Schedule B7

APPENDIX B

Equations for Derivation of HILs and Interim HILs

Contents
Equations for derivation of HILs and interim HILs

1 Equations for derivation of HILs and interim HILs

1.1 Introduction

This appendix presents the equations used in the derivation of soil health investigation levels (HILs) and interim soil vapour HILs. The appendix does not present all equations and methodologies that may be considered in conducting a site-specific assessment, rather it presents those equations used in deriving the HILs presented in Schedule B7. The derivation of HILs requires the consideration of a number of exposure pathways. With respect to the soil HILs, the following pathways are considered (as relevant for the exposure scenarios and compounds considered):

- Ingestion of soil and/or dust (indoors). The ingestion rate adopted for the characterisation of this pathway is a combined value reflecting both sources; hence, the calculation undertaken is a combined calculation.
- Dermal absorption during contact with soil and/or dust (indoors that may be derived from outdoor soil). As with the calculation of ingestion, the calculation of dermal absorption is based on absorption from both sources combined.
- Inhalation of dust generated from outdoor soil (where surface cover is poor) both outdoors and indoors (including resuspension of dust indoors).

Inhalation of volatile chemicals in soil indoors and outdoors has been considered in the derivation of interim soil vapour HILs.

Worked examples of the HIL A calculations using the equations presented in this Appendix for cadmium and benzo(a)pyrene are included in Attachments A and B respectively.

1.2 General equations

The approach adopted in the derivation of soil HILs is consistent with the approach adopted in the derivation of previous HILs (NEPC 1999) and in other jurisdictions including the USA (in the derivation of preliminary remediation goals (US EPA 1992; US EPA 2002) and regional screening levels (US EPA 2012)) and the UK and New Zealand (in the derivation of soil guideline values (MfE 2011; EA 2009])).

Very generally, a soil health investigation level (HIL) for an exposure pathway (x), where a threshold approach is adopted, can be back-calculated by setting the estimated intake for a chemical (i) to the acceptable intake allowable from soil for that chemical (i), then rearranging the equation as follows:

$$HIL_{x,i}\ (mg/kg) = \frac{\text{Acceptable Intake}}{\text{Intake from Contamination}} = \frac{(\text{acceptable intake}_i\ \text{from soil}) \times (\text{body weight}) \times (\text{averaging time})}{(\text{contact rate}_i) \times (\text{exposure frequency}) \times (\text{exposure duration})}$$

Equation 1

Similarly, HILs can be derived for other pathways of exposure and for non-threshold carcinogenic effects as relevant. The final HIL is calculated by combining the pathway-specific HILs as noted below:

$$HIL\left(mg/kg\right) = \frac{1}{\left[\frac{1}{HIL_{ingestion}}\right] + \left[\frac{1}{HIL_{dermal}}\right] + \left[\frac{1}{HIL_{plant\ uptake}}\right] + \left[\frac{1}{HIL_{dust}}\right]}$$

Equation 2

where:

$HIL_{ingestion}$	= derived soil guideline associated with the ingestion of soil and dust by young child and/or adult, refer to **Equations 3, 4 and 5**
HIL_{dermal}	= derived soil guideline associated with dermal absorption of contaminant in soil/dust by young child and/or adult, refer to **Equations 6, 7 and 8**
$HIL_{plant\ uptake}$	= derived soil guideline associated with ingestion of contaminant in home-grown fruit and vegetable produce by young child and/or adult (where relevant), refer to **Equations 15 to 18**
HIL_{dust}	= derived soil guideline associated with inhalation of contaminants in dust by young child and/or adult, refer to **Equations 9, 10 and 11**

This approach assumes that the pathways of exposure are all complete and are additive, and that the toxicological end point considered for all pathways of exposure are the same or additive.
The contribution of each individual pathway ($HIL_{pathway}$) to the total HIL has been calculated (and presented in Appendix A) as follows:

$$\%\text{pathway contribution} = (1/HIL_{pathway})/(1/HIL) \times 100\ (\%)$$

For volatile compounds, only interim soil vapour HILs have been derived. This has been conducted on the basis of calculations relevant to inhalation of volatile contaminants in air by a young child and/or adult, refer to **Equations 12, 13 and 14.**

1.3 Pathway-specific equations

1.3.1 Ingestion of soil/dust

<u>Threshold contaminants (2–3-year-old child for HILs A, B and C and adult for HIL D)</u>

$$HIL_{ingestion}\,(mg/kg) = \frac{(TRV_o(100\% - BI_o)) \times BW_C \times AT_T}{IR_{SC} \times BA_o \times CF \times EF \times ED_C}$$ **Equation 3**

where:

TRV_o	= toxicity reference value relevant for the quantification of oral intakes, (as mg/kg/day for threshold contaminants)
BI_o	= background intakes relevant to oral/dermal exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (as % of the TRVo)
IR_{SC}	= ingestion rate of soil/dust by young child (for HILs A, B and C) and adult (HIL D) (mg/day)
BA_o	= oral bioavailability (unitless, expressed as a fraction of 1)
CF	= conversion factor of 1×10^{-6} to convert mg to kg
EF	= exposure frequency (days/year)
ED_C	= exposure duration for young child (for HILs A, B and C) and adult (HIL D) (years)
BW_C	= body weight of young child (for HILs A, B and C) and adult (HIL D) (kg)
AT_T	= averaging time for threshold contaminants (days, = ED x 365 days)

<u>Non-threshold contaminants (lifetime exposures)</u>

$$HIL_{ingestion}\,(mg/kg) = \frac{TR}{\text{Intake Factor}_o \times TRV_o}$$ **Equation 4**

$$\text{Intake Factor}_o\ (\text{kg/kg/day}) = \sum\left(\frac{IRs_x \times BAo \times CF \times EF_x \times ED_x}{BW_x \times AT_{NT}}\right)$$ **Equation 5**

where:

TRV_o	= toxicity reference value relevant for the quantification of oral intakes, (as $(mg/kg/day)^{-1}$ for non-threshold contaminants)
TR	= target risk for non-threshold contaminants (unitless)
$\sum$	= signifies the sum over all receptor groups *x* considered (in the HILs derived these groups include a child (C) and adult (A))
IRs_X	= ingestion rate of soil/dust by each receptor group *x* (mg/day)
BAo	= oral bioavailability (unitless)
CF	= conversion factor of $1x10^{-6}$ to convert mg to kg
EFx	= exposure frequency relevant to exposures by each receptor group *x* (days/year)
EDx	= exposure duration relevant to exposures by each receptor group *x* (years)
BWx	= body weight relevant to each receptor group *x* (kg)
AT_{NT}	= averaging time for non-threshold contaminants (days, = 70 years x 365 days)

1.3.2 Dermal contact with soil/dust

Threshold contaminants (2–3-year-old child for HILs A, B and C and adult for HIL D)

$$HIL_{dermal}\ (mg/kg) = \frac{(TRV_D(100\% - BI_O)) \times BW_C \times AT_T}{SA_C \times AF \times DAF \times CF \times EF \times ED_C}$$ **Equation 6**

where:

TRV_D	= toxicity reference value relevant for the quantification of dermal intakes, (as mg/kg/day for threshold contaminants)
BI_O	= background intakes relevant to oral/dermal exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (fraction relevant to the % allocated to background intakes)
SA_C	= exposed skin surface area for young child (for HILs A, B and C) and adult (HIL D) (cm^2)
AF	= soil-to-skin adherence factor ($mg/cm^2/day$)
DAF	= dermal absorption factor, (chemical-specific) (unitless)
CF	= conversion factor of $1x10^{-6}$ to convert mg to kg
EF	= exposure frequency (days/year)
ED_C	= exposure duration for young child (for HILs A, B and C) and adult (HIL D) (years)
BW_C	= body weight of young child (for HILs A, B and C) and adult (HIL D) (kg)
AT_T	= averaging time for threshold contaminants (days, = ED x 365 days)

Non-threshold contaminants (lifetime exposures)

$$HIL_{dermal}\ (mg/kg) = \frac{TR}{Intake\ Factor_D \times TRV_D}$$ **Equation 7**

$$Intake\ Factor_D\ (kg/kg/day) = \sum\left(\frac{SA_x \times AF \times DAF \times CF \times EF_x \times ED_x}{BW_x \times AT_{NT}}\right)$$ **Equation 8**

where:

TRV_D	= toxicity reference value relevant for the quantification of dermal intakes, (as $(mg/kg/day)^{-1}$ for non-threshold contaminants)
TR	= target risk for non-threshold contaminants (unitless)
$\sum$	= signifies the sum over all receptor groups *x* considered (in the HILs derived these groups include a child (C) and adult (A))
SA_x	= exposed skin surface area for all receptor groups *x* (cm^2)
AF	= soil-to-skin adherence factor ($mg/cm^2/day$)
DAF	= dermal absorption factor, (chemical-specific) (unitless)
CF	= conversion factor of $1x10^{-6}$ to convert mg to kg
EF_x	= exposure frequency relevant to exposures by all receptor groups *x* (days/year)
ED_x	= exposure duration relevant to exposures by all receptor groups *x* (years)
BW_x	= body weight relevant to each receptor group *x* (kg)
AT_{NT}	= averaging time for non-threshold contaminants (days, = 70 years x 365 days)

1.3.3 Inhalation of dust

Threshold contaminants (2–3-year-old child for HILs A, B and C and adult for HIL D)

$$HIL_{dust}(mg/kg) = \frac{(TRV_i(100\% - BI_i)) \times AT_T}{\left[\left[\frac{1}{PEF_o} \times ET_{co}\right] + \left[\frac{1}{PEF_i} \times TF \times ET_{ci}\right]\right] \times RF \times EF \times ED_C}$$ **Equation 9**

where:

TRV_i	= toxicity reference value relevant for the quantification of inhalation intakes, (as $mg/m^{3)}$
BI_i	= background intakes relevant to inhalation exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (fraction relevant to the % allocated to background intakes)
$PEF_{i,o}$	= particulate emission factor (or dust loading) for outdoor (O) or indoor (I) air (m^3/kg)
$ET_{ci,co}$	= exposure time outdoors (O) or indoors (I) for young child (for HILs A, B and C) and adult (HIL D) (hours/day)
TF	= indoor dust transport factor (unitless)
RF	= lung retention factor relevant for the inhalation of dust from site (unitless)
EF	= exposure frequency (days/year)
ED_C	= exposure duration for young child (for HILs A, B and C) and adult (HIL D) (years)
AT_T	= averaging time for threshold contaminants (hours, = ED x 365 days x 24 hours)

Non-threshold contaminants (lifetime exposures)

$$HIL_{dust}\ (mg/kg) = \frac{TR}{Intake\ Factor_{dust} \times TRV_i}$$ **Equation 10**

$$Intake\ Factor_{dust}(kg/m^3) = \sum \left(\frac{\left[\left[\frac{1}{PEF_o} \times ET_o\right] + \left[\frac{1}{PEF_i} \times TF \times ET_i\right]\right] \times RF \times EF_x \times ED_x}{AT_{NT}} \right)$$ **Equation 11**

where:

TRV_i	= toxicity reference value relevant for the quantification of inhalation intakes, (as $(mg/m^{3)-1}$ for non-threshold contaminants)
TR	= target risk for non-threshold contaminants (unitless)
$\sum$	= signifies the sum over all receptor groups *x* considered (in the HILs derived, these groups include a child (C) and adult (A))
$PEF_{i,o}$	= particulate emission factor (or dust loading) for outdoor (O) or indoor (I) air (m^3/kg)
$ET_{i,o}$	= exposure time indoors (I) and outdoors (O) for adults and children (as relevant) (hours/day)
TF	= indoor dust transport factor (unitless)
RF	= lung retention factor relevant for the inhalation of dust from site (unitless)
EF_x	= exposure frequency for all receptor groups *x* (days/year)
ED_x	= exposure duration for all receptor groups *x* (years)
AT_{NT}	= averaging time for non-threshold contaminants (hours, = 70 years x 365 days x 24 hours)

1.3.4 Inhalation of volatiles

No soil HILs have been derived for volatile compounds, hence this section only presents the approach adopted in the derivation of interim soil vapour HILs.

For the derivation of soil vapour HILs, an attenuation factor has been adopted that relates the indoor air concentration to the soil vapour concentration.

The interim soil vapour HIL (based on indoor air exposures) has then been derived on the basis of the following equations:

Threshold contaminants (2–3-year-old child for HILs A, B and C and adult for HIL D)

$$\text{Interim soil vapour HIL}\,(mg/m^3) = \frac{(TRV_i(100\% - BI_i)) \times AT_T}{\alpha \times ET_{Ci} \times EF \times ED_C}$$ **Equation 12**

where:

TRV_i	= toxicity reference value relevant for the quantification of inhalation intakes, (as mg/m$^{3)}$
BI_i	= background intakes relevant to inhalation exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (fraction relevant to the % allocated to background intakes)
α	= soil vapour to indoor air attenuation factor (unitless)
ET_{ci}	= exposure time indoors (I) for young child (for HILs A, B and C) and adult (HIL D) (hours/day)
EF	= exposure frequency (days/year)
ED_C	= exposure duration for young child (for HILs A, B and C) and adult (HIL D) (years)
AT_T	= averaging time for threshold contaminants (hours, = ED x 365 days x 24 hours)

Non-threshold contaminants (lifetime exposures)

$$\text{Interim soil vapour HIL}\,(mg/m^3) = \frac{TR}{\text{Intake Factor}_{volatile} \times TRV_i}$$ **Equation 13**

$$\text{Intake Factor}_{volatile}(\text{unitless}) = \sum\left(\frac{\alpha \times ET_{ix} \times EF_x \times ED_x}{AT_{NT}}\right)$$ **Equation 14**

where:

TRV_i	= toxicity reference value relevant for the quantification of inhalation intakes, (as (mg/m$^{3)-1}$ for non-threshold contaminants)
TR	= target risk for non-threshold contaminants (unitless)
∑	= signifies the sum over all receptor groups *x* considered (in the HILs derived, these groups include a child (C) and adult (A))
α	= soil vapour to indoor air attenuation factor (unitless)
ET_i	= exposure time indoors (I) (hours/day)
EF_x	= exposure frequency for all receptor groups (days/year)
ED_x	= exposure duration for all receptor groups (years)
AT_{NT}	= averaging time for non-threshold contaminants (hours, = 70 years x 365 days x 24 hours)

1.3.5 Ingestion of produce

Intake factors relevant to the estimation of exposures associated with the ingestion of contaminants following uptake into home-grown fruit and vegetable crops (considered as below-ground tuber vegetables (tuber) and root vegetables (root) and above-ground green vegetables (green) and tree fruit (fruit)) are as follows:

<u>Threshold contaminants (2–3-year-old child for HIL A only)</u>

$$HIL_{plantuptake}(mg/kg) = \frac{(TRV_o(100\% - BI_O)) \times BW_C \times AT_T}{UF_V \times EF \times ED_C}$$ **Equation 15**

$$UF_{VC}(kg/day) = F_{HG} \times \left(\left[CF_{tuber} \times C_{tuber}\right] + \left[CF_{root} \times C_{root}\right] + \left[CF_{green} \times C_{green}\right] + \left[CF_{fruit} \times C_{fruit}\right]\right)$$ **Equation 16**

where:

TRV_o	= toxicity reference value relevant for the quantification of oral intakes, (as mg/kg/day for threshold contaminants);
BI_O	= background intakes relevant to oral/dermal exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (fraction relevant to the % allocated to background intakes)
UF_{VC}	= plant uptake factor calculated for the consumption of home-grown produce by young children (kg/day)
CF_y	= plant concentration factors relevant for produce type (y), (chemical-specific) (mg/kg fresh weight produce to mg/kg dry weight soil)
C_y	= consumption rate of each produce type (y) (kg/day)
F_{HG}	= fraction of all fruit and vegetable produce consumed that is home-grown (unitless)
EF	= exposure frequency (days/year)
ED_C	= exposure duration for young children (years)
BW_C	= body weight of young child (kg)
AT_T	= averaging time for threshold contaminants (days, = ED x 365 days)

Non-threshold contaminants (lifetime exposures)

$$HIL_{plantuptake}\ (mg/kg) = \frac{TR}{Intake\ Factor_{plant} \times TRVo}$$ **Equation 17**

$$Intake\ Factor_{plant}\ (kg/kg/day) = \sum \left(\frac{UF_{Vx} \times EF_x \times ED_x}{BW_x \times AT_{NT}} \right)$$ **Equation 18**

where:

TRV_o	= toxicity reference value relevant for the quantification of oral intakes, (as $(mg/kg/day)^{-1}$ for non-threshold contaminants)
TR	= target risk for non-threshold contaminants (unitless)
$\sum$	= signifies the sum over all receptor groups *x* considered (in the HILs derived, these groups include a child (C) and adult (A))
UF_{yx}	= plant uptake factors calculated using Equation 16 for both adults and children (kg/day)
EF_x	= exposure frequency for all receptor groups *x* (days/year)
ED_x	= exposure duration for all receptor groups *x* (years)
BW_x	= body weight for all receptor groups *x* (kg)
AT_{NT}	= averaging time for non-threshold contaminants (days, = 70 years x 365 days)

Note that the calculation of intakes derived from home-grown produce has been included in the derivation of HIL A where relevant. However, it is noted that, for some compounds such as metals, the assessment of intakes derived from the consumption of home-grown produce as well as intakes derived from the diet (as estimated from total diet surveys) results in double counting of intakes that may be derived from produce.

To address the potential for double counting of these intakes it is assumed that 50% of the intake derived from home-grown produce (10% of total intake) is already accounted for in the data available on intakes derived from all dietary sources. Hence, the derivation of the HIL for plant uptake for metals has been adjusted to address this issue (refer to Appendix A for compound-specific data).

1.4 Calculation of particulate emission factor

Soil-derived dust concentrations in outdoor air have been estimated using a particulate emission factor (PEF) using the approach outlined by US EPA (1996; 2002) and EA (2009). The PEF represents an estimate of the relationship between the concentration of a contaminant in soil and its concentration in air as a consequence of dust resuspension. Dust particles considered in the PEF are assumed to be less than 10 µm is diameter. This has been calculated using the following equation:

$$PEF_o\,(m^3/kg) = \frac{Q/C \times 3600}{0.036 \times (1-V) \times \left(\frac{U_m}{U_t}\right)^3 \times F_x}$$ **Equation 19**

where:

PEF_O = particulate emission factor outdoors (mg/kg soil per mg/m^3 air)

Q/C = air dispersion factor which describes the dispersion of soil particles in the atmosphere of a theoretical outdoor box. A value of 90.8 (g/m^2/s per kg/m^3) has been used in the derivation of HILs. The value is a default value recommended by US EPA (2002) for small sites (0.5 acres).

V = the fraction of outdoor surface cover (0= bare soil), dimensionless (0.75 for HIL A, 0.9 for HIL B and 0.8 for HIL D)

U_m = mean annual wind speed at a height of 10m (m/s), assumed to be 8.75 km/hr (or 2.4 m/s) based on the average 9 am and 3 pm winds from Canberra

U_t = threshold value of wind speed at a height of 10m (m/s), which is how much wind is required to generate dust at a given site from an erodible surface. A default value of 7.2 m/s has been used in the derivation of HILs (EA 2009)

F_x = empirical function calculated based on the ratio of mean and threshold wind speeds as noted by EA (2009). For the derivation of HILs the following was used:

$$F_x = 0.18 \times (8x^3 + 12x)\exp(-x^2), \quad \text{where} \quad x = 0.886\frac{U_t}{U_m}$$ **Equation 20**

The PEF calculated for indoor air (and outdoors for HIL C) is based on a dust loading factor. The PEF is calculated as follows:

$$PEF_i\,(m^3/kg) = \frac{1}{DL \times 10^{-6}}$$ **Equation 21**

where:

DL = dust loading factor (mg dust/m^3 air)

10^{-6} = conversion factor for mg to kg

1.5 Calculation of plant concentration factors

The concentration of contaminants in edible portions of fruit and vegetables is estimated from the relationship between soil and plant and described using a soil-to-plant concentration factor (CF_x).

For inorganic contaminants, the CF_x values are derived from available literature (relevant to below- or above-ground crops).

