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APPENDIX A

ILLUSTRATIONS OF CHEMICALS THAT "LIMIT" REMEDIATION

In many cases, one or two chemicals will drive the cleanup at a site, and the resulting cumulative medium or site risk will be approximately equal to the potential risk associated with the individual remediation goals for these chemicals. These "limiting chemicals" are generally either chemicals that are responsible for much of the baseline risk (because of either high toxicity or presence in high concentrations), or chemicals that are least amenable to the selected treatment method. By cleaning up these chemicals to their goals, the other chemicals typically will be cleaned up to levels much lower than their corresponding goals. The example given in the box below provides a simple illustration of this principle.

The actual circumstances for most remediations will be much more complex than those described in the example (e.g., chemicals will be present at different baseline concentrations and will be treated/removed at differing rates); however, the same principle of one or perhaps two chemicals limiting the site cleanup usually applies, even in more complex cases.

Unless much is known about the performance of a remedy with respect to all the chemicals present at the site, it may not be possible to determine which of the site contaminants will drive the final risk until well into remedy implementation. Therefore, it generally is not possible to predict the cumulative risk that will be present at the site during or after remediation. In some situations, enough will be known about the site conditions and the performance of the remedy to estimate post-remedy concentrations of chemicals or to identify the chemical(s) that will dominate the residual risk. If this type of information is available, it may be necessary to modify the risk-based remediation goals for individual chemicals.

SIMPLE ILLUSTRATION OF A CHEMICAL THAT LIMITS REMEDIATION

Two chemicals (A and B) are present in ground water at a site at the same baseline concentrations. Remediation goals were identified for both A and B. Chemical A's goal is 0.5 ug/L, which is associated with a potential risk of 10^{-6}. Chemical B's goal is 10 ug/L, which is also associated with a potential risk of 10^{-6}. The calculated cumulative risk at remediation goals is therefore 2×10^{-6}. Assuming for the purposes of this illustration that A and B are treated or removed at the same rate, then the first chemical to meet its goal will be B. Remediation must continue at this site, however, until the goal for chemical A has been met. When the concentration of A reaches 0.5 ug/L, then remediation is complete. A is at its goal and has a risk of 10^{-6}. B is at 1/20 of its goal with a risk of 5×10^{-8}. The total risk ($1 \times 10^{-6} + 5 \times 10^{-8}$) is approximately 10^{-6} and is due to the presence of A.

This example illustrates that the final risk for a chemical may not be equal to the potential risk associated with its remediation goal, and, in fact, can be much less than this risk. Although the potential risk associated with Chemical B's goal is 10^{-6}, the final residual risk associated with B is 5×10^{-8}. Thus, if one were to calculate the cumulative risk at PRGs prior to remedy implementation, one would estimate total medium risk of 2×10^{-6}, however, the residual cumulative risk after remediation is 1×10^{-6}.

APPENDIX B

RISK EQUATIONS FOR INDIVIDUAL EXPOSURE PATHWAYS

This appendix presents individual risk equations for each exposure pathway presented in Chapter 3. These individual risk equations can be used and rearranged to derive full risk equations required for calculating risk-based PRGs. Depending on the exposure pathways that are of concern for a land-use and medium combination, different individual risk equations can be combined to derive the full equation reflecting the cumulative risk for each chemical within the medium. See Chapter 3 for examples of how equations are combined and how they need to be rearranged to solve for risk-based PRGs. Note that in this appendix, the term HQ is used to refer to the risk level associated with noncarcinogenic effects since the equations are for a single contaminant in an individual exposure pathway.

The following sections list individual risk equations for the ground water, surface water, and soil pathways. Risk equations for exposure pathways not listed below can be developed and combined with those listed. In particular, dermal exposure and ingestion of ground water contaminated by soil leachate, for which guidance is currently being developed by EPA, could be included in the overall exposure pathway evaluation.

B.1 GROUND WATER OR SURFACE WATER — RESIDENTIAL LAND USE

Both the ingestion of water and the inhalation of volatiles are included in the standard default equations in Section 3.1.1. If only one of these exposure pathways is of concern at a particular site, or if one or both of these pathways needs to be combined with additional pathways, a site-specific equation can be derived.

