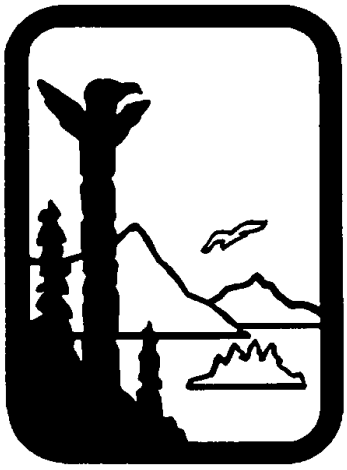
State of Alaska

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

DIVISION OF SPILL PREVENTION AND RESPONSE
CONTAMINATED SITES PROGRAM



Cumulative Risk Guidance

June 9, 2008

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PURPOSE AND OVERVIEW

The Alaska Department of Environmental Conservation (DEC) has developed rules for determining the necessity for and degree of cleanup required to protect human health, safety, and welfare and the environment at contaminated sites under the Contaminated Sites Program (CS). These regulations are found at 18 AAC 75, Article 3. The purpose of this Guidance is to clarify DEC policy for calculating cumulative risk.

If applying soil cleanup levels under methods two, three, or four found in 18 AAC 75.340 or applying groundwater cleanup levels found in 18 AAC 75.345, a responsible party must ensure that cumulative carcinogenic risk and hazard index standards are not exceeded. Under 18 AAC 75.325(g), if using method two or three for applicable soil cleanup levels or applying groundwater cleanup levels, a responsible person shall ensure that, "…after completing site cleanup, the risk from hazardous substances does not exceed a cumulative carcinogenic risk standard of 1 in 100,000 across all exposure pathways and a cumulative non-carcinogenic risk standard at a hazard index of 1 across all exposure pathways."

Under 18 AAC 75.325(h), a responsible person proposing an alternative cleanup level under method four shall ensure that, "…the risk from hazardous substances does not exceed a cumulative carcinogenic risk standard of 1 in 100,000 across all exposure pathways and a cumulative non-carcinogenic risk standard at a hazard index of 1 for all exposure pathways."

Under method four and 18 AAC 75.325(h), "…the department may consider a risk standard consistent with the range acceptable under 40 C.F.R. 300.430, revised as of July 1, 2002." This risk range applies to carcinogens only. Under 40 C.F.R. 300.430, an acceptable risk standard is an excess cancer risk to an individual of 1 in 10,000 to 1 in 1,000,000. Consideration of the risk standard mentioned above will be based on site-specific conditions, land use, hazardous substance characteristics, statutory compliance, protection of human health, safety, and welfare, and the environment, ability of cleanup to be implemented, long-term and short-term effectiveness, use of treatment technologies, public comment, and cost.

This guidance clarifies the steps involved in calculating cumulative risk. This guidance is specific to methods two and three although method four is addressed in areas as a reference. For calculating cumulative risk under method four, please refer to DEC's *Risk Assessment Procedures Manual.*

BACKGROUND ON CUMULATIVE RISK

Cumulative risk is defined as the sum of risks resulting from multiple sources and pathways to which humans are exposed. When more than one hazardous substance is present at a site or multiple exposure pathways exist, the cleanup levels in Table B1 of 18 AAC 75.341 and Table C of 18 AAC 75.345 may need to be adjusted downward. The cumulative cancer risk remaining at the site when cleanup is completed must not exceed 1 in 100,000 (1×10^{-5}) and the cumulative non-carcinogenic hazard index (HI) must not exceed 1. Tables B1 and B2 of 18 AAC 75.341 and Table C of 18 AAC 75.345 are hereinafter referred to simply as "Table B1," "Table B2," and "Table C," respectively.

The approach for calculating cumulative risk is as follows:

1. Develop a site specific conceptual site model (CSM) showing completed exposure pathways that need to be evaluated.

2. For each contaminant, record the exposure media, exposure route, concentration to remain on-site following cleanup, and pathway specific risk-based concentration (RBC).

3. Indicate whether the contaminant is considered a carcinogen, non-carcinogen, or both.

4. For each carcinogen, risk is calculated by dividing the site concentration remaining on-site by the applicable RBC and multiplying by the risk management level of 1×10^{-5}. Cumulative carcinogenic risk is the summation of all the risks from each exposure pathway and exposure route (see Equation 1).

$$\text{Cumulative Risk} = \Sigma[(\text{Concentration} \div \text{RBC}) \times 10^{-5}] \qquad \textbf{Eq. 1}$$

5. For each non-carcinogen, the hazard quotient (HQ) is calculated by dividing the site concentration remaining on-site by the applicable RBC and multiplying by the risk management level of 1. The hazard index (HI) is the summation of all HQs across all pathways that are affecting the same target organ or system endpoint (see Equation 2).

$$\text{HI} = \Sigma[(\text{Concentration} \div \text{RBC}) \times 1] \qquad \textbf{Eq. 2}$$

A site-specific CSM should be used to identify complete exposure pathways on-site and will help address data quality objectives. A CSM should include the source of contamination, release/transport mechanisms, contact media (i.e. soil, air, or groundwater), exposure route (i.e. direct contact, inhalation,) and receptor (i.e. current/future resident, subsistence user, or biota). Methods two and three soil cleanup levels are assumed to be protective of inhalation of volatilization from soil to ambient air, direct contact with soil, and ingestion of groundwater. All other pathways that are shown to be complete based on the site-specific CSM should be investigated. These pathways can be addressed under method four.

