcinogenic health effects are termed reference doses (RfDs). The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure (via oral or inhalation routes) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful effects during a lifetime (e.g., organ damage, developmental effects, reproductive effects, etc.). A margin of safety (e.g., uncertainty and modifying factors) to compensate for limitations in the toxicity data is built into the RfD to characterize noncancer effects.

Chapter 4: Methods for Calculating Cancer Risk and Noncancer Hazards

Risk assessment can be defined as the process of determining the potential of hazardous substances to cause harm (i.e., cancer risk or noncancer effects). For carcinogens, cancer risk may be estimated by multiplying the estimated chemical intake (averaged over a lifetime) by the cancer potency factor (CPF). The noncancer hazard for a chemical (expressed as a hazard quotient [HQ]) is estimated by dividing the estimated chemical intake (averaged over the period of exposure) by its reference dose (RfD).

The Method B and C risk-based equations presented in the MTCA rule have been arranged to calculate a cleanup level based on the following inputs:

- Chemical intake[16] based on RME assumptions
- Chemical-specific toxicity (i.e., CPF or RfD)
- Target excess cancer risk or noncancer hazard[17]

Human health risk-based cleanup levels under MTCA are based on prescribed target excess cancer risk and noncancer hazard goals, both for individual hazardous substances and for combined (additive) effects. Evaluating the combined effects from multiple chemicals requires estimating the total cancer risk and HI (i.e., forward risk calculations). Under both Method B and C, the total excess cancer risk from multiple chemicals and/or exposure pathways may not exceed 1E-05 or an HI of 1 (*see* WAC 173-340-705[i] (4) and WAC 173-340-706[ii] (4)).

Presented below are several methods that may be used to evaluate the total cancer risk and HI from exposure to multiple hazardous substances.

4.1 Estimating risk and HQ from pre-calculated method B and C cleanup levels

If no changes are proposed to the default RME assumptions under Method B or C, and the chemical-specific data in Ecology's CLARC[vii] database are applied, then cancer risk and noncancer hazard may be calculated from the Method B and C cleanup levels (CULs) by setting up and solving for "Risk" or "HQ" in the general proportion relationships shown below. This

[16] The chemical intake (a.k.a., dose) is an estimate of the amount, frequency, and duration of human exposure (via oral, dermal, or inhalation routes) to a hazardous substance in the environment (e.g., soil, water, air, etc.) and is expressed in mg/kg-day.

[17] Cancer-based cleanup levels are set at a 1E-06 risk level under Method B, and 1E-05 under Method C. Noncancer-based cleanup levels are set at an HQ of 1 under both Method B and C.

simplified method may be used with any media based on pre-calculated Method B and C risk-based levels presented in CLARC.

Simplified equation using **cancer-based Method B** cleanup levels

$$\frac{Method\ B\ CUL_{cancer}}{\text{Target Risk} = \text{1E-06}} = \frac{Media\ Conc.}{\boldsymbol{Risk}}\quad or\quad \boldsymbol{Risk} = \frac{Media\ Conc. \times (\text{1E-06})}{Method\ B\ CUL_{cancer}}$$

Simplified equation using **cancer-based Method C** cleanup levels

$$\frac{Method\ C\ CUL_{cancer}}{\text{Target Risk} = \text{1E-05}} = \frac{Media\ Conc.}{\boldsymbol{Risk}}\quad or\quad \boldsymbol{Risk} = \frac{Media\ Conc. \times (\text{1E-05})}{Method\ C\ CUL_{cancer}}$$

Simplified equation using **noncancer-based Method B or C** cleanup levels

$$\frac{Method\ B\ CUL_{noncancer}}{\text{Target HQ} = 1} = \frac{Media\ Conc.}{\boldsymbol{HQ}}\quad or\quad \boldsymbol{HQ} = \frac{Media\ Conc. \times (1)}{Method\ B\ CUL_{noncancer}}$$

> **Note**: In the equations above, the CLARC[vii] Method B or C Cleanup Level (CUL) and "Media Conc." must be in the same units (e.g., mg/kg or µg/L).

As an example, the cancer risk and HQ for benzene at a soil concentration of 20 mg/kg may be estimated based on the Method B default exposure assumptions provided in MTCA Equations 740-1 and -2 as follows:

Cancer risk

$$\frac{Method\ B\ CUL_{cancer}\ (18\ mg/kg)}{\text{Target Risk} = \text{1E-06}} = \frac{Media\ Conc.\,(20\ mg/kg)}{\boldsymbol{Risk}}\quad or\quad \boldsymbol{Risk} = \frac{20\ mg/kg\ \times (\text{1E-06})}{18\ mg/kg}\quad or\ \text{1.1E-06}$$

Noncancer HQ

$$\frac{Method\ B\ Soil\ CUL_{noncancer}\ (320\ mg/kg)}{\text{Target HQ} = 1} = \frac{Media\ Conc.\,(20\ mg/kg)}{\boldsymbol{HQ}}\quad or\quad \boldsymbol{HQ} = \frac{20\ mg/kg \times (1)}{320\ mg/kg}\quad or\ 0.063$$

> **Note**: Examples provided in this guidance of calculating risk and HI to evaluate the combined impacts (i.e., additive) from exposure to multiple chemicals use the simplified method described above (*see* Chapter 5).

4.2 Estimating risk and HQ by rearranging the MTCA equations

Site-specific risk calculations can be made by rearranging the MTCA cleanup level equations to solve for cancer risk or HQ as presented in **Attachment A**. This method is an option if alternate exposure assumptions are used (i.e., different from the Method B or C defaults) to derive a site-specific Modified Method B or C cleanup level, or a remediation level. This method may also be useful for evaluating concurrent exposure to soil via ingestion and dermal contact. The types of exposure parameters that may be changed to derive a cleanup level or remediation level are discussed in the MTCA rule (*see* WAC 173-340-708[iii] (10)).

Note: One could also calculate cancer risk and noncancer hazard from the site-specific Modified Method B and C CULs, or a remediation level, by setting up and solving for “Risk” or “HQ” using the simplified method. That is, in the simplified equations, replace the standard Method B and C CULs from CLARC with the calculated site-specific modified levels, or a remediation level (the target risk and HQ remains the same).

Important: Any proposed change to the default exposure parameters provided in the MTCA rule should be made in coordination with the Ecology site manager.

Chapter 5: Adjusting Cleanup Levels

Instructions (with practical examples) on making downward adjustments to cleanup levels (CULs) to comply with total site cancer risk and noncancer hazard thresholds under MTCA are provided below.

5.1 Adjustments for total carcinogenic risk

MTCA human health cleanup levels for individual carcinogens (i.e., chemicals that may cause cancer) shall not exceed a cancer risk of 1E-06 under Method B (*see* WAC 173-340-705[i] (2)(c)(ii)), and 1E-05 under Method C (*see* WAC 173-340-706[ii] (2)(c)(ii)). Cancer risk is derived by multiplying a human health receptor (e.g., a child or adult resident) estimated lifetime average daily intake[18] (a.k.a., dose) of a hazardous substance by the cancer potency factor (CPF). The total cancer risk is derived by summing the cancer risk for all carcinogens[19]. This approach is in accordance with the MTCA cleanup rule (*see* WAC 173-340-708[iii] (5)(b)) and is consistent with EPA superfund risk assessment guidance (EPA, 1989) in which risks associated with carcinogens are considered additive with the same toxicological endpoint (i.e., cancer). Adjustments to Method B and C cleanup levels are required if, without adjustments, the total excess cancer risk from multiple hazardous substances and/or exposure pathways at a site would exceed 1E-05.

5.2 Adjustments for noncancer toxic effects

MTCA human health cleanup levels for individual noncarcinogens are based on achieving an HQ of 1. An HQ is derived by comparing a human health receptor estimated average daily intake[20] (a.k.a., dose) of a hazardous substance to the reference dose (i.e., HQ = average daily intake / reference dose). If the average daily intake is higher than the reference dose (RfD), then there is a potential for a noncancer health effect to occur, and the HQ is greater than 1. When there are multiple noncarcinogenic chemicals of concern at a site, the HQs for each are summed up to derive an HI. The HI is an expression of the additivity of noncarcinogenic health effects. The principle of additivity assumes that similar organ systems and health endpoints will be affected by COCs identified in site media. As such, and consistent with EPA superfund risk assessment guidance (EPA, 1989), MTCA allows noncancer HQs from multiple chemicals to be segregated by similar type of toxic response when evaluating compliance with the noncancer target HI of 1 (*see* WAC 173-340-708(5)(b))[21].

[18] The cancer intake is averaged over a lifetime (MTCA uses 75 years).
[19] It's noted that all radionuclides are carcinogenic, and thus radionuclide risks are also additive.
[20] The noncancer intake is averaged over the actual exposure duration.
[21] Note that the first step in evaluating noncarcinogenic effects is to calculate the unsegregated HI. If the unsegregated HI is less than or equal to 1 (at one significant figure), no further evaluation is needed. Segregation

Note: For site screening and selection of chemicals of potential concern under Methods B and C, one approach to account for additive impacts from multiple noncarcinogens is to modify the MTCA noncancer-based cleanup levels to reflect an HQ of 0.1 (divide the noncancer-based cleanup level by 10). The rationale for using an HQ of 0.1 for screening is when multiple noncarcinogens are present at a site, the total HI could exceed 1 if each were screened using an HQ of 1. That is, using an HQ of 1 for screening may result in eliminating some noncarcinogens that would otherwise significantly contribute to an HI of greater than 1. *Methods of site screening to account for multiple noncarcinogens should be made in coordination with the Ecology site manager*.

The information provided in the CLARC[vii] noncancer effects table can be used to calculate HIs for groups of chemicals with similar types of noncancer effects. Groupings can be made by major noncancer effect categories such as neurotoxicity, developmental toxicity, reproductive toxicity, immunotoxicity, and adverse effects by target organ system. This information is presented in the CLARC noncancer effects table by exposure route (i.e., ingestion or inhalation). As an example, HQs for ethylbenzene and toluene can be summed together because they both affect the same target organ (i.e., kidney) via oral exposure. **Attachment B** to this guidance contains a list of toxicity classifications and their meaning. This list was taken from EPA's IRIS database[viii] and is used in CLARC's noncancer effects table.

5.3 Steps for adjusting cleanup levels for additive risk and hazard

Under Methods B and C, CULs need to be set at levels that are at least as stringent as applicable state and federal laws (i.e., ARARs) and are protective of human health and the environment. The general process for evaluating whether or not CULs need to be downward adjusted is summarized below (more detail on the process is provided in **Examples 1 and 2** in the next section).

Step 1. Identify the lowest ARAR level and evaluate whether it's sufficiently protective. ARARs for an individual chemical are considered sufficiently protective under MTCA if they are less than or equal to a risk of 1E-05 or an HQ of 1. Compare the minimum ARAR level to MTCA calculated cancer (risk = 1E-05) and/or noncancer (HQ =1) risk-based levels. Note that Method B cancer-based levels may be converted to a 1E-05 risk by multiplying the level by 10. Use the ARAR without adjustment if it's lower than or equal to a risk of 1E-05 and an HQ of 1 and proceed to Step 4. Proceed to Step 2 if it exceeds. For chemicals that lack an ARAR, proceed to Step 3.

of noncancer hazards by similar type of toxic response can be complex and assistance from a toxicologist is recommended.

Step 2. Downward adjust the ARAR if it's not sufficiently protective. For protection of the cancer endpoint, downward adjust the ARAR to a risk of 1E-05. For noncancer effects, downward adjust the ARAR to an HQ of 1. Use the minimum adjusted ARAR level and proceed to Step 4.

Step 3. COCs that lack an ARAR. For chemicals that lack an ARAR, identify the minimum Method B or C human health risk-based equation level (between cancer risk and noncancer hazard). Use the minimum level and proceed to Step 4.

Step 4. Levels based on all relevant transport and exposure pathways. Compare the minimum levels identified in Steps 1 through 3 to levels based on other relevant transport and exposure pathways (e.g., soil leaching). Use the minimum level as the CUL and proceed to Step 5.

Step 5. Calculate the total cancer risk and noncancer hazard. Once the ARAR adjustments are complete and the minimum CUL is identified, use the proportion relationships shown in Chapter 4, Methods for Calculating Cancer Risk, to calculate the total cancer risk and noncancer hazard across all COCs. The CULs need only be adjusted if the cancer risk exceeds 1E-05 or the noncancer HI exceeds 1, both at one significant figure.

Step 6. Downward adjust based on total cancer risk and noncancer hazard. If the target thresholds for additive risk and/or HI are exceeded (1E-05 and 1, respectively; at one significant figure), it is usually efficient to first downward adjust for additive cancer risk before adjusting for additive noncancer hazard. This is because CULs based on cancer risk are usually lower than CULs based on noncancer hazard.

Examples of adjusting for additive cancer risk and noncancer hazard are provided below.

5.4 Example 1

This hypothetical example has 24 chemicals of concern in soil based on the results of a remedial investigation (RI) and feasibility study (FS)[22]. The site is being evaluated under Method B.

Evaluation of Cancer Risks

Because cancer risk is generally the driver (i.e., stricter) in the development of risk-based cleanup levels, the total cancer risk from all COCs is estimated **as a first step** in adjusting cleanup levels under this scenario. As shown in **Table 1** , with the exception of 2,4,6-trichlorophenol, cancer-based Method B cleanup levels are lower than their respective noncancer based levels at an HQ of 1.

Table 1: Method B Cleanup Levels and Total Cancer Risk (Example 1)

COC	Data Group	Soil Method B Noncancer CUL (mg/kg) (1)	Soil Method B Cancer CUL (mg/kg) (2)	Selected Soil Method B CUL (mg/kg) (3)	Cancer Risk @ CUL (4)
2,3,7,8-TCDD	Dioxins	9.3E-05	1.3E-05	1.3E-05	1.00E-06
Benzo(a)pyrene[23]	cPAHs	24	0.19	0.19	1.00E-06
Benzene	VOCs	320	18	18	1.00E-06
Toluene	VOCs	6400	—	6,400	NE
Ethylbenzene	VOCs	8000	—	8,000	NE
Total xylenes	VOCs	16000	—	16,000	NE
Tetrachloroethylene (PCE)	VOCs	480	480	480	1.00E-06
Trichloroethylene (TCE)	VOCs	40	12	12	1.00E-06
cis-1,2-Dichloroethylene	VOCs	160	—	160	NE
trans-1,2-Dichloroethylene	VOCs	1600	—	1,600	NE
Vinyl chloride	VOCs	240	0.67	0.67	1.00E-06
Pentachlorophenol	Herbicides	400	2.5	2.5	1.00E-06
2,3,4,6-Tetrachlorophenol	Phenols	2400	—	2,400	NE
2,4,6-Trichlorophenol	Phenols	80	91	80	8.79E-07
Aldrin	Pesticides	2.4	0.059	0.059	1.00E-06

[22] This scenario is designed to illustrate when and how adjustments may be required to cancer- and noncancer-based cleanup levels to achieve the MTCA additive risk-based goal 1E-05 and HI of 1. For simplification, the scenario only includes evaluation of human direct contact with soil via incidental ingestion based on the default RME assumptions under Method B. Depending on the conceptual site model, Ecology can require additional pathways (e.g., groundwater protection, dermal contact, and soil vapors) to protect human health (*see* WAC 173-340-740[vi] (1)(c) and (3)(b)).

[23] Ecology uses toxicity equivalent factors (TEFs) to evaluate the toxicity and assess the cancer risk for environmental mixtures of carcinogenic polycyclic aromatic hydrocarbon (cPAHs). cPAH mixtures are converted to a "cPAH TEQ" concentration using the TEF approach outlined in Ecology's Implementation Memorandum No. 10 (*see* https://apps.ecology.wa.gov/publications/documents/1509049.pdf). This concentration represents the total toxic equivalent (TEQ) concentration for the cPAH mixture and is compared to the soil Method B cleanup level for benzo(a)pyrene (shown in the table). For noncancer effects, benzo(a)pyrene is evaluated individually based on its oral RfD (the other cPAHs lack noncancer toxicity criteria).