For organic contaminants, there is a range of equations available that is based on experimental data. Where relevant, plant uptake of organic compounds has been estimated in the derivation of HILs using the equations presented by EA (2009), which are detailed as follows (refer to EA (2009) for further explanation of the basis for these equations):

Root Crops

$$CF_{root}\ (mg/kg\ fw\ plant\ per\ mg/kg\ dw\ soil) = \frac{\left(\dfrac{Q}{K_{oc} \times F_{oc}}\right)}{\dfrac{Q}{\left[\dfrac{W}{\rho_p} + \dfrac{L}{\rho_p} \times 1.22 K_{ow}^{0.77}\right]} + (k_g + K_m)\ \rho_p\ RV}$$

Equation 22

where:

Q	= transpiration stream flow rate, (cm^3/day) (assumed equal to the default of 1000)
K_{oc}	=organic carbon–water partition coefficient for the contaminant, (cm^3/g) (compound-specific)
F_{oc}	= fraction of organic carbon in the soil, (unitless)
K_{ow}	= octanol–water partition coefficient, (unitless) (compound-specific)
W	= root water content, (g/g) (assumed equal to the default of 0.89)
L	= root lipid content on a mass basis, (g/g) (assumed equal to the default of 0.025)
ρ_p	= plant root density, (g/$cm^{3)}$ (assumed equal to the default of 1)
k_g	= first order growth rate constant, per day (assumed equal to the default of 0.1)
K_m	= first order metabolism rate constant, (per day) (assumed equal to the default of 0)
RV	= root volume, ($cm^{3)}$ (assumed equal to the default of 1000)

Tuber Crops

Calculations presented for tuber crops are based on potatoes as representative crops for this group.

$$CF_{tuber}\,(mg/kg\ fw\ plant\ per\ mg/kg\ dw\ soil) = \frac{k_1}{k_2 + k_g}$$

Equation 23

where:

$$k_1 = k_2\left(\frac{K_{pw}}{K_{oc} \times F_{oc}}\right)$$ **Equation 24**

$$K_{pw} = \left(\frac{W}{\rho_p}\right) + (f_{ch}K_{ch}) + \left(\frac{L}{\rho_p}\right)1.22K_{ow}^{0.77}$$ **Equation 25**

$$k_2 = \frac{23\left(\frac{3600D_{water}(W^{7/3}/\rho_p)}{K_{pw}}\right)}{R^2}$$ **Equation 26**

where:

k_1	= rate of chemical flux into the potato, (per hour) (Equation 24)
k_2	= rate of chemical flux out of the potato, (per hour) (Equation 26)
k_g	= exponential rate of growth of the potato, (per hour) (assumed equal to the default of 0.0014)
F_{oc}	= fraction of organic carbon in the soil, (unitless)
K_{oc}	=organic carbon–water partition coefficient for the contaminant, (cm^3/g) (compound-specific)
D_{water}	= chemical diffusion coefficient in water, (m^2/s) (compound-specific)
ρ_p	= potato tissue density, ($g/cm^{3)}$ (assumed equal to the default of 1)
R	= radius of the potato, (m) (assumed equal to the default of 0.04)
W	= water content of potato, (g/g) (assumed equal to the default of 0.79)
K_{pw}	= equilibrium partition coefficient between potato and water, (cm^3/g) (Equation 25)
f_{ch}	= fraction of carbohydrates in the potato, (unitless) (assumed equal to the default of 0.209)
L	= lipid content of potato on a mass basis, (g/g) (assumed equal to the default of 0.001)
K_{ow}	= octanol–water partition coefficient, (unitless) (compound-specific)
K_{ch}	= carbohydrate–water partition coefficient, (cm^3/g) (calculated from chemical lipophilicity according to the following table)

Chemical log K_{ow}	Chemical K_{ch} (cm^3/g)
<0	0.1
≥0 but <1	0.2
≥1 but <2	0.5
≥2 but <3	1
≥3 but <4	2
≥4	3

Green Vegetables

$$CF_{green} = (10^{0.95\log K_{OW} - 2.05} + 0.82) \times (0.784 \times 10^{-0.434(\log K_{OW} - 1.78)^2/2.44}) \times \left(\frac{\rho_S}{\theta_{WS} + (\rho_S . K_{OC} . f_{OC})} \right)$$

(mg/kg fresh weight [fw] plant per mg/kg dry weight [dw] soil)

Equation 27

where:

K_{oc} =organic carbon–water partition coefficient for the contaminant, (cm^3/g) (compound-specific)

f_{oc} = fraction of organic carbon in the soil, (unitless)

K_{ow} = octanol-water partition coefficient, (unitless) (compound-specific)

ρ_s = dry soil bulk density, (g/cm^{3})

θ_{WS} = soil-water content by volume, (cm^3/cm^{3})

Tree Fruit

$$CF_{fruit}\,(\text{mg/kg fw plant per mg/kg dw soil}) = \frac{0.001 \times (M_f Q_{fruit} DM_{fruit}) \left(\frac{C_{stem}}{K_{wood}} \right) / M_f}{C_{soil}}$$

Equation 28

where:

$$C_{stem}(mg/g) = \frac{\left[\left(\frac{C_{soil}}{K_{oc} F_{oc}} \right) 0.756 e^{\frac{-(\log K_{ow} - 2.5)^2}{2.58}} \right] \left[\frac{Q}{M} \right]}{\frac{Q}{K_{wood} M} + k_e + k_g}$$

Equation 29

$$\log K_{wood} = -0.27 + 0.632 \log K_{ow}$$

Equation 30

where:

M_f	= mass of fruit, (g fw) (assumed equal to the default of 1)
Q_{fruit}	= water flow rate per unit mass of fruit, (cm^3/g fw) (assumed equal to the default of 20)
DM_{fruit}	= dry matter content of fruit, (g/g) (assumed equal to the default of 0.16)
C_{stem}	= chemical concentration in the woody stem (mg/g) (Equation 29)
K_{wood}	= wood–water partition coefficient, (mg/g dw wood per mg/cm^3 water) (Equation 30)
C_{soil}	= total chemical concentration in soil, (mg/kg dw) (assumed to be 1 for establishing ratio)
K_{oc}	= organic carbon–water partition coefficient for the contaminant, (cm^3/g) (compound-specific)
f_{oc}	= fraction of organic carbon in the soil, (unitless)
K_{ow}	= octanol–water partition coefficient, (unitless) (compound-specific)
Q	= transpiration stream flow rate, (cm^3/year) (assumed equal to the default of 25,000,000)
M	= mass of the woody stem, (g dw) (assumed equal to the default of 50,000)
k_e	= rate of chemical metabolism, (per year) (assumed equal to the default of 0)
k_g	= rate of dilution due to wood growth, (per year) (assumed equal to the default of 0.01)

1.6 Bibliography

EA 2009, *Updated technical background to the CLEA model,* Science report SC050021/SR3, Environment Agency, Bristol, UK.

MfE 2011, *Methodology for deriving soil guideline values protective of human health*, New Zealand Ministry for the Environment, Wellington, New Zealand.

NEPC 1999, National Environment Protection (Assessment of Site Contamination) Measure, National Environment Protection Council, Australia.

US EPA 1992, *Supplemental guidance to RAGS: calculating the concentration term*, 9285.7-08, Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, Washington, DC, USA.

US EPA 1996, *Soil Screening Guidance: Technical Background Document*, EPA/540/R-95/128, United States Environmental Protection Agency, Washington, DC, USA.