Each contaminant detected above one-tenth of the Tables B1 inhalation or direct contact or Table C cleanup levels must be included in cumulative risk calculations. For these contaminants, record the exposure media, exposure route, concentration to remain on-site following cleanup,

and the RBC. Appendix A provides an example of a worksheet that can be used to organize the above information for calculating cumulative risk.

It is important to note that the cumulative risk standard must be met *following* site cleanup. For soil, the site concentration to be used in cumulative risk calculations is the maximum concentration, unless the department approves an appropriate statistical method, in which case compliance will be based on the mean soil concentration at the 95th percent upper confidence limit (UCL), under 18 AAC 75.380(c)(1). For groundwater, the site concentration is the maximum concentration, as described in 18 AAC 75.380(c)(2).

The RBC for method two soil inhalation and direct contact pathways can be found in Appendix B. RBCs correspond to the concentration in soil that would cause an adverse effect through the inhalation or ingestion routes of exposure. RBCs are calculated using the equations presented in DEC's *Cleanup Levels Guidance* (June 9, 2008) and takes into account default exposure and soil/aquifer data as well as toxicological data specific to the compound of interest. Note that the RBC may be different from the cleanup level in Table B1. Some cleanup levels in Table B1 are capped at the soil saturation concentration and therefore correspond to a risk or HQ lower than the department standard. Also, some contaminants have both carcinogenic and non-carcinogenic effect and the cleanup level listed in the aforementioned table corresponds to the lowest concentration causing an effect. For example, aldrin causes both carcinogenic and non-carcinogenic effects when exposure is through the direct contact route. The cleanup level in Table B1 corresponds with the carcinogenic effect because it is at a lower concentration than the non-carcinogenic effect. Also as an example, ethylbenzene is considered a carcinogen for the inhalation pathway. Therefore, when calculating cumulative risk for ethylbenzene, both carcinogenic and non-carcinogenic risk should be calculated for the inhalation pathway, but only non-carcinogenic risk should be calculated for the direct contact pathway.

The RBC for groundwater and method three alternative cleanup levels for soil must be calculated on a site-specific basis using DEC's *Cleanup Levels Guidance* (June 9, 2008).

Contaminants are generally divided into two basic groups, those that have a carcinogenic effect and those that have a non-carcinogenic effect. Cumulative carcinogenic risk and non-carcinogenic hazard index are calculated separately. Some compounds can cause both effects and are included in both cumulative risk calculations.

CARCINOGENS

Risks from exposure to carcinogens are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen (EPA, 1989). Under 18 AAC 75.990(12), DEC defines a carcinogen as "…a substance that meets the criteria of the descriptors "Carcinogenic to Humans" or "Likely to Be Carcinogenic to Humans" according to EPA's *Guidelines for Carcinogen Risk Assessment*, –EPA/630/P-03/001F (March 2005), adopted by reference.

Cumulative carcinogenic risk is the summation of all risks from each exposure pathway and exposure route. The cumulative carcinogenic risk equation is shown in Equation 1. Unless demonstrated otherwise, cancer risks resulting from exposure to two or more carcinogens are assumed to be additive. The cumulative carcinogenic risk equation assumes that there are no synergistic or antagonistic chemical interactions.

NON-CARCINOGENS

Under 18 AAC 75.990(69), DEC defines a non-carcinogen as "…a hazardous substance with adverse health effects on humans other than cancer." The non-carcinogenic HQ represents the ratio of estimated intake of a chemical to the estimated intake at which there are no observed adverse effects. The HI is the summation of all of the HQs for all pathways and exposure routes that affect the same target organ or system endpoint.

For non-carcinogens, the health threats resulting from exposure to two or more hazardous substances with similar types of toxic response are assumed to be additive. However, many non-carcinogens have varying toxic effects and therefore assuming that these effects are additive may not be valid.

Non-carcinogenic compounds affect different target organs or systems by different mechanisms of toxicity. To accurately assess the possible effects of non-carcinogenic compounds, the HI can be segregated by target organ or system endpoint and mechanism of toxicity consistent with EPA's *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part A) – Interim Final* (1989), *Guidelines for the Health Risk Assessment of Chemical Mixtures* (1986), and *Supplemental Guidance for Conducting Health Risk Assessment of Chemical Mixtures* (2000). Since the mechanism of toxicity is not well understood for many compounds, the department will evaluate segregation of the HI by target organ alone.

CHEMICALS TO INCLUDE

Contaminants detected at greater than or equal to one-tenth of the table values are included in cumulative risk calculations. For method two and three cleanups, 18 AAC 75.340(k) states that chemicals in soil detected at one-tenth or more of the Tables B1 direct contact and inhalation cleanup levels must be included when calculating cumulative risk. One-tenth of the direct contact or inhalation value listed in Table B1 for the appropriate climate zone is used as the criteria for which compounds will be included in cumulative risk calculations.

When conducting a method four risk assessment, compounds found at levels that correspond to greater than the risk based benchmarks of 1×10^{-6} risk or HQ of 0.1 will be retained for further analysis and are therefore included in the cumulative risk calculations. See DEC's *Risk Assessment Procedures Manual* for more information.

