DEPARTMENT OF ECOLOGY
State of Washington

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Subject: Groundwater cleanup levels for upland sites along the Lower Duwamish Waterway

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Background and Scope

This memorandum has been prepared at the request of TCP's Northwest Regional Office. It is intended to provide technical support for the development of groundwater cleanup levels for upland cleanup sites in the vicinity of the Lower Duwamish Waterway cleanup site in King County, Washington (Figure 1). The memorandum describes the process under the Model Toxics Control Act (MTCA) for determining these values and provides preliminary recommendations. Actual cleanup levels at individual sites will depend on additional site-specific factors that are described later in this memo.

The recommendations in this memorandum are applicable to upland sites where monitoring shows upland contamination is either entering or likely to enter the Duwamish River through the groundwater. *It is not intended to be used to establish discharge limits for permitted or unpermitted discharges nor water quality criteria for the Duwamish River and other surface waters within this area. Those limits and criteria must be established under water quality law.*

This memo was prepared by Pete Kmet with assistance from Arthur Buchan (ecologic and groundwater concentrations protective of sediment) and Jim White (human health concentrations). Questions regarding this memo can be directed to any of these staff.

What the MTCA Rule Requires

In general, WAC 173-340-720 requires that groundwater cleanup levels be set at concentrations that protect for drinking water beneficial uses, unless the groundwater qualifies as nonpotable. A determination of whether the groundwater qualifies as nonpotable must be made on a site-specific basis, based on the criteria in WAC 173-340-720(2). This memo does not address which upland sites within the vicinity of the Lower Duwamish Waterway qualify for a nonpotable groundwater cleanup level.

If a site is determined to have nonpotable groundwater, then WAC 173-340-720(6) provides two options: either use potable groundwater cleanup levels anyway using one of the methods

specified in WAC 173-340-720; or, develop nonpotable groundwater cleanup levels using a site-specific risk assessment.

WAC 173-340-720 also requires groundwater cleanup levels to be protective of surface water beneficial uses unless it can be demonstrated that the hazardous substances in the groundwater are not likely to reach surface water. [1] The exposure pathway of concern is the discharge of contaminated groundwater into the surface water and the protection of aquatic organisms living in that surface water and sediment, and persons that consume those organisms. Exposure can occur directly through migration and seepage of the groundwater into the surface water and sorption onto the sediments, or indirectly through groundwater intercepted by ditches, foundation drains, temporary construction dewatering systems, utility corridors, and stormwater systems (including stormwater pipes, which typically are not water-tight), that then drain to surface water. This pathway is the focus of this memorandum.

For the groundwater to surface water exposure pathway, WAC 173-340-720 requires that the methods specified in WAC 173-340-730 for establishing surface water cleanup levels be used to develop groundwater cleanup levels protective of surface water. [2]

In general, WAC 173-340-730 requires surface water cleanup levels to be protective of aquatic organisms and persons that consume these organisms. More specifically, it requires surface water cleanup levels to be at least as stringent as: [3]

- Applicable state and federal laws;
- Concentrations protective of wildlife, fish and other aquatic life;
- Concentrations protective of human health (such as through consumption of fish and shellfish); and
- Drinking water, for surface waters classified as suitable for domestic water supply under WAC 173-201A (Washington State surface water quality standards).

Table 602 in WAC 173-201A does not list domestic water use as a beneficial use for the lower 11 miles of the Duwamish River. Therefore, for the purposes of this memo, it is presumed that groundwater cleanup levels protective of surface water for sites within the Lower Duwamish Waterway will not need to address drinking water use. This may not be the case if contaminants from the upland site are discharging to a freshwater tributary to this water body or the groundwater is otherwise determined to be potable (such as because of the need to protect a lower drinking water aquifer).

In addition, both WAC 173-340-720(1)(c) and 730(1)(d) require cleanup levels that would not directly or indirectly cause violations of cleanup standards in other media, including the sediment cleanup standards. And, if a conditional point of compliance is used, WAC 173-340-720(8)(d) requires groundwater discharges not result in violations of sediment cleanup levels published in WAC 173-204.

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[1] For example, WAC 173-340-720(6)(c)(i)(E) (site specific risk assessment for nonpotable groundwater) states in part "The (groundwater) cleanup levels will not exceed the surface water cleanup levels derived under WAC 173-340-730 … unless it can be demonstrated that the hazardous substances are not likely to reach surface water." Similar language is found in Method A, Method B, and Method C groundwater cleanup levels based on drinking water beneficial use.

[2] For example, see WAC 173-340-720(6)(c)(i)(E) for non-potable groundwater cleanup levels. Similar language is found in the subsections describing Method A, B, and C groundwater cleanup levels for potable groundwater.

[3] For example, see WAC 173-730(3)(b)(i)–(iv). Similar language is found in the subsections describing Method A and Method C surface water cleanup levels.

WAC 173-201A-260(3)(e) requires that marine water criteria be applied where the vertically averaged daily maximum salinity values are greater than one part per thousand (ten parts per thousand for bacteria).[4] Water Quality Program staff have indicated that the Lower Duwamish Waterway study area of the Duwamish River shown in Figure 1 has been designated as marine water under WAC 173-201A. Thus, for the purposes of this memo, the surface water quality criteria are assumed to be based on the marine water quality criteria.

Table 1 presents contaminant concentrations in groundwater-discharging-to-surface-water that are anticipated, based on the above conceptual framework, to be protective of marine aquatic organisms (including benthic organisms) and persons consuming those organisms, for twenty-nine (29) individual hazardous substances and mixtures. These substances were identified by the Lower Duwamish Waterway Team as the most likely contaminants to be found at upland sites in the Lower Duwamish Waterway. The policy and scientific rationale used to determine the values in Table 1 are described in more detail in the table notes and subsequent text.

Note that these values have not been adjusted for the practical quantitation limits and natural background concentrations for groundwater as required by WAC 173-340-730(5)(c) when establishing cleanup standards, should that be necessary. Also, if multiple chemicals with similar toxic effects on human health are present at a site, under WAC 173-340-730(5)(b), these concentrations may need to be further adjusted so that the additive risk does not exceed the acceptable thresholds in the rule (hazard index ≤ 1 and cancer risk $\leq 1\times10^{-5}$). These adjustments will need to be made on a site-specific basis. An adjustment for additive risk is not needed for contaminants with cleanup levels controlled by protection of the environment (wildlife, fish and other aquatic life). Rather, if multiple chemicals are present, it may be appropriate to otherwise account for additive environmental effects by, for example, conducting bioassays with the groundwater and sediments contaminated by the groundwater to determine if the combined effect is an environmental concern.

It should also be noted that these values only address the groundwater-to-surface-water exposure pathway. Under WAC 173-340-720(6), if a nonpotable groundwater cleanup level is established using a site-specific risk assessment, then other potential exposure pathways should be evaluated to determine if they might require a more stringent cleanup level. In particular, some values in Table 1 exceed recommended groundwater vapor intrusion screening levels for volatile contaminants (see Cleanup Levels and Risk Calculation [CLARC] Database, available at https://fortress.wa.gov/ecy/clarc/CLARCHome.aspx). Other potential exposure pathways that should be evaluated in a site-specific risk assessment (in addition to surface water) include worker and resident contact with groundwater within excavations or ditches, and worker and resident direct contact with soils in contact with groundwater, either in an excavation, or brought to the ground surface where contact can occur. Given the stringency of many of the surface water standards, it is unlikely pathways other than vapor intrusion could control cleanup levels but they could be relevant for evaluating remedies using partial cleanup and containment.

[4] One part per thousand equals 1,000 mg/L; 10 parts per thousand equals 10,000 mg/L.

Figure 1: Area of the Lower Duwamish Waterway addressed by this memo (Source: EPA, November, 2014)

Table 1: Toxic contaminant concentrations anticipated to be protective of human health and aquatic life for groundwater discharging to marine surface water in the Lower Duwamish Waterway. (1)

Parameter	CAS Number	Human Health (µg/L) (2)	Aquatic Life (µg/L) (3)	Protect Sediment (µg/L) (4)	Recommended Value (µg/L) (5)
METALS					
Arsenic, inorganic	7440-38-2	0.14	36	236 / 222	0.14
Barium	7440-39-3	(no value)	200		200
Cadmium	7440-43-9	8.8	8.8	698 / 1.2	1.2
Chromium (III)	16065-83-1	67,308	27.4	260 / 0.1	0.1
Chromium (VI)	18540-29-9	50	50		50
Copper	7440-50-8	3.1	3.1	17,254 / 14	3.1
Lead	7439-92-1	8.1	8.1	45 / 19	8.1
Mercury	7439-97-6	0.025	0.025	7.8 / 2.0	0.025
Silver	7440-22-4	1.9	1.9 acute	685 / 55	1.9 (acute)
Zinc	7440-66-6	81	81	6,549 / 773	81
ORGANICS					
Benzene	71-43-2	58	80		58
Bis(2-ethylhexyl)phthalate	117-81-7	0.37	360	0.42	0.37
Butyl benzyl phthalate	85-68-7	0.10	3.4	0.36	0.1
Carcinogenic PAHs (Total)		0.00013 (6)	(see note 7)	0.0049 (8)	0.00013
Benzo(a)anthracene	56-55-3	0.0013	0.012	0.31	0.0013
Benzo(a)pyrene	50-32-8	0.00013	0.022	0.10	0.00013
Benzo(b)fluoranthene	205-99-2	0.0013	0.017		0.0013
Benzo(k)fluoranthene	207-08-9	0.013	0.017		0.013
Chrysene	218-01-9	0.031	0.07	0.28	0.031
Dibenzo(a,h)anthracene	53-70-3	0.00013	0.0014	0.0068	0.00013
Indeno(1,2,3-cd)pyrene	193-39-5	0.0013	0.0027	0.0099	0.0013
Dioxin/Furans (Total)		5.10E-09 (9)	(see note 10)	(see note 11)	5.10E-09
Dioxin - 2,3,7,8 TCDD	1746-01-6	5.10E-09	1.20E-05	4.23E-07	5.10E-09
Napthalene	91-20-3	1,368	1.4	81	1.4
PCBs (Total) (see note 12)	1336-36-3	6.40E-05	0.03	0.00013 – 0.093	6.40E-05
Pentachlorophenol	87-86-5	0.04	7.9	30 / 43	0.04
Tributyltin	56-35-9	0.0074	0.0074		0.0074
Trichloroethylene	79-01-6	7.0	194		7.0
Vinyl Chloride	75-01-4	1.6	210		1.6

Notes to Table 1:

(1) The values in this table consider neither adjustments for human exposure to multiple contaminants with similar toxic effects under WAC 173-340-730(5)(a), nor adjustments for groundwater practical quantitation limits or groundwater natural background under WAC 173-340-730(5)(c). These adjustments may need to be made on a site-specific basis. For example, the surface water criterion for arsenic is well below typical natural background groundwater concentrations and will need to be adjusted upward accordingly. These values also do not consider other potential exposure pathways, such as vapor intrusion, which will need to be considered on a site-specific basis.