COC	Data Group	Soil Method B Noncancer CUL (mg/kg) (1)	Soil Method B Cancer CUL (mg/kg) (2)	Selected Soil Method B CUL (mg/kg) (3)	Cancer Risk @ CUL (4)
Azobenzene	Pesticides	—	9.1	9.1	1.00E-06
Chlordane	Pesticides	40	2.9	2.9	1.00E-06
Chlorpyrifos	Pesticides	80	—	80	NE
4,4'-DDD	Pesticides	40	4.2	4.2	1.00E-06
4,4'-DDE	Pesticides	40	2.9	2.9	1.00E-06
4,4'-DDT	Pesticides	40	2.9	2.9	1.00E-06
Dieldrin	Pesticides	4	0.063	0.063	1.00E-06
Lindane (gamma-BHC)	Pesticides	24	0.91	0.91	1.00E-06
Toxaphene	Pesticides	7.2	0.91	0.91	1.00E-06
Total Risk					**2E-05****

Notes:

"—" Noncancer (i.e., RfD) or cancer toxicity criteria (i.e., CPF) are not available to calculate a Method B risk-based cleanup level.

NE = Cancer toxicity criteria (i.e., CPF) is not available. Chemical evaluated as a noncarcinogen.

(1) The soil Method B noncancer CUL is based on a HQ of 1 (values taken from CLARC[vii]).

(2) The soil Method B cancer CUL is based on a cancer risk of 1E-06 (values taken from CLARC).

(3) The selected Method B CUL is the lowest between the cancer and noncancer-based Method B levels.

(4) **Bold and asterisked (**)** value exceeds the MTCA target risk threshold of 1E-05 for total risk. Total risk has been expressed to one significant figure. Cancer risk for 2,4,6-trichlorophenol at its noncancer-based level (i.e., 80 mg/kg) was calculated from its Soil Method B Cancer-based CUL (based on a risk of 1E-06) by setting up and solving for "Risk" in the proportion relationship shown below.

$$\frac{Method\ B\ Soil\ CUL_{cancer}\ (91\ mg/kg)}{1\text{E-}06} = \frac{80\ mg/kg}{\boldsymbol{Risk}} \quad or\ \ \boldsymbol{Risk} = \frac{80\ mg/kg \times (1\text{E-}06)}{91\ mg/kg}$$

Development of cleanup levels based on cancer risk

The total risk generated from all COCs at the selected Method B CUL is 1.69E-05 (or 2E-05 at one significant figure). This exceeds the allowable MTCA additive risk threshold of 1E-05. Soil cleanup levels in this example need to be adjusted downward such that the additive risk does not exceed 1E-05 at one significant figure. As part of this process, decisions need to be made on which cleanup levels need to be adjusted downward (i.e., below a risk of 1E-06) to meet the additive risk goal. This is essentially a budgeting exercise. Specifically, the MTCA rule says that "…cancer risks resulting from exposure to multiple hazardous substances may be apportioned between hazardous substances **in any combination** as long as the total excess cancer risk does not exceed one in one hundred thousand (1E-05)…" (WAC 173-340-708[iii] (5)(d)). Also, risks for individual carcinogens may not exceed 1E-06. What this provision means is that to adjust for additive risk, you could decide to set the cleanup level for some carcinogens at the 1E-06 risk level and for other carcinogens at a lower level, as long as the total risk doesn't exceed 1E-05 at one significant figure. As an example, if it is known that a certain carcinogen at a site is easier to cleanup than other co-located contaminants (e.g., its nature and extent is limited to shallower soil depths that are easier to excavate or it’s less mobile), you may want to target that carcinogen for downward adjustment to a lower cleanup level. In this scenario, there are 17 carcinogenic COCs, and all but one have cleanup levels set at a risk of 1E-06. The simplest approach is to downward adjust cleanup levels evenly for the 16 carcinogens where the cancer-based Method B soil cleanup level is the driver (i.e., lower than the noncancer-based cleanup level). Steps under this approach are summarized below.

Step 1. Assign the acceptable individual risk level of 1E-06 to all 16 carcinogens targeted for downward cleanup level adjustment and 8.79E-07 for 2,4,6-trichlorophenol. This results in a total risk of 1.69E-05.

Step 2. Take the total risk of 1.69E-05 generated from the individual carcinogens and subtract the allowable total risk of 1E-05 at one significant figure (i.e., 1.69E-05 – 1.49E-05). This results in a balance of 1.98E-06 that may be distributed evenly among the 16 carcinogens targeted for downward adjustment (i.e., 1.98E-06 ÷ 16 = 1.24E-07).

Step 3. Downward adjust the target risk level for the 16 carcinogens by subtracting 1.24E-07 from the acceptable individual chemical risk level of 1E-06 (i.e., 1E-06 – 1.24E-07). This results in a target risk level of 8.76E-07. This risk level is used rather than the default of 1E-06 to derive adjusted cleanup levels for the 16 carcinogens. No downward adjustment based on cancer effects is needed for 2,4,6-trichlorophenol since the noncancer-based level of 80 mg/kg generates a risk less than 1E-06.

Step 4. Downward adjustment to a risk of 8.76E-07 for the 16 carcinogens may be calculated from their Soil Method B Cancer CUL (based on a 1E-06 risk level) by setting up and solving for “CUL_{adj}” in the proportion relationship shown below.

$$\frac{Method\ B\ Soil\ CUL_{cancer}}{\text{1E-06}} = \frac{\boldsymbol{CUL_{adj}}}{\text{8.76E-07}} \quad or \quad \boldsymbol{CUL_{adj}} = \frac{Method\ B\ Soil\ CUL_{cancer} \times (\text{8.76E-07})}{\text{1E-06}}$$

Adjustments made to cleanup levels to achieve a total risk of 1E-05 at one significant figure are shown in **Table 2** below.

Table 2: Adjustments to Cancer-Based Soil Cleanup Levels (Example 1)

COC	Data Group	Soil Method B Cancer CUL (mg/kg) (1)	Soil Method B Cancer CUL_{adj} (mg/kg) (2)	Cancer Risk @ CUL
2,3,7,8-TCDD	Dioxins	1.3E-05	**1.1E-05****	8.76E-07
cPAH TEQ	cPAHs	0.19	**0.17****	8.76E-07
Benzene	VOCs	18	**16****	8.76E-07
Toluene	VOCs	—	—	—
Ethylbenzene	VOCs	—	—	—
Total xylenes	VOCs	—	—	—
Tetrachloroethylene (PCE)	VOCs	480	**420****	8.76E-07
Trichloroethylene (TCE)	VOCs	12	**11****	8.76E-07
cis-1,2-Dichloroethylene	VOCs	—	—	—
trans-1,2-Dichloroethylene	VOCs	—	—	—
Vinyl chloride	VOCs	0.67	**0.59****	8.76E-07
Pentachlorophenol	Herbicides	2.5	**2.2****	8.76E-07
2,3,4,6-Tetrachlorophenol	Phenols	—	—	—
2,4,6-Trichlorophenol	Phenols	91	**80****	8.79E-07
Aldrin	Pesticides	0.059	**0.052****	8.76E-07
Azobenzene	Pesticides	9.1	**8.0****	8.76E-07
Chlordane	Pesticides	2.9	**2.5****	8.76E-07
Chlorpyrifos	Pesticides	—	—	—
4,4'-DDD	Pesticides	4.2	**3.7****	8.76E-07
4,4'-DDE	Pesticides	2.9	**2.5****	8.76E-07
4,4'-DDT	Pesticides	2.9	**2.5****	8.76E-07
Dieldrin	Pesticides	0.063	**0.055****	8.76E-07
Lindane (gamma-BHC)	Pesticides	0.91	**0.8****	8.76E-07
Toxaphene	Pesticides	0.91	**0.8****	8.76E-07
Total Risk				**1.49E-05 or 1E-05**

Notes:

“—" Cancer toxicity criteria (i.e., CPF) is not available. Chemical evaluated as a noncarcinogen.

(1) Soil Method B Cancer CUL is based on a cancer risk of 1E-06 (values taken from CLARC[vii]). The seven chemicals that lack a Soil Method B Cancer CUL (identified as “— “) have noncancer-based cleanup levels based on a HQ of 1 (not included in this table).

(2) Adjusted cleanup levels (CUL_{adj}) are **bolded and asterisked (**)** and have been rounded to two significant figures. With the exception of 2,4,6-trichlorophenol, soil Method B Cancer CUL_{adj} values are based on a cancer risk of 8.76E-07. The stricter noncancer-based level of 80 mg/kg generates a risk of 8.79E-07 for 2,4,6-trichlorophenol.

Evaluation of noncancer hazard

The first step in evaluating noncarcinogenic effects is to calculate the unsegregated HI. For this scenario, we already know the unsegregated HI exceeds 1 since seven of the COCs lack cancer toxicity criteria and have cleanup levels that are noncancer based at an HQ of 1. As a result, the evaluation proceeds to segregation of noncancer hazards by similar type of toxic response. Note that this process can be complex and assistance from a toxicologist is recommended. For illustration purposes, the unsegregated HI generated by the 16 adjusted cancer-based cleanup levels (based on a risk of 8.76E-07; labelled “c”) and the unadjusted noncancer-based cleanup levels for the rest of the COCs (labelled “nc”) are shown in **Table 3** below.

Table 3: Unsegregated Noncancer HI (Example 1)

COC	Data Group	Soil Method B CULs (mg/kg) (1)		Noncancer Hazard @ CUL (mg/kg) (2)
2,3,7,8-TCDD	Dioxins	1.1E-05	c	0.12
Benzo(a)pyrene	cPAHs	0.17	c	0.0069
Benzene	VOCs	16	c	0.049
Toluene	VOCs	6,400	nc	**1.00****
Ethylbenzene	VOCs	8,000	nc	**1.00****
Total xylenes	VOCs	16,000	nc	**1.00****
Tetrachloroethylene (PCE)	VOCs	420	c	0.88
Trichloroethylene (TCE)	VOCs	11	c	0.26
cis-1,2-Dichloroethylene	VOCs	160	nc	**1.00****
trans-1,2-Dichloroethylene	VOCs	1,600	nc	**1.00****
Vinyl chloride	VOCs	0.59	c	0.0024
Pentachlorophenol	Herbicides	2.2	c	0.0055
2,3,4,6-Tetrachlorophenol	Phenols	2,400	nc	**1.00****
2,4,6-Trichlorophenol	Phenols	80	nc	**1.00****
Aldrin	Pesticides	0.052	c	0.022
Azobenzene	Pesticides	8.0	c	—
Chlordane	Pesticides	2.5	c	0.064
Chlorpyrifos	Pesticides	80	nc	**1.00****
4,4'-DDD	Pesticides	3.7	c	0.092
4,4'-DDE	Pesticides	2.5	c	0.064
4,4'-DDT	Pesticides	2.5	c	0.064
Dieldrin	Pesticides	0.055	c	0.014
Lindane (gamma-BHC)	Pesticides	0.80	c	0.033
Toxaphene	Pesticides	0.80	c	0.11
Hazard Index (HI)				**10****

Notes:

“—" An oral RfD is not available to calculate a Method B noncancer-based cleanup level for azobenzene.

c = Cancer-based CUL

nc = Noncancer-based CUL

(1) This column includes the adjusted Soil Method B Cancer CULs from **Table 2** and the noncancer-based Soil Method B values from **Table 1** for the rest of the COCs. Although 2,4,6-trichlorophenol is a carcinogen, the noncancer-based Method B soil cleanup level of 80 mg/kg is used because it’s lower than the cancer-based level of 91 mg/kg.

(2) **Bold and asterisked (**)** values equal or exceed the MTCA target hazard threshold of 1. HQs based on adjusted cancer-based CULs were calculated from their Soil Method B Noncancer-based CUL (based on a HQ of 1) by setting up and solving for "HQ" in the proportion relationship shown below. Note that the full unrounded adjusted cancer-based CULs were used to calculate the HQ.

$$\frac{Method\ B\ Soil\ CUL_{noncancer}}{\mathrm{HQ}\ (1)} = \frac{Adjusted\ CUL_{cancer}}{\boldsymbol{HQ}}\ \ or\ \ \boldsymbol{HQ} = \frac{Adjusted\ CUL_{cancer} \times HQ\ (1)}{Method\ B\ Soil\ CUL_{noncancer}}$$

Development of cleanup levels based on noncancer hazard

Soil cleanup levels in this scenario need further adjustment based on noncancer effects since the unsegregated HI (10) exceeds the target of 1. The information provided in the CLARC[vii] noncancer effects table can be used to calculate HIs for groups of chemicals with similar types of noncancer effects. Groupings can be made by major noncancer effect categories such as neurotoxicity, developmental toxicity, reproductive toxicity, immunotoxicity, and adverse effects by target organ system. As shown in **Table 4** below, the COCs in Example 1 have been segregated by toxic endpoint to further evaluate noncancer hazards for compliance.

Table 4: Summary Information from the CLARC Noncancer Effects Table (Example 1)

COC	Noncancer Organ/System Affected
2,3,7,8-TCDD	Developmental; endocrine; reproductive
Benzo(a)pyrene	Developmental; nervous
Benzene	Immune
Toluene	Urinary
Ethylbenzene	Hepatic (liver); urinary (kidney)
Total xylenes	Other
Tetrachloroethylene (PCE)	Nervous; ocular
Trichloroethylene (TCE)	Developmental; immune
cis-1,2-Dichloroethylene	Urinary
trans-1,2-Dichloroethylene	Immune
Vinyl chloride	Hepatic
Pentachlorophenol	Hepatic
2,3,4,6-Tetrachlorophenol	Hepatic
2,4,6-Trichlorophenol	Reproductive
Aldrin	Hepatic
Chlordane	Hepatic
Chlorpyrifos	Nervous
4,4'-DDD	Hepatic
4,4'-DDE	Hepatic
4,4'-DDT	Hepatic
Dieldrin	Hepatic
Lindane (gamma-BHC)	Hepatic; urinary
Toxaphene	Endocrine

Based on the segregation by toxic endpoints shown above, separate HIs may be calculated for the groupings of COCs shown in **Table 5**.

Table 5: COCs Segregated by Noncancer Organ/System (Example 1)

Noncancer System Affected	COCs
Developmental	2,3,7,8-TCDD, benzo(a)pyrene, TCE
Endocrine (thyroid)	2,3,7,8-TCDD, toxaphene
Reproductive	2,3,7,8-TCDD, 2,4,6-trichlorophenol
Immune	Benzene, TCE, trans-1,2-dichloroethylene
Urinary (kidney)	Toluene, ethylbenzene, cis-1,2-dichloroethylene, lindane (gamma-BHC)
Hepatic (liver)	Ethylbenzene, vinyl chloride, pentachlorophenol, 2,3,4,6-tetrachlorophenol, aldrin, chlordane, 4,4'-DDD, 4,4'-DDE, 4,4'-DDT, dieldrin, lindane (gamma-BHC)
Other (body weight/mortality)	Total xylenes
Nervous	Benzo(a)pyrene, PCE, chlorpyrifos
Ocular (eyes)	PCE

HIs calculated for each toxic endpoint are shown in **Table 6**.