<u>Petroleum Hydrocarbons</u>

The department does not require GRO, DRO, and RRO to be included in cumulative risk calculations. See the section on *Accounting for Petroleum Hydrocarbons* for more information.

PCBs

Polychlorinated biphenyls (PCBs) are included in cumulative risk calculations although the cleanup levels are determined on a site-specific basis, based on land use, or through a site-specific risk assessment. If separate congener or Aroclor concentrations are presented, the appropriate toxicological data can be used to calculate cancer risk. At the time of this document, EPA's *Integrated Risk Information System* (IRIS) has individual assessments for three different Aroclors: Aroclor 1016, Aroclor 1248, and Aroclor 1254. If PCBs are presented as a total concentration, the highest cancer slope factor and reference dose should be used.

Dioxins

Risks to dioxins are calculated based on a 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) toxicity equivalent (TEQ) approach and should be included in cumulative risk calculations. Toxicity equivalency factors (TEFs) are used to compare the relative toxicity of individual dioxin-like compounds to the more toxic TCDD. Included in this calculation are dioxins, furans, and dioxin-like PCBs. The TEQ approach is based on the assumption that dioxin and dioxin-like compounds act through the same mechanism of toxicity. The TEF for TCDD is equal to one, whereas the TEF values for all other dioxins and dioxin-like compounds are equal to less than one. The TEQ is defined as the product of the concentration of an individual dioxin-like compound and the corresponding TEF for that compound. The total TEQ is the sum of the TEQ for each of the congeners in a given mixture.

$$\text{Total TEQ} = \Sigma (C_i * TEF_i) \qquad \textbf{Eq. 3}$$

Once the total TEQ is calculated, this value can be compared to the dioxin slope factor and the risk can be calculated. The most up-to-date toxicological data and TEFs should be used when calculating risk to dioxins.

Lead

Lead contamination in soil or groundwater is not included in cumulative risk calculations. EPA found it inappropriate to apply a reference dose or cancer slope factor to lead (IRIS, 1988). The residential lead soil cleanup level in Table B1 is based on the Integrated Exposure Uptake Biokinetic (IEUBK) model. Soil cleanup levels for lead are site-specific, based on land use, and groundwater cleanup levels are presented in Table C. In addition, an alternative cleanup level may be proposed under a site-specific risk assessment. See Notes to Tables B1 and B2 for more details.

Please contact DEC's risk assessor for more information on how PCBs, dioxins, and lead are handled in cumulative risk calculations.

ADDING CHEMICALS NOT IN DEC TABLES

When encountering chemicals on-site that are not included in Tables B1, B2, or C, contact DEC. The first step is to establish Risk-Based Concentrations (RBCs) using the equations presented in

DEC's *Cleanup Levels Guidance* (June 9, 2008). The RBC will correspond to the route-specific cleanup level equations (inhalation and direct contact). Toxicity and chemical data specific to the compound of concern will be needed. Toxicity data can be obtained from EPA's IRIS, EPA's *Provisional Peer Reviewed Toxicity Values (PPRTVs*), or other accepted source. Chemical data can be obtained from an accepted chemistry source such as the Risk Assessment Information System (RAIS) website found at http://rais.ornl.gov/.

Once a RBC is determined and validated by DEC, the compound can be included in cumulative risk calculations using the same methods presented above.

ACCOUNTING FOR BACKGROUND CONCENTRATIONS

DEC recommends the use of the U.S. Environmental Protection Agency's *Guidance for Comparing Background and Chemical Concentrations in Soil for Comprehensive Environmental Response Compensation and Liability Act (CERCLA) Sites*, for determining if compounds found on-site are attributable to background levels. If a chemical found at the site is shown to be solely attributable to the naturally occurring background concentrations, then the chemical is not included in the cumulative risk calculations.

ACCOUNTING FOR PETROLEUM HYDROCARBONS

Individual risks from each petroleum fraction must be calculated; however, they are not included in a cumulative risk calculation with other petroleum fractions or with other chemicals in the tables, as explained below.

Each petroleum fraction is a mixture of many different chemicals. The Total Petroleum Hydrocarbon Criteria Working Group identified indicator contaminants within petroleum that can be evaluated individually. There is toxicological information available for each indicator compound. This information can be used to determine cleanup and risk levels. These indicator chemicals are presented in the table below. Although these are the currently considered indicator compounds for petroleum, all compounds detected at greater than 1/10 their RBC must be included for cumulative risk.

INDICATOR COMPOUNDS
FOR PETROLEUM CONTAMINATED SITES

! *Volatiles (BTEX)*
- Benzene*
- Toluene
- Ethylbenzene*
- Total xylenes

! *Polynuclear Aromatic Hydrocarbons (PAHs)* -
- Acenaphthene
- Acenaphthylene
- Anthracene
- Benzo(a)anthracene*
- Benzo(b)fluroranthene*
- Benzo(k)fluoranthene*
- Benzo(g,h,i)perylene
- Benzo(a)pyrene*
- Chrysene *
- Dibenzo(a,h)anthracene*
- Fluoranthene
- Fluorene
- Indeno(1,2,3-cd)pyrene*
- Naphthalene
- Phenanthrene
- Pyrene

! *Metals as required on a case by case basis*
- Arsenic*
- Barium
- Cadmium
- Chromium
- Lead
- Nickel
- Vanadium

! *Others as needed on a case by case basis*
- Ethylene dibromide (EDB)*
- 1,2-dichloroethane (EDC)*
- Methyl tert-butyl ether (MTBE)*
- Volatile organic compounds (VOCs)*

Note:

"*" = carcinogenic

The carcinogenic risk of petroleum can be adequately evaluated by determining the risk from carcinogenic indicator compounds. Using the same rationale, non-carcinogenic effects of petroleum can be evaluated by calculating the HI for the indicator contaminants listed in Tables B1 and C. Therefore, the department believes that calculating cumulative risk for the indicator contaminants, in addition to other contaminants on-site, is protective of the cumulative risk to petroleum exposure.