(2) See the Appendix for a description of basis for these values and related calculations. Several of these values are Applicable or Relevant and Appropriate Requirements (ARARs) that are based on protection of aquatic life but also meet the MTCA human health risk standards. The values for chromium III and naphthalene are calculated modified Method B values using a fish consumption rate of 97.5 g/day. (Notes to Table 1 continue on the next page)

(3) See Table 5 for the basis for these values. These values are anticipated to be protective of not only aquatic life but also marine mammals and wildlife.

(4) See Table A-8 for the basis for these values. Values were calculated only for those substances for which EPA has established a sediment cleanup level in the November, 2014 Record of Decision (ROD). The first values for the metals and pentachlorophenol were calculated assuming a groundwater pH of 6.8; the second values were calculated for a pH of 8.0 (marine water). Since the valence state of chromium was not identified in the ROD, chromium III was assumed for that sediment calculation. See the discussion of sediment cleanup levels later in this memo for additional information.

(5) This is the lowest value of the three exposure pathways evaluated in this memo.

(6) To determine compliance for human health for total carcinogenic polycyclic aromatic hydrocarbons (cPAHs), two standards must be met:

- Under the National Recommended Water Quality Criteria and the National Toxics Rule, on which the values for the individual cPAHs are based,[5] the human health standard for each individual cPAH must be met, and;
- Under the MTCA rule, the total cPAH must be met using the cleanup level for benzo(a)pyrene as the reference chemical and the toxicity equivalency factor (TEF) approach described in WAC 173-340-708(8)(e).

(7) There is no numeric value for environmental effects for total cPAHs. The aquatic toxicity value must be met for each individual cPAH.

(8) Use the TEF approach described in WAC 173-340-708(8)(e) to determine compliance with this value.

(9) To determine compliance for human health for dioxins, two standards must be met:

- Under the National Recommended Water Quality Criteria, the human health standard for 2,3,7,8 TCDD must be met, and:
- Under the MTCA rule, the total dioxin/furan mixture value must be met using the cleanup level for 2,3,7,8 TCDD as the reference chemical and the TEF approach described in WAC 173-340-708(8)(d).

(10) There is no numeric value for environmental effects for total dioxins/furans. The human health toxicity value is expected to be protective of aquatic life.

(11) Use the value for 2,3,7,8 TCDD as the reference chemical and the TEF approach described in WAC 173-340-708(8)(d) and CLARC to determine compliance.

(12) Under the National Recommended Water Quality Criteria, which this value is based on, "total PCBs" is defined as the sum of all congener or all isomer or homolog or Aroclor analyses. The analytical method for determining compliance (i.e. measuring Aroclors or congeners) will need to be established on a site-specific basis. Note that there is no need to establish separate cleanup levels for individual Aroclors, as the total PCB value is more stringent. The range for protection of sediment is the range of values calculated for the Aroclors 1016, 1254, and 1260 (see Table A-8), which were identified by the Lower Duwamish Waterway Team as contaminants of concern.

[5] The value for chrysene is from the National Toxics Rule; the values for all other cPAHs are based on the National Recommended Water Quality Criteria.

Beneficial Uses

Under WAC 173-340-730(1), surface water cleanup levels must be set at concentrations that are protective of the beneficial uses identified under WAC 173-201A. Beneficial uses for the Lower Duwamish Waterway are described in Table 2, which requires some explanation. WAC 173-201A-602 lists the applicable uses for the lower 11 miles of the Duwamish River, which is classified as a "good" quality freshwater. However, the Lower Duwamish Waterway section of that 11-mile segment is saline due to tidal action. According to Water Quality Program, a marine category comparable to the river's freshwater category, or "good" quality, should be used in this situation.[6] The beneficial uses for "good" quality marine waters are listed in the second column in Table 2 and are the applicable uses for the Lower Duwamish Waterway.

The water quality criteria for conventional pollutants for the beneficial uses detailed in Table 2 are provided in Table 3. Although the focus of this memo is on marine waters, both freshwater and marine criteria have been provided, should they be needed for other purposes. *The second column in Table 3 are the applicable criteria for the marine waters in the Lower Duwamish Waterway.*

The relevance of these conventional water quality criteria to groundwater-discharging-to-surface-water are as follows:

- **Temperature:** Elevated groundwater temperatures are typically not a function of the level of contamination. If there is an active warm water discharge, or if in-situ natural reactions or treatment creates an exothermic reaction, this could be a site-specific issue.
- **Dissolved Oxygen:** Groundwater is typically naturally below the surface water quality criteria for dissolved oxygen, so it isn't practical to apply the dissolved oxygen criteria to groundwater.
- **Total Dissolved Gas:** Total dissolved gas is a parameter of concern with supersaturated dam overflows and is unlikely to be a concern at contaminated sites.
- **pH:** The pH of the groundwater can be affected by the chemical properties of the waste materials such as the high pH in leachate from cement kiln dust. pH can also be affected by biological degradation (typically resulting in slightly acidic conditions) and chemical processes within the soil and groundwater. As such, pH is a relevant parameter to consider on a site-specific basis.
- **Turbidity:** Turbidity in groundwater is primarily a function of the type of formation in which a monitoring well is screened, well development, and the well construction, not the level of site contamination.
- **Bacterial Contamination:** Bacterial contamination, typically the result of sewage or animal waste, is not expected to be a contaminant of concern in groundwater at upland cleanup sites within the Lower Duwamish Waterway.
- **Aesthetic Values:** Impairment of aesthetic values are those that offend the senses of sight, smell, touch, or taste of the water, typically caused by excessive nutrients from sewage or animal waste. Excessive nutrients in groundwater are not expected to be an issue at upland cleanup sites. However, impairment of aesthetic values caused by releases of toxic substances, such as petroleum, may need to be addressed on a site-specific basis.

[6] Based on Water Quality Program Guidance, available here: http://partnerweb/sites/WQ/pwg/permitGuidance/Application of WQ Criteria in Brackish Waters-June 2015.pdf

Table 2: Beneficial uses for the Lower Duwamish Waterway.

Lower 11 miles Duwamish River (WAC 173-201A-602)	Comparable Marine Use Category Lower Duwamish Waterway (WAC 173-201A-612)
Aquatic life uses Rearing/Migration only	**Good quality aquatic life uses:** Salmonid migration and rearing; Other fish migration, rearing, and spawning; Clam, oyster and mussel rearing and spawning; Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning
Shellfish Harvesting Not applicable	**Shellfish Harvesting** Shellfish harvesting
Recreational Uses: Secondary contact recreation	**Recreational Uses:** Secondary contact recreation
Water Supply Uses Industrial water Agricultural water Stock water	**Water Supply Uses** Not applicable
Miscellaneous Uses: Wildlife habitat Harvesting Commerce/Navigation Boating Aesthetics	**Miscellaneous Uses:** Wildlife habitat Harvesting Commerce/Navigation Boating Aesthetics

Table 3: Water quality criteria for conventional pollutants for the Lower Duwamish Waterway.

Parameter	Duwamish River (good quality freshwater) WAC 173-201A-200	Lower Duwamish Waterway (good quality marine water) WAC 173-201A-210
Temperature	17.5°C (63.5°F)	19°C (66.2°F)
Dissolved Oxygen	6.5 mg/L	5.0 mg/L
Total Dissolved Gas	≤ 110% of saturation	*No criteria*
Turbidity	≤ 10 NTU over background when background is 50 NTU or less; 20% increase in turbidity when background is > 50 NTU	≤ 10 NTU over background when background is 50 NTU or less; 20% increase in turbidity when background is > 50 NTU
pH	6.5 to 8.5 with a human caused variation of less than 0.2 units	7.0 to 8.5 with a human caused variation of less than 0.2 units
Secondary contact recreation (enterococci organisms)	Geometric mean ≤ 200 colonies/100 mL plus < 10% of all samples exceeding 400 colonies/100mL	Geometric mean ≤ 70 colonies/100 mL plus ≤ 10% of all samples exceeding 208 colonies/100mL
Aesthetics (WAC 173-201A-260)	Does not offend sight, smell, touch or taste	Does not offend sight, smell, touch or taste

Thus, for the water quality criteria for conventional pollutants, only pH and aesthetic impacts will likely need to be considered when setting groundwater cleanup levels on a site-specific basis.

However, the remainder of these criteria have been provided in Table 3 for general reference should these be issues at a site or need to be addressed for another exposure pathway, such as surface water runoff.

MTCA Methods for Establishing Cleanup Levels

For toxics substances, the same beneficial uses in Table 2 must be protected when establishing cleanup levels under MTCA. Within this framework, WAC 173-340-730 provides three methods for establishing surface water cleanup levels–Method A, Method B, and Method C. It is recommended that Method B be used because:

- Method A for surface water is intended for simple sites. The Lower Duwamish Waterway has multiple sites, many contaminants (some of which do not have ARARs) and complex exposure pathways. Method A is not suitable for these types of sites.
- Method C is intended for sites where there is less exposure to residual contamination, such as for workers at industrial property. For surface water this is incorporated into the Method C calculation by the use of a lower fish diet fraction (Method C assumes 0.2 or 20% of fish and shellfish consumed is from the site). Use of a lower fish diet fraction is not appropriate in the Lower Duwamish Waterway, where higher than normal exposure is expected due to fish and shellfish harvesting by tribal and Asian Pacific Islander populations that frequent this area.[7] For this reason, Method C is not suitable for sites where the groundwater cleanup levels are based on protection of surface water in the Lower Duwamish Waterway. It should be noted that even if a site could qualify for Method C, the cleanup levels for many chemicals would be the same as for Method B because many of the cleanup levels under Method C would be based on the same applicable state and federal laws (ARARs) and aquatic toxicity information as Method B.[8]
- Method B is intended for all other sites. Thus, Method B has been used to establish the values recommended in this memo.

Under Method B, WAC 173-340-730(3)(b) requires surface water cleanup levels to be at least as stringent as all of the following:

- Concentrations established under applicable state and federal laws (ARARs) including:
    - Water quality criteria published in the water quality standards for surface waters of the state of Washington, WAC 173-201A;
    - Water quality criteria based on the protection of aquatic organisms (acute and chronic criteria) and human health published under section 304 of the Clean Water Act *unless it can be demonstrated that such criteria are not relevant and appropriate for a specific surface water body or hazardous substance*; [9] and

[7] Record of Decision, Lower Duwamish Waterway Superfund Site, USEPA, November, 2014.