Table 6: Summary of Noncancer HIs by Toxic Endpoint (Example 1)

COC	Developmental	Endocrine (thyroid)	Reproductive	Immune	Urinary (kidney)	Hepatic (liver)	Other (body weight/mortality)	Nervous	Ocular (eyes)
2,3,7,8-TCDD	0.12	0.12	0.12	—	—	—	—	—	—
Benzo(a)pyrene	0.0069	—	—	—	—	—	—	0.0069	—
Benzene	—	—	—	0.049	—	—	—	—	—
Toluene	—	—	—	—	1	—	—	—	—
Ethylbenzene	—	—	—	—	1	1	—	—	—
Total xylenes	—	—	—	—	—	—	1	—	—
Tetrachloroethylene (PCE)	—	—	—	—	—	—	—	0.88	0.88
Trichloroethylene (TCE)	0.26	—	—	0.26	—	—	—	—	—
cis-1,2-Dichloroethylene	—	—	—	—	1	—	—	—	—
trans-1,2-Dichloroethylene	—	—	—	1	—	—	—	—	—
Vinyl chloride	—	—	—	—	—	0.0024	—	—	—
Pentachlorophenol	—	—	—	—	—	0.0055	—	—	—
2,3,4,6-Tetrachlorophenol	—	—	—	—	—	1	—	—	—
2,4,6-Trichlorophenol	—	—	1	—	—	---	—	—	—
Aldrin	—	—	—	—	—	0.022	—	—	—
Azobenzene	—	—	—	—	—	---	—	—	—
Chlordane	—	—	—	—	—	0.064	—	—	—
Chlorpyrifos	—	—	—	—	—	---	—	1	—
4,4'-DDD	—	—	—	—	—	0.092	—	—	—
4,4'-DDE	—	—	—	—	—	0.064	—	—	—
4,4'-DDT	—	—	—	—	—	0.064	—	—	—
Dieldrin	—	—	—	—	—	0.014	—	—	—
Lindane (gamma-BHC)	—	—	—	—	0.033	0.033	—	—	—
Toxaphene	—	0.11	—	—	—	—	—	—	—
Hazard Index (HI)	0.4	0.2	1	1	**3***	**2***	1	**2***	0.9

Notes:

(1) **Bold and asterisked (*)** values exceed the MTCA target hazard threshold of 1 at one significant figure (i.e., 1.49) for additive impacts.

As shown in **Table 6** above, the urinary (kidney), hepatic (liver), and nervous toxic endpoints (i.e., organ/system) generated HIs greater than 1. As such, downward adjustments need to be applied to the cleanup levels associated with the COCs that are included within these groupings to meet the target HI threshold of 1. As part of this process, decisions need to be made on which cleanup levels will be adjusted downward (i.e., below an HQ of 1) to meet the HI goal of 1. As for carcinogens, this is essentially a budgeting exercise and downward adjustments can be made to any of the COCs within their respective groupings, as along as the HI does not exceed 1.

In this scenario, the COCs that significantly contribute to the HI for each toxic endpoint grouping are those that lack cancer toxicity criteria. As such, their respective noncancer-based Method B soil levels are based on an HQ of 1. The simplest approach is to downward adjust the noncancer-based cleanup levels for these COCs evenly within their respective toxic endpoint groupings. Steps under this approach are summarized below.

- **Urinary (kidney)** – Noncancer-based cleanup levels for toluene, ethylbenzene, and cis-1,2-dichloroethylene are all based on an HQ of 1 and significantly contribute to the HI of 3 for this toxic endpoint. To adjust the cleanup levels, take the HI generated from the individual noncarcinogens (i.e., 3.03) and subtract the allowable total HI of 1.49 at one significant figure (i.e., 3.03 – 1.49). This results in a balance of 1.54 that may be distributed evenly among toluene, ethylbenzene, and cis-1,2-dichloroethylene which are targeted for downward adjustment (i.e., 1.54 ÷ 3 = 0.514). Downward adjust the target HQ for toluene, ethylbenzene, and cis-1,2-dichloroethylene by subtracting 0.514 from the acceptable individual chemical HQ level of 1 (i.e., 1 – 0.514). This results in a target HQ of 0.486. This HQ is used rather than the default of 1 to derive adjusted cleanup levels for toluene, ethylbenzene, and cis-1,2-dichloroethylene.

- **Hepatic (liver)** – Noncancer-based cleanup levels for ethylbenzene and 2,3,4,6-tetrachlorophenol are based on an HQ of 1 and significantly contribute to the HI of 2.36 for this toxic endpoint. To adjust the cleanup levels, take the HI generated from the individual noncarcinogens (i.e., 2.36) and subtract the allowable total HI of 1.49 at one significant figure (i.e., 2.36 – 1.49). This results in a balance of 0.869 that may be distributed evenly among ethylbenzene and 2,3,4,6-tetrachlorophenol which are targeted for downward adjustment (i.e., 0.869 ÷ 2 = 0.435). Downward adjust the target HQ for ethylbenzene and 2,3,4,6-tetrachlorophenol by subtracting 0.435 from the acceptable individual chemical HQ level of 1 (i.e., 1 – 0.435). This results in a target HQ of 0.565 for each (0.565 × 2 = 1.131). **Note:** The cleanup level for ethylbenzene has already been adjusted based on kidney effects to a lower HQ of 0.486 (*see* bullet above). Using an HQ of 0.486 for ethylbenzene allows the HQ for 2,3,4,6-tetrachlorophenol to increase slightly from 0.565 to 0.645 (0.486 + 0.645 = 1.131). These HQs are used rather than the default of 1 to derive adjusted cleanup levels for ethylbenzene (@ HQ 0.486) and 2,3,4,6-tetrachlorophenol (@ HQ 0.645).

- **Nervous** – The noncancer-based cleanup level for chlorpyrifos is based on an HQ of 1 and significantly contributes to the HI of 1.88 for this toxic endpoint. To adjust the cleanup levels, take the HI of 1.88 generated from the individual noncarcinogens and subtract the allowable total HI of 1.49 at one significant figure (i.e., 1.88 – 1.49). This results in a balance of 0.393 that may be assigned to chlorpyrifos. Downward adjust the target HQ for chlorpyrifos by subtracting 0.393 from the acceptable individual chemical HQ level of 1 (i.e., 1 – 0.393). This results in a target HQ of 0.607. This HQ is used rather than the default of 1 to derive adjusted cleanup levels for chlorpyrifos.

Downward adjustments based on the adjusted HQs above (identified as HQ_{adj} in the formula below) for each COC may be calculated from their Soil Method B Noncancer CUL (based on a HQ of 1) by setting up and solving for "CUL_{adj}" in the proportion relationship below.

$$\frac{Method\ B\ Soil\ CUL_{nonancer}}{\mathrm{HQ\ (1)}} = \frac{\boldsymbol{CUL_{adj}}}{HQ_{adj}}\ \ or\ \ \boldsymbol{CUL_{adj}} = \frac{Method\ B\ Soil\ CUL_{noncancer} \times HQ_{adj}}{\mathrm{HQ\ (1)}}$$

Adjustments made to cleanup levels to achieve an HI of 1 for the toxic endpoints above are shown in **Table 7** below.

Table 7: Adjusted Cleanup Levels by Toxic Endpoint (Example 1)

COC	Urinary (Kidney) CUL_{adj} (mg/kg)	Hepatic (Liver) CUL_{adj} (mg/kg)	Nervous CUL_{adj} (mg/kg)
Toluene	6,400 **(3,100*)**	—	—
Ethylbenzene	8,000 **(3,900*)**	8,000 **(3,900*)**	—
cis-1,2-dichloroethylene	160 **(78*)**	—	—
2,3,4,6-Tetrachlorophenol	—	2,400 **(1,500*)**	—
Chlorpyrifos	—	—	80 **(49*)**

Notes:
CUL_{adj} = Adjusted cleanup levels (CUL_{adj}) are in parenthesis and **bolded and asterisked (*)**. Note that the adjusted cleanup levels are rounded to 2 significant figures. Method B noncancer-based soil levels at a HQ of 1 are also provided for reference (not bolded or in parenthesis).

The final recommended cleanup levels for the COCs in Example 1 are presented in **Table 8** below.

Table 8: Final Soil Cleanup Levels (Example 1)

COC	Final CUL (mg/kg) (1)	Cancer Risk @ CUL	Urinary (Kidney) HQ @ CUL	Hepatic (Liver) HQ @ CUL	Nervous HQ @ CUL
2,3,7,8-TCDD	1.1E-05	8.76E-07	—	—	—
Benzo(a)pyrene	0.17	8.76E-07	—	—	0.0069
Benzene	16	8.76E-07	—	—	—
Toluene	3,100	—	0.486	—	—
Ethylbenzene	3,900	—	0.486	0.486	—
Total xylenes	16,000	—	—	—	—
Tetrachloroethylene (PCE)	420	8.76E-07	—	—	0.88
Trichloroethylene (TCE)	11	8.76E-07	—	—	—
cis-1,2-Dichloroethylene	78	—	0.486	—	—
trans-1,2-Dichloroethylene	1,600	—	—	—	—
Vinyl chloride	0.59	8.76E-07	—	0.0024	—
Pentachlorophenol	2.2	8.76E-07	—	0.0055	—
2,3,4,6-Tetrachlorophenol	1,500	—	—	0.645	—
2,4,6-Trichlorophenol	80	8.79E-07	—	—	—
Aldrin	0.052	8.76E-07	—	0.022	—
Azobenzene	8.0	8.76E-07	—	—	—
Chlordane	2.5	8.76E-07	—	0.064	—
Chlorpyrifos	49	—	—	—	0.607
4,4'-DDD	3.7	8.76E-07	—	0.092	—
4,4'-DDE	2.5	8.76E-07	—	0.064	—
4,4'-DDT	2.5	8.76E-07	—	0.064	—
Dieldrin	0.055	8.76E-07	—	0.014	—
Lindane (gamma-BHC)	0.80	8.76E-07	0.033	0.033	—
Toxaphene	0.80	8.76E-07	—	—	—
Totals	—	**1.49E-05 or 1E-05**	**1.49 or 1**	**1.49 or 1**	**1.49 or 1**

Discussion

For most MTCA sites, soil cleanup levels are also set at concentrations that are protective of groundwater beneficial use (e.g., soil leaching levels protective of potable groundwater). Cleanup levels based on soil leaching are commonly much lower than human direct contact levels[24]. At most sites, if soil leaching levels are applied as the CUL to estimate cancer risk and noncancer hazard from human direct contact, the total cancer risk and noncancer HI are not likely to exceed 1E-05 and 1, respectively. For example, using the minimum between the risk-based human direct contact level and the soil leaching level for protection of potable groundwater in Example 1 yields a total cancer risk of 5E-06 and an unsegregated HI of 0.7.

[24] Hydrophopic compounds with high organic carbon partitioning coefficients (Koc) and low water solubility (e.g., cPAHs, dioxins, some pesticides) are less mobile and tend to bind to soil or sediment than to leach into water. As a result, soil leaching levels for some of these compounds (e.g., cPAHs) may be higher than human health risk-based levels.

Cancer risk and noncancer hazards (i.e., HQs) based on soil leaching levels may be calculated using the formulas below. Note that the soil leaching level and the Method B soil CUL must be in the same units (e.g., mg/kg).

$$\frac{Method\ B\ Soil\ CUL_{cancer}}{\text{1E-06}} = \frac{Soil\ Leaching\ Level}{\boldsymbol{Risk}}\ \ or\ \ \boldsymbol{Risk} = \frac{Soil\ Leaching\ Level \times (\text{1E-06})}{Method\ B\ Soil\ CUL_{cancer}}$$

$$\frac{Method\ B\ Soil\ CUL_{nonancer}}{\text{HQ} = 1} = \frac{Soil\ Leaching\ Level}{\boldsymbol{HQ}}\ \ or\ \ \boldsymbol{HQ} = \frac{Soil\ Leaching\ Level \times\ HQ\ (1)}{Method\ B\ Soil\ CUL_{noncancer}}$$

5.5 Example 2

Under MTCA, cleanup levels established under Methods A, B, and C must be protective of concentrations established under applicable state and federal laws known as ARARs (*see* WAC 173-340-700[ix] (5)). ARARs do not, by themselves, necessarily define human health protectiveness. That is, some ARARs may be established at concentrations higher than the relevant MTCA equation values (e.g., due to technical or analytical limitations). As such, ARARs used as the basis for a cleanup level may need to be adjusted to meet the maximum acceptable levels of risk and noncancer hazard allowed under MTCA. This is an example of adjusting ARAR-based cleanup levels in groundwater under Method B to comply with the additive cancer risk goal of 1E-05 and a noncancer hazard (HI) of 1.[25]

ARARs for an individual chemical are considered sufficiently protective under MTCA if they are associated with no more than a risk of 1E-05 or an HQ of 1. Otherwise, they must be adjusted downward so that the **total cancer risk and HI** at the site (i.e., additive from multiple chemicals and/or exposure pathways) do not exceed these limits (*see* WAC 173-340-705[i] (5)).

Note: Method A cleanups may be performed without consideration of additive effects. For example, due to multiple pathways of exposure, or due to multiple hazardous substances. *See Ecology's Guidance on the Use of Method A, B, and C Cleanup Levels and Mixing Methods*[x] (Ecology, 2022b).

For this example, a release of chlorinated solvents from a dry cleaner has resulted in impacts to on-site potable groundwater. Contaminants of concern (COC) in groundwater include 1,1-dichloroethylene (1,1-DCE), cis- and trans-1,2-dichloroethylene (cis- and trans-1,2-DCE), tetrachloroethylene (PCE), trichloroethylene (TCE), and vinyl chloride (VC). In this hypothetical

[25] Examples of ARAR-based soil cleanup levels include the Method A values for total polychlorinated biphenyl (PCB) mixtures (*see* MTCA Tables 740-1 and 745-1). For example, the Method B cancer-based CUL for total PCBs is 0.5 mg/kg and the ARAR-based unrestricted land use value is 1 mg/kg (*see* 40 CFR 761.61). The ARAR-based unrestricted value of 1 mg/kg generates a risk of 2E-06 and is considered to be a sufficiently protective ARAR under Method B, as long as the total site risk and HI do not exceed 1E-05 and 1, respectively.

scenario, the vapor intrusion (VI) pathway screened out as a pathway of concern based on collection of soil gas under a Tier 2 evaluation per Ecology's VI guidance[xi] (Ecology, 2022a).

Note: Method B is being used in this example to illustrate how to make adjustments for additive risk. See *Ecology's Guidance on the Use of Method A, B, and C Cleanup Levels and Mixing Methods*[x] for details on selecting a cleanup method (Ecology, 2022b).

Evaluation of ARARs

When developing concentrations protective of human health under MTCA, a key decision criterion for whether an ARAR can be used to establish a cleanup level is whether the ARAR is considered "sufficiently protective". All of the COCs in this example have maximum contaminant levels (MCLs) promulgated by EPA (40 CFR 141[xii]) and the Washington State Board of Health (WAC 246-290[xiii]). **Table 9** below shows the noncancer HQ and cancer risk generated for each COC at their respective MCL concentrations.

Table 9: Noncancer Hazard and Cancer Risk at the MCL Concentration (Example 2)

COC	GW Method B Noncancer CUL (µg/L) (1)	GW Method B Cancer CUL (µg/L) (1)	MCL (µg/L)	Noncancer HQ @ MCL (2)	Cancer Risk @ MCL (2)
1,1-Dichloroethene (1,1-DCE)	400	—	7	0.018	—
cis-1,2-Dichloroethene (cis-1,2-DCE)	16	—	70	**4.4****	—
trans-1,2-Dichloroethene (trans-1,2-DCE)	160	—	100	0.63	—
Tetrachloroethylene (PCE)	48	21	5	0.1	2.4E-07
Trichloroethylene (TCE)	4	0.54	5	**1.3****	9.3E-06
Vinyl chloride (VC)	24	0.029	2	0.08	**6.9E-05****
Totals				**HI = 6****	**8E-05****

Notes:

"—" Cancer toxicity criteria (i.e., CPF) is not available. Chemical evaluated as a noncarcinogen.

(1) Groundwater Method B Noncancer and Cancer CULs are based on a cancer risk of 1E-06 and an HQ of 1, respectively (values taken from CLARC[vii]).