The department understands that there are petroleum constituents that will not be evaluated using this method. For many of these constituents the toxicity of the compounds has not yet been determined or there is minimal risk due to exposure. Petroleum is a chemical mixture. Under EPA's *Guidelines for the Health Risk Assessment of Chemical Mixtures* (1986), the most preferred method for evaluating the risk to chemical mixtures is to use toxicological data for the mixture itself. Many mixtures have different toxicological properties than their constituents. At

this time, there is not enough toxicological data available to calculate risk to the full petroleum fractions other than using a surrogate approach to determine toxicity. The department will continue to investigate this issue to provide a protective method of evaluating risk.

CUMULATIVE RISK CALCULATIONS FOR METHOD THREE

If alternative cleanup levels have been developed under method three, the risk or HQ from each constituent and the cumulative risk is calculated similar to that mentioned above. The site concentration following cleanup is divided by the RBC and the quotient is multiplied by the target risk standard. The RBC for method three inhalation cleanup levels must be calculated and not obtained from the Appendix A spreadsheet. To calculate the RBC for method three alternative cleanup levels, use the equations presented in DEC's *Cleanup Levels Guidance* (June 9, 2008) and the site-specific data used to calculate alternative cleanup levels. Also, an internet accessible method three web calculator is available at

http://www.dec.state.ak.us/spar/cs/webcalc/.

The web calculator calculates the cumulative risk where alternative cleanup levels have been proposed under method three.

ADDITIONAL PATHWAYS TO INVESTIGATE

When developing site-specific alternative cleanup levels, exposure pathways other than those specified in Tables B1, B2 and C may be complete based on the site-specific conceptual site model. Tables B1, B2 and C include the following exposure routes: direct contact with soil, which is protective of ingestion and dermal exposure to soil, inhalation of volatilization from soil to ambient air, and ingestion of groundwater. In general, ingestion of fugitive dust is deemed a protected exposure route under the direct contact to soil pathway. This may not be the case where dust is generated by human activity or where fugitive dust compounds of potential concern are present as presented in the following table. All completed pathways must be included in cumulative risk calculations including those pathways not addressed in Tables B1 and C.

Fugitive Dust Contaminants of Potential Concern

Aldrin
Barium
Berryllium
Cadmium
Chlordane
Chromium
Dioxin
Heaptachlor
Hepatchlor Epoxide
Alpha-Hexachlorocyclohexane
Beta-Hexachlorocyclohexane
Toxaphene

For example, in addition to the pathways identified above, volatilization to indoor air or ingestion of subsistence foods may also be complete pathways. If these pathways are complete they must be considered in the cumulative risk calculations. The site specific Conceptual Site Model (CSM) will designate which exposure pathways are completed and, therefore, which are included in cumulative risk calculations.

CUMULATIVE RISK AND GROUNDWATER

Table C groundwater cleanup levels are expected to be protective of the ingestion of groundwater. Unless it is shown that the groundwater at the site is not used or could not potentially be used for human consumption, it should be assumed that the ingestion of groundwater pathway is complete. Chemicals found at one-tenth the Table C values need to be included in the cumulative risk calculations.

Table C values were developed using EPA's maximum contaminant levels (MCLs),or RBCs. RBCs are based on toxicological data and risk to human health per Equations 1 or 2 in DEC's *Cleanup Levels Guidance* (June 9, 2008). MCLs are federally determined levels that incorporate other factors including feasibility and cost.

The risk screening levels associated with groundwater ingestion are shown in Appendix B. For some chemicals, the cleanup level in Table C exceeds the cumulative risk standard. The following compounds exceed the cancer risk standard of 1×10^{-5} when set at the Table C levels:

Table C Level Exceeds Cancer Risk Standard

Arsenic
Benzo(A)Pyrene
Beryllium
1,4-Dichlorobenzene
1,1-Dichloroethylene
Heptachlor
Heptachlor Epoxide
Hexachlorobenzene
Lindane (Gamma-Hexachlorocyclohexane)
Pcbs
Tetrachloroethylene (Pce)
Trichloroethylene (Tce)
Toxaphene
Vinyl Chloride

The following compounds exceed the HQ of 1.0 when set at the Table C levels:

Table C Level Exceeds HQ Of 1.0

Chlorobenzene
Dioxin (2,3,7,8-Tcdd)
Hexachloro-1,3-Butadiene
Hexachloroethane
Xylenes

In these cases, the cumulative risk at the site should be calculated by both including these chemicals and not including these chemicals. Decisions to set cleanup levels at either the Table C values or values that correspond to less than or equal to the cumulative risk standards will be made based on DEC delegated authority.