[8] WAC 173-340-706 also allows the use of Method C where a site specific demonstration can be made that there are significant limitations preventing achieving Methods A and B cleanup levels (area background, greater overall threat, or technically impossible to achieve). However, these factors cannot override the need for the cleanup levels to be protective of human health.

[9] These are now called National Recommended Water Quality Criteria and were last updated in June of 2015. An example of these criteria that are not relevant and appropriate to the LDW is those parts of the criteria based on

- National Toxics Rule (40 C.F.R. Part 131).

Note: Where an ARAR exceeds a noncancer hazard quotient of one (1) or a carcinogenic risk of 1×10^{-5}, WAC 173-34-730(5)(b) requires the ARAR to be adjusted downward so these risk thresholds are met.

- For substances for which environmental effects-based concentrations have not been established under applicable state or federal laws, concentrations that are estimated to result in no adverse effects on the protection and propagation of wildlife, fish, and other aquatic life.
- For substances for which sufficiently protective, health-based criteria or standards have not been established under state and federal laws, concentrations that protect human health as determined using the formulae in the rule.
- Potable water cleanup levels, for surface waters classified as suitable for use as a domestic water supply under WAC 173-201A. As noted earlier, it is assumed this is not a relevant surface water exposure pathway along the Lower Duwamish Waterway. (However, it may still be relevant for groundwater at some sites within this area.)

Developing Concentrations Protective of Human Health

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". The MTCA rule does not explicitly define this phrase, but WAC 173-340-730(5)(b) requires cleanup levels for individual substances based on ARARs to meet a hazard quotient ≤ 1 and a carcinogenic risk $\leq 1\times10^{-5}$. So it is logical to conclude that these same risk levels can be used to interpret this phrase.

As noted earlier, the MTCA rule identifies the following sources of ARARs for marine waters:

- Water quality standards for surface waters of the state of Washington, WAC 173-201A;
- Water quality criteria published under Section 304 of the Clean Water Act (National Recommended Water Quality Criteria, with values for several substances most recently updated in June 2015);[10] and
- National Toxics Rule (40 C.F.R. Part 131, adopted in 1992).

The available ARARs are summarized in Table 4. Where these standards are based on protection of human health, they are based on a hazard quotient of 1 and a cancer risk of 1×10^{-6}. Although these criteria meet the acceptable levels of risk under MTCA on their face, many of these standards use different fish consumption rates, toxicity factors, and bioconcentration/ bioaccumulation assumptions than are used in MTCA. In addition, several of these standards are based on protection of aquatic life, not human health.

Furthermore, in the Lower Duwamish Waterway both Ecology and EPA have acknowledged that a higher level of exposure is expected due to fish harvesting by tribal and Asian Pacific Islander populations that frequent this area. For example, in the Lower Duwamish Waterway Record of

drinking water exposure, since the Lower Duwamish Waterway is a marine water and use as a drinking water supply is not a beneficial use of this water body.

[10] It should be noted that Ecology's Water Quality Program has not adopted the National Recommended Water Quality Criteria as surface water standards in Washington State. However, these Criteria are relevant and appropriate *by rule* under MTCA, and thus are included for the Lower Duwamish Waterway.

Decision (USEPA, 2014), which Ecology concurred with, EPA used a fish consumption rate of 97.5 grams/day to develop sediment cleanup levels.

For these reasons, the Method B equations were used to back-calculate the level of human health risk posed by the most stringent of these ARARs to determine if they were "sufficiently protective" under MTCA. For completeness, this was done using both the Standard Method B equations which use a fish consumption rate of 54 grams/day (and a fish diet fraction of 0.5), and Modified Method B using a fish consumption rate of 97.5 grams/day (and a fish diet fraction of 1). See the Appendix for a description of the procedure used and related calculations.

The conclusion of these calculations is that the most stringent ARAR for each chemical falls within the acceptable level of risk under MTCA, and thus is considered "sufficiently protective" of human health. This is the case using both the Standard Method B assumptions and the higher fish consumption rate under Modified Method B. Accordingly, that ARAR was used as the basis for nearly all the values recommended for protection of human health in Table 1. The only two not based on an ARAR are the values for chromium III and naphthalene, which are based on modified Method B (calculated using a fish consumption rate of 97.5 g/day from the ROD), since no ARAR is available for these chemicals.

Developing Concentrations Protective of the Environment

Development of concentrations protective of organisms that live in the marine environment is more straight-forward, since no analysis for acceptable risk is necessary. Consistent with the above discussion, the following procedure was used to derive surface water concentrations protective of the environment. The results of this procedure are summarized in Table 5 and provide the basis for the recommendations in Table 1 for the values protective of aquatic life.

- ***Check to see if a chemical has one or more ARARs based on protection of aquatic life:*** Select the lowest of these values.
- ***If a chemical does not have an ARAR, consult the literature:*** Consult available references to determine concentrations protective of wildlife, fish, and other aquatic life. Select the lowest peer-reviewed value. For the Lower Duwamish Waterway, the following references were consulted to find a no-effects level: [11]
    - **Oak Ridge National Laboratory (ORNL):** These are screening ecological benchmarks from the Oak Ridge National Laboratory - Risk Assessment Information System (University of Tennessee, 2013). These values were used to identify chemical concentrations that are at or below effects thresholds for a range of aquatic organisms. The lowest of the screening benchmarks (acute or chronic) for a marine surface water was considered.
    - **NOAA Screening Quick Reference Tables (SQuiRTs):** These are screening ecological benchmarks from SQuiRTs (NOAA, 2008). This database uses current USEPA information from the National Recommended Water Quality Criteria, generally followed by Tier II Secondary Acute Values or available standards and guidelines from other regulatory agencies. The lowest of the screening benchmarks (acute or chronic) for a marine surface water was considered.

[11] This review was conducted in June, 2015. If significant time passes before cleanup levels are established at a site, it may be appropriate to check these sources for updates.

- **Other published peer-reviewed literature:** *Ecotoxicological Environmental Risk Limits for Total Petroleum Hydrocarbons on the Basis of Internal Lipid Concentrations – Environmental Toxicology and Chemistry* (Verbruggen et al., 2008), and *Euro Chlor Risk Assessment for the Marine Environment OSPARCOM Region – North Sea – Environmental Monitoring and Assessment* (De Rooij et al., 2004), were considered as applicable literature to be included in this review.
- **EcoTox (USEPA):** The EcoTox database provides single chemical toxicity information for aquatic and terrestrial life (USEPA, 2015). No observed effects concentration (NOEC) and no observable effects level (NOEL) endpoints were queried for salt water for barium.

- ***If no ARARs or literature values are available, use bioassays to determine a concentration that will result in no adverse effects on wildlife, fish and aquatic life:*** WAC 173-340-730(3)(b)(ii) authorizes the use of whole effluent toxicity testing (WET testing) using the protocols described in WAC 173-205 to make this demonstration for fish and aquatic life. Either ARARs or literature values were found for all chemicals, therefore this step should not be necessary. However, it may be appropriate to conduct such testing to override literature values or to test for additive effects of chemical mixtures, like petroleum.[12]

Protection of Sediment

As noted earlier, both WAC 173-340-720(1)(c) and 173-340-730(1)(d) require cleanup levels that do not directly or indirectly cause violations of cleanup standards in other media, including sediment cleanup standards. Furthermore, if a conditional point of compliance is used, WAC 173-340-720(8)(d) requires groundwater discharges not result in violations of sediment cleanup levels published in WAC 173-204.[13]

EPA identified sediment cleanup level concentrations in its 2014 Record of Decision. Those values are compiled in Table 6. When establishing groundwater cleanup levels protective of surface water, it is necessary to check to determine if there is a potential for contaminants in the groundwater that enters surface water to be absorbed onto sediment in the Lower Duwamish Waterway at concentrations that would violate these sediment cleanup levels.

One way to evaluate this exposure pathway is to rearrange the 3-phase model in WAC 173-340-747(4) to determine what groundwater concentration has the potential to cause an exceedance of these sediment cleanup levels. The derivation of this formula and a summary of the calculations are described in the Appendix.

When using this model, it is assumed the contaminants in the groundwater would end up in the sediment pore water at that same concentration as in the groundwater, are in chemical equilibrium with the sediments, are present as individual chemicals (not as a mixture), and are fully bioavailable. These are likely conservative assumptions (that is, overestimates sediment concentrations).

Another limitation is that the soil organic carbon-water partitioning coefficients (Koc) used in these calculations are based on fresh water, not marine water. The high concentrations of salts in marine water vs. freshwater could affect the absorption of these chemicals onto sediment.

[12] While bioassays can be used to override literature values, they cannot be used to override ARARs.
[13] WAC 173-340-720(8)(d) uses the term "sediment quality values". This terminology was changed to "sediment cleanup levels", the term used here, in the revisions to WAC 173-240 adopted in February, 2013.

Several researchers have found that the presence of salinity can increase the sorption of hydrophobic organic chemicals but it is unclear how significant this is at this site.[14]

We also know that marine water typically has a higher pH than freshwater. For example, a review of available information during the 2001 MTCA rulemaking concluded that the pH of groundwater in Washington State is typically slightly acidic (<7). However, surface water measurements taken in the Lower Duwamish Waterway were found to have an average pH of 7.4, with the highest reading of 8.0 (seawater typically has a pH of 8.1–8.2).[15]

While the sorption of non-ionic organic contaminants is not expected to be sensitive to pH, it is known that the pH of water can significantly affect the solubility and sorption of metals and pentachlorophenol onto soil and sediment.[16] To account for this effect, the calculation was conducted for metals and pentachlorophenol using distribution coefficients (Kds) at both pH 6.8 (the pH used to develop the Kds in Table 747-3 in the MTCA rule) and pH 8 (for marine waters). The most stringent resulting pore water concentration for each contaminant was then compared to concentrations based on protection of aquatic life and humans consuming aquatic organisms. This simulates a scenario where these contaminants dissolved in groundwater are sorbed onto sediment as the lower pH groundwater mixes with the higher pH marine surface water contained within the pore space in the sediment.

Note that the valence state of chromium in the sediment was not identified in the ROD. However, the sediment cleanup level for chromium in WAC 173-204-562, which this calculation is based on, is for total chromium. Since chromium III is typically the valence state for chromium in a reducing environment, such as that for sediment, the Kds for chromium III were used in the calculations.

The results of these calculations are summarized in Table A-8 in the Appendix and are the basis for the recommendations in Table 1 for protection of sediment. With the above limitations, these values represent groundwater concentrations that should not cause the sediment to exceed EPA's sediment cleanup levels. These tables include calculations for only those substances for which EPA has set sediment cleanup levels.