(2) **Bold and asterisked (**)** values exceed the MTCA noncancer HQ/HI threshold of 1, or the target cancer risk threshold of 1E-05 for ARAR-based cleanup levels. Noncancer HQ and cancer risk at the MCL concentration were calculated from Groundwater Method B risk-based levels by setting up and solving for "HQ" or "Risk" in the proportion relationships shown below.

$$\frac{Method\ B\ GW\ CUL_{noncancer}}{\mathrm{HQ\ (1)}} = \frac{MCL}{\boldsymbol{HQ}} \quad or \quad \boldsymbol{HQ} = \frac{MCL \times HQ\ (1)}{Method\ B\ GW\ CUL_{noncancer}}$$

$$\frac{Method\ B\ GW\ CUL_{cancer}}{\mathrm{1E\text{-}06}} = \frac{MCL}{\boldsymbol{Risk}} \quad or \quad \boldsymbol{Risk} = \frac{MCL \times (\mathrm{1E\text{-}06})}{Method\ B\ GW\ CUL_{cancer}}$$

As shown in **Table 9** above, if the potable groundwater ARAR-based MCLs for the COCs are applied as the cleanup levels under this scenario, the HI (6) and additive risk (8E-05) exceed the MTCA thresholds of 1 and 1E-05, respectively. Risk-based results generated at the MCLs (i.e., ARAR-based CUL) show that the HQs for cis-1,2-DCE and TCE each exceed 1, and the cancer risk for VC exceeds 1E-05. Based on these results, downward adjustments of one or more MCLs is required.

Development of cleanup levels based on cancer risk

An example of how a downward adjustment may be made to comply with ARARs and to meet the cumulative risk target under this scenario is provided below. COCs that are evaluated based on cancer effects include PCE, TCE, and VC. The MCLs for TCE and VC are targeted for downward adjustment since they are not sufficiently protective (i.e., TCE exceeds its noncancer threshold; VC exceeds its cancer threshold).

Step 1. Downward adjust the MCL for TCE to its Method B noncancer-based level of 4 µg/L to comply with an HQ of 1. Add up the risk due to PCE at its MCL of 5 µg/L (2.38E-07; *see* Table 9) and TCE at its Method B noncancer-based CUL of 4 µg/L (7.41E-06; *see* equation below). This equals a risk of 7.65E-06.

$$\frac{TCE\ Method\ B\ GW\ CUL_{cancer}(0.54\ \mu g/L)}{\text{1E-06}} = \frac{4\ \mu g/L}{\text{Risk}}\ \ or\ \ \boldsymbol{Risk} = \frac{4\ \mu g/L \times (\text{1E-06})}{0.54\ \mu g/L} = \text{7.41E-06}$$

Step 2. Subtract 7.65E-06 from the allowable total risk of 1E-05 at one significant figure (i.e., 1.49E-05 – 7.65E-06). This results in a balance of 7.25E-06 that may be assigned to VC which is targeted for downward adjustment. That is, the VC MCL of 2 µg/L needs to be adjusted downward to be sufficiently protective as an individual ARAR and to comply with the total risk threshold of 1E-05.

Step 3. Downward adjustment to a risk of 7.25E-06 for VC may be calculated from its Groundwater Method B Cancer CUL (based on a 1E-06 risk level) by setting up and solving for "CUL_{adj}" in the proportion relationship shown below.

$$\frac{Method\ B\ CUL_{cancer}(0.029\ \mu g/L)}{\text{1E-06}} = \frac{\boldsymbol{CUL_{adj}}}{\text{7.25E-06}}\ \ or\ \ \boldsymbol{CUL_{adj}} = \frac{0.029\ \mu g/L \times (\text{7.25E-06})}{\text{1E-06}} = 0.21 \mu g/L$$

Cleanup level adjustments made to comply with ARARs and to achieve a total risk of 1E-05 at one significant figure are shown in **Table 10** below.

Table 10: Adjustments to Cancer-Based Cleanup Levels for Groundwater COCs (Example 2)

COC	Groundwater Method B Cancer CUL (µg/L) (1)	MCL (µg/L)	CUL or CUL_{adj} (µg/L) (2)	Cancer Risk (3)
Tetrachloroethylene (PCE)	21	5	5	2.38E-07
Trichloroethylene (TCE)	0.54	5	**4****	**7.41E-06**[a]
Vinyl chloride (VC)	0.029	2	**0.21****	**7.25E-06**[a]
Totals	—		—	**1.49E-05 (1E-05)**

Notes:

[a] = Cleanup levels for TCE and VC may exceed a 1E-06 risk since they are ARAR-based.

(1) The Groundwater Method B Cancer CUL is based on a cancer risk of 1E-06 (values taken from CLARC[vii]).

(2) Adjustments made to the cleanup levels (CUL_{adj}) are **bolded and asterisked (**)**. The CUL_{adj} of 0.21 µg/L for VC is rounded to two significant figures, and the CUL_{adj} of 4 µg/L for TCE is its Method B noncancer-based potable groundwater level (@ HQ of 1).

(3) Cancer risks were calculated based on the MCL for PCE and the adjusted cleanup levels (CUL_{adj}) for TCE and VC. This generates a total risk of 1.49E-05 rounded to 1E-05 at one significant figure.

Development of Cleanup Levels based on Noncancer Hazard

ARAR-based groundwater cleanup levels in this scenario need further adjustment to meet the HI threshold of 1. As shown in **Table 11** below, the COCs may be segregated by toxic endpoint (i.e., organ/system) to further evaluate noncancer hazards for compliance.

Table 11: Summary Information from the CLARC Noncancer Effects Table (Example 2)

COC	Noncancer Organ/System Affected
1,1-Dichloroethene (1,1-DCE)	Hepatic
cis-1,2-Dichloroethene (cis-1,2-DCE)	Urinary
trans-1,2-Dichloroethene (trans-1,2-DCE)	Immune
Tetrachloroethylene (PCE)	Nervous; ocular
Trichloroethylene (TCE)	Developmental; immune
Vinyl chloride (VC)	Hepatic

Based on the toxic endpoints shown above, separate HIs may be calculated for the groupings of COCs listed in **Table 12**.

Table 12: COCs Segregated by Noncancer Organ/System (Example 2)

Noncancer System Affected	COCs
Developmental	TCE

Noncancer System Affected	COCs
Immune	trans-1,2-DCE, TCE
Urinary (kidney)	cis-1,2-DCE
Hepatic (liver)	1,1-DCE, VC
Nervous; Ocular (eyes)	PCE

HIs segregated by toxic endpoint are shown in **Table 13**.

Table 13: Summary of Noncancer HIs by Toxic Endpoint (Example 2)

COC	MCL or MCL_{adj} (µg/L)	Developmental	Immune	Urinary (kidney)	Hepatic (liver)	Nervous; Ocular (eyes)
1,1-Dichloroethene (1,1-DCE)	7	—	—	—	0.0175	—
cis-1,2-Dichloroethene (cis-1,2-DCE)	70	—	—	4.38	—	—
trans-1,2-Dichloroethene (trans-1,2-DCE)	100	—	0.625	—	—	—
Tetrachloroethylene (PCE)	5	—	—	—	—	0.104
Trichloroethylene (TCE)	4 (MCL_{adj})	1	1	—	—	—
Vinyl chloride (VC)	0.21 (MCL_{adj})	—	—	—	0.00875	—
Hazard Index (HI)		1	**2***	**4***	0.03	0.1

Notes:

MCL_{adj} = As part of the ARAR and cancer risk evaluation, the MCL for TCE was adjusted to meet an HQ of 1. Also, the MCL for VC was adjusted to meet the additive risk threshold of 1E-05 (1.49E-05 at one significant figure).

Bold and asterisked (*) values exceed the MTCA target hazard threshold of 1 at one significant figure (i.e., 1.49) for additive impacts.

As shown in **Table 13**, the immune and urinary (kidney) toxic endpoints generate HIs greater than 1. As such, downward adjustments need to be applied to the cleanup levels associated with the COCs that are included within these groupings to meet the target HI threshold of 1. Downward adjustments are summarized below.

- **Immune** – As part of the ARAR evaluation and development of cancer-based groundwater cleanup levels, the MCL for TCE (5 µg/L) was downward adjusted to its Method B noncancer-based groundwater cleanup level (4 µg/L) to be sufficiently protective at an HQ of 1. TCE's adjusted MCL significantly contributes to the HI of 2 for the immune toxic endpoint. To further downward adjust the MCL for TCE, take the HI generated from trans-1,2-DCE and TCE (0.625 + 1 = 1.625) and subtract the allowable total HI of 1.49 at one significant figure (i.e., 1.625 – 1.49 = 0.135). Next, subtract the balance of 0.135 that from the TCE HQ of 1 (1 – 0.135). This results in a target HQ of 0.865 for TCE. This HQ is used rather than the default of 1 to further downward adjust the MCL for TCE.

  Downward adjustment to the TCE MCL based on its adjusted HQ of 0.865 (identified as HQ_{adj} in the formula below) may be calculated from its Groundwater Method B Noncancer

CUL (Meth B GW CUL_{nc}) by setting up and solving for "CUL_{adj}" in the proportion relationship below.

$$\frac{Meth\ B\ GW\ CUL_{nc}(4\ \mu g/L)}{\mathrm{HQ}\ (1)} = \frac{\boldsymbol{CUL_{adj}}}{HQ_{adj}(0.865)}\ \ or\ \ \boldsymbol{CUL_{adj}} = \frac{4\ \mu g/L \times\ 0.865}{\mathrm{HQ}\ (1)}$$

Based on an adjusted HQ of 0.865, the MCL for TCE gets adjusted from 4 µg/L down to 3.46 µg/L or 3.5 µg/L rounded to two significant figures. Note that rounding up to 3.5 µg/L results in a HI of 1.5 (or 2 at one significant figure) for the immune system endpoint. Therefore, 3.4 µg/L is selected as the adjusted CUL for TCE.

- **Urinary (kidney)** – cis-1,2-DCE is the only COC that contributes to the urinary (kidney) toxic endpoint. The MCL for cis-1,2-DCE (70 µg/L) generates an HQ of 4.4. As a result, the MCL for cis-1,2-DCE needs to be adjusted down to its Method B noncancer-based potable groundwater level of 16 µg/L (based on an HQ of 1).

Final VC Adjustment – Using 3.4 µg/L as the final cleanup level for TCE allows for some additional risk to be added to vinyl chloride to achieve a total cancer risk of 1.49E-05. Final groundwater CULs for PCE (5 µg/L) and TCE (3.4 µg/L) generate a risk of 6.53E-06 (2.38E-07 + 6.29E-06; *see* equations below).

$$\text{PCE} = \frac{Method\ B\ GW\ CUL_{cancer}\ (21\ \mu g/L)}{\mathrm{1E\text{-}06}} = \frac{CUL\ (5\ \mu g/L)}{\boldsymbol{Risk}}\ \ or\ \ \boldsymbol{Risk} = \frac{5\ \mu g/L \times (\mathrm{1E\text{-}06})}{21\ \mu g/L} = \mathrm{2.38E\text{-}07}$$

$$\text{TCE} = \frac{Method\ B\ GW\ CUL_{cancer}\ (0.54\ \mu g/L)}{\mathrm{1E\text{-}06}} = \frac{CUL\ (3.4\ \mu g/L)}{\boldsymbol{Risk}}\ \ or\ \ \boldsymbol{Risk} = \frac{3.4\ \mu g/L \times (\mathrm{1E\text{-}06})}{0.54\ \mu g/L} = \mathrm{6.29E\text{-}06}$$

Subtracting this risk from the target threshold of 1E-05 (or 1.49E-05 at one significant figure) results in a risk balance of 8.37E-06 that can be allocated to vinyl chloride. The groundwater CUL for vinyl chloride at a risk of 8.37E-06 is 0.2427 µg/L (or 0.24 µg/L rounded to two significant figures). This CUL was calculated from its Method B groundwater CUL as shown in the equation below.

$$\frac{Method\ B\ GW\ CUL_{cancer}(0.029\ \mu g/L)}{\mathrm{1E\text{-}06}} = \frac{\boldsymbol{CUL}}{\mathrm{8.37E\text{-}06}}\ \ or\ \ \boldsymbol{CUL} = \frac{0.029\ \mu g/L \times (\mathrm{8.37E\text{-}06})}{\mathrm{1E\text{-}06}}$$

The final recommended cleanup levels for the COCs in Example 2 are presented in **Table 14**.

Table 14: Final Groundwater Cleanup Levels (Example 2)

COC	Final CUL (µg/L)	Cancer Risk @ CUL	Urinary (Kidney) HQ @ CUL	Immune HQ @ CUL
1,1-Dichloroethene (1,1-DCE)	7	—	—	—
cis-1,2-Dichloroethene (cis-1,2-DCE)	16	—	1	—
trans-1,2-Dichloroethene (trans-1,2-DCE)	100	—	—	0.625
Tetrachloroethylene (PCE)	5	2.38E-07	—	—

COC	Final CUL (µg/L)	Cancer Risk @ CUL	Urinary (Kidney) HQ @ CUL	Immune HQ @ CUL
Trichloroethylene (TCE)	3.4	6.29E-06	—	0.85
Vinyl chloride (VC)	0.24	8.28E-06	—	—
Totals	—	**1.48E-05 or 1E-05**	**1**	**1.48 or 1**

Discussion

Concentrations of these chlorinated chemicals in groundwater are expected to decrease as part of future remedial actions (e.g., monitored natural attenuation or active treatment). In this example, cleanup levels for 1,1-DCE, trans-1,2-DCE, and PCE are set at their respective MCLs and will remain the same. The CUL for cis-1,2-DCE will also remain the same because it's been adjusted to its Method B potable groundwater noncancer-based CUL. However, the concentration of TCE to comply with an HI of 1 for the immune toxic endpoint, and VC to achieve a total risk of 1E-05, are expected to change as the plume attenuates (i.e., concentrations decrease). For example, if PCE and TCE concentrations in the plume attenuated to 2.5 and 3 µg/L, respectively, the cleanup level for VC would change from 0.24 µg/L to 0.27 µg/L to achieve the total risk threshold of 1E-05 (at one significant figure). Also, if PCE and TCE are attenuated to non-detect levels, then it might be appropriate to change the cleanup level for VC to 0.29 µg/L.

Note: When CULs have been adjusted to account for additive risk and noncancer HI in this type of scenario, it's important to coordinate with Ecology when considering how they may be impacted during long-term monitoring as concentrations are reduced in the plume over time.

Chapter 6: Acronyms

µg/L	Microgram per liter
1,1-DCE	1,1-Dichloroethylene
ADAF	Age-Dependent Adjustment Factor
ARAR	Applicable or Relevant and Appropriate Requirements
AT	Averaging time
CES	Concise explanatory statement
CFR	Code of federal regulations
cis-1,2-DCE	cis-1,2-Dichloroethylene
CLARC	Cleanup levels and risk calculation
COC	Chemical of concern
Conc.	Concentration
cPAHs	Carcinogenic polycyclic aromatic hydrocarbons
CPF	Cancer potency factor
CUL	Cleanup level
Ecology	Washington State Department of Ecology
ED	Exposure duration
EF	Exposure Frequency
ELE	Early-life exposure
EPA	United States Environmental Protection Agency
FS	Feasibility study
GI	Gastrointestinal absorption conversion factor (unitless)
HI	Hazard index
HQ	Hazard quotient
IRIS	Integrated risk information system
kg-day/mg	Kilogram-day per milligram
MCL	Maximum contaminant levels
mg/kg	Milligram per kilogram
mg/kg-day	Milligram per kilogram-day
MTCA	Model Toxics Control Act
NHL	Non-Hodgkin lymphoma (NHL)
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethylene
PQL	Practical Quantitation Limit
RAGS	Risk Assessment Guidance for Superfund
REL	Remediation level
RfD	Reference dose
RI	Remedial investigation
Risk	Cancer risk
RME	Reasonable maximum exposure
SW	Surface Water
TCDD	Tetrachlorodibenzo-p-dioxin
TCE	Trichloroethylene
TCP	Toxics Cleanup Program
TEF	Toxicity equivalence factor
TEQ	Toxicity equivalents
TPH	Total petroleum hydrocarbons
trans-1,2-DCE	trans-1,2-Dichloroethylene
VC	Vinyl chloride
VI	Vapor intrusion
VOC	Volatile organic compound
WAC	Washington administrative code

Chapter 7: References

Ecology (Washington State Department of Ecology), 2001. *Concise Explanatory Statement for the Amendments to the Model Toxics Control Act Cleanup Regulation Chapter 173-340 WAC*[iv]. Publication Number: 01-09-043. February 12, 2001.