ROUNDING IN CUMULATIVE RISK

Under 18 AAC 75.325(g), a responsible person must ensure that, after completing site cleanup using methods two or three, the risk from hazardous substances does not exceed a cumulative carcinogenic risk standard of 1 in 100,000 across all exposure pathways and a cumulative non-carcinogenic risk standard at a hazard index of 1 for all exposure pathways. Similarly, under 18 AAC 75.325(h), a responsible person proposing an alternative cleanup level for soil or groundwater based on a site-specific risk assessment under method four must ensure that the risk from hazardous substances does not exceed the cumulative carcinogenic risk standard of 1 in 100,000 across all exposure pathways and the cumulative non-carcinogenic risk standard at a hazard index of 1 for all exposure pathways.

Both cumulative risk summations, the Incremental Lifetime Cancer Risk and the Hazard Index should be expressed using one significant figure for clean ups under methods two, three and four. Individual chemical cancer risk and hazard quotients should be rounded to two significant figures. Standard rounding procedures must be adhered to such that:

- Starting from the leftmost significant digit, move to the right until you have as many digits as you are allowed to keep. Then look to the immediate right and note the number present.
- If the number to the right is a 5, 6, 7, 8, or 9, round the last significant digit up one. If the number to the right is a 4, 3, 2, 1, or 0, keep the last significant digit the same.

Therefore, the rounding procedures and cumulative risk standards are consistent between methods two, three, and four.

ECOLOGICAL RECEPTORS

The non-carcinogenic HI is calculated for ecological receptors. The ecological non-carcinogenic risk management level is set at a HI of 1. Carcinogens are not considered to be of concern for ecological receptors. The HI is the sum of HQs across multiple exposure routes and exposure pathways (see Equation 4). The HQ is calculated by dividing the dose by a risk-based ecological benchmark.

$$HI = \Sigma \text{ Dose} \div \text{Benchmark} \qquad \textbf{Eq. 4}$$

If the HI exceeds 1, the individual HQs should be retained for further evaluation. See DEC's *Risk Assessment Procedures Manual* for additional information.

REFERENCES

Alaska Department of Environmental Conservation. 2002 *Oil and Hazardous Substances Pollution Control Regulations 18AAC 75, Articles 3 and 9.*

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APPENDICES

Appendix A: Worksheet for Calculating Cumulative Risk

Worksheet for Calculating Cumulative Risk

Chemicals of Concern	Exposure Media	Exposure Route	Site Conc.	RBC	Units (mg/kg or mg/L)

Footnotes:
mg/kg = milligrams per kilogram
mg/L – milligrams per liter
RBC = risk based concentration

Appendix B: Human Health Risk Based Concentrations

CAS Number	Hazardous Substance	Soil Direct Contact NC Arctic (mg/kg)	Soil Direct Contact C Arctic (mg/kg)	Soil Inhalation NC Arctic (mg/kg)	Soil Inhalation C Arctic (mg/kg)	Soil Direct Contact NC <40 (mg/kg)	Soil Direct Contact C <40 (mg/kg)	Soil Inhalation NC <40 (mg/kg)	Soil Inhalation C <40 (mg/kg)	Soil Direct Contact NC >40 (mg/kg)	Soil Direct Contact C >40 (mg/kg)	Soil Inhalation NC >40 (mg/kg)	Soil Inhalation C >40 (mg/kg)	GW NC (mg/L)	GW C (mg/L)