In comparing these calculated pore water values to the concentrations based on protection of aquatic life and humans consuming aquatic organisms, only cadmium and chromium III had a lower pore water concentration for the sediment pathway, and this only occurred when a Kd at a pH of 8 was used. For the remainder of the contaminants of concern identified in EPA's Record of Decision for the Lower Duwamish Waterway, the concentrations protective of sediment do not appear to be a controlling exposure pathway within the range of pH examined.

While pH should be a good indicator of the sorption potential of cadmium and chromium as the groundwater transitions into marine water, given the complexity of the geochemical processes occurring in this zone, using pH as an indicator may overestimate the sorption of these metals. Because of the difference this pathway makes in the groundwater cleanup level for these two contaminants, at sources where either of these contaminants are a concern, additional research and investigation may be worthwhile. This could include a more thorough review of the literature, use of a different model, measurements of relevant geochemical parameters,

[14] See for example, Turner and Rawling (2001) and You, Jia and Pan (2010).
[15] Sources: WAC 173-340, 2001 Concise Explanatory Statement and "Rising Acidity in the Ocean: The Other CO2 Problem", Scientific American, September 1, 2008. 58 pH measurements from Ecology's EIM system for in the Lower Duwamish Waterway at the 1st Avenue Bridge between 2004 and 2008 were an average of 7.4, median of 7.4, with the lowest value of 7.0 and the highest value of 8.0 (Personal communication, Richard Thomas, NWRO).
[16] Soil Screening Guidance: Technical Background Document, EPA/540/R-95/12B, USEPA, May, 1998.

measurement of pore water and soil/sediment concentrations within this transition zone (including valence-speciation), and sediment bioassays, to confirm or eliminate this as an exposure pathway of concern for a particular source.

Compliance Monitoring

It should be noted that the approach taken in this memo evaluates each chemical individually. Where there are multiple contaminants present, they could act antagonistically or synergistically to decrease or increase the effects on aquatic life and bioaccumulation in higher trophic organisms. For this reason, it is recommended that sediment bioassays be conducted to measure the combined toxic effects, and measurement of actual bioaccumulation in the species present in the Lower Duwamish Waterway be part of the long term compliance monitoring plan for this site.

Table 4: Applicable, relevant and appropriate surface water quality standards under WAC 173-340-730 for toxic substances in marine waters

Substance	CAS Number	ARARs (all values µg/L)					Most Stringent ARAR (µg/L)
		Human Health		Aquatic Life			
		40 CFR 131.36 NTR	Section 304 NRWQC	40 CFR 131.36 NTR	WAC 173-201A	Section 304 NRWQC	
Arsenic, inorganic	7440-38-2	0.14 (c)	0.14 (c)	36	36	36	0.14
Barium	7440-39-3						
Cadmium	7440-43-9			9.3	9.3	8.8	8.8
Chromium (III)	16065-83-1						
Chromium (VI)	18540-29-9			50	50	50	50
Copper	7440-50-8			2.4*	3.1	3.1	3.1
Lead	7439-92-1			8.1	8.1	8.1	8.1
Mercury	7439-97-6	0.15		0.025	0.025	0.94	0.025
Silver	7440-22-4			1.9 (acute)	1.9 (acute)	1.9 (acute)	1.9
Zinc	7440-66-6		26,000	81	81	81	81
Benzene	71-43-2	71 (c)	16-58 (c)**				58
Bis(2-ethylhexyl)phthalate	117-81-7	5.9 (c)	0.37 (c)				0.37
Butyl benzyl phthalate	85-68-7		0.10 (c)				0.10
Total cPAHs							
Benzo(a)anthracene	56-55-3	0.031 (c)	0.0013 (c)				0.0013
Benzo(a)pyrene	50-32-8	0.031 (c)	0.00013 (c)				0.00013
Benzo(b)fluoranthene	205-99-2	0.031 (c)	0.0013 (c)				0.0013
Benzo(k)fluoranthene	207-08-9	0.031 (c)	0.013 (c)				0.013
Chrysene	218-01-9	0.031 (c)	0.13 (c)				0.031
Dibenzo(a,h)anthracene	53-70-3	0.031 (c)	0.00013 (c)				0.00013
Indeno(1,2,3-cd)pyrene	193-39-5	0.031 (c)	0.0013 (c)				0.0013
2,3,7,8 TCDD	1746-01-6	1.40E-08 (c)	5.10E-09 (c)				5.10E-09
Napthalene	91-20-3						
PCBs (total)***	1336-36-3	0.00017 (c)	0.000064 (c)		0.03	0.03	0.000064
Aroclor 1016	12674-11-2			0.03			0.03
Aroclor 1254	11097-69-1			0.03			0.03
Aroclor 1260	11096-82-5			0.03			0.03
Pentachlorophenol	87-86-5	8.2 (c)	0.04 (c)	7.9	7.9	7.9	0.04
Tributyltin	56-35-9				0.0074	0.0074	0.0074
Trichloroethylene	79-01-6	81 (c)	7.0 (c)				7.0
Vinyl Chloride	75-01-4	525 (c)	1.6 (c)				1.6

A blank cell means no value has been promulgated or published under the authority cited.

NTR = National Toxics Rule (40 CFR 131.36), last updated in 1992. When based on protection of human health, uses a fish consumption rate (FCR) = 6.5 g/day and fish diet fraction (FDF) = 1.

NRWQC = National Recommended Water Quality Criteria developed under Section 304 of the Federal Clean Water Act, last updated in June, 2015. When based on protection of human health, uses a FCR of either 17.5 or 22 g/day and a FDF = 1 for most substances. One noted exception is arsenic, which uses a FCR = 6.5 g/day.

"Aquatic life" means the standard is based on aquatic toxicity. This is also considered protective of marine mammals and wildlife.

(c) = based on a carcinogenic risk of 1×10^{-6}; all other human health based NTR and WQC values are based on noncancer risk.

* The 2.4 µg/L value in the NTR requires a site-specific "water effects ratio" (WER). EPA has not established a method for determining a WER for marine waters, and has since replaced this approach with 3.1 µg/L for marine waters in the NRWQC. This later value (3.1 µg/L) is used by Ecology's Water Quality Program for marine waters, and thus has been incorporated here.

** A range of values is provided for benzene under the NRWQC, reflecting the cancer slope factor recommended range of 0.015 to 0.055. EPA recommends the upper end of the recommended range be used (58 µg/L).

*** Under WAC 173-201A total PCBs equals the sum of Aroclor 1242, 1254, 1221, 1232, 1248, 1260, and 1016. Under the NTR and NRWQC, total PCBs equals the sum of all congener or all isomer or homolog or Aroclor analyses.

Table 5: Toxic substance concentrations based on protection of aquatic life for groundwater discharging to marine surface water and recommended value

Substance	CAS Number	Aquatic-Based Water Quality Standards (µg/L)			Concentrations Protective of Aquatic Life from Literature Sources (µg/L)					Most Stringent Concentration µg/L
		NTR 40 CFR	WAC 173-201A	NRWQC	ORNL	SQuiRT	Verbruggen et al.	De Rooij, et al.	EcoTox	
Arsenic, inorganic	7440-38-2	36	36	36						36
Barium	7440-39-3					200			500	200
Cadmium	7440-43-9	9.3	9.3	8.8						8.8
Chromium (III)	16065-83-1				56	27.4				27.4
Chromium (VI)	18540-29-9	50	50	50						50
Copper	7440-50-8	2.4*	3.1	3.1						3.1
Lead	7439-92-1	8.1	8.1	8.1						8.1
Mercury	7439-97-6	0.025	0.025	0.94						0.025
Silver	7440-22-4			1.9 (acute)						1.9 (acute)
Zinc	7440-66-6	81	81	81						81
Benzene	71-43-2				109	110	80			80
Bis(2-ethylhexyl)phthalate	117-81-7					360				360
Butyl benzyl phthalate	85-68-7				29.4	3.4				3.4
Total cPAHs										
Benzo(a)anthracene	56-55-3					300	0.012			0.012
Benzo(a)pyrene	50-32-8					300	0.022			0.022
Benzo(b)fluoranthene	205-99-2					300	0.017			0.017
Benzo(k)fluoranthene	207-08-9					300	0.017		300	0.017
Chrysene	218-01-9					300	0.07			0.07
Dibenzo(a,h)anthrecene	53-70-3					300	0.0014			0.0014
Indeno(1,2,3-cd)pyrene	193-39-5					300	0.0027			0.0027
Dioxin/Furans	1746-01-6				1.20E-05					1.20E-05
Napthalene	91-20-3				1.4	1.4	2.0			1.4
PCBs **	1336-36-3		0.03	0.03						0.03
Aroclor 1016	12674-11-2	0.03								0.03
Aroclor 1254	11097-69-1	0.03								0.03
Aroclor 1260	11096-82-5	0.03								0.03
Pentachlorophenol	87-86-5	7.9	7.9	7.9						7.9
Tributyltin	56-35-9		0.0074							0.0074
Trichloroethylene	79-01-6				194	200				194
Vinyl Chloride	75-01-4							210		210

A blank cell means no value has been promulgated or published under the reference cited.
NTR 40CFR = National Toxics Rule, USEPA 40 CFR 131.36
WAC 173-201 = WAC 173-201A-240. Toxic Substances.
NRWQC = National Recommended Water Quality Criteria published by EPA under Section 304 of the Federal Clean Water Act. Aquatic Life Criteria Table
ORNL = Oak Ridge National Laboratory - The Risk Information System. University of Tennessee. Chemical/Marine or Salt Water Screening Benchmarks
SQuiRT = NOAA Screening Quick Reference Tables
EcoTox = USEPA's EcoTox Database. No observed effects concentration (NOEC) and No observable effects level (NOEL) for marine/salt water
While the term "aquatic life" is used here, these values are also considered protective of marine mammals and wildlife.

* The 2.4 µg/L value in the NTR requires a site-specific "water effects ratio" (WER). EPA has not established a method for determining a WER for marine waters, and has since replaced this approach with 3.1 µg/L for marine waters in the NRWQC. This later value (3.1 µg/L) is used by Ecology's Water Quality Program for marine waters, and thus has been incorporated here.
** Under 201A total PCBs is the sum of Aroclor 1242, 1254, 1221, 1232, 1248, 1260, and 1016. Under the NRWQC it is the sum of all congener or all isomer or homolog or Aroclor analyses.