Ecology, 2022a. *Guidance for Evaluating Vapor Intrusion in Washington State. Investigation and Remedial Action. Toxics Cleanup Program*[xiv]. Washington State Department of Ecology. Publication No. 09-09-047. March 2022.

Ecology, 2022b. *Guidance on the Use of Method A, B, and C Cleanup Levels and Mixing Methods.* [xv] December 2022.

EPA (United States Environmental Protection Agency), 1989. *Risk Assessment Guidance for Superfund, Part A: Human Health Evaluation Manual*[xvi]. Interim Final. Office of Emergency and Remedial Response. Washington, D.C. EPA/540/1-89/002. December 1989.

EPA, 1991. *Risk Assessment Guidance for Superfund, Part B, Development of Risk-based Preliminary Remediation Goals*[xvii]. OSWER Directive 9285.7-01B. December 1991.

Attachment A: Calculating Cancer Risk and Noncancer Hazards from MTCA Cleanup Level Equations

Each of the MTCA equations may be rearranged to solve for cancer risk or HQ. This method is an option if alternate exposure assumptions are used (i.e., different from the Method B defaults) to derive a site-specific Modified Method B or C level, or a remediation level. One could also calculate cancer risk and noncancer hazard from the site-specific Modified Method B and C CULs, or remediation level, by setting up and solving for "Risk" or "HQ" using the simplified equation formulas presented in Chapter 4 of the main text. The types of exposure parameters that may be changed to derive a cleanup level or remediation level are discussed in the MTCA rule (*see* WAC 173-340-708[iii] (1))[26].

MTCA cleanup level equations rearranged to solve for cancer risk or HQ are presented for each media (i.e., soil, groundwater, surface water, and air)[27].

Note: Exposure frequency (EF) and averaging time (AT) in the MTCA cleanup level equations as presented in the rule are reduced to present a more simplified equation than EPA uses in Superfund risk assessment. For example, since Ecology's residential cleanup level equation assumes an EF of 365 days/year, and the noncancer AT is equal to the exposure duration (ED) in years multiplied by 365 days/year, a simplified equation can be used that identifies the EF as 1. The residential exposure assumption of 365 days/year for EF is reduced and can be expressed as 1 when AT is expressed in years rather than days. For industrial land uses that qualify under Method C based on soil exposure, the EF factor is 0.4 or 146 days/year (i.e., 0.4 × 365 days). For illustration, the math behind the reduced equations is shown below for Method B and C noncancer soil exposure. To better show the math, the partial equations below have been rearranged in the form of a forward HQ calculation where AT is in the denominator. Reduced terms to derive the EF factor are underlined.

Method B Soil (Equation 740-1) – Rearranged to calculate HQ

(EF × ED) ÷ AT = ($\underline{365\ d/y}$ × 6 y) ÷ (6 y × $\underline{365\ d/y}$). In Equation 740-1, Ecology reduced this to an AT of 6 yrs, an ED of 6 yrs, and an EF factor of 1 (365 d/y ÷ 365 d/y).

Method C Soil (Equation 745-1) – Rearranged to calculate HQ

(EF × ED) ÷ AT = ($\underline{146\ d/y}$ × 20 y) ÷ (20 y × $\underline{365\ d/y}$). In Equation 745-1, Ecology reduced this to an AT of 20 yrs, an ED of 20 yrs, and an EF factor of 0.4 (146 d/y ÷ 365 d/y).

The equations presented below are consistent with the MTCA cleanup level equations but are expanded to include AT in days (or hours as in the air equations) and EF in days/year—consistent with EPA's approach. **Default values** provided in the MTCA rule are provided for reference.

[26] Any proposed change to the default exposure parameters provided in the MTCA rule should be made in coordination with the Ecology site manager.
[27] These equations can easily be converted to a chemical intake (a.k.a., dose) in mg/kg-day by excluding the noncancer (i.e., RfD) or cancer (i.e., CPF) toxicity values.

Soil equations (WAC 173-340-740[vi] and WAC 173-340-745[xviii])

Equations 740-1 and 745-1:
Method B and C[28] **noncancer-based** soil equations (based on incidental ingestion)

$$HQ = \frac{C_{soil} \times SIR \times AB1 \times EF \times ED}{ABW \times UCF \times AT_{nc} \times RfD_o}$$

Variable	Description	Method B Eq. 740-1	Method C Eq. 745-1
HQ	Hazard quotient	unitless	unitless
C_{soil}	Soil concentration	mg/kg	mg/kg
SIR	Soil ingestion rate	200 mg/day	50 mg/day
AB1	Gastrointestinal absorption fraction	1.0, unitless	1.0, unitless
EF	Exposure frequency	365 days/year	146 days/year
ED	Exposure duration	6 years	20 years
ABW	Average body weight	16 kg	70 kg
UCF	Unit conversion factor	1,000,000 mg/kg	1,000,000 mg/kg
AT_{nc}	Noncancer averaging time *(ED × 365 days/year)*	2,190 days	7,300 days
RfD_o	Oral reference dose	mg/kg-day	mg/kg-day

Equations 740-2 and 745-2:
Method B and C[28] **cancer-based** soil equations (based on incidental ingestion)

$$Risk = \frac{C_{soil} \times SIR \times AB1 \times EF \times ED \times CPF_o}{ABW \times UCF \times AT_c}$$

Variable	Description	Method B Eq. 740-2	Method C Eq. 745-2
Risk	Excess cancer risk	unitless	unitless
C_{soil}	Soil concentration	mg/kg	mg/kg
SIR	Soil ingestion rate	200 mg/day	50 mg/day
AB1	Gastrointestinal absorption fraction	1.0, unitless[29]	1.0, unitless[29]
EF	Exposure frequency	365 days/year	146 days/year
ED	Exposure duration	6 years	20 years
ABW	Average body weight	16 kg	70 kg
UCF	Unit conversion factor	1,000,000 mg/kg	1,000,000 mg/kg
AT_c	Cancer averaging *time (75 years × 365 days/year)*	27,375 days	27,375 days
CPF_o	Oral cancer potency factor	kg-day/mg	kg-day/mg

[28] Method C soil cleanup levels may be applied at sites qualifying as industrial property under WAC 173-340-745[xviii] as cited in WAC 173-340-706[ii].
[29] May use 0.6 for mixtures of dioxins and/or furans.

Equation 740-2 **modified for mutagens**:
Method B **cancer-based** soil equation (based on incidental ingestion)

Use this equation to calculate cancer risk from carcinogens identified with a documented **mutagenic mode of action.** Exposure to these types of carcinogens may result in greater effects during early-life exposure (ELE) versus similar exposures later in life. More information can be found in Ecology's *Guidance for Assessing Risk from Early-Life Exposure to Carcinogens*[xix]. Calculations specific to vinyl chloride and TCE (both mutagens) are discussed below.

$$Risk = \frac{C_{soil} \times ELE_{soil} \times AB1 \times EF \times CPF_o}{UCF \times AT_c}$$

$$ELE_{soil} = \frac{ADAF_{<2yr} \times ED_{<2yr} \times SIR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times SIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{soil}	Soil concentration	mg/kg
ELE_{soil}	Early-life exposure adjustment factor	400 mg-year/kg-day
ADAF	Age-dependent adjustment factor (unitless)	$ADAF_{<2yr}$ = 10 $ADAF_{2\text{-}6yr}$ = 3
SIR	Soil ingestion rate	200 mg/day (<2yr; 2-6yr)
AB1	Gastrointestinal absorption fraction	1.0, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs $ED_{2\text{-}6yr}$ = 4 yrs
ABW	Average body weight	16 kg (<2yr; 2-6yr)
UCF	Unit conversion factor	1,000,000 mg/kg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days
CPF_o	Oral cancer potency factor	kg-day/mg

Vinyl Chloride

EPA's reassessment of vinyl chloride toxicity concludes that higher cancer risks result from exposure to vinyl chloride early in life compared to exposure during adulthood. Two cancer slope factors are in IRIS with one used to evaluate adult cancer risks and the other used to evaluate the increased susceptibility to cancer of children from vinyl chloride exposures. In accordance with our CLARC guidance for vinyl chloride[xx], the higher slope factor that accounts for continuous lifetime exposure from birth (1.5 kg-day/mg) should be used to account for risks due to early-life exposures via the oral route. As such, the vinyl chloride CPF_o of 1.5 kg-day/mg may be used directly in MTCA Equation 740-2 without application of ADAFs to calculate risk[30].

[30] For exposure scenarios where the RME is determined to be exclusively for non-pregnant adults (no children or pregnant women), Ecology may consider using a CPF_o of 0.75 kg-day/mg (*see* our CLARC guidance for vinyl chloride).

Equation 740-2 **modified for TCE mutagenic toxicity**:
Method B **cancer-based** soil equation (based on incidental ingestion)

As discussed in CLARC guidance for TCE[xxi], EPA developed its cancer values by adding together the increased risks of three separate types of cancer: kidney cancer, liver cancer, and non-Hodgkin lymphoma (NHL). EPA determined that TCE causes kidney cancer through a mutagenic mode of action, but liver cancer and NHL do not involve a mutagenic mode of action. As such, EPA assigns a greater weight to the kidney cancer portion of the value (via ADAFs) than the liver cancer and NHL portions. To account for this, two separate toxicity adjustment factors are incorporated into the equation.

$$Risk = \frac{C_{soil} \times Total\ ELE\ Adjustment\ Factor \times AB1 \times EF \times CPF_o}{UCF \times AT_c}$$

Total ELE adjustment factor for soil = Kidney cancer + (NHL + Liver cancer)

$$Kidney\ cancer = \frac{ADAF_{<2yr} \times MAF \times ED_{<2yr} \times SIR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times MAF \times ED_{2\text{-}6yr} \times SIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

$$NHL + Liver\ cancer = \frac{CAF \times ED_{<2yr} \times SIR_{<2yr}}{ABW_{<2yr}} + \frac{CAF \times ED_{2\text{-}6yr} \times SIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{soil}	Soil concentration	mg/kg
Total ELE adjustment factor	Early-life exposure adjustment factor	141.619 mg-year/kg-day[31]
ADAF	Age-dependent adjustment factor (unitless)	$ADAF_{<2yr}$ = 10, $ADAF_{2\text{-}6yr}$ = 3
MAF	Toxicity adjustment factor for mutagenic kidney endpoint. *MAF = CPF_o Kidney ÷ Total CPF_o = 0.00933 ÷ 0.046*	0.202826, unitless[31]
CAF	Toxicity adjustment factor for NHL/Liver endpoint. *CAF= (CPF_o NHL + CPF_o Liver) ÷ Total CPF_o = 0.0371 ÷ 0.046*	0.806522, unitless[31]
SIR	Soil ingestion rate	200 mg/day (<2yr; 2-6yr)
AB1	Gastrointestinal absorption fraction	1.0, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs $ED_{2\text{-}6yr}$ = 4 yrs
ABW	Average body weight	16 kg (<2yr; 2-6yr)
UCF	Unit conversion factor	1,000,000 mg/kg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days
CPF_o	TCE oral cancer potency factor	0.046 kg-day/mg

[31] Use the full unrounded values for the Total ELE Adjustment Factor, MAF, and CAF.

Equations 740-3 and 745-3:
Method B and C[32] **noncancer-based** soil equations for petroleum mixtures (based on concurrent incidental ingestion and dermal contact)

This equation has been modified to calculate an HQ rather than an HI. For petroleum mixtures (a.k.a., total petroleum hydrocarbons; TPH), the HI represents the sum of the HQs calculated for each petroleum component (e.g., petroleum fraction or chemical) measured in a sample. Note that Ecology's Workbook for calculating cleanup levels for petroleum contaminated sites (MTCATPH 12.0 Excel workbook version 12.0)[xxii] allows you to calculate cleanup levels for petroleum mixtures for soil (based on concurrent ingestion and dermal contact) using MTCA Methods B or C. However, you cannot alter the default RME exposure parameters for soil direct contact in the workbook.

Note: Using the simplified method described in section 4.1, a TPH cleanup level (based on an HI of 1) can be derived by dividing the total TPH concentration by the calculated HI (i.e., sum of the HQs).

$$HQ(i) = \frac{C_{soil} \times EF \times ED \times \left[\left(SIR \times AB1 \times \frac{1}{RfD_o}\right) + \left(SA \times AF \times ABS \times \frac{1}{RfDd}\right)\right]}{ABW \times AT_{nc} \times UCF}$$

Variable	Description	Method B Eq. 740-3	Method C Eq. 745-3
HQ(i)	Hazard quotient for petroleum component (i)	unitless	unitless
C_{soil}	Soil concentration	mg/kg	mg/kg
SIR	Soil ingestion rate	200 mg/day	50 mg/day
AB1	Gastrointestinal absorption fraction	1.0, unitless	1.0, unitless
SA	Dermal surface area	2,200 cm^2	2,500 cm^2
AF	Adherence factor	0.2 mg/cm^2-day	0.2 mg/cm^2-day
ABS	Dermal absorption fraction	chemical-specific or MTCA default, unitless	chemical-specific or MTCA default, unitless
EF	Exposure frequency	365 days/year	255.5 days/year[33]
ED	Exposure duration	6 years	20 years
ABW	Average body weight	16 kg	70 kg
UCF	Unit conversion factor	1,000,000 mg/kg	1,000,000 mg/kg
AT_{nc}	Noncancer averaging time *(ED × 365 days/year)*	2,190 days	7,300 days
RfD_o	Oral reference dose	mg/kg-day	mg/kg-day
RfD_d	Dermal reference dose *(RfD_o × GI*[34])	mg/kg-day	mg/kg-day

[32] Method C soil cleanup levels may be applied at sites qualifying as industrial property under WAC 173-340-745[xviii] as cited in WAC 173-340-706[ii].
[33] The EF factor in the MTCA rule in Equation 745-3 is 0.7. This equates to 255.5 days/year (0.7 × 365). Use the full unrounded EF of 255.5 days/year to be consistent with the MTCA default EF of 0.7.
[34] GI = Gastrointestinal absorption conversion factor (unitless).

Equations 740-4 and 745-4:
Method B and C[35] **noncancer-based** soil equations for hazardous substances other than petroleum mixtures (based on concurrent incidental ingestion and dermal contact)

$$HQ = \frac{C_{soil} \times EF \times ED \times \left[\left(SIR \times AB1 \times \frac{1}{RfD_o}\right) + \left(SA \times AF \times ABS \times \frac{1}{RfD_d}\right)\right]}{ABW \times AT_{nc} \times UCF}$$

Variable	Description	Method B Eq. 740-4	Method C Eq. 745-4
HQ(i)	Hazard quotient for petroleum component (i)	unitless	unitless
C_{soil}	Soil concentration	mg/kg	mg/kg
SIR	Soil ingestion rate	200 mg/day	50 mg/day
AB1	Gastrointestinal absorption fraction	1.0, unitless	1.0, unitless
SA	Dermal surface area	2,200 cm^2	2,500 cm^2
AF	Adherence factor	0.2 mg/cm^2-day	0.2 mg/cm^2-day
ABS	Dermal absorption fraction	chemical-specific or MTCA defaults; unitless	chemical-specific or MTCA defaults; unitless
EF	Exposure frequency	365 days/year	255.5 days/year[36]
ED	Exposure duration	6 years	20 years
ABW	Average body weight	16 kg	70 kg
UCF	Unit conversion factor	1,000,000 mg/kg	1,000,000 mg/kg
AT_{nc}	Noncancer averaging time *(ED × 365 days/year)*	2,190 days	7,300 days
RfD_o	Oral reference dose	mg/kg-day	mg/kg-day
RfD_d	Dermal reference dose *(RfD_o × GI[37])*	mg/kg-day	mg/kg-day

[35] Method C soil cleanup levels may be applied at sites qualifying as industrial property under WAC 173-340-745[xviii] as cited in WAC 173-340-706[ii].
[36] The EF factor in the MTCA rule in Equation 745-4 is 0.7. This equates to 255.5 days/year (0.7 × 365). Use the full unrounded EF of 255.5 days/year to be consistent with the MTCA default EF of 0.7.
[37] GI = Gastrointestinal absorption conversion factor (unitless).