355-72-782	2-Amino-4,6-Dinitrotoluene	26				20				16				0.0073	
194-06-510	4-Amino-2,6-Dinitrotoluene	26				19				16				0.0073	
83-32-9	Acenaphthene	3700				2800				2300				2.2	
208-96-8	Acenaphthylene	3700				2800				2300				2.2	
67-64-1	Acetone	123000		102000		91300		68600		74700		51100		33	
309-00-2	Aldrin	2.6	0.40		14	1.9	0.30		9.6	1.6	0.24		7.2	0.0011	0.000050
120-12-7	Anthracene	27800				20600				16800				11	
71-43-2	Benzene	550	200	170	17	410	150	110	11	330	120	85	8.5	0.15	0.015
56-55-3	Benzo(a)anthracene		6.6		1100		4.9		760		4.0		570		0.0012
205-99-2	Benzo(b)fluoranthene		6.6		9600		4.9		6500		4.0		4800		0.0012
207-08-9	Benzo(k)fluoranthene		66		97800		49		65700		40		49000		0.012
65-85-0	Benzoic Acid	428000				317000				259000				150	
191-24-2	Benzo(g,h,i)perylene	1900				1400				1100				1.1	
50-32-8	Benzo(a)pyrene		0.66		780		0.49		530		0.4		390		0.00012
111-44-4	Bis(2-chloroethyl)ether		10		4.9		7.5		3.3		6.2		2.5		0.00077
117-81-7	Bis(2-ethylhexyl)phthalate	1100	300			820	220			670	180			0.73	0.061
75-27-4	Bromodichloromethane	2700	180		15	2030	130		10	1700	110		7.3	0.73	0.014
75-25-2	Bromoform	2700	1400		630	2030	1100		420	1700	860		320	0.73	0.11
71-36-3	Butanol	8800				6500				5300				3.7	
104-51-8	n-Butylbenzene	1400		440		1010		290		830		220		0.37	
135-98-8	sec-Butylbenzene	1400		330		1010		220		830		160		0.37	
98-06-6	tert-Butylbenzene	1400		390		1010		260		830		200		0.37	
85-68-7	Butyl Benzyl Phthalate	18800	3900			13900	2900			11400	2400			7.3	
86-74-8	Carbazole		390				290				230				0.043
75-15-0	Carbon Disulfide	6500		1900		4800		1300		3900		940		3.7	
56-23-5	Carbon Tetrachloride	96	86		4.5	71	64		3.1	58	52		2.3	0.026	0.0066
57-74-9	Chlordane	56	26	1900	640	41	19	1300	430	34	15	960	320	0.018	0.0024
106-47-8	p-Chloroaniline	350	130			260	94			210	77			0.15	0.016
108-90-7	Chlorobenzene	2700		470		2030		320		1700		240		0.73	
124-48-1	Chlorodibromomethane	2700	130		21	2030	99		14	1700	81		11	0.73	0.010
75-00-3	Chloroethane	54800	3900		53	40600	2900		36	33200	2300		27	15	0.29
67-66-3	Chloroform	1400	1800		4.7	1010	1400		3.2	830	1100		2.4	0.37	0.14
91-58-7	2-Chloronaphthalene	6300		33200		4700		22300		3800		16600		2.9	
95-57-8	2-Chlorophenol	680		3800		510		2500		420		1900		0.18	
218-01-9	Chrysene		660		239000		490		160000		400		120000		0.12
72-54-8	DDD	240	41			181	30			150	25			0.073	0.0035
72-55-9	DDE		29				21				18				0.0025
50-29-3	DDT	61	29		2200	45	21		1500	37	18		1100	0.018	0.0025
53-70-3	Dibenzo(a,h)anthracene		0.66		2300		0.49		1500		0.400		1200		0.00012
132-64-9	Dibenzofuran	270				200				170				0.073	
84-74-2	Di-n-butyl phthalate	10700				7900				6500				3.7	
117-84-0	Di-n-octyl phthalate	4200				3100				2500				1.5	
94-75-7	2,4-D	1200				860				710				0.37	
95-50-1	1,2-Dichlorobenzene	12300		2900		9100		2000		7500		1500		3.3	
541-73-1	1,3-Dichlorobenzene	12300		2500		9100		1670		7500		1200		3.3	
106-46-7	1,4-Dichlorobenzene		470	10400	44		350	7000	30		280	5200	22		0.035
91-94-1	3,3-Dichlorobenzidine		15				11				9.2				0.0019
75-71-8	Dichlorodifluoromethane	27400		570		20300		380		16600		280		7.3	
75-34-3	1,1-Dichloroethane	27400		2300		20300		1600		16600		1200		7.3	