Table 6: Toxic substance groundwater concentrations anticipated to be protective of sediment cleanup levels in ROD

Substance	CAS Number	Sediment Cleanup Level Human Health (mg/Kg) (1)	Sediment Cleanup Level Benthic (mg/Kg) (2)	Sediment Cleanup Level Benthic (mg/Kg OC) (3)	Converted Sediment Cleanup Level Benthic (mg/Kg) (4)	Most Stringent Sediment Cleanup Level (mg/Kg)
Arsenic, inorganic	7440-38-2	7				7
Arsenic, inorganic	7440-38-2		57			57
Cadmium	7440-43-9		5.1			5.1
Chromium (III)	16065-83-1		260			260
Copper	7440-50-8		390			390
Lead	7439-92-1		450			450
Mercury	7439-97-6		0.41			0.41
Silver	7440-22-4		6.1			6.1
Zinc	7440-66-6		410			410
Bis(2-ethylhexyl)phthalate	117-81-7			47	0.89	0.89
Butyl benzyl phthalate	85-68-7			4.9	0.093	0.093
Total cPAHs (5)		0.09				0.09
Benzo(a)anthracene	56-55-3		110		2.09	2.09
Benzo(a)pyrene	50-32-8		99		1.88	1.88
Chrysene	218-01-9			110	2.09	2.09
Dibenzo(a,h)anthracene	53-70-3			12	0.23	0.23
Indeno(1,2,3-cd)pyrene	193-39-5			34	0.65	0.65
Total Dioxins/Furans (6)		2.0E-6				2.0E-6
Napthalene	91-20-3			99	1.88	1.88
PCBs (fish consumption)	1336-36-3	0.002				0.002
PCBs (benthic toxicity)	1336-36-3			12	0.23	0.23
Pentachlorophenol	87-86-5		0.36			0.36

A blank means no values was established in EPA's Record of Decision for Lower Duwamish Waterway, 2014 (ROD).

(1) To protect for seafood consumption and direct human contact, from Table 19 in EPA's ROD. The arsenic, dioxin and PCB values are based on sediment background. The cPAH value is the most stringent of the human direct contact values (90 µg/kg for selected beaches; 150 µg/kg for clamming; 380 µg/kg for all other locations)

(2) To protect benthic invertebrates, from Table 20 in EPA's ROD. The valence state of chromium was not identified in the ROD but the value in WAC 173-204-562 which this is based on is for total chromium. Since chromium typically is in the form of chromium III in the environment, this valence state was assumed for this calculation.

(3) To protect benthic invertebrates, organic carbon normalized values from Table 20 in EPA's ROD.

(4) mg/Kg OC X 0.019 = mg/kg dry weight (assuming 1.9% foc); Metals and some organics did not need to be converted.

(5) Based on benzo(a)pyrene.

(6) Based on 2,3,7,8 TCDD.

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Appendix A

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The following procedure was used to determine surface water concentrations protective of human health.

- ***Check to see if a chemical has one or more ARARs:*** Select the lowest of these values. In some cases the lowest ARAR is based on protection of aquatic life (not human health).
- ***Calculate Method B values using Standard Method B equations (54 g/day and FDF =0.5)***
  - **For non-carcinogens:**
    - **Table A-1:** Standard Method B values calculated with Equation 730-1 using updated toxicity information.
  - **For carcinogens:**
    - **Table A-2:** Standard Method B values calculated with Equation 730-2 using updated toxicity information.
- ***Evaluate the lowest ARAR for each chemical for protectiveness using Standard Method B:*** **(Table A-3)**
  - **For non-carcinogen health effects**, the ARAR is divided by the most stringent Standard Method B value from Table A-1 to calculate a hazard quotient. If the hazard quotient is 1 or less, then the ARAR is considered protective for non-cancer health effects. Only Aroclors 1016 and 1254 exceeded this threshold.[17]
  - **For carcinogenic health effects**, the ARAR is divided by the most stringent Standard Method B value from Tables A-2 to determine the level of cancer risk. If the resulting value is 10 or less (equivalent to 1×10^{-5}), the ARAR is considered protective for cancer health effects. Only Aroclors 1016 and 1254, exceeded this threshold.
  - ***If necessary, adjust the ARAR downward to the MTCA risk thresholds:*** If the level of risk for an ARAR exceeded a hazard quotient of one (1), or an excess cancer risk of one in one hundred thousand (1×10^{-5}), the ARAR is adjusted downward so these risk thresholds are not exceeded. This adjustment only needed to be made for Aroclors 1016 and 1254.[18]
- ***If a chemical does not have an ARAR:*** Use the lowest value calculated with Standard Method B using Equations 730-1 and 730-2 as the cleanup level. This was needed for only two chemicals—chromium III and naphthalene.
- ***Evaluate the lowest ARAR for each chemical for protectiveness using Modified Method B:*** **(Tables A-4 to A-6)** Repeat the evaluation for protectiveness using Modified Method B and the fish consumption rate in EPA's Record of Decision (97.5 g/day and fish diet fraction of 1.0).
- ***If a chemical does not have an ARAR:*** Use the lowest value calculated with Modified Method B using Equations 730-1 and 730-2 as the cleanup level. This was needed for only two chemicals—chromium III and naphthalene.

[17] The three Aroclors included in this evaluation (1016, 1254 & 1260) were specifically identified by the Lower Duwamish Waterway Team at Ecology's Northwest Regional Office as contaminants of concern at upland sites along the waterway.

[18] While this adjustment is shown for completeness, the total PCB standard is considerably more stringent than the standards for individual PCB Aroclors. As a result, this adjustment under MTCA has no practical effect on the outcome of the analysis that the total PCB ARAR meets the MTCA risk thresholds.

Table A-1: Standard Method B surface water calculations for noncarcinogens using Equation 730-1

Substance	CAS #	Rfd (mg/kg-day)	ABW (kg)	UCF1 (µg/mg)	UCF2 (g/L)	HQ (unitless)	AT (years)	BCF (L/kg)	FCR (g/day)	FDF (unitless)	ED (years)	Result (µg/L)
Arsenic, inorganic	7440-38-2	0.0003	70	1,000	1,000	1.0	30	44	54	0.5	30	18
Barium	7440-39-3	0.02	70	1,000	1,000	1.0	30	NV	54	0.5	30	
Cadmium	7440-43-9	0.001	70	1,000	1,000	1.0	30	64	54	0.5	30	40
Chromium (III)	16065-83-1	1.5	70	1,000	1,000	1.0	30	16	54	0.5	30	243,056
Chromium (VI)	18540-29-9	0.003	70	1,000	1,000	1.0	30	16	54	0.5	30	486
Copper	7440-50-8	0.04	70	1,000	1,000	1.0	30	36	54	0.5	30	2,881
Lead	7439-92-1	NV	70	1,000	1,000	1.0	30	NV	54	0.5	30	
Mercury	7439-97-6	NV	70	1,000	1,000	1.0	30	NV	54	0.5	30	
Silver	7440-22-4	0.005	70	1,000	1,000	1.0	30	0.5	54	0.5	30	25,926
Zinc	7440-66-6	0.3	70	1,000	1,000	1.0	30	47	54	0.5	30	16,548
Benzene	71-43-2	0.004	70	1,000	1,000	1.0	30	5.2	54	0.5	30	1,994
Bis(2-ethylhexyl)phthalate	117-81-7	0.02	70	1,000	1,000	1.0	30	130	54	0.5	30	399
Butyl benzyl phthalate	85-68-7	0.2	70	1,000	1,000	1.0	30	414	54	0.5	30	1,252
Total cPAHs												
Benzo(a)anthracene	56-55-3	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
Benzo(a)pyrene	50-32-8	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
Benzo(b)fluoranthene	205-99-2	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
Benzo(k)fluoranthene	207-08-9	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
Chrysene	218-01-9	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
Dibenzo(a,h)anthracene	53-70-3	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
Indeno(1,2,3-cd)pyrene	193-39-5	NV	70	1,000	1,000	1.0	30	30	54	0.5	30	
2,3,7,8 TCDD	1746-01-6	7E-10	70	1,000	1,000	1.0	30	5,000	54	0.5	30	3.63E-07
Napthalene	91-20-3	0.02	70	1,000	1,000	1.0	30	10.5	54	0.5	30	4,938
PCBs	1336-36-3	NV	70	1,000	1,000	1.0	30	NV	54	0.5	30	
Aroclor 1016	12674-11-2	0.00007	70	1,000	1,000	1.0	30	31,200	54	0.5	30	0.0058
Aroclor 1254	11097-69-1	0.00002	70	1,000	1,000	1.0	30	31,200	54	0.5	30	0.00166
Aroclor 1260	11096-82-5	NV	70	1,000	1,000	1.0	30	NV	54	0.5	30	
Pentachlorophenol	87-86-5	0.005	70	1,000	1,000	1.0	30	11	54	0.5	30	1,178
Tributyltin	56-35-9	0.0003	70	1,000	1,000	1.0	30	NV	54	0.5	30	
Trichloroethylene	79-01-6	0.0005	70	1,000	1,000	1.0	30	10.6	54	0.5	30	122
Vinyl Chloride	75-01-4	0.003	70	1,000	1,000	1.0	30	1.17	54	0.5	30	6,648

Equation 730-1 $$\text{SWCUL (µg/L)} = \frac{\text{Rfd x ABW x UCF1 x UCF2 x HQ x AT}}{\text{BCF x FCR x FDF x ED}}$$

NV = No value available; Rfd = reference dose; ABW = average body weight; UCF1 and UCF2 are unit conversion factors; HQ = hazard quotient; AT = averaging time;

BCF = bioconcentration factor; FCR = fish consumption rate; FDF = fish diet fraction; ED = exposure duration

Equation values for the Rfd are from June 2015 CLARC tables; values for the BCF are from CLARC (i.e. NTR values).