Equations 740-5 and 745-5: Method B and C[38] **cancer-based** soil equations for hazardous substances other than petroleum mixtures (based on concurrent incidental ingestion and dermal contact)

$$Risk = \frac{C_{soil} \times EF \times ED \times [(SIR \times AB1 \times CPF_o) + (SA \times AF \times ABS \times CPF_d)]}{ABW \times AT_c \times UCF}$$

Variable	Description	Method B Eq. 740-5	Method C Eq. 745-5
Risk	Excess cancer risk	unitless	unitless
C_{soil}	Soil concentration	mg/kg	mg/kg
SIR	Soil ingestion rate	200 mg/day	50 mg/day
AB1	Gastrointestinal absorption fraction	1.0, unitless[39]	1.0, unitless[39]
SA	Dermal surface area	2,200 cm^2	2,500 cm^2
AF	Adherence factor	0.2 mg/cm^2-day	0.2 mg/cm^2-day
ABS	Dermal absorption fraction	chemical-specific or MTCA defaults; unitless	chemical-specific or MTCA defaults; unitless
EF	Exposure frequency	365 days/year	255.5 days/year[40]
ED	Exposure duration	6 years	20 years
ABW	Average body weight	16 kg	70 kg
UCF	Unit conversion factor	1,000,000 mg/kg	1,000,000 mg/kg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days	27,375 days
CPF_o	Oral cancer potency factor	kg-day/mg	kg-day/mg
CPF_d	Dermal cancer potency factor *(CPF_o ÷ GI[41])*	kg-day/mg	kg-day/mg

[38] Method C soil cleanup levels may be applied at sites qualifying as industrial property under WAC 173-340-745[xviii] as cited in WAC 173-340-706[ii].
[39] May use 0.6 for mixtures of dioxins and/or furans.
[40] The EF factor in the MTCA rule in Equation 745-5 is 0.7. This equates to 255.5 days/year (0.7 × 365). Use the full unrounded EF of 255.5 days/year to be consistent with the MTCA default EF of 0.7.
[41] GI = Gastrointestinal absorption conversion factor (unitless).

Equation 740-5 (**modified for mutagens**): Method B **cancer-based** soil equation (based on concurrent incidental ingestion and dermal contact)

Use this equation to calculate cancer risk from carcinogens identified with a documented **mutagenic mode of action.** Exposure to these types of carcinogens may result in greater effects during early-life exposure (ELE) versus similar exposures later in life. More information can be found in Ecology's *Guidance for Assessing Risk from Early-Life Exposure to Carcinogens***Error! Bookmark not defined.**. Calculations specific to vinyl chloride and TCE (both mutagens) are discussed after this equation.

$$Risk = \frac{C_{soil} \times \left[\left(ELE_{ingest\text{-}adj} \times AB1 \times CPF_o\right) + \left(ELE_{dermal\text{-}adj} \times ABS \times CPF_d\right)\right] \times EF}{UCF \times AT_c}$$

$$ELE_{ingest\text{-}adj}\ (soil\ ingestion) = \frac{ADAF_{<2yr} \times ED_{<2yr} \times SIR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times SIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

$$ELE_{dermal\text{-}adj}\ (dermal\ contact) = \frac{ADAF_{<2yr} \times ED_{<2yr} \times SA_{<2yr} \times AF_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times SA_{2\text{-}6yr} \times AF_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{soil}	Soil concentration	mg/kg
$ELE_{ingest\text{-}adj}$	Early-life exposure adjustment factor for soil ingestion	400 mg-year/kg-day
$ELE_{dermal\text{-}adj}$	Early-life exposure adjustment factor for soil dermal contact	880 mg-year/kg-day
ADAF	Age-dependent adjustment factor	$ADAF_{<2yr}$ = 10 (unitless) $ADAF_{2\text{-}6yr}$ = 3 (unitless)
SIR	Soil ingestion rate	200 mg/day (<2yr; 2-6yr)
AB1	Gastrointestinal absorption fraction	1.0, unitless
SA	Dermal surface area	2,200 cm^2 (<2yr; 2-6yr)
AF	Adherence factor	0.2 mg/cm^2-day (<2yr; 2-6yr)
ABS	Dermal absorption fraction	chemical-specific or MTCA defaults; unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs $ED_{2\text{-}6yr}$ = 4 yrs
ABW	Average body weight	16 kg (<2yr; 2-6yr)
UCF	Unit conversion factor	1,000,000 mg/kg
AT_c	Cancer averaging time (*75 years × 365 days/year*)	27,375 days
CPF_o	Oral cancer potency factor	kg-day/mg
CPF_d	Dermal cancer potency factor *(CPF_o ÷ GI[42])*	kg-day/mg

[42] GI = Gastrointestinal absorption conversion factor (unitless).

Vinyl Chloride

EPA's reassessment of vinyl chloride toxicity concludes that exposure to vinyl chloride early in life results in higher cancer risks than exposure during adulthood. There are two cancer slope factors in IRIS; one used to evaluate adult cancer risks and the other to evaluate the increased susceptibility to cancer of children from vinyl chloride exposures. In accordance with our CLARC guidance for vinyl chloride[xx], the higher slope factor that accounts for continuous lifetime exposure from birth (1.5 kg-day/mg) should be used to account for risks due to early-life exposures via the oral route. As such, the vinyl chloride CPF_o 1.5 kg-day/mg for the oral route and the CPF_d (1.5 kg-day/mg ÷ 0.8[43]) for the dermal route may be used directly in MTCA Equation 740-5 without application of ADAFs to calculate risk[44].

Equation 740-5 **modified for TCE mutagenic toxicity**: Method B **cancer-based** soil equation (based on concurrent incidental ingestion and dermal contact)

As discussed in our CLARC guidance for TCE**Error! Bookmark not defined.**, EPA developed its cancer values by adding together the increased risks of three separate types of cancer: kidney cancer, liver cancer, and non-Hodgkin lymphoma (NHL). EPA determined that TCE causes kidney cancer through a mutagenic mode of action, but liver cancer and NHL do not involve a mutagenic mode of action. As such, EPA assigns a greater weight to the kidney cancer portion of the value (via ADAFs) than the liver cancer and NHL portions. To account for this, there are two separate toxicity adjustment factors in this equation.

$$Risk = \frac{C_{soil} \times \left[\left(ELE_{ingest\text{-}adj} \times AB1 \times CPF_o\right) + \left(ELE_{dermal\text{-}adj} \times ABS \times CPF_d\right)\right] \times EF}{UCF \times AT_c}$$

ELE adjustment factor for **soil ingestion** = **Kidney cancer + (NHL + Liver cancer)**

$$Kidney\ cancer = \frac{ADAF_{<2yr} \times MAF \times ED_{<2yr} \times SIR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times MAF \times ED_{2\text{-}6yr} \times SIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

$$NHL + Liver\ cancer = \frac{CAF \times ED_{<2yr} \times SIR_{<2yr}}{ABW_{<2yr}} + \frac{CAF \times ED_{2\text{-}6yr} \times SIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

ELE adjustment factor for **soil dermal contact** = **Kidney cancer + (NHL + Liver cancer)**

$$Kidney\ cancer = \frac{ADAF_{<2yr} \times MAF \times ED_{<2yr} \times SA_{<2yr} \times AF_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times MAF \times ED_{2\text{-}6yr} \times SA_{2\text{-}6yr} \times AF_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

$$NHL + Liver\ cancer = \frac{CAF \times ED_{<2yr} \times SA_{<2yr} \times AF_{<2yr}}{ABW_{<2yr}} + \frac{CAF \times ED_{2\text{-}6yr} \times SA_{2\text{-}6yr} \times AF_{2\text{-}6yr}}{ABW_{2\text{-}6yr}}$$

[43] 0.8 is the Gastrointestinal absorption conversion factor (GI) assigned to vinyl chloride since it's volatile.

[44] For exposure scenarios where the RME is determined to be exclusively for non-pregnant adults (no children or pregnant women), Ecology may consider using a CPF_o of 0.75 kg-day/mg (*see* our CLARC guidance for vinyl chloride[xx]).

Equation 740-5 modified for TCE mutagenic toxicity (*continued*)

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{soil}	Soil concentration	mg/kg
$ELE_{ingest-adj}$	Early-life exposure adjustment factor for soil ingestion	141.619 mg-year/kg-day[45]
$ELE_{dermal-adj}$	Early-life exposure adjustment factor for soil dermal contact	311.563 mg-year/kg-day[45]
ADAF	Age-dependent adjustment factor	$ADAF_{<2yr}$ = 10 (unitless) $ADAF_{2-6yr}$ = 3 (unitless)
MAF	Toxicity adjustment factor for mutagenic kidney endpoint. *MAF = CPF_o Kidney ÷ Total CPF_o = 0.00933 ÷ 0.046*	0.202826, unitless[45]
CAF	Toxicity adjustment factor for NHL/Liver endpoint *CAF = (CPF_o NHL + CPF_o Liver) ÷ Total CPF_o = 0.0371 ÷ 0.046*	0.806522, unitless[45]
SIR	Soil ingestion rate	200 mg/day (<2yr; 2-6yr)
AB1	Gastrointestinal absorption fraction	1.0, unitless
SA	Dermal surface area	2,200 cm^2 (<2yr; 2-6yr)
AF	Adherence factor	0.2 mg/cm^2-day (<2yr; 2-6yr)
ABS	Dermal absorption fraction	0.03, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs ED_{2-6yr} = 4 yrs
ABW	Average body weight	16 kg (<2yr; 2-6yr)
UCF	Unit conversion factor	1,000,000 mg/kg
AT_c	Cancer averaging time (*75 years × 365 days/year*)	27,375 days
CPF_o	TCE oral cancer potency factor	0.046 kg-day/mg
CPF_d	TCE dermal cancer potency factor (*derived by CPF_o ÷ GI*[46])	0.0575 kg-day/mg

[45] Use the full unrounded value for $ELE_{ingest-adj}$, $ELE_{dermal-adj}$, MAF, and CAF. Note that the MAF and CAF are the same for oral and dermal routes of exposure.

[46] 0.8 is the Gastrointestinal absorption conversion factor (GI) assigned to TCE since it's volatile.

Groundwater Equations (WAC 173-340-720[v])

Equation 720-1: Method B and C[47] **noncancer-based** groundwater equation (based on potable water ingestion)

$$HQ = \frac{C_{gw} \times DWIR \times INH \times DWF \times EF \times ED}{ABW \times UCF \times AT_{nc} \times RfD_o}$$

Variable	Description	Method B
HQ	Hazard quotient	unitless
C_{gw}	Groundwater concentration	µg/L
DWIR	Drinking water ingestion rate	1 L/day
INH	Inhalation correction factor	2 for volatile organics, 1 for all others (unitless)
DWF	Drinking water fraction	1.0, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	6 years
ABW	Average body weight	16 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_{nc}	Noncancer averaging time (*ED × 365 days/year*)	2,190 days
RfD_o	Oral reference dose	mg/kg-day

Equation 720-2: Method B and C[47] **cancer-based** groundwater equation (based on potable water ingestion)

$$Risk = \frac{C_{gw} \times DWIR \times INH \times DWF \times EF \times ED \times CPF_o}{ABW \times UCF \times AT_c}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{gw}	Groundwater concentration	µg/L
DWIR	Drinking water ingestion rate	2 L/day
INH	Inhalation correction factor	2 for volatile organics, 1 for all others (unitless)
DWF	Drinking water fraction	1.0; unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	30 years
ABW	Average body weight	70 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days
CPF_o	Oral cancer potency factor	kg-day/mg

[47] Method C groundwater cleanup levels may be applied on a conditional basis **if** the site meets the strict conditions identified in WAC 173-340-706[ii]. Method C groundwater cleanup levels are calculated using MTCA Equations 720-1 and 720-2. *See* WAC 173-340-720(5)(b)(iii)(A)[v] for Method C groundwater default exposure parameters for noncarcinogens, and WAC 173-340-720(5)(b)(iii)(B) for carcinogens. Method C levels **must** comply with ARARs (WAC 173-340-706).

Equation 720-2 **modified for mutagens**:

Method B **cancer-based** groundwater equation (based on potable water ingestion)

Use this equation to calculate cancer risk from carcinogens identified with a documented mutagenic mode of action**.** Exposure to these types of carcinogens may result in greater effects during early-life exposure (ELE) versus similar exposures later in life. For more information see Ecology's *Guidance for Assessing Risk from Early-Life Exposure to Carcinogens***Error! Bookmark not defined.**.

Calculations specific to vinyl chloride and TCE (both mutagens) are discussed on the next page.

$$Risk = \frac{C_{gw} \times ELE_{gw} \times INH \times DWF \times EF \times CPF_o}{UCF \times AT_c}$$

$$ELE_{gw} = \frac{ADAF_{<2yr} \times ED_{<2yr} \times DWIR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times DWIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{ADAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times DWIR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{ADAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times DWIR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

Variable	Description	Method B
Risk	Excess cancer risk	Unitless
C_{gw}	Groundwater concentration	µg/L
ELE_{gw}	Early-life exposure adjustment factor	3.26 liter-year/kg-day[48]
ADAF	Age-dependent adjustment factor (unitless)	$ADAF_{<2yr}$ = 10 $ADAF_{2\text{-}6yr}$ = 3 $ADAF_{6\text{-}16y}$ = 3 $ADAF_{16\text{-}30y}$ = 1)
DWIR	Drinking water ingestion rate	$DWIR_{<2yr}$ = 1 L/day $DWIR_{2\text{-}6yr}$ = 1 L/day $DWIR_{6\text{-}16yr}$ = 2 L/day $DWIR_{16\text{-}30yr}$ = 2 L/day
INH	Inhalation correction factor	2 for volatile organics, 1 for all others (unitless)
DWF	Drinking water fraction	1.0, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs $ED_{2\text{-}6yr}$ = 4 yrs $ED_{6\text{-}16yr}$ = 10 yrs $ED_{16\text{-}30yr}$ = 14 yrs
ABW	Average body weight	$ABW_{<2yr}$ = 16 kg $ABW_{2\text{-}6yr}$ = 16 kg $ABW_{6\text{-}16yr}$ = 70 kg $ABW_{16\text{-}30yr}$ = 70 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days
CPF_o	Oral cancer potency factor	kg-day/mg

[48] Use the full unrounded value for the ELE Adjustment Factor.

Vinyl Chloride

EPA's reassessment of vinyl chloride toxicity concludes that higher cancer risks result from exposure to vinyl chloride early in life compared to exposure during adulthood. Two cancer slope factors are in IRIS: One used to evaluate adult cancer risks and the other used to evaluate the increased susceptibility to cancer of children from vinyl chloride exposures. In accordance with our CLARC guidance for vinyl chloride[xx], the higher slope factor that accounts for continuous lifetime exposure from birth (1.5 kg-day/mg) should be used to account for risks due to early-life exposures via the oral route. As such, the vinyl chloride CPF_o of 1.5 kg-day/mg may be used directly in MTCA Equation 720-2 without applying ADAFs to calculate risk[49].