US EPA 2002, *Supplemental guidance for developing soil screening levels for Superfund sites*, OSWER 9355.4-24, United States Environmental Protection Agency, Washington, DC, USA.

US EPA 2012, *Regional Screening Levels* (formerly PRGs), Screening Levels for Chemical Contaminants, United States Environmental Protection Agency, Pacific Southwest, Region 9, Washington, DC, USA, available from http://www.epa.gov/region9/superfund/prg/.

2 Attachment A

2.1 Worked Example: Calculation of HIL A for cadmium

This attachment provides further detail on the calculation of the low-density residential (HIL A) calculation for cadmium based on the equations presented in this appendix, exposure assumptions presented in Table 5 of the main schedule and the information presented in Appendix A for cadmium. The calculations presented are also summarised in Appendix C.
Based on the information presented in Appendix A, the HIL for cadmium has been undertaken on the basis that it is a threshold contaminant, where the most sensitive receptor is a child aged 2–3 years. Hence only threshold calculations have been undertaken for this chemical, where the following assumptions have been used from Appendix A:

Oral TRV (TRV_O) = 0.0008 mg/kg/day (WHO 2010)
Dermal absorption (DAF) = negligible (0%)
Inhalation TRV (TRV_I) = 0.000005 mg/m^3 (WHO 2000)
Background intakes from other sources:
BI_O = 60% for oral intakes
BI_i = 20% for inhalation

Calculation for Ingestion of Soil/dust

Based on Equation 3, the $HIL_{ingestion}$ is calculated for cadmium as follows:

$$HIL_{ingestion}\,(mg/kg) = \frac{(TRV_o(100\% - BI_o)) \times BW_C \times AT_T}{IR_{SC} \times BA_o \times CF \times EF \times ED} = \frac{0.0008 \text{ x } 40\% \text{ x} 15 \text{ x } 2190}{100 \text{ x } 100\% \text{ x } 0.000001 \text{x } 365 \text{ x } 6} = 48$$

(mg/kg)

Equation 3

where:

TRV_o = toxicity reference value relevant for the quantification of oral intakes, (as mg/kg/day for threshold contaminants) = 0.0008 mg/kg/day
BI_o = background intakes relevant to oral/dermal exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (% of the TRVo) = 60% for oral intakes
IR_{SC} = ingestion rate of soil/dust by young child (mg/day) = 100 mg/day
BA_o = oral bioavailability (unitless, expressed as a fraction of 1) = 100% or 1 for cadmium
CF = conversion factor of 1×10^{-6} to convert mg to kg
EF = exposure frequency (days/year) = 365 days per year
ED_C = exposure duration for young child (years) = 6 years
BW_C = body weight of young child (kg) = 15 kg
AT_T = averaging time for threshold contaminants (days, = ED x 365 days) = 6 x 365 = 2190 days

Calculation for Dermal Absorption from Soil/dust

Based on information presented in Appendix A, dermal absorption of cadmium in soil in considered negligible and hence no calculation is required for this pathway.

Calculation for Inhalation of Dust

Based on Equation 9, the HIL_{dust} is calculated for cadmium as follows:

$$HIL_{dust}(mg/kg) = \frac{(TRV_i(100\% - BI_i)) \times AT_T}{\left[\left[\frac{1}{PEF_o} \times ET_{co}\right] + \left[\frac{1}{PEF_i} \times TF \times ET_{ci}\right]\right] \times RF \times EF \times ED_C} = \frac{0.000005 \, x \, 80\% \, x \, 52560}{\left[\left[\frac{4}{3x10^{10}}\right] + \left[\frac{0.5 \, x \, 20}{2.6x10^{7}}\right]\right] x \, 0.375 \, x \, 365 \, x \, 6}$$

$= 665$ (mg/kg)

Equation 9

where:

TRV_i	= toxicity reference value relevant for the quantification of inhalation intakes, (as mg/m^3) = 0.000005 mg/m^3
BI_i	= background intakes relevant to inhalation exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (fraction relevant to the % allocated to background intakes) = 20% for inhalation intakes
$PEF_{i,o}$	= particulate emission factor (or dust loading) for outdoor (O) or indoor (I) air (m^3/kg) = calculated as below using Equations 19 to 21, PEFo = $3x10^{10}$ and PEFi = $2.6x10^7$ (m^3/kg)
$ET_{ci,co}$	= exposure time outdoors (O) or indoors (I) for young child (hours/day) = 4 hours/day outdoors and 20 hours per day indoors
TF	= indoor dust transport factor (unitless) = 0.5
RF	= lung retention factor relevant for the inhalation of dust from site (unitless) = 0.375
EF	= exposure frequency (days/year) = 365 days per year
ED_C	= exposure duration for young child (years) = 6 years
AT_T	= averaging time for threshold contaminants (hours, = ED x 365 days x 24 hours) = 6 x 365 x 24 = 52 560 hours

$$PEF_o(m^3/kg) = \frac{Q/C \; x \; 3600}{0.036 \; x \; (1-V) \; x \; (\frac{U_m}{U_t})^3 \; x \; F_x} = \frac{90.8 \, x \, 3600}{0.036 \, x \, 0.25 \, x \, (\frac{2.4}{7.2})^3 \, x \, 0.032} = 3x10^{10}$$

Equation 19

where:

PEF_O	= particulate emission factor outdoors (mg/kg soil per mg/m^3 air)
Q/C	= air dispersion factor which describes the dispersion of soil particles in the atmosphere of a theoretical outdoor box. A value of 90.8 (g/m^2/s per kg/m^3) has been used in the derivation of HILs. The value is a default value recommended by US EPA (2002) for small sites (0.5 acres).
V	= the fraction of outdoor surface cover (0= bare soil), (unitless) = 0.75
U_m	= mean annual wind speed at a height of 10m (m/s), assumed to be 8.75 km/hr (or 2.4 m/s) based on the average 9 am and 3 pm winds from Canberra
U_t	= threshold value of wind speed at a height of 10m (m/s), which is how much wind is required to generate dust at a given site from an erodible surface. A default value of 7.2 m/s has been used in the derivation of HILs (EA 2009a)
F_x	= empirical function calculated based on the ratio of mean and threshold wind speeds as noted by EA (2009a) = 0.032 based on the following:

$F_x = 0.18 \times (8x^3 + 12x)\exp(-x^2)$, where $x = 0.886\frac{U_t}{U_m} = 0.886\frac{7.2}{2.4} = 2.6$ **Equation 20**

$$PEF_i\,(m^3/kg) = \frac{1}{DL \times 10^{-6}} = 2.6x10^7$$

Equation 21

where:

DL = dust loading factor (mg dust/m³ air) = 39 µg/m³ = 0.039 mg/m³ (as per Section 5.3.3.2 of Schedule B7)