Table A-2: Standard Method B surface water calculations for carcinogens using Equation 730-2

Substance	CAS #	Risk (unitless)	AWB (kg)	AT (years)	UCF1 (µg/mg)	UCF2 (g/L)	CPF (kg-day/mg)	BCF (L/kg)	FCR (g/day)	FDF (unitless)	ED (years)	Result (µg/L)
Arsenic, inorganic	7440-38-2	0.000001	70	75	1,000	1,000	1.5	44	54	0.5	30	0.098
Barium	7440-39-3	0.000001	70	75	1,000	1,000	NV	NV	54	0.5	30	
Cadmium	7440-43-9	0.000001	70	75	1,000	1,000	NV	64	54	0.5	30	
Chromium (III)	16065-83-1	0.000001	70	75	1,000	1,000	NV	16	54	0.5	30	
Chromium (VI)	18540-29-9	0.000001	70	75	1,000	1,000	NV	16	54	0.5	30	
Copper	7440-50-8	0.000001	70	75	1,000	1,000	NV	36	54	0.5	30	
Lead	7439-92-1	0.000001	70	75	1,000	1,000	NV	NV	54	0.5	30	
Mercury	7439-97-6	0.000001	70	75	1,000	1,000	NV	NV	54	0.5	30	
Silver	7440-22-4	0.000001	70	75	1,000	1,000	NV	0.5	54	0.5	30	
Zinc	7440-66-6	0.000001	70	75	1,000	1,000	NV	47	54	0.5	30	
Benzene	71-43-2	0.000001	70	75	1,000	1,000	0.055	5.2	54	0.5	30	22.7
Bis(2-ethylhexyl)phthalate	117-81-7	0.000001	70	75	1,000	1,000	0.014	130	54	0.5	30	3.56
Butyl benzyl phthalate	85-68-7	0.000001	70	75	1,000	1,000	0.0019	414	54	0.5	30	8.24
Total cPAHs												
Benzo(a)anthracene	56-55-3	0.000001	70	75	1,000	1,000	0.73	30	54	0.5	30	0.296
Benzo(a)pyrene	50-32-8	0.000001	70	75	1,000	1,000	7.3	30	54	0.5	30	0.0296
Benzo(b)fluoranthene	205-99-2	0.000001	70	75	1,000	1,000	0.73	30	54	0.5	30	0.296
Benzo(k)fluoranthene	207-08-9	0.000001	70	75	1,000	1,000	0.073	30	54	0.5	30	2.96
Chrysene	218-01-9	0.000001	70	75	1,000	1,000	0.0073	30	54	0.5	30	29.6
Dibenzo(a,h)anthracene	53-70-3	0.000001	70	75	1,000	1,000	7.3	30	54	0.5	30	0.0296
Indeno(1,2,3-cd)pyrene	193-39-5	0.000001	70	75	1,000	1,000	0.73	30	54	0.5	30	0.296
2,3,7,8 TCDD	1746-01-6	0.000001	70	75	1,000	1,000	130,000	5,000	54	0.5	30	9.97E-09
Napthalene	91-20-3	0.000001	70	75	1,000	1,000	NV	10.5	54	0.5	30	
PCBs	1336-36-3	0.000001	70	75	1,000	1,000	2	31,200	54	0.5	30	0.000104
Aroclor 1016	12674-11-2	0.000001	70	75	1,000	1,000	0.07	31,200	54	0.5	30	0.00297
Aroclor 1254	11097-69-1	0.000001	70	75	1,000	1,000	2	31,200	54	0.5	30	0.000104
Aroclor 1260	11096-82-5	0.000001	70	75	1,000	1,000	2	NV	54	0.5	30	
Pentachlorophenol	87-86-5	0.000001	70	75	1,000	1,000	0.4	11	54	0.5	30	1.47
Tributyltin	56-35-9	0.000001	70	75	1,000	1,000	NV	NV	54	0.5	30	
Trichloroethylene	79-01-6	0.000001	70	75	1,000	1,000	0.0464	10.6	54	0.5	30	13.2
Vinyl Chloride	75-01-4	0.000001	70	75	1,000	1,000	1.5	1.17	54	0.5	30	3.69

Equation 730-2 $$\text{SWCUL (µg/L)} = \frac{\text{Risk x ABW x AT x UCF1 x UCF2}}{\text{CPF x BCF x FCR x FDF x ED}}$$

NV = No value available; Risk = cancer risk; ABW = average body weight; AT = averaging time; UCF1 and UCF2 are unit conversion factors; CPF = cancer potency factor;

BCF = bioconcentration factor; FCR = fish consumption rate; FDF = fish diet fraction; ED = exposure duration

Equation values for the CPFs are from June 2015 CLARC tables; values for the BCFs are from CLARC (i.e. NTR values).

Table A-3: Analysis of human health protectiveness of ARARs using the Standard Method B values from Tables A-1 and A-2 for comparison and the resulting recommended groundwater concentrations for protection of human health

Substance	CAS Number	Most Stringent ARAR (1) (µg/L)	Non Cancer Toxicity Calc (3)			Cancer Toxicity Calc (4)			Ground Water Conc (µg/L)	Basis for Value
			Std Method B Noncancer (2) (µg/L)	ARAR HH Toxicity HQ	Adjusted ARAR (HQ=1)	Std Method B Cancer (2) (µg/L)	ARAR HH Toxicity 10^{-6} Risk	Adjusted ARAR (10^{-5} Risk)		
Arsenic, inorganic	7440-38-2	0.14	17.7	0.0079		0.098	1.4256		0.14	ARAR
Barium	7440-39-3									
Cadmium	7440-43-9	8.8	40.5	0.2172					8.8	ARAR
Chromium (III)	16065-83-1		243,056						243,056	Method B
Chromium (VI)	18540-29-9	50	486	0.1029					50	ARAR
Copper	7440-50-8	3.1	2,881	0.0011					3.1	ARAR
Lead	7439-92-1	8.1							8.1	ARAR
Mercury	7439-97-6	0.025							0.025	ARAR
Silver	7440-22-4	1.9	25,926	0.0001					1.9	ARAR
Zinc	7440-66-6	81	16,548	0.0049					81	ARAR
Benzene	71-43-2	58	1,994	0.0291		22.7	2.5551		58	ARAR
Bis(2-ethylhexyl)phthalate	117-81-7	0.37	399	0.0009		3.56	0.1039		0.37	ARAR
Butyl benzyl phthalate	85-68-7	0.10	1,252	0.0001		8.24	0.0121		0.1	ARAR
Total cPAHs										
Benzo(a)anthracene	56-55-3	0.0013				0.296	0.0044		0.0013	ARAR
Benzo(a)pyrene	50-32-8	0.00013				0.0296	0.0044		0.00013	ARAR
Benzo(b)fluoranthene	205-99-2	0.0013				0.296	0.0044		0.0013	ARAR
Benzo(k)fluoranthene	207-08-9	0.013				2.96	0.0044		0.013	ARAR
Chrysene	218-01-9	0.031				29.6	0.0010		0.031	ARAR
Dibenzo(a,h)anthracene	53-70-3	0.00013				0.00296	0.0044		0.00013	ARAR
Indeno(1,2,3-cd)pyrene	193-39-5	0.0013				0.296	0.0044		0.0013	ARAR
2,3,7,8 TCDD	1746-01-6	5.10E-09	3.63E-07	0.0141		9.97E-09	0.5115		5.10E-09	ARAR
Napthalene	91-20-3		4,938						4,938	Method B
PCBs (total)	1336-36-3	0.000064				0.000104	0.6162		0.000064	ARAR
Aroclor 1016	12674-11-2	0.03	0.00582	5.1576	0.0058	0.00297	10.1088	0.0297	0.000064	total PCB ARAR
Aroclor 1254	11097-69-1	0.03	0.00166	18.0514	0.0017	0.000104	288.8229	0.00104	0.000064	total PCB ARAR
Aroclor 1260	11096-82-5	0.03							0.000064	total PCB ARAR
Pentachlorophenol	87-86-5	0.04	1,178	0.000003		1.47	0.0272		0.04	ARAR
Tributyltin	56-35-9	0.0074							0.0074	ARAR
Trichloroethylene	79-01-6	7.0	122	0.0574		13.2	0.5303		7.0	ARAR
Vinyl Chloride	75-01-4	1.6	6,648	0.0002		3.69	0.4336		1.6	ARAR

(1) From Table 4. Total PCBs equals the sum of all congener or all isomer or homolog or Aroclor analyses.

(2) Standard Method B uses a fish consumption rate of 54 g/day and fish diet fraction of 0.5.

(3) The non-cancer toxicity calculation = ARAR/Modified Method B calculated value. If resulting HQ > 1, then ARAR may not meet MTCA acceptable non cancer risk threshold of HQ = 1. These values are highlighted in red, with the ARAR adjusted to HQ = 1. Only Aroclors 1016 & 1254 exceeded this threshold, however the ARAR for total PCBs is more stringent and overrides these adjusted values.

(4) The cancer toxicity calculation = ARAR/Modified Method B calculated value. If resulting cancer risk $>10\times10^{-6}$, then ARAR may not meet MTCA acceptable cancer risk threshold of 1×10^{-5}. These values are highlighted, with the ARAR adjusted to 1×10^{-5}. Only Aroclors 1016 & 1254 exceeded this threshold, however the ARAR for total PCBs is more stringent and overrides this adjustment.

Table A-4: Modified Method B surface water calculations for noncarcinogens using Equation 730-1, modified using FCR = 97.5 g/day and FDF = 1

Substance	CAS #	Rfd (mg/kg-day)	ABW (kg)	UCF1 (µg/mg)	UCF2 (g/L)	HQ (unitless)	AT (years)	BCF (L/kg)	FCR (g/day)	FDF (unitless)	ED (years)	Result (µg/L)
Arsenic, inorganic	7440-38-2	0.0003	70	1,000	1,000	1.0	30	44	97.5	1	30	4.9
Barium	7440-39-3	0.02	70	1,000	1,000	1.0	30	NV	97.5	1	30	
Cadmium	7440-43-9	0.001	70	1,000	1,000	1.0	30	64	97.5	1	30	11
Chromium (III)	16065-83-1	1.5	70	1,000	1,000	1.0	30	16	97.5	1	30	67,308
Chromium (VI)	18540-29-9	0.003	70	1,000	1,000	1.0	30	16	97.5	1	30	135
Copper	7440-50-8	0.04	70	1,000	1,000	1.0	30	36	97.5	1	30	798
Lead	7439-92-1	NV	70	1,000	1,000	1.0	30	NV	97.5	1	30	
Mercury	7439-97-6	NV	70	1,000	1,000	1.0	30	NV	97.5	1	30	
Silver	7440-22-4	0.005	70	1,000	1,000	1.0	30	0.5	97.5	1	30	7,179
Zinc	7440-66-6	0.3	70	1,000	1,000	1.0	30	47	97.5	1	30	4,583
Benzene	71-43-2	0.004	70	1,000	1,000	1.0	30	5.2	97.5	1	30	552
Bis(2-ethylhexyl)phthalate	117-81-7	0.02	70	1,000	1,000	1.0	30	130	97.5	1	30	110
Butyl benzyl phthalate	85-68-7	0.2	70	1,000	1,000	1.0	30	414	97.5	1	30	347
Total cPAHs												
Benzo(a)anthracene	56-55-3	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
Benzo(a)pyrene	50-32-8	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
Benzo(b)fluoranthene	205-99-2	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
Benzo(k)fluoranthene	207-08-9	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
Chrysene	218-01-9	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
Dibenzo(a,h)anthracene	53-70-3	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
Indeno(1,2,3-cd)pyrene	193-39-5	NV	70	1,000	1,000	1.0	30	30	97.5	1	30	
2,3,7,8 TCDD	1746-01-6	7E-10	70	1,000	1,000	1.0	30	5,000	97.5	1	30	0.00000010
Napthalene	91-20-3	0.02	70	1,000	1,000	1.0	30	10.5	97.5	1	30	1,368
PCBs	1336-36-3	NV	70	1,000	1,000	1.0	30	31,200	97.5	1	30	
Aroclor 1016	12674-11-2	0.00007	70	1,000	1,000	1.0	30	31,200	97.5	1	30	0.0016
Aroclor 1254	11097-69-1	0.00002	70	1,000	1,000	1.0	30	31,200	97.5	1	30	0.00046
Aroclor 1260	11096-82-5	NV	70	1,000	1,000	1.0	30	NV	97.5	1	30	
Pentachlorophenol	87-86-5	0.005	70	1,000	1,000	1.0	30	11	97.5	1	30	326
Tributyltin	56-35-9	0.0003	70	1,000	1,000	1.0	30	NV	97.5	1	30	
Trichloroethylene	79-01-6	0.0005	70	1,000	1,000	1.0	30	10.6	97.5	1	30	34
Vinyl Chloride	75-01-4	0.003	70	1,000	1,000	1.0	30	1.17	97.5	1	30	1,841

Equation 730-1 $$SWCUL\ (\mu g/L) = \frac{Rfd \times ABW \times UCF1 \times UCF2 \times HQ \times AT}{BCF \times FCR \times FDF \times ED}$$

NV = No value available; Rfd = reference dose; ABW = average body weight; UCF1 and UCF2 are unit conversion factors; HQ = hazard quotient; AT = averaging time;

BCF = bioconcentration factor; FCR = fish consumption rate; FDF = fish diet fraction; ED = exposure duration

Equation values for the Rfd are from June 2015 CLARC tables; values for the BCF are from CLARC (i.e. NTR values).