Equation 720-2 **modified for TCE mutagenic toxicity**:
Method B **cancer-based** groundwater equation (based on potable water ingestion)

As discussed in our CLARC guidance for TCE**Error! Bookmark not defined.**, EPA developed its cancer values by adding together the increased risks of three separate types of cancer: kidney cancer, liver cancer, and non-Hodgkin lymphoma (NHL). EPA determined that TCE causes kidney cancer through a mutagenic mode of action, but liver cancer and NHL do not involve a mutagenic mode of action. As such, EPA assigns a greater weight to the kidney cancer portion of the value (via ADAFs) than the liver cancer and NHL portions. To account for this, two separate toxicity adjustment factors are incorporated into the modified equation.

$$Risk = \frac{C_{gw} \times Total\ ELE\ adjustment\ factor \times INH \times DWF \times EF \times CPF_o}{UCF \times AT_c}$$

Total ELE adjustment factor for groundwater = Kidney cancer + (NHL + Liver cancer)

$$Kidney\ cancer = \frac{ADAF_{<2yr} \times MAF_{<2yr} \times ED_{<2yr} \times DWIR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times MAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times DWIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{ADAF_{6\text{-}16yr} \times MAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times DWIR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{ADAF_{16\text{-}30yr} \times MAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times DWIR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

$$NHL + Liver\ cancer = \frac{\text{CAF} \times ED_{<2yr} \times DWIR_{<2yr}}{ABW_{<2yr}} + \frac{CAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times DWIR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{CAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times DWIR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{CAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times DWIR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

[49] For exposure scenarios where the RME is determined to be exclusively for non-pregnant adults (no children or pregnant women), Ecology may consider using a CPF_o of 0.75 kg-day/mg (*see* our CLARC guidance for vinyl chloride[xxxx]).

Equation 720-2 modified for TCE mutagenic toxicity (continued on next page)

Variable	Description	Method B	
Risk	Excess cancer risk	unitless	
C_{gw}	Groundwater concentration	µg/L	
Total ELE adjustment factor	Early-life exposure adjustment factor	1.516 liter-year/kg-day[50]	
ADAF	Age-dependent adjustment factor (unitless)	$ADAF_{<2yr}$ = 10 $ADAF_{6-16yr}$ = 3	$ADAF_{2-6yr}$ = 3 $ADAF_{16-30yr}$ = 1
MAF	Toxicity adjustment factor for mutagenic kidney endpoint: *CPF_o Kidney ÷ Total CPF_o = 0.00933 ÷ 0.046*	0.202826, unitless[50]	
CAF	Toxicity adjustment factor for NHL/Liver endpoint: *(CPF_o NHL + CPF_o Liver) ÷ Total CPF_o = 0.0371 ÷ 0.046*	0.806522, unitless[50]**Error! Bookmark not defined.**	
DWIR	Drinking water ingestion rate	$DWIR_{<2yr}$ = 1 L/day $DWIR_{6-16yr}$ = 2 L/day	$DWIR_{2-6yr}$ = 1 L/day $DWIR_{16-30yr}$ = 2 L/day
INH	Inhalation correction factor	2, unitless	
DWF	Drinking water fraction	1.0, unitless	
EF	Exposure frequency	365 days/year	
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs ED_{6-16yr} = 10 yrs	ED_{2-6yr} = 4 yrs $ED_{16-30yr}$ = 14 yrs
ABW	Average body weight	$ABW_{<2yr}$ = 16 kg ABW_{6-16yr} = 70 kg	ABW_{2-6yr} = 16 kg $ABW_{16-30yr}$ = 70 kg
UCF	Unit conversion factor	1,000 µg/mg	
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days	
CPF_o	TCE oral cancer potency factor	0.046 kg-day/mg	

[50] Use the full unrounded value for the ELE adjustment factor, MAF, and CAF.

Equation 720-3:
Method B **noncancer-based** groundwater equation for petroleum mixtures (based on potable water ingestion)

Equation 720-3 as presented below has been modified to calculate an HQ rather than an HI. For petroleum mixtures, the HI represents the sum of the HQs calculated for each petroleum component (e.g., petroleum fraction or chemical) measured in a sample. Note that Ecology's Workbook for calculating cleanup levels for petroleum contaminated sites (MTCATPH 12.0 Excel workbook version 12.0)[xxii] allows you to calculate cleanup levels for petroleum mixtures for groundwater using MTCA Method B. However, the default RME exposure parameters for potable groundwater ingestion cannot be altered in the workbook.

Note: Using the simplified method described in section 4.1, a TPH cleanup level (based on an HI of 1) can be derived by dividing the total TPH concentration by the calculated HI (i.e., sum of the HQs).

$$HQ(i) = \frac{C_{gw} \times DWIR \times INH \times DWF \times EF \times ED}{ABW \times UCF \times AT_{nc} \times RfD_o}$$

Variable	Description	Method B
HQ(i)	Hazard quotient for petroleum component (i)	unitless
C_{gw}	Groundwater concentration	µg/L
DWIR	Drinking water ingestion rate	1 L/day
INH	Inhalation correction factor	2 for volatile organics, 1 for all others (unitless)
DWF	Drinking water fraction	1.0; unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	6 years
ABW	Average body weight	16 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_{nc}	Noncancer averaging time *(ED × 365 days/year)*	2,190 days
RfD_o	Oral reference dose	mg/kg-day

Surface Water (SW) equations (WAC 173-340-730[xxiii])

Equation 730-1: Method B and C[51] **noncancer-based** SW equation (based on fish consumption)

$$HQ = \frac{C_{sw} \times BCF \times FCR \times FDF \times EF \times ED}{ABW \times UCF1 \times UFC2 \times AT_{nc} \times RfD_o}$$

Variable	Description	Method B
HQ	Hazard quotient	unitless
C_{sw}	Surface water concentration	µg/L
BCF	Bioconcentration factor (chemical-specific)	L/kg
FCR	Fish consumption rate	54 grams/day
FDF	Fish diet fraction	0.5, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	30 years
ABW	Average body weight	70 kg
UCF1	Unit conversion factor	1,000 µg/mg
UCF2	Unit conversion factor	1,000 grams/kg
AT_{nc}	Noncancer averaging time (*ED × 365 days/year*)	10,950 days
RfD_o	Oral reference dose	mg/kg-day

Equation 730-2:
Method B and C[51] **cancer-based** SW equation (based on fish consumption)

$$Risk = \frac{C_{sw} \times BCF \times FCR \times FDF \times EF \times ED \times CPF_o}{ABW \times UCF1 \times UFC2 \times AT_c}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{sw}	Surface water concentration	µg/L
BCF	Bioconcentration factor (chemical-specific)	L/kg
FCR	Fish consumption rate	54 grams/day
FDF	Fish diet fraction	0.5, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	30 years
ABW	Average body weight	70 kg
UCF1	Unit conversion factor	1,000 µg/mg
UCF2	Unit conversion factor	1,000 grams/kg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days

[51] Method C surface water cleanup levels may be applied on a conditional basis **if** the site meets the strict conditions identified in WAC 173-340-706[ii]. Method C surface water cleanup levels are calculated using MTCA Equations 730-1 and -2. *See* WAC 173-340-730(4)(b)(iii)(A)[xxiii] for Method C surface water default exposure parameters for noncarcinogens, and WAC 173-340-730(4)(b)(iii)(B) for carcinogens. Note that Method C levels **must** comply with ARARs (WAC 173-340-706[ii]).

CPF_o	Oral cancer potency factor	kg-day/mg

Equation 730-2 (**modified for mutagens**): Method B **cancer-based** surface water equation (based on fish consumption)

This equation should be used to calculate cancer risk from carcinogens identified with a documented **mutagenic mode of action.** Exposure to these types of carcinogens may result in greater effects during early-life exposure (ELE) versus similar exposures later in life. More information can be found in Ecology's *Guidance for Assessing Risk from Early-Life Exposure to Carcinogens***Error! Bookmark not defined.**.

Calculations specific to vinyl chloride and TCE (both mutagens) are discussed on the next page.

$$Risk = \frac{C_{sw} \times ELE_{sw} \times BCF \times FDF \times EF \times CPF_o}{UCF1 \times UFC2 \times AT_c}$$

$$ELE_{sw} = \frac{ADAF_{<2yr} \times ED_{<2yr} \times FCR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times FCR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{ADAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times FCR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{ADAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times FCR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

Variable	Description	Method B	
Risk	Excess cancer risk	Unitless	
C_{sw}	Surface water concentration	µg/L	
ELE_{gw}	Early-life exposure adjustment factor	141.9 gram-year/kg-day[52]	
ADAF	Age-dependent adjustment factor	$ADAF_{<2yr}$ = 10 $ADAF_{6\text{-}16y}$ = 3	$ADAF_{2\text{-}6yr}$ = 3 $ADAF_{16\text{-}30y}$ = 1 (unitless)
FCR	Fish consumption rate	54 grams/day (<2yr; 2-6yr; 6-16yr; 16-30yr)	
BCF	Bioconcentration factor (chemical-specific)	L/kg	
FDF	Fish diet fraction	0.5, unitless	
EF	Exposure frequency	365 days/year	
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs $ED_{6\text{-}16yr}$ = 10 yrs	$ED_{2\text{-}6yr}$ = 4 yrs $ED_{16\text{-}30yr}$ = 14 yrs
ABW	Average body weight	$ABW_{<2yr}$ = 16 kg $ABW_{6\text{-}16yr}$ = 70 kg	$ABW_{2\text{-}6yr}$ = 16 kg $ABW_{16\text{-}30yr}$ = 70 kg
UCF1	Unit conversion factor	1,000 µg/mg	
UCF2	Unit conversion factor	1,000 grams/kg	
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days	
CPF_o	Oral cancer potency factor	kg-day/mg	

[52] Use the full unrounded value for the ELE Adjustment Factor.

Vinyl Chloride

EPA's reassessment of vinyl chloride toxicity concludes that higher cancer risks result from exposure to vinyl chloride early in life compared to exposure during adulthood. Two cancer slope factors are in IRIS with one used to evaluate adult cancer risks and the other used to evaluate the increased susceptibility to cancer of children from vinyl chloride exposures. In accordance with our CLARC guidance for vinyl chloride[xx], the higher slope factor that accounts for continuous lifetime exposure from birth (1.5 kg-day/mg) should be used to account for risks due to early-life exposures via the oral route. As such, the vinyl chloride CPF_o of 1.5 kg-day/mg may be used directly in MTCA Equation 730-2 without application of ADAFs to calculate risk[53].

Equation 730-2 modified for TCE mutagenic toxicity: Method B **cancer-based** surface water equation (based on fish consumption)

As discussed in our CLARC guidance for TCE**Error! Bookmark not defined.**, EPA developed its cancer values by adding together the increased risks of three separate types of cancer (kidney cancer, liver cancer, and non-Hodgkin lymphoma [NHL]). EPA determined that TCE causes kidney cancer through a mutagenic mode of action, but liver cancer and NHL do not involve a mutagenic mode of action. As such, EPA assigns a greater weight to the kidney cancer portion of the value (via ADAFs) than the liver cancer and NHL portions. To account for this, two separate toxicity adjustment factors are incorporated into this equation.

$$Risk = \frac{C_{sw} \times Total\ ELE\ Adjustment\ Factor \times BCF \times FDF \times EF \times CPF_o}{UCF1 \times UFC2 \times AT_c}$$

Total ELE adjustment factor for surface water = Kidney cancer + (NHL + Liver cancer)

$$Kidney\ cancer = \frac{ADAF_{<2yr} \times MAF_{<2yr} \times ED_{<2yr} \times FCR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times MAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times FCR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{ADAF_{6\text{-}16yr} \times MAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times FCR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{ADAF_{16\text{-}30yr} \times MAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times FCR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

$$NHL + Liver\ cancer = \frac{CAF_{<2yr} \times ED_{<2yr} \times FCR_{<2yr}}{ABW_{<2yr}} + \frac{CAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times FCR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{CAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times FCR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{CAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times FCR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

[53] For exposure scenarios where the RME is determined to be exclusively for non-pregnant adults (no children or pregnant women), Ecology may consider using a CPF_o of 0.75 kg-day/mg (*see* our CLARC guidance for vinyl chloride[xx]).

Equation 730-2 modified for TCE mutagenic toxicity (continued)

Variable	Description	Method B
Risk	Excess cancer risk	Unitless
C_{sw}	Surface water concentration	µg/L
Total ELE adjustment factor	Early-life exposure adjustment factor	60.054 gram-year/kg-day [54]
ADAF	Age-dependent adjustment factor	$ADAF_{<2yr}$ = 10 $ADAF_{2-6yr}$ = 3 $ADAF_{6-16yr}$ = 3 $ADAF_{16-30yr}$ = 1 (unitless)
MAF	Toxicity adjustment factor for mutagenic kidney endpoint: *CPF_o Kidney ÷ Total CPF_o* = 0.00933 ÷ 0.046	0.202826, unitless[54]
CAF	Toxicity adjustment factor for NHL/Liver endpoint: *(CPF_o NHL + CPF_o Liver) ÷ Total CPF_o* = 0.0371 ÷ 0.046	0.806522, unitless[54]
FCR	Fish consumption rate	54 grams/day (<2yr; 2-6yr; 6-16yr; 16-30yr)
BCF	Bioconcentration factor	11 L/kg
FDF	Fish diet fraction	0.5, unitless
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs ED_{2-6yr} = 4 yrs ED_{6-16yr} = 10 yrs $ED_{16-30yr}$ = 14 yrs
ABW	Average body weight	$ABW_{<2yr}$ = 16 kg ABW_{2-6yr} = 16 kg ABW_{6-16yr} = 70 kg $ABW_{16-30yr}$ = 70 kg
UCF1	Unit conversion factor	1,000 µg/mg
UCF2	Unit conversion factor	1,000 grams/kg
AT_c	Cancer averaging time *(75 years × 365 days/year)*	27,375 days
CPF_o	Oral cancer potency factor	0.046 kg-day/mg

[54] Use the full unrounded value for the ELE Adjustment Factor, MAF, and CAF.

Air Equations (WAC 173-340-750[xxiv])

Equation 750-1:
Method B and C[55] **noncancer-based** air equation (based on inhalation of air)

$$HQ = \frac{C_{air} \times BR \times ABS \times ET \times EF \times ED}{ABW \times UCF \times AT_{nc} \times RfD_i}$$

Variable	Description	Method B
HQ	Hazard quotient	unitless
C_{air}	Air concentration	µg/m^3
BR	Breathing rate	10 m^3/day
ABS	Inhalation absorption fraction	1.0, unitless
ET	Exposure time	24 hours/day[56]
EF	Exposure frequency	365 days/year
ED	Exposure duration	6 years
ABW	Average body weight	16 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_{nc}	Noncancer averaging time (*ED × 365 days/year × 24 hours/day*)	52,560 hours
RfD_i	Inhalation reference dose	mg/kg-day

Equation 750-2:
Method B and C[55] **cancer-based** air equation (based on air inhalation of air)

$$Risk = \frac{C_{air} \times BR \times ABS \times ET \times EF \times ED \times CPF_i}{ABW \times UCF \times AT_c}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{air}	Air concentration	µg/m^3
BR	Breathing rate	20 m^3/day
ABS	Inhalation absorption fraction	1.0, unitless
ET	Exposure time	24 hours/day[56]
EF	Exposure frequency	365 days/year
ED	Exposure duration	30 years
ABW	Average body weight	70 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_c	Cancer averaging time (*75 years × 365 days/year × 24 hours/day*)	657,000 hours
CPF_i	Inhalation cancer potency factor	kg-day/mg

[55] Method C air cleanup levels may be applied at sites qualifying as industrial property under WAC 173-340-745[xviii] as cited in WAC 173-340-706[ii]. Method C air cleanup levels are calculated using MTCA Equations 750-1 and -2 with some modifications to the exposure parameters. For noncarcinogens, the average body weight shall be 70 kg and the estimated breathing rate shall be 20 m^3/day (*see* WAC 173-340-750[xxiv] (4)(b)(ii)(A)). For carcinogens, the same default values under Method B are used to estimate risk under Method C. However, Method C air cleanup levels for individual chemicals are based on a 1E-05 cancer risk rather than 1E-06 (*see* WAC 173-340-750(4)(b)(ii)(B)).