10^{-6} = conversion factor for mg to kg

Calculation for Ingestion of Cadmium via Home-grown Produce

Based on Equations 15 and 16, the $HIL_{plant\ uptake}$ is calculated for cadmium as follows:

$$HIL_{plantuptake}\,(mg/kg) = \frac{(TRV_o(100\% - BI_O)) \times BW_C \times AT_T}{UF_V \times EF \times ED_C} = \frac{0.0008\,x\,40\%\,15\,x\,2190}{0.00044\,x\,365\,x\,6} = 11(mg/kg)$$

Equation 15

$$UF_{VC}\,(kg/day) = F_{HG} \times ([CF_{tuber} \times C_{tuber}] + [CF_{root} \times C_{root}] + [CF_{green} \times C_{green}] + [CF_{fruit} \times C_{fruit}])$$ **Equation 16**

where:

TRV_o = toxicity reference value relevant for the quantification of oral intakes, (as mg/kg/day for threshold contaminants) = 0.0008 mg/kg/day;

BI_O = background intakes relevant to oral/dermal exposures (from sources other than soil, which include food, water, air and consumer products where relevant) (fraction relevant to the % allocated to background intakes) = 60%

UF_{VC} = plant uptake factor calculated for the consumption of home-grown produce by young children (kg/day) = $4.4x10^{-4}$ kg/day based on Equation 16

CF_y = plant concentration factors relevant for produce type (y), (chemical-specific) (mg/kg fresh weight produce to mg/kg dry weight soil), see table below

C_y = consumption rate of each produce type (y) (kg/day), see table below

F_{HG} = fraction of all fruit and vegetable produce consumed that is home-grown (unitless) = 10% or 0.1 as per Schedule B7

EF = exposure frequency (days/year) = 365 days per year

ED_C = exposure duration for young children (years) = 6 years

BW_C = body weight of young child (kg) = 15 kg

AT_T = averaging time for threshold contaminants (days, = ED x 365 days) = 2190 days

For cadmium the plant uptake factors, or concentration factors, (CF_y) for the different produce types are presented in Appendix A. The consumption rate of each produce type, by young children, is presented in Table 7 in Schedule B7. These are both summarised for cadmium in the following table. These have been used in Equation 16 to calculate the plant uptake factor for young children.

Produce Group	Plant Uptake Factors or Concentration Factors CF_y (mg/kg produce fresh weight per mg/kg soil) (EA 2009c) – from Appendix A	Child consumption rate for each produce group (kg/day) – from Table 7 in Schedule B7
Green vegetables	0.052	0.055
Root vegetables	0.029	0.017
Tuber vegetables	0.031	0.028
Tree fruit	0.0014	0.18

As noted in Appendix A, and the calculation sheets in Appendix C, as background intakes (via ingestion) are dominated by intakes from food sources, the inclusion of uptakes from home-grown produce as well as all other food sources results in some double counting of cadmium intakes via food sources. As discussed in Section 1.3.5 to correct for this double counting, the calculated HIL from plant uptake has been adjusted by a factor of 2-fold (which has the effect of reducing the contribution from this pathway by 50%).
Hence the calculated HIL plant uptake = 21 mg/kg (after rounding)

Calculation of the Residential HIL from all Exposure Pathways

The final HIL is calculated by combining the pathway-specific HILs calculated above using Equation 2 (for the complete pathways of exposure) (as rounded):

$$\mathrm{HIL}\,(\mathrm{mg/kg}) = \frac{1}{\left[\frac{1}{\mathrm{HIL}_{\mathrm{ingestion}}}\right]+\left[\frac{1}{\mathrm{HIL}_{\mathrm{plant\ uptake}}}\right]+\left[\frac{1}{\mathrm{HIL}_{\mathrm{dust}}}\right]} = \frac{1}{\frac{1}{48}+\frac{1}{21}+\frac{1}{665}} = 15\,\mathrm{mg/kg}$$

Equation 2

As noted in Appendix A, for cadmium an HIL A of 15 mg/kg has been calculated using the above equations. The value of 15 mg/kg is considered to be essentially the same (with consideration of uncertainties and accuracy of HIL calculations) as the existing HIL of 20 mg/kg. There is no new data available that suggests that the existing HIL is not adequately protective and that, given the level of uncertainty in the calculation of any HIL, the existing HIL A of 20 mg/kg has been retained in the NEPM.

2.2 Bibliography

EA 2009a, *Updated technical background to the CLEA model,* Science report SC050021/SR3, Environment Agency, Bristol, UK.

EA 2009b, *Soil Guideline Values for cadmium in soil*, Science Report SC050021/Cadmium SGV, Environment Agency, Bristol, UK.

EA 2009c, *Supplementary information for the derivation of SGV for cadmium*, Science Report SC050021/Technical review cadmium, Environment Agency, Bristol, UK.

WHO 2000, *Air Quality Guidelines for Europe, 2nd edn,* World Health Organization, Geneva.

WHO 2010, Joint FAO/WHO Expert Committee on Food Additives (JECFA), Seventy-third meeting, Geneva, 8–17 June 2010, Summary and Conclusions, Issued 24 June 2010.

US EPA 2002, *Supplemental guidance for developing soil screening levels for Superfund sites*, OSWER 9355.4-24, United States Environmental Protection Agency, Washington, DC, USA.

3 Attachment B

3.1 Worked Example: Calculation of HIL A for benzo(a)pyrene

This attachment provides further detail on the calculation of the low-density residential (HIL A) calculation for benzo(a)pyrene (BaP) based on the equations presented in this appendix, exposure assumptions presented in Table 5 of the main schedule and the information presented in Appendix A for BaP. The calculations presented are also summarised in Appendix C.
Based on the information presented in Appendix A, BaP has been considered to be a genotoxic carcinogen where the HIL has been calculated on the basis of a non-threshold approach, considering exposures over a lifetime (i.e. as a child and adult). The assessment of BaP is complex (as outlined in Appendix A), where the following have been considered in the derivation of the HIL:

Recommendation for BaP and carcinogenic PAHs as BaP TEF
Oral TRV (TRV_O) = 0.208 $(mg/kg/day)^{-1}$ (MfE 2011) for all routes of exposure
Value has been compared with TRV_O = 0.5 $(mg/kg/day)^{-1}$ (WHO 2011) for all routes of exposure
Dermal absorption factor (DAF) = 0.06 (or 6%) (MfE 2011)
Note: early lifetime exposures to BaP may need to be addressed in the quantification of exposure as per US EPA (2005).

As discussed in Appendix A, when determining the HIL A value, calculations have been undertaken for BaP where the TRVo from MfE (2011) and WHO (2011) have been considered, where early lifetime exposures have been considered and where the dermal-specific toxicity reference value has also been considered. For the purpose of this worked example, calculations have been presented that support the HIL A value adopted, which is based on the TRVo available from WHO (2011), consideration of early lifetime exposures and no additional consideration of the dermal-specific toxicity reference value.