Table A-5: Modified Method B surface water calculations for carcinogens using Equation 730-2, modified using FCR = 97.5 g/day and FDF = 1

Substance	CAS #	Risk (unitless)	AWB (kg)	AT (years)	UCF1 (µg/mg)	UCF2 (g/L)	CPF (kg-day/mg)	BCF (L/kg)	FCR (g/day)	FDF (unitless)	ED (years)	Result (µg/L)
Arsenic, inorganic	7440-38-2	0.000001	70	75	1,000	1,000	1.5	44	97.5	1	30	0.027
Barium	7440-39-3	0.000001	70	75	1,000	1,000	NV	NV	97.5	1	30	
Cadmium	7440-43-9	0.000001	70	75	1,000	1,000	NV	64	97.5	1	30	
Chromium (III)	16065-83-1	0.000001	70	75	1,000	1,000	NV	16	97.5	1	30	
Chromium (VI)	18540-29-9	0.000001	70	75	1,000	1,000	NV	16	97.5	1	30	
Copper	7440-50-8	0.000001	70	75	1,000	1,000	NV	36	97.5	1	30	
Lead	7439-92-1	0.000001	70	75	1,000	1,000	NV	NV	97.5	1	30	
Mercury	7439-97-6	0.000001	70	75	1,000	1,000	NV	NV	97.5	1	30	
Silver	7440-22-4	0.000001	70	75	1,000	1,000	NV	0.5	97.5	1	30	
Zinc	7440-66-6	0.000001	70	75	1,000	1,000	NV	47	97.5	1	30	
Benzene	71-43-2	0.000001	70	75	1,000	1,000	0.055	5.2	97.5	1	30	6.3
Bis(2-ethylhexyl)phthalate	117-81-7	0.000001	70	75	1,000	1,000	0.014	130	97.5	1	30	0.99
Butyl benzyl phthalate	85-68-7	0.000001	70	75	1,000	1,000	0.0019	414	97.5	1	30	2.28
Total cPAHs												
Benzo(a)anthracene	56-55-3	0.000001	70	75	1,000	1,000	0.73	30	97.5	1	30	0.082
Benzo(a)pyrene	50-32-8	0.000001	70	75	1,000	1,000	7.3	30	97.5	1	30	0.0082
Benzo(b)fluoranthene	205-99-2	0.000001	70	75	1,000	1,000	0.73	30	97.5	1	30	0.082
Benzo(k)fluoranthene	207-08-9	0.000001	70	75	1,000	1,000	0.073	30	97.5	1	30	0.82
Chrysene	218-01-9	0.000001	70	75	1,000	1,000	0.0073	30	97.5	1	30	8.2
Dibenzo(a,h)anthracene	53-70-3	0.000001	70	75	1,000	1,000	7.3	30	97.5	1	30	0.0082
Indeno(1,2,3-cd)pyrene	193-39-5	0.000001	70	75	1,000	1,000	0.73	30	97.5	1	30	0.082
2,3,7,8 TCDD	1746-01-6	0.000001	70	75	1,000	1,000	130,000	5,000	97.5	1	30	2.46E-09
Napthalene	91-20-3	0.000001	70	75	1,000	1,000	NV	10.5	97.5	1	30	
PCBs	1336-36-3	0.000001	70	75	1,000	1,000	2	31,200	97.5	1	30	0.000029
Aroclor 1016	12674-11-2	0.000001	70	75	1,000	1,000	0.07	31,200	97.5	1	30	0.00082
Aroclor 1254	11097-69-1	0.000001	70	75	1,000	1,000	2	31,200	97.5	1	30	0.000029
Aroclor 1260	11096-82-5	0.000001	70	75	1,000	1,000	2	NV	97.5	1	30	
Pentachlorophenol	87-86-5	0.000001	70	75	1,000	1,000	0.4	11	97.5	1	30	0.41
Tributyltin	56-35-9	0.000001	70	75	1,000	1,000	NV	NV	97.5	1	30	
Trichloroethylene	79-01-6	0.000001	70	75	1,000	1,000	0.0464	10.6	97.5	1	30	3.65
Vinyl Chloride	75-01-4	0.000001	70	75	1,000	1,000	1.5	1.17	97.5	1	30	1.02

Equation 730-2 $$SWCUL\ (\mu g/L) = \frac{Risk \times ABW \times AT \times UCF1 \times UCF2}{CPF \times BCF \times FCR \times FDF \times ED}$$

NV = No value available; Risk = cancer risk; ABW = average body weight; AT = averaging time; UCF1 and UCF2 are unit conversion factors; CPF = cancer potency factor;

BCF = bioconcentration factor; FCR = fish consumption rate; FDF = fish diet fraction; ED = exposure duration

Equation values for the CPFs are from June 2015 CLARC tables; values for the BCFs are from CLARC (i.e. NTR values).

Table A-6: Analysis of human health protectiveness of ARARs using the Modified Method B values from Tables A-4 and A-5 for comparison and the resulting recommended groundwater concentrations for protection of human health

Substance	CAS Number	Most Stringent ARAR (1) (µg/L)	Non Cancer Toxicity Calc (3)			Cancer Toxicity Calc (4)			Ground Water Conc (µg/L)	Basis for Value
			Modified B Noncancer (µg/L) FCR = 97.5 (2)	ARAR HH Toxicity HQ	Adjusted ARAR (HQ=1)	Modified B Cancer (µg/L) FCR = 97.5 (2)	ARAR HH Toxicity 10^{-6} Risk	Adjusted ARAR (1×10^{-5} Risk)		
Arsenic, inorganic	7440-38-2	0.14	4.9	0.0286		0.0272	5.1480		0.14	ARAR
Barium	7440-39-3									
Cadmium	7440-43-9	8.8	11.2	0.7845					8.8	ARAR
Chromium (III)	16065-83-1		67,308						67,308	Mod. Method B
Chromium (VI)	18540-29-9	50	135	0.3714					50	ARAR
Copper	7440-50-8	3.1	798	0.0030					3.1	ARAR
Lead	7439-92-1	8.1							8.1	ARAR
Mercury	7439-97-6	0.025							0.025	ARAR
Silver	7440-22-4	1.9	7,179	0.0003					1.9	ARAR
Zinc	7440-66-6	81	4,583	0.0177					81	ARAR
Benzene	71-43-2	58	552	0.1051		6.3	9.2063		58	ARAR
Bis(2-ethylhexyl)phthalate	117-81-7	0.37	110	0.0034		0.99	0.3737		0.37	ARAR
Butyl benzyl phthalate	85-68-7	0.10	347	0.0003		2.28	0.0439		0.1	ARAR
Total cPAHs										
Benzo(a)anthracene	56-55-3	0.0013				0.082	0.0159		0.0013	ARAR
Benzo(a)pyrene	50-32-8	0.00013				0.0082	0.0159		0.00013	ARAR
Benzo(b)fluoranthene	205-99-2	0.0013				0.0082	0.0159		0.0013	ARAR
Benzo(k)fluoranthene	207-08-9	0.013				0.082	0.0159		0.013	ARAR
Chrysene	218-01-9	0.031				8.2	0.0038		0.031	ARAR
Dibenzo(a,h)anthracene	53-70-3	0.00013				0.0082	0.0159		0.00013	ARAR
Indeno(1,2,3-cd)pyrene	193-39-5	0.0013				0.082	0.0159		0.0013	ARAR
2,3,7,8 TCDD	1746-01-6	5.10E-09	1.01E-07	0.0507		2.76E-09	1.8469		5.10E-09	ARAR
Napthalene	91-20-3		1,368						1,368	Mod. Method B
PCBs (total)	1336-36-3	0.000064				0.000029	2.2250		0.000064	ARAR
Aroclor 1016	12674-11-2	0.03	0.0016	18.6245	0.0016	0.00082	36.5040	0.0082	0.000064	total PCB ARAR
Aroclor 1254	11097-69-1	0.03	0.00046	65.1857	0.00046	0.000029	1042.9714	0.00029	0.000064	total PCB ARAR
Aroclor 1260	11096-82-5	0.03							0.000064	total PCB ARAR
Pentachlorophenol	87-86-5	0.04	326	0.0001		0.41	0.0976		0.04	ARAR
Tributyltin	56-35-9	0.0074							0.0074	ARAR
Trichloroethylene	79-01-6	7.0	34	0.2059		365	1.9178		7.0	ARAR
Vinyl Chloride	75-01-4	1.6	1,841	0.0009		1.02	1.5686		1.6	ARAR

(1) From Table 4. Total PCBs equals the sum of all congener or all isomer or homolog or Aroclor analyses.

(2) Modified Method B includes modification of the fish consumption rate to 97.5 g/day and fish diet fraction of 1.

(3) The non-cancer toxicity calculation = ARAR/Modified Method B calculated value. If resulting HQ > 1, then ARAR may not meet MTCA acceptable non cancer risk threshold of HQ = 1. These values are highlighted in red, with the ARAR adjusted to HQ = 1. Only Aroclors 1016 & 1254 exceeded this threshold, however the ARAR for total PCBs is more stringent and overrides these values.