The parameters used in the equations presented in the remainder of this section are explained in the following text box.

B.1.1 INGESTION

The cancer risk due to ingestion of a contaminant in water is calculated as follows:

PARAMETERS FOR SURFACE WATER/GROUND WATER — RESIDENTIAL LAND USE

Parameter	Definition	Default Value
C	chemical concentration in water (mg/L)	—
SF_i	inhalation cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
SF_o	oral cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr for cancer risk 30 yr for noncancer HI (equal to ED)
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
K	volatilization factor (L/m^3)	0.0005 x 1000 L/m^3 (Andelman 1990)
IR_a	daily indoor inhalation rate (m^3/day)	15 m^3/day
IR_w	daily water ingestion rate (L/day)	2 L/day

Risk from ingestion of water (adult) = $\frac{SF_o \times C \times IR_w \times EF \times ED}{BW \times AT \times 365 \text{ days/yr}}$

The noncancer HQ due to ingestion of a contaminant in water is calculated as follows:

HQ due to ingestion of water (adult) = $\frac{C \times IR_w \times EF \times ED}{RfD_o \times BW \times AT \times 365 \text{ days/yr}}$

B.1.2 INHALATION OF VOLATILES

The cancer risk due to inhalation of a volatile contaminant in water is calculated as follows:

Risk from inhalation of volatiles in water (adult) = $\frac{SF_i \times C \times K \times IR_a \times EF \times ED}{BW \times AT \times 365 \text{ days/yr}}$

The noncancer HQ due to inhalation of a volatile contaminant in water is calculated as follows:

HQ due to inhalation of volatiles in water (adult) = $\frac{C \times K \times IR_a \times EF \times ED}{RfD_i \times BW \times AT \times 365 \text{ days/yr}}$

B.2 SOIL — RESIDENTIAL LAND USE

Only the first exposure pathway below — ingestion of soil — is included in the standard default equations in Section 3.1.2. If additional exposure pathways, including inhalation of volatiles and/or inhalation of particulates, are of concern at a particular site, then a site-specific equation can be derived.

The parameters used in the equations presented in the remainder of this section are explained in the text box below.

B.2.1 INGESTION OF SOIL

The cancer risk from ingestion of contaminated soil is calculated as follows:

Risk from ingestion of soil = $\frac{SF_o \times C \times 10^{-6} \text{ kg/mg} \times EF \times IF_{soil/adj}}{AT \times 365 \text{ days/yr}}$

The noncancer HQ from ingestion of contaminated soil is calculated as follows:

HQ from ingestion of soil = $\frac{C \times 10^{-6} \text{ kg/mg} \times EF \times IF_{soil/adj}}{RfD_o \times AT \times 365 \text{ days/yr}}$

B.2.2 INHALATION OF VOLATILES

The cancer risk caused by inhalation of volatiles released from contaminated soil is:

Risk from inhalation of volatiles = $\frac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/VF)}{AT \times BW \times 365 \text{ days/yr}}$

The equation for calculating the noncancer HQ from inhalation of volatiles released from soil is:

PARAMETERS FOR SOIL — RESIDENTIAL LAND USE

Parameter	Definition	Default Value
C	chemical concentration in soil (mg/kg)	—
SF_i	inhalation cancer slope factor ($(mg/kg\text{-}day)^{-1}$)	chemical-specific
SF_o	oral cancer slope factor ($(mg/kg\text{-}day)^{-1}$)	chemical-specific
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr for cancer risk 30 yr for noncancer HI (equal to ED)
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
IR_a	daily indoor inhalation rate (m^3/day)	15 m^3/day
$IF_{soil/adj}$	age-adjusted soil ingestion factor (mg-yr/kg-day)	114 mg-yr/kg-day
VF	soil-to-air volatilization factor (m^3/kg)	chemical specific (see Section 3.3.1)
PEF	particulate emission factor (m^3/kg)	4.63×10^9 m^3/kg (see Section 3.3.2)

$$\text{HQ from inhalation of volatiles} = \frac{C \times ED \times EF \times IR_{air} \times (1/VF)}{RfD_i \times BW \times AT \times 365\ \text{days/yr}}$$