Calculation for Ingestion of Soil/dust

Based on Equations 3 and 4, as well as the age-adjustment factors outlined by US EPA (2005), the $HIL_{ingestion}$ is calculated for BaP as follows:

$$HIL_{ingestion}\,(mg/kg) = \frac{TR}{Intake\,Factor_o \times TRV_o}$$ **Equation 4**

$$Intake\,Factor_o\,(kg/kg/day) = \sum\left(\frac{IRs_x \times BAo \times CF \times EF_x \times ED_x}{BW_x \times AT_{NT}}\right)$$ **Equation 5**

where:

TRV_o = toxicity reference value relevant for the quantification of oral intakes, (as $(mg/kg/day)^{-1}$ for non-threshold contaminants) = 0.5 $(mg/kg/day)^{-1}$

TR = target risk for non-threshold contaminants (unitless) = $1x10^{-5}$

$\sum$	= signifies the sum over all receptor groups *x* considered (in the HILs derived, these groups include a child (C) and adult (A))
IRs_X	= ingestion rate of soil/dust by each receptor group *x* (mg/day) = 50 mg/day for adults and 100 mg/day for young children
BAo	= oral bioavailability (unitless) = 100% or 1 for BaP
CF	= conversion factor of $1x10^{-6}$ to convert mg to kg
EFx	= exposure frequency relevant to exposures by each receptor group *x* (days/year) = 365 days/year for both adults and children
EDx	= exposure duration relevant to exposures by each receptor group *x* (years) = 6 years for young children and 29 years for adults
BWx	= body weight relevant to each receptor group *x* (kg) = 15kg for young children and 70 kg for adults
AT_{NT}	= averaging time for non-threshold contaminants (days, = 70 years x 365 days) = 25 550 days

The calculated intake factor has taken into account age-adjustment factors that relate to the potential for exposures during childhood to be more sensitive than those later in life. This has been undertaken using the age adjustment factors (ADAF) outlined by US EPA (2005). The adjustment factors are as follows:

- ADAF = 10 during the first 2 years of life
- ADAF = 3 for ages 2 through to less than 16 years
- ADAF = 1 for ages 16 through to 70 years.

The lifetime risk calculations undertaken for non-threshold compounds (based on the equations in this appendix) are based on exposures that occur as a young child aged 0–5 years, and then as an adult from ages 6 and older. The ADAFs have been applied within these calculations as follows:

$$\text{Intake Factor}_o\ (kg/kg/day) = 10\ x\ \frac{IR_c(100\,mg/day)\ x\ BA_O(1)\ x\ CF\ (1x10^{-6}\ mg/kg)\ x\ EF_C(365\,days/year)\ x\ 2\ (\text{years for ADAF})}{BW_C(15kg)\ x\ AT\ (25550days)}$$

$$+3\ x\ \frac{IR_c(100\,mg/day)\ x\ BA_O(1)\ x\ CF\ (1x10^{-6}\ mg/kg)\ x\ EF_C(365\,days/year)\ x\ 4\ (\text{years for ADAF from ages } 2-5)}{BW_C(15kg)\ x\ AT\ (25550days)}$$

$$+3\ x\ \frac{IR_A(50\,mg/day)\ x\ BA_O(1)\ x\ CF\ (1x10^{-6}\ mg/kg)\ x\ EF_A(365\,days/year)\ x\ 10\ (\text{years for ADAF from ages } 6-15)}{BW_A(70kg)\ x\ AT\ (25550days)}$$

$$+1x\ \frac{IR_A(50\,mg/day)\ x\ BA_O(1)\ x\ CF\ (1x10^{-6}\ mg/kg)\ x\ EF_A(365\,days/year)\ x\ 19\ (\text{years for ADAF from ages } 16-35)}{BW_A(70kg)\ x\ AT\ (25550days)}$$

$$= 3.5x10^{-6}\ (kg/kg/day)$$

Based on the above the following is then calculated:

$$HIL_{ingestion}\ (mg/kg) = \frac{TR(1x10^{-5})}{\text{Intake Factor}_o\ (3.5x10^{-6}\ kg/kg/day) \times TRV_o(0.5\,(mg/kg/day)^{-1})} = 5.6\ (mg/kg)$$

Calculation for Dermal Absorption from Soil/dust

Based on Equations 7 and 8, as well as the age-adjustment factors outlined by US EPA (2005), the HI_{dermal} is calculated for BaP as follows:

Non-threshold contaminants (lifetime exposures)

$$HIL_{dermal}\ (mg/kg) = \frac{TR}{Intake\ Factor_D \times TRV_D}$$ **Equation 7**

$$Intake\ Factor_D\ (kg/kg/day) = \sum\left(\frac{SA_x \times AF \times DAF \times CF \times EF_x \times ED_x}{BW_x \times AT_{NT}}\right)$$ **Equation 8**

where:

TRV_D	= toxicity reference value relevant for the quantification of dermal intakes, (as $(mg/kg/day)^{-1}$ for non-threshold contaminants) = 0.5 $(mg/kg/day)^{-1}$
TR	= target risk for non-threshold contaminants (unitless) = $1x10^{-5}$
∑	= signifies the sum over all receptor groups *x* considered (in the HILs derived, these groups include a child (C) and adult (A))
SA_x	= exposed skin surface area for all receptor groups *x* (cm^2) = 2700 cm^2 for young children and 6300 cm^2 for adults
AF	= soil to skin adherence factor ($mg/cm^2/day$) = 0.5 $mg/cm^2/day$
DAF	= dermal absorption factor, (chemical-specific) (unitless) = 6% or 0.06 for BaP
CF	= conversion factor of $1x10^{-6}$ to convert mg to kg
EF_x	= exposure frequency relevant to exposures by all receptor groups *x* (days/year) = 365 days per year for adults and children
ED_x	= exposure duration relevant to exposures by all receptor groups *x* (years) = 6 years as child from 0–5 years and 29 years as adult aged 6 and older
BW_x	= body weight relevant to each receptor group *x* (kg) = 15 kg for young children and 70 kg for adults
AT_{NT}	= averaging time for non-threshold contaminants (days, = 70 years x 365 days) = 25 550 days

As noted above for the calculation of the soil ingestion HIL, age-adjustment factors have been incorporated into the calculation of the intake factor, with the calculations considered as follows:

$$\text{Intake Factor}_D\ (kg/kg/day) =$$

$$10\,x\,\frac{SA_C(2700cm^2)\,x\,AF(0.5mg/cm^2/day)\,x\,DAF(0.06)\,x\,CF(1x10^{-6})\,x\,EF_C(365d/yr)\,x\,2\,(\text{years for ADAF})}{BW_C(15kg)\,x\,AT(25550days)}$$

$$+3\,x\,\frac{SA_C(2700cm^2)\,x\,AF(0.5mg/cm^2/day)\,x\,DAF(0.06)\,x\,CF(1x10^{-6})\,x\,EF_C(365d/yr)\,x\,4\,(\text{years for ADAF from ages } 2-5)}{BW_C(15kg)\,x\,AT(25550days)}$$

$$+3\,x\,\frac{SA_A(6300cm^2)\,x\,AF(0.5mg/cm^2/day)\,x\,DAF(0.06)\,x\,CF(1x10^{-6})\,x\,EF_A(365d/yr)\,x\,10\,(\text{years for ADAF from ages } 6-15)}{BW_A(70kg)\,x\,AT(25550days)}$$

$$+1x\,\frac{SA_A(6300cm^2)\,x\,AF(0.5mg/cm^2/day)\,x\,DAF(0.06)\,x\,CF(1x10^{-6})\,x\,EF_A(365d/yr)\,x\,19\,(\text{years for ADAF from ages } 16-35)}{BW_A(70kg)\,x\,AT(25550days)}$$

$$= 4.3x10^{-6}\ (kg/kg/day)$$

Based on the above, the following is then calculated:

$$HIL_{dermal}\ (mg/kg) = \frac{TR(1x10^{-5})}{\text{Intake Factor}_D\ (4.3x10^{-6}\ kg/kg/day) \times TRV_D(0.5\,(mg/kg/day)^{-1})} = 4.6\ (mg/kg)$$