(4) The cancer toxicity calculation = ARAR/Modified Method B calculated value. If resulting cancer risk > 10×10^{-6}, then ARAR may not meet MTCA acceptable cancer risk threshold of 1×10^{-5}. These values are highlighted, with the ARAR adjusted to 1×10^{-5}. Only Aroclors 1016 & 1254 exceeded this threshold, however the ARAR for total PCBs is more stringent and overrides these values.

Table A-7: Lower Duwamish Waterway pH measurements at the East Marginal Way Bridge

Field Collection Date (1)	pH Value	Field Collection Date (2)	pH Value	
1/14/2004	7.5	9/13/2006	7.2	
2/11/2004	7.4	10/11/2006	7.3	
3/10/2004	7.2	11/15/2006	7.3	
4/14/2004	7.5	12/13/2006	7.7	
5/12/2004	7.6	1/10/2007	7.3	
6/16/2004	7.4	2/7/2007	7.3	
7/14/2004	7.5	3/7/2007	7.3	
8/11/2004	7.2	4/4/2007	7.2	
10/12/2004	7.7	5/9/2007	7.5	
11/10/2004	7.4	6/6/2007	7.06	
12/7/2004	7.5	7/5/2007	7.88	
1/11/2005	7.3	8/8/2007	7.82	
2/16/2005	7.9	9/5/2007	7.12	
3/16/2005	7.4	10/10/2007	7.41	
4/13/2005	7.8	11/7/2007	7.11	
5/11/2005	7.4	12/12/2007	7.91	
6/15/2005	7.5	1/9/2008	7.17	
7/13/2005	7.5	2/6/2008	7.11	
8/10/2005	7.3	3/5/2008	7.35	
9/14/2005	7.4	4/9/2008	7.43	
10/12/2005	7.2	5/7/2008	7.01	
11/16/2005	7.1	6/12/2008	7.45	
12/14/2005	7.6	7/9/2008	7.15	
2/15/2006	7.5	8/6/2008	7.15	
3/15/2006	7.9	9/4/2008	7.13	
4/12/2006	7.0	10/8/2008	7.09	
5/10/2006	7.6	11/5/2008	7.18	
6/14/2006	8.0 (high)	12/3/2008	7.15	
7/12/2006	7.0 (low)	9/13/2006		
8/16/2006	7.5			
			Overall Average	**7.4**
			Overall Median	**7.4**

(1) Hydrolab Surveyor Multi-Parameter Probe

(2) Measurement with Multi-Parameter Water Quality Field Meter/Probe

Source: EIM download by Richard Thomas, NWRO

Table A-8: Calculation of groundwater concentrations anticipated to be protective of sediment

Substance	CAS No.	Sediment Cleanup Level (Cs) (mg/Kg) (1)	Units Conversion Factor (mg/kg)	Soil Water (0w) (cc/cc) (2)	Bulk Density (Pb) (g/cc) (3)	(Koc) (ml/g) (4)	Fraction Organic (foc) (%) (5)	Distribution Coefficient (Kd) (cc/g) (6)	Dilution Factor (DF) (unitless)	Groundwater Concentration (Cw) (µg/L) (6)
Arsenic, inorganic	7440-38-2	7.0	0.001	0.615	1.02			29 / 31	1	236 / 222
Arsenic, inorganic	7440-38-2	57	0.001	0.615	1.02			29 / 31	1	1,925 / 1,804
Cadmium	7440-43-9	5.1	0.001	0.615	1.02			6.7 / 4,300	1	698 / 1.2
Chromium (III)	16065-83-1	260	0.001	0.615	1.02			1,000 / 4,300,000	1	260 / 0.1
Copper	7440-50-8	390	0.001	0.615	1.02			22 / 28,500	1	17,254 / 14
Lead	7439-92-1	450	0.001	0.615	1.02			10,000 / 23,270	1	45 / 19
Mercury	7439-97-6	0.41	0.001	0.615	1.02			52 / 200	1	7.8 / 2.0
Silver	7440-22-4	6.1	0.001	0.615	1.02			8.3 / 110	1	685 / 55
Zinc	7440-66-6	410	0.001	0.615	1.02			62 / 530	1	6,549 / 773
Bis(2-ethylhexyl)phthalate	117-81-7	0.89	0.001	0.615	1.02	111,123	1.9%	2,222	1	0.42
Butyl benzyl phthalate	85-68-7	0.093	0.001	0.615	1.02	13,746	1.9%	275	1	0.36
Total cPAHs		0.09	0.001	0.615	1.02	968,774	1.9%	19,375	1	0.0049
Benzo(a)anthracene	56-55-3	2.09	0.001	0.615	1.02	357,537	1.9%	7,151	1	0.3076
Benzo(a)pyrene	50-32-8	1.88	0.001	0.615	1.02	968,774	1.9%	19,375	1	0.1021
Chrysene	218-01-9	2.09	0.001	0.615	1.02	398,000	1.9%	7,960	1	0.28
Dibenzo(a,h)anthracene	53-70-3	0.23	0.001	0.615	1.02	1,789,101	1.9%	35,782	1	0.0068
Indeno(1,2,3-cd)pyrene	193-39-5	0.65	0.001	0.615	1.02	3,470,000	1.9%	69,400	1	0.0099
Total dioxins		0.000002	0.001	0.615	1.02	249,100	1.9%	4,982	1	4.23E-07
Napthalene	91-20-3	1.88	0.001	0.615	1.02	1,191	1.9%	23.82	1	81
PCBs (total-fish consumption)	1336-36-3	0.002	0.001	0.615	1.02	309,000	1.9%	5,871	1	0.00034
PCBs (total-benthic toxicity)	1336-36-3	0.23	0.001	0.615	1.02	309,000	1.9%	5,871	1	0.039
Aroclor 1016 (fish consumption)	12674-11-2	0.002	0.001	0.615	1.02	107,285	1.9%	2,038	1	0.00098
Aroclor 1254 (fish consumption)	11097-69-1	0.002	0.001	0.615	1.02	130,500	1.9%	2,480	1	0.00081
Aroclor 1260 (fish consumption)	11096-82-5	0.002	0.001	0.615	1.02	822,422	1.9%	15,626	1	0.00013
Aroclor 1016 (benthic toxicity)	12674-11-2	0.23	0.001	0.615	1.02	107,285	1.9%	2,038	1	0.11
Aroclor 1254 (benthic toxicity)	11097-69-1	0.23	0.001	0.615	1.02	130,500	1.9%	2,480	1	0.093
Aroclor 1260 (benthic toxicity)	11096-82-5	0.23	0.001	0.615	1.02	822,422	1.9%	15,626	1	0.015
Pentachlorophenol	87-86-5	0.36	0.001	0.615	1.02	592 / 410	1.9%	11.2 / 7.8	1	30 / 43

(1) From Lower Duwamish Waterway ROD, EPA November 2014; OC normalized concentrations converted by multiplying by 0.019 (1.9%) TOC. (see Table 6 in the body of this memo)

(2) Midpoint value from Lower Duwamish Waterway Remedial Investigation.

(3) Calculated value using 61.5% porosity and 2.65 g/cc particle density from Lower Duwamish Waterway Remedial Investigation. ((1-0.615) × 2.65 g/cc = 1.02 g/cc)

(4) From Table 747-1 in WAC 173-340-900; chrysene & indeno (1,2,3-cd) pyrene from June, 2015 CLARC tables; used Koc for 2,3,7,8 TCDD from October 2015 EPA PRG's for total dioxin calculation; pentachlorophenol Koc from Table 747-2 (first value for pH of 6.8, second value for pH of 8).

(5) Average value from Lower Duwamish Waterway Remedial Investigation.

(6) Organic Kd = Koc * foc (Equation 747-2 in WAC 173-340-747); 1st metals Kd for pH of 6.8; 2nd Kd for pH of 8.0 (i.e. [based on pH 6.8]/[based on pH8.0]). Sources of pH 6.8 Kds from Table 747-3 except silver from EPA May 1996 Soil Screening Guidance. Sources of pH 8.0 from EPA May 1996 Soil Screening Guidance, except lead from "Understanding Variation in Partition Coefficient (Kd) Values, EPA 402-R-99-004B, August 1999", copper from "Review of Copper Partitioning Coefficients in the Aquatic Environment and Processes Causing the Observed Variation, EU 2005"

(7) Default dilution factor for saturated soil (WAC 173-340-747)

(8) Three phase model equation modified to solve for water concentration; assumes zero air porosity (equation 747-1 in WAC 173-340-747)

$$Cw = Cs/((UCF \times DF) \times (Kd + (0w/Pb)))$$ See next page for derivation.

Derivation of formula for calculating a groundwater concentration that is anticipated to meet the sediment cleanup standards established in EPA's Record of Decision (ROD)

Start with Equation 747-1:

$$C_s = C_w(UCF)DF\left[K_d + \frac{(\theta_w + \theta_a H_{cc})}{\rho_b}\right] \text{ (Equation 747-1)}$$

Since sediment should be saturated, with all the soil pores filled with water, that portion of the formula calculating the mass in the vapor phase ($\theta_a H_{cc}$) can be eliminated since θ_a = zero.

$$C_s = C_w(UCF)DF\left[K_d + \frac{\theta_w}{\rho_b}\right]$$

Rearranging to solve for a water concentration, results in the following formula:

$$C_w = \frac{C_s}{UCFxDF\left[K_d + \frac{\theta_w}{\rho_b}\right]}$$

Where:

C_s = Sediment concentration (mg/kg)

C_w = Sediment pore water concentration (i.e. groundwater concentration) (µg/L)

UCF = Unit conversion factor (1 mg/1,000 µg)

DF = Dilution factor (dimensionless); used a value of 1 for saturated sediment per WAC 173-340-747(4)(e).

K_d = Distribution coefficient (L/kg)

= K_{oc} x f_{oc} (for hydrophobic organics per equation 747-2 in WAC 173-340-747(4))

Where:

K_{oc} = Soil organic carbon-water partitioning coefficient (ml/g)

f_{oc} = Fraction of organic carbon in sediment (g/g);

Used a value of 1.9% or 0.019 g/g for sediment, based on data in the Lower Duwamish Waterway Remedial Investigation.

θ_w = Water-filled porosity (ml water/ml soil); used a value of 0.615, based on data in the Lower Duwamish Waterway Remedial Investigation.

θ_a = Air-filled soil porosity (ml air/ml soil); used a value of 0 for saturated sediment per WAC 173-340-747(4)(e).

H_{cc} = Henry's law constant (dimensionless)

ρ_b = Dry soil bulk density (kg/L); calculated value using a particle density of 2.65 g/cc and assuming that part of the sediment volume not occupied by water filled porosity is solid sediment particles.

ρ_b = (1-0.615) × 2.65 g/cc = 1.02 kg/L