Appendix B: Human Health Risk-Based Concentrations

CAS Number	Hazardous Substance	Soil Direct Contact NC Arctic (mg/kg)	Soil Direct Contact C Arctic (mg/kg)	Soil Inhalation NC Arctic (mg/kg)	Soil Inhalation C Arctic (mg/kg)	Soil Direct Contact NC <40 (mg/kg)	Soil Direct Contact C <40 (mg/kg)	Soil Inhalation NC <40 (mg/kg)	Soil Inhalation C <40 (mg/kg)	Soil Direct Contact NC >40 (mg/kg)	Soil Direct Contact C >40 (mg/kg)	Soil Inhalation NC >40 (mg/kg)	Soil Inhalation C >40 (mg/kg)	GW NC (mg/L)	GW C (mg/L)
107-06-2	1,2-Dichloroethane	2700	120		7.1	2030	91		4.8	1700	75		3.6	0.73	0.0094
75-35-4	1,1-Dichloroethylene	6800	19	540	1.3	5070	14	360	0.85	4100	11	270	0.63	1.8	0.0014
156-59-2	*cis*-1,2-Dichloroethylene	1400		190		1010		130		830		95		0.37	
156-60-5	*trans*-1,2-Dichloroethylene	2700		240		2030		160		1700		120		0.73	
120-83-2	2,4-Dichlorophenol	310				230				190				0.11	
78-87-5	1,2-Dichloropropane		160	26	7.9		120	18	5.3		100	13	4.0		0.013
542-75-6	1,3-Dichloropropene	4100	110	140	40	3040	83	93	27	2500	68	69	20	1.1	0.0085
60-57-1	Dieldrin	4.4	0.43		10	3.2	0.32		6.7	2.7	0.26		5.02	0.0018	0.000053
84-66-2	Diethyl phthalate	83500				61900				50600				29	
105-67-9	2,4-Dimethylphenol	1800				1300				1100				0.73	
131-11-3	Dimethyl phthalate	1040000				773000				633000				370	
528-29-0	1,2-Dinitrobenzene	11				7.8				6.4				0.0037	
99-65-0	1,3-Dinitrobenzene	9.6		240		7.1		160		5.8		120		0.0037	
100-25-4	1,4-Dinitrobenzene	8.8				6.5				5.3				0.0037	
51-28-5	2,4-Dinitrophenol	210				160				130				0.073	
121-14-2	2,4-Dinitrotoluene	210	12			150	8.8			120	7.2			0.073	0.0013
606-20-2	2,6-Dinitrotoluene	100	12			76	8.9			63	7.3			0.037	0.0013
123-91-1	1,4-Dioxane		730				540				440				0.077
1746-01-6	2,3,7,8-TCDD (Dioxin)		0.000063		0.0023		0.000047		0.0015		0.000038		0.0011		0.0000000057
122-39-4	Diphenylamine	2200				1600				1300				0.91	
115-29-7	Endosulfan	820				610				500				0.22	
72-20-8	Endrin	2.7				2.0				1.7				0.011	
100-41-4	Ethylbenzene	13700		7600	160	10100		5100	110	8300		3800	81	3.7	
106-93-4	EDB (1,2-Dibromoethane)	1200	5.6	210	0.89	910	4.2	140	0.60	750	3.4	100	0.44	0.33	0.00043
107-21-1	Ethylene glycol	175000				130000				106000				73	
206-44-0	Fluoranthene	2500				1900				1500				1.5	
86-73-7	Fluorene	3200				2300				1900				1.5	
76-44-8	Heptachlor	49	1.7		16	37	1.3		11	30	1.0		8.1	0.018	0.00019
1024-57-3	Heptachlor epoxide	1.3	0.86		8.7	0.95	0.63		5.8	0.78	0.52		4.4	0.00047	0.000094
118-74-1	Hexachlorobenzene	70	4.3		2.2	52	3.2		1.5	43	2.60		1.1	0.029	0.00053
87-68-3	Hexachloro-1,3-butadiene	18	88		11	13	65		7.2	11	53		5.4	0.007	0.01092
319-84-6	alpha-Hexachlorocyclohexane		1.6		12		1.2		8.3		0.95		6.2		0.00014
319-85-7	beta-Hexachlorocyclohexane		5.5		110		4.0		75		3.3		56		0.00047
58-89-9	gamma-Hexachlorocyclohexane	37	7.6			27	5.6			22	4.6			0.011	0.00066
77-47-4	Hexachlorocyclopentadiene	530		3.0		390		2.0		320		1.5		0.22	
67-72-1	Hexachloroethane	88	490		250	65	360		170	53	300		130	0.037	0.061
121-82-4	Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	390	97			290	72			240	59			0.11	0.0077
302-01-2	Hydrazine		2.3		1.5		1.7		0.98		1.4		0.73		0.00028
193-39-5	Indeno(1,2,3-c,d)pyrene		6.6		20400		4.9		13700		4.00		10200		0.0012
78-59-1	Isophorone	17500	7200			13000	5300			10600	4400			7.3	0.90
98-82-8	Isopropylbenzene	13700		3300		10100		2200		8300		1700		3.7	
72-43-5	Methoxychlor	440				320				270				0.18	
74-83-9	Methyl bromide	190		21		140		14		120		11		0.051	
74-87-3	Methyl chloride		860	260	37		640	180	25		520	130	19		0.066
78-93-3	MEK	82100		169000		60800		114000		49800		84600		22	
108-10-1	MIBK	11000		70300		8100		47200		6600		35200		2.9	
74-95-3	Methylene Bromide	1400		560		1010		370		830		280		0.37	
75-09-2	Methylene Chloride	8200	1500	14400	240	6100	1100	9700	160	5000	910	7200	120	2.2	0.11