B.2.3 INHALATION OF PARTICULATES

Cancer risk due to inhalation of contaminated soil particulates is calculated as:

$$\text{Risk from inhalation of particulates} = \frac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/PEF)}{AT \times BW \times 365\ \text{days/yr}}$$

The noncancer HQ from particulate inhalation is calculated using this equation:

$$\text{HQ from inhalation of particulates} = \frac{C \times ED \times EF \times IR_{air} \times (1/PEF)}{RfD_i \times BW \times AT \times 365\ \text{days/yr}}$$

B.3 SOIL — COMMERCIAL/ INDUSTRIAL LAND USE

All three of the exposure pathways detailed below are included in the standard default equation in Section 3.2.2. If only one or some combination of these exposure pathways are of concern at a particular site, a site-specific equation can be derived.

The parameters used in the equations presented in the remainder of this section are explained in the text box below.

B.3.1 INGESTION OF SOIL

The cancer risk from ingestion of contaminated soil is calculated as follows:

$$\text{Risk from ingestion of soil} = \frac{SF_o \times C \times 10^{-6}\ \text{kg/mg} \times EF \times ED \times IR_{soil}}{BW \times AT \times 365\ \text{days/yr}}$$

The noncancer HQ from ingestion of contaminated soil is calculated as follows:

$$\text{HQ from ingestion of soil} = \frac{C \times 10^{-6}\ \text{kg/mg} \times EF \times ED \times IR_{soil}}{RfD_o \times BW \times AT \times 365\ \text{days/yr}}$$

B.3.2 INHALATION OF VOLATILES

The cancer risk caused by inhalation of volatiles released from contaminated soil is:

$$\text{Risk from inhalation of volatiles} = \frac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/VF)}{AT \times BW \times 365\ \text{days/yr}}$$

The equation for calculating the noncancer HQ from inhalation of volatiles released from soil is:

$$\text{HQ from inhalation of volatiles} = \frac{C \times ED \times EF \times IR_{air} \times (1/VF)}{RfD_i \times BW \times AT \times 365\ \text{days/yr}}$$

Note that the VF value has been developed specifically for these equations; it may not be applicable in other technical contexts.

PARAMETERS FOR SOIL — COMMERCIAL/INDUSTRIAL LAND USE

Parameter	Definition	Default Value
C	chemical concentration in soil (mg/kg)	—
SF_i	inhalation cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
SF_o	oral cancer slope factor ((mg/kg-day)$^{-1}$)	chemical-specific
RfD_o	oral chronic reference dose (mg/kg-day)	chemical-specific
RfD_i	inhalation chronic reference dose (mg/kg-day)	chemical-specific
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	70 yr for cancer risk 30 yr for noncancer HI (equal to ED)
EF	exposure frequency (days/yr)	250 days/yr
ED	exposure duration (yr)	25 yr
IR_{air}	workday inhalation rate (m^3/day)	20 m^3/day
IR_{soil}	soil ingestion rate (mg/day)	50 mg/day
VF	soil-to-air volatilization factor (m^3/kg)	chemical specific (see Section 3.3.1)
PEF	particulate emission factor (m^3/kg)	4.63×10^9 m^3/kg (see Section 3.3.2)

B.3.3 INHALATION OF PARTICULATES

Cancer risk due to inhalation of contaminated soil particulates is calculated as:

$$\text{Risk from inhalation of particulates} = \frac{SF_i \times C \times ED \times EF \times IR_{air} \times (1/PEF)}{AT \times BW \times 365 \text{ days/yr}}$$

The noncancer HQ from particulate inhalation is calculated using this equation:

$$\text{HQ from inhalation} = \frac{C \times ED \times EF \times IR_{air} \times (1/PEF)}{RfD_i \times BW \times AT \times 365 \text{ days/yr}}$$