[56] Method B and C air cleanup level equations assume that receptors are exposed continuously (i.e., 24 hours/day; 365 days/year) over the exposure period. As such, the expanded equations presented here to calculate HQ and risk include exposure time (ET), and the AT is expressed in hours instead of days.

Equation 750-2 modified for mutagens:

Method B **cancer-based** air equation (based on inhalation of air)

Use this equation to calculate cancer risk from carcinogens identified with a documented **mutagenic mode of action**. Exposure to these types of carcinogens may result in greater effects during early-life exposure (ELE) versus similar exposures later in life. There is more information in Ecology's *Guidance for Assessing Risk from Early-Life Exposure to Carcinogens***Error! Bookmark not defined.**.

Calculations specific to vinyl chloride and TCE (both mutagens) are discussed on the next page.

$$Risk = \frac{C_{air} \times ELE_{air} \times ABS \times ET \times EF \times CPF_i}{UCF \times AT_c}$$

$$ELE_{air} = \frac{ADAF_{<2yr} \times ED_{<2yr} \times BR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times BR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{ADAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times BR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{ADAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times BR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

Variable	Description	Method B	
Risk	Excess cancer risk	unitless	
C_{air}	Air concentration	µg/m^3	
ELE_{air}	Early-life exposure adjustment factor	32.6 m^3-year/kg-day[57]	
ADAF	Age-dependent adjustment factor	$ADAF_{<2yr}$ = 10 $ADAF_{6\text{-}16yr}$ = 3	$ADAF_{2\text{-}6yr}$ = 3 $ADAF_{16\text{-}30yr}$ = 1 (unitless)
BR	Breathing rate	$BR_{<2yr}$ = 10 m^3/day $BR_{6\text{-}16yr}$ = 20 m^3/day	$BR_{2\text{-}6yr}$ = 10 m^3/day $BR_{16\text{-}30yr}$ = 20 m^3/day
ABS	Inhalation absorption fraction	1.0, unitless	
ET	Exposure time	24 hours/day	
EF	Exposure frequency	365 days/year	
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs $ED_{6\text{-}16yr}$ = 10 yrs	$ED_{2\text{-}6yr}$ = 4 yrs $ED_{16\text{-}30yr}$ = 14 yrs
ABW	Average body weight	$ABW_{<2yr}$ = 16 kg $ABW_{6\text{-}16yr}$ = 70 kg	$ABW_{2\text{-}6yr}$ = 16 yrs $ABW_{16\text{-}30yr}$ = 70 kg
UCF	Unit conversion factor	1,000 µg/mg	
AT_c	Cancer averaging time (*75 years × 365 days/year × 24 hours/day*)	657,000 hours	
CPF_i	Inhalation cancer potency factor	kg-day/mg	

[57] Use the full unrounded value for the ELE Adjustment Factor.

Vinyl Chloride

EPA's reassessment of vinyl chloride toxicity concludes that higher cancer risks result from exposure to vinyl chloride early in life compared to exposure during adulthood. Two cancer slope factors are in IRIS: one used to evaluate adult cancer risks and the other used to evaluate the increased susceptibility to cancer of children from vinyl chloride exposures. In accordance with our CLARC guidance for vinyl chloride[xx], the higher slope factor that accounts for continuous lifetime exposure from birth (0.0308 kg-day/mg)[58] should be used to account for risks due to early-life exposures via the inhalation route. As such, the vinyl chloride CPF_i of 0.0308 kg-day/mg may be used directly in MTCA Equation 750-2 without application of ADAFs to calculate risk[59].

Equation 750-2 (**modified for TCE mutagenic toxicity**)

Method B **cancer-based** groundwater equation (based on inhalation of air)

As discussed in our CLARC guidance for TCE**Error! Bookmark not defined.**, EPA developed its cancer values by adding together the increased risks of three separate types of cancer: kidney cancer, liver cancer, and non-Hodgkin lymphoma (NHL). EPA determined that TCE causes kidney cancer through a mutagenic mode of action, but liver cancer and NHL do not involve a mutagenic mode of action. As such, EPA assigns a greater weight to the kidney cancer portion of the value (via ADAFs) than the liver cancer and NHL portions. To account for this, two separate toxicity adjustment factors are incorporated into this equation.

$$Risk = \frac{C_{air} \times Total\ ELE\ Adjustment\ Factor \times ABS \times ET \times EF \times CPF_i}{UCF \times AT_c}$$

Total ELE adjustment factor for air = Kidney cancer + (NHL + Liver cancer)

$$Kidney\ cancer = \frac{ADAF_{<2yr} \times MAF_{<2yr} \times ED_{<2yr} \times BR_{<2yr}}{ABW_{<2yr}} + \frac{ADAF_{2\text{-}6yr} \times MAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times BR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{ADAF_{6\text{-}16yr} \times MAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times BR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{ADAF_{16\text{-}30yr} \times MAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times BR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

$$NHL + Liver\ cancer = \frac{CAF_{<2yr} \times ED_{<2yr} \times BR_{<2yr}}{ABW_{<2yr}} + \frac{CAF_{2\text{-}6yr} \times ED_{2\text{-}6yr} \times BR_{2\text{-}6yr}}{ABW_{2\text{-}6yr}} + \frac{CAF_{6\text{-}16yr} \times ED_{6\text{-}16yr} \times BR_{6\text{-}16yr}}{ABW_{6\text{-}16yr}} + \frac{CAF_{16\text{-}30yr} \times ED_{16\text{-}30yr} \times BR_{16\text{-}30yr}}{ABW_{16\text{-}30yr}}$$

[58] MTCA expresses inhalation toxicity criteria as an inhaled dose. The inhalation unit risk factor for vinyl chloride (8.8E-06 $m^3/\mu g$) is converted to an inhalation cancer potency factor based on adjustments for body weight (70 kg) and breathing rate (20 m^3/day).

[59] For exposure scenarios where the RME is determined to be exclusively for non-pregnant adults (no children or pregnant women), Ecology may consider using a CPF_i of 0.016 kg-day/mg (*see* our CLARC guidance for vinyl chloride[xxxx]).

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{air}	Air concentration	µg/m^3
Total ELE	Early-life exposure adjustment factor	15.651 m^3-year/kg-day[60]
ADAF	Age-dependent adjustment factor	$ADAF_{<2yr}$ = 10 $ADAF_{2-6yr}$ = 3 $ADAF_{6-16yr}$ = 3 $ADAF_{16-30yr}$ = 1 (unitless)
MAF	Toxicity adjustment factor for mutagenic kidney *endpoint: CPF_i Kidney ÷ Total CPF_i = 0.0035 ÷ 0.0144*	0.243, unitless[60]
CAF	Toxicity adjustment factor for NHL/Liver endpoint: *(CPF_i NHL + CPF_i Liver) ÷ Total CPF_i = 0.0105 ÷ 0.0144*	0.729, unitless[60]
BR	Breathing rate	$BR_{<2yr}$ = 10 m^3/day BR_{2-6yr} = 10 m^3/day BR_{6-16yr} = 20 m^3/day $BR_{16-30yr}$ = 20 m^3/day
ABS	Inhalation absorption fraction	1.0, unitless
ET	Exposure time	24 hours/day
EF	Exposure frequency	365 days/year
ED	Exposure duration	$ED_{<2yr}$ = 2 yrs ED_{2-6yr} = 4 yrs ED_{6-16yr} = 10 yrs $ED_{16-30yr}$ = 14 yrs
ABW	Average body weight	$ABW_{<2yr}$ = 16 kg ABW_{2-6yr} = 16 yrs ABW_{6-16yr} = 70 kg $ABW_{16-30yr}$ = 70 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_c	Cancer averaging time (*75 years × 365 days/year × 24 hours/day*)	657,000 hours
CPF_i	Inhalation cancer potency factor	kg-day/mg

[60] Use the full unrounded values for the ELE adjustment factor, MAF, and CAF.

Modified air equations for commercial workers

Ecology developed Vapor Intrusion Screening Levels for Worker[xxv] guidance in 2022. It presents recommended exposure assumptions to derive risk-based indoor air levels for **adult commercial workers** in buildings that are not used for residential purposes. Below are the modified air equations with recommended exposure assumptions to calculate HQ and risk for adult commercial workers.

Equation 750-1:
Adult worker modified **noncancer-based** air equation (based on inhalation of air)

$$HQ = \frac{C_{air} \times BR \times ABS \times ET \times EF \times ED}{ABW \times UCF \times AT_{nc} \times RfD_i}$$

Variable	Description	Method B
HQ	Hazard quotient	unitless
C_{air}	Air concentration	µg/m^3
BR	Breathing rate	20 m^3/day
ABS	Inhalation absorption fraction	1.0, unitless
ET	Exposure time	9 hours/day
EF	Exposure frequency	250 days/year
ED	Exposure duration	25 years
ABW	Average body weight	70 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_{nc}	Noncancer averaging time (*ED × 365 days/year × 24 hours/day*)	219,000 hours
RfD_i	Inhalation reference dose	mg/kg-day

Equation 750-2:
Adult worker modified **cancer-based** air equation (based on inhalation of air)

$$Risk = \frac{C_{air} \times BR \times ABS \times ET \times EF \times ED \times CPF_i}{ABW \times UCF \times AT_c}$$

Variable	Description	Method B
Risk	Excess cancer risk	unitless
C_{air}	Air concentration	µg/m^3
BR	Breathing rate	20 m^3/day
ABS	Inhalation absorption fraction	1.0, unitless
ET	Exposure time	9 hours/day
EF	Exposure frequency	250 days/year
ED	Exposure duration	25 years
ABW	Average body weight	70 kg
UCF	Unit conversion factor	1,000 µg/mg
AT_c	Cancer averaging time (*75 years × 365 days/year × 24 hours/day*)	657,000 hours
CPF_i	Inhalation cancer potency factor	kg-day/mg

Attachment B: Toxicity Classifications and their Meaning

This list was taken from EPA's IRIS database[viii] and is used in CLARC's Noncancer Effects Table.

Cardiovascular Includes heart and blood vessels (including arteries, capillaries, and veins).

Dermal Relating to the skin, which consists of two main layers, the epidermis and dermis. Also includes hair follicles, sweat glands, sebaceous glands, and nails.

Developmental A life stage that includes the period prior to conception (either parent), the prenatal period, and the postnatal period to the time of sexual maturation. Developmental effects may be detected at any point in the lifespan of the organism and include: (1) death of the developing organism, (2) structural abnormality, (3) altered growth, and (4) functional deficiency. Teratogenicity is generally used to refer to malformations only (i.e., a permanent structural change that may adversely affect survival, development, or function).

Endocrine Includes the thyroid gland, parathyroid, hypothalamus, pineal gland, adrenal gland, pituitary gland, pancreas (see also Gastrointestinal), thymus (see also Immune), and testis and ovary (see also Reproductive).

Gastrointestinal Includes mouth/oral cavity (including tongue), esophagus, stomach, pancreas (see also Endocrine), small intestine (including duodenum, jejunum, and ileum), and large intestine (including cecum, colon, rectum, and anus).

Hematologic Includes blood plasma, red blood cells (erythrocytes), platelets (thrombocytes), and bone marrow (where blood cells are produced). White blood cells (leukocytes) are part of the Hematologic system but are included under the Immune system because of their role in the body's defense against infectious organisms and foreign substances.

Hepatic Includes liver, bile duct, and gall bladder.

Immune Includes white blood cells (leukocytes; see also Hematologic), bone marrow, thymus, spleen, and lymphatic system.

Musculoskeletal Includes muscle, connective tissue (ligaments, tendons, and cartilage), and bones.

Nervous Includes the central nervous system (CNS; brain and spinal cord) and peripheral nervous system (PNS; nerves and ganglia that relay information between the CNS and other parts of the body to regulate sensory, motor, and autonomic processes).

Neurotoxicity involves structural or functional changes in the CNS or PNS. Structural changes include neuroanatomical or histologic alterations. Functional changes include neurochemical alterations (e.g., neurotransmitter levels), neurophysiological alterations (e.g., nerve conduction), or behavioral effects (e.g., learning; sensory function).

Developmental neurotoxicity is neurotoxicity manifested during development, including changes to the growth or organization of CNS or PNS structures, as well as alterations to the appearance or maturation of different nervous system functions (see also Developmental).

Ocular Includes all parts of the eyeball (lens, retina, cornea, etc.), the muscles that position the eye, eyelids, lachrymal/lacrimal glands, and, in some non-human species, the Harderian gland.

Other Includes effects not associated with a specific organ system, including changes in body weight, decreased survival, and other nonspecific toxicity (e.g., abnormal appearance, changes in clinical chemistry parameters that could not be attributed to an organ system, and increased hemosiderin deposition).

Also includes reference values based on studies that showed no effects at the highest exposure level tested (e.g., a no-observed-adverse-effect level or NOAEL). In these cases, because an adverse effect was not identified, an affected organ or system could be assigned.

Reproductive Includes alterations to the male or female reproductive organs, related endocrine system (see also Endocrine), or pregnancy outcomes. Manifestations may include adverse effects on onset of puberty, gamete production and transport, reproductive cycle normality, sexual behavior, fertility, gestation, parturition, lactation, developmental toxicity, premature reproductive senescence, or modification in other functions dependent on the integrity of the reproductive system.

Female reproductive structures include the uterus, endometrium, ovaries, including eggs, follicles, and corpora lutea (see also Endocrine), fallopian tubes, cervix, vagina, and vulva. Also includes mammary gland and breast.

Male reproductive structures include the testes (see also Endocrine), epididymides, and vas deferens (including sperm); scrotum; seminal vesicles; coagulating glands; prostate gland; and penis. Because of the association between reproductive and urinary system structures, particularly in males, the term urogenital (or genitourinary) system is often used.

Respiratory Includes the nasal passages, pharynx, larynx, trachea, bronchi, and lungs.

Urinary Includes the kidneys, ureter, urinary bladder, and urethra. Also referred to as the excretory or renal system. Because of the association between reproductive and urinary system structures, particularly in males, the term urogenital (or genitourinary) system is often used.

Endnotes

[i] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-705

[ii] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-706

[iii] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-708

[iv] https://apps.ecology.wa.gov/publications/summarypages/0109043.html

[v] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-720

[vi] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-740

[vii] https://ecology.wa.gov/CLARC

[viii] https://www.epa.gov/iris/iris-descriptions-organssystems

[ix] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-700

[x] https://www.ezview.wa.gov/Portals/_1987/Documents/Documents/MixingMethodsABC.pdf

[xi] https://apps.ecology.wa.gov/publications/summarypages/0909047.html

[xii] https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

[xiii] https://app.leg.wa.gov/wac/default.aspx?cite=246-290

[xiv] https://apps.ecology.wa.gov/publications/summarypages/0909047.html

[xv] https://www.ezview.wa.gov/Portals/_1987/Documents/Documents/MixingMethodsABC.pdf

[xvi] https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part

[xvii] https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-b

[xviii] https://app.leg.wa.gov/wac/default.aspx?cite=173-340-745

[xix] https://fortress.wa.gov/ecy/ezshare/tcp/CLARC/EarlyLifeExposureToCarcinogens.pdf

[xx] https://www.ezview.wa.gov/Portals/_1987/Documents/Documents/VinylChloride_2005.pdf

[xxi] https://www.ezview.wa.gov/Portals/_1987/Documents/Documents/Trichloroethylene_Guidance.pdf

[xxii] https://ecology.wa.gov/PetroleumCleanupTools

[xxiii] https://app.leg.wa.gov/wac/default.aspx?cite=173-340-730

[xxiv] https://app.leg.wa.gov/WAC/default.aspx?cite=173-340-750

[xxv] https://fortress.wa.gov/ecy/ezshare/tcp/CLARC/GUIDANCE_VaporIntrusionScreeningLevels-Workers.pdf