Appendix B: Human Health Risk-Based Concentrations

CAS Number	Hazardous Substance	Soil Direct Contact NC Arctic (mg/kg)	Soil Direct Contact C Arctic (mg/kg)	Soil Inhalation NC Arctic (mg/kg)	Soil Inhalation C Arctic (mg/kg)	Soil Direct Contact NC <40 (mg/kg)	Soil Direct Contact C <40 (mg/kg)	Soil Inhalation NC <40 (mg/kg)	Soil Inhalation C <40 (mg/kg)	Soil Direct Contact NC >40 (mg/kg)	Soil Direct Contact C >40 (mg/kg)	Soil Inhalation NC >40 (mg/kg)	Soil Inhalation C >40 (mg/kg)	GW NC (mg/L)	GW C (mg/L)
22967-92-6	Mercury (Methyl)	10				7.7				6.3				0.0037	
90-12-0	1-Methylnaphthalene	380		1100		280		760		230		560		0.15	
91-57-6	2-Methylnaphthalene	380		1100		280		750		230		560		0.15	
95-48-7	2-Methylphenol (o-cresol)	4400				3200				2700				1.8	
108-39-4	3-Methylphenol (m-cresol)	4400				3200				2700				1.8	
106-44-5	4-Methylphenol (p-cresol)	480				350				290				0.18	
1634-04-4	MTBE		6200	28900	440		4600	19400	290		3800	14500	220		0.47
91-20-3	Naphthalene	1900		180	42	1400		120	28	1100		92	21	0.73	
98-95-3	Nitrobenzene	68		180		51		120		41		90		0.018	
55-63-0	Nitroglycerin		400				300				250				0.050
556-88-7	Nitroguanidine	8800				6500				5300				3.7	
62-75-9	n-Nitrosodimethylamine	1.1	0.22		0.28	0.81	0.16		0.19	0.66	0.13		0.14	0.00029	0.000017
86-30-6	n-Nitrosodiphenylamine	1300	1009			960	750			780	610			0.73	0.17
621-64-7	n-Nitroso-di-n-propylamine		0.71				0.52				0.43				0.00012
88-72-2	2-Nitrotoluene	1010	35			750	26			610	21			0.37	0.0037
99-08-1	3-Nitrotoluene	2030				1500				1200				0.73	
99-99-0	4-Nitrotoluene	1010	470			750	350			610	290			0.37	0.050
103-65-1	n-Propylbenzene	1400		440		1010		290		830		220		0.37	
2691-41-0	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	6200				4600				3700				1.8	
87-86-5	Pentachlorophenol	2400	52			1800	39			1500	32			1.1	0.0071
85-01-8	Phenanthrene	27800				20600				16800				11	
108-95-2	Phenol	31300				23200				19000				11	
133-63-63	PCB		3.8		25		2.8		17		2.3		13		0.00043
57-55-6	Propylene glycol	43900		1200		32500		840		26600		620		18	
129-00-0	Pyrene	1900				1400				1100				1.10	
100-42-5	Styrene	27000		12900		20300		8700		16600		6500		7.3	
79-34-5	1,1,2,2-Tetrachloroethane	8200	56		8.1	6100	42		5.5	5000	34		4.1	2.2	0.0043
127-18-4	Tetrachloroethylene (PCE)	1400	21	2200	15	1010	15	1500	10	830	13	1100	7.3	0.37	0.0016
108-88-3	Toluene	11000		30400		8100		20400		6600		15200		2.9	
8001-35-2	Toxaphene		10		570		7.5		380		6.2		290		0.00077
688-73-3	Tributyltin (as Tributyltin Oxide)	26				19				16				0.01	
120-82-1	1,2,4-Trichlorobenzene	1400		130		1010		84		830		63		0.37	
71-55-6	1,1,1-Trichloroethane	27400		7200		20300		4800		16600		3600		7.3	
79-00-5	1,1,2-Trichloroethane	550	200		17	410	150		11	330	120		8.6	0.15	0.015
79-01-6	Trichloroethylene (TCE)	41	28	160	0.85	30	21	107	0.57	25	17	80	0.42	0.01	0.0021
95-95-4	2,4,5-Trichlorophenol	8800				6500				5300				3.7	
88-06-2	2,4,6-Trichlorophenol		620		6100		460		4100		380		3000		0.077
93-72-1	2,4,5-TP	700				520				430				0.29	
96-18-4	1,2,3-Trichloropropane	820	1.60		0.26	610	1.2		0.17	500	0.97		0.13	0.22	0.00012
76-13-1	Trichlorotrifluoroethane	4106000		115000		3040000		77400		2490000		57700		1100	
75-69-4	Trichlorofluoromethane	41100		1600		30400		1100		24900		820		11	
95-63-6	1,2,4-Trimethylbenzene	6800		74		5070		49		4100		37		1.8	
108-67-8	1,3,5-Trimethylbenzene	6800		64		5070		43		4100		32		1.8	
99-35-4	1,3,5-Trinitrobenzene	3800				2800				2300				1.1	
479-45-8	2,4,6-Trinitrophenylmethylnitramine (Tetryl)	550				400				330				0.15	
118-96-7	2,4,6-Trinitrotoluene (TNT)	60	320			44	240			36	190			0.02	0.028
108-05-4	Vinyl Acetate	137000		2300		101000		1500		83000		1100		37	
75-01-4	Vinyl chloride (Chloroethene)	410	7.5	240	6.4	300	5.5	160	4.3	250	4.5	120	3.2	0.11	0.00057

Appendix B: Human Health Risk-Based Concentrations

CAS Number	Hazardous Substance	Soil Direct Contact NC Arctic (mg/kg)	Soil Direct Contact C Arctic (mg/kg)	Soil Inhalation NC Arctic (mg/kg)	Soil Inhalation C Arctic (mg/kg)	Soil Direct Contact NC <40 (mg/kg)	Soil Direct Contact C <40 (mg/kg)	Soil Inhalation NC <40 (mg/kg)	Soil Inhalation C <40 (mg/kg)	Soil Direct Contact NC >40 (mg/kg)	Soil Direct Contact C >40 (mg/kg)	Soil Inhalation NC >40 (mg/kg)	Soil Inhalation C >40 (mg/kg)	GW NC (mg/L)	GW C (mg/L)
1330-20-7	Xylenes (total)	27000		800		20300		540		16600		400		7.3	
7440-36-0	Antimony	55				41				33				0.015	
7440-38-2	Arsenic	34	6.1			25	4.5			21	3.7			0.011	0.00057
7440-39-3	Barium	27000				20300				16600				7.3	
7440-41-7	Beryllium	270	2.6			200	1.9			170	1.6			0.073	0.00020
7440-43-9	Cadmium	110				79				65				0.037	
7440-47-3	Chromium (Total)	410				304				250				0.11	
16065-83-1	Chromium +3	205000				152000				124000				55	
18540-29-9	Chromium +6	410				300				250				0.110	
7440-50-8	Copper	5500				4100				3300				1.5	
57-12-5	Cyanide	2700				2030				1700				0.73	
7439-92-1	Lead														
7439-97-6	Mercury	41		26		30		18		25		13		0.011	
7440-02-0	Nickel	2700				2030				1700				0.7	
7790-98-9	Perchlorate	96				71				58				0.026	
7782-49-2	Selenium	680				510				420				0.18	
7440-22-4	Silver	680				510				420				0.18	
7440-28-0	Thallium	11				8.1				6.6				0.003	
7440-62-2	Vanadium	960				710				580				0.256	
7723-14-0	White Phosphorus	2.7				2.0				1.7				0.00073	
7440-66-6	Zinc	41100				30400				24900				11	

Footnotes:
c = carcinogen,
nc = non-carcinogen,
mg/kg = milligrams per kilogram,
mg/L = milligrams per liter