Calculation for Inhalation of Dust

Based on Equations 10 and 11, the HIL_{dust} is calculated for BaP as follows:

$$HIL_{dust}\ (mg/kg) = \frac{TR}{\text{Intake Factor}_{dust} \times TRV_i}$$ **Equation 10**

$$\text{Intake Factor}_{dust}\,(kg/m^3) = \sum\left(\frac{\left[\left[\frac{1}{PEF_o} \times ET_o\right] + \left[\frac{1}{PEF_i} \times TF \times ET_i\right]\right] \times RF \times EF_x \times ED_x}{AT_{NT}}\right)$$ **Equation 11**

where:

TRV_i	= toxicity reference value relevant for the quantification of inhalation intakes, (as $(mg/m^3)^{-1}$ for non-threshold contaminants) = 0.14 $(mg/m^3)^{-1}$ (based on the TRVo and conversion based on inhalation of 20 m^3/day and a body weight of 70 kg)
TR	= target risk for non-threshold contaminants (unitless) = $1x10^{-5}$
$\sum$	= signifies the sum over all receptor groups *x* considered (in the HILs derived, these groups include a child (C) and adult (A))
$PEF_{i,o}$	= particulate emission factor (or dust loading) for outdoor (O) or indoor (I) air (m^3/kg), calculated as outlined below
$ET_{i,o}$	= exposure time indoors (I) and outdoors (O) for adults and children (as relevant) (hours/day) = 20 hours indoors and 4 hours outdoors for both young children and adults
TF	= indoor dust transport factor (unitless) = 0.5
RF	= lung retention factor relevant for the inhalation of dust from site (unitless) = 0.375
EF_x	= exposure frequency for all receptor groups *x* (days/year) = 365 days per year for both young children and adults
ED_x	= exposure duration for all receptor groups *x* (years) = 6 years as child from 0–5 years and 29 years as adult aged 6 and older
AT_{NT}	= averaging time for non-threshold contaminants (hours, = 70 years x 365 days x 24 hours) = 613 200 hours

$$PEF_o\,(m^3/kg) = \frac{Q/C \times 3600}{0.036 \times (1-V) \times (\frac{U_m}{U_t})^3 \times F_x} = \frac{90.8 \times 3600}{0.036 \times 0.25 \times (\frac{2.4}{7.2})^3 \times 0.032} = 3x10^{10}$$

Equation 19

where:

PEF_O	= particulate emission factor outdoors (mg/kg soil per mg/m^3 air)
Q/C	= air dispersion factor which describes the dispersion of soil particles in the atmosphere of a theoretical outdoor box. A value of 90.8 (g/m^2/s per kg/m^3) has been used in the derivation of HILs. The value is a default value recommended by US EPA (2002) for small sites (0.5 acres).
V	= the fraction of outdoor surface cover (0= bare soil), (unitless) = 0.75
U_m	= mean annual wind speed at a height of 10m (m/s), assumed to be 8.75 km/hr (or 2.4 m/s) based on the average 9 am and 3 pm winds from Canberra
U_t	= threshold value of wind speed at a height of 10m (m/s), which is how much wind is required to generate dust at a given site from an erodible surface. A default value of 7.2 m/s has been used in the derivation of HILs (EA 2009)
F_x	= empirical function calculated based on the ratio of mean and threshold wind speeds as noted by EA (2009) = 0.032 based on the following:

$$F_x = 0.18 \times (8x^3 + 12x)\exp(-x^2), \quad \text{where} \quad x = 0.886\frac{U_t}{U_m} = 0.886\frac{7.2}{2.4} = 2.6$$

Equation 20

$$PEF_i\,(m^3/kg) = \frac{1}{DL \times 10^{-6}} = 2.6x10^7$$

Equation 21

where:

DL = dust loading factor (mg dust/m^3 air) = 39 µg/m^3 = 0.039 mg/m^3 (as per Section 5.3.3.2 of Schedule B7)

10^{-6} = conversion factor for mg to kg

As noted above for the calculation of the soil ingestion HIL, age-adjustment factors have been incorporated into the calculation of the intake factor, with the calculations considered as follows:

$$\text{Intake Factor}_{dust}(kg/m^3) = 10\,x\,\frac{\left[\left[\frac{1}{PEF_o(3x10^{10})}\times ET_o(4hrs)\right]+\left[\frac{1}{PEF_i(2.6x10^7)}\times TF(0.5)\times ET_i(20hrs)\right]\right]\times RF(0.375)\times EF_C(365d/yr)\times ED_C(2\text{ yrs for ADAF})}{AT_{NT}(613200hrs)}$$

$$+3\,x\,\frac{\left[\left[\frac{1}{PEF_o(3x10^{10})}\times ET_o(4hrs)\right]+\left[\frac{1}{PEF_i(2.6x10^7)}\times TF(0.5)\times ET_i(20hrs)\right]\right]\times RF(0.375)\times EF_C(365d/yr)\times ED_C(4\text{ yrs for ADAF for ages }2-5)}{AT_{NT}(613200hrs)}$$

$$+3\,x\,\frac{\left[\left[\frac{1}{PEF_o(3x10^{10})}\times ET_o(4hrs)\right]+\left[\frac{1}{PEF_i(2.6x10^7)}\times TF(0.5)\times ET_i(20hrs)\right]\right]\times RF(0.375)\times EF_A(365d/yr)\times ED_A(10\text{ yrs for ADAF for ages }6-15)}{AT_{NT}(613200hrs)}$$

$$+1x\,\frac{\left[\left[\frac{1}{PEF_o(3x10^{10})}\times ET_o(4hrs)\right]+\left[\frac{1}{PEF_i(2.6x10^7)}\times TF(0.5)\times ET_i(20hrs)\right]\right]\times RF(0.375)\times EF_A(365d/yr)\times ED_A(19\text{ yrs for ADAF for ages }16-35)}{AT_{NT}(613200hrs)}$$

$$= 7x10^{-9}\ (kg/m^3)$$

Based on the above, the following is then calculated:

$$HIL_{dust}\ (mg/kg) = \frac{TR(1x10^{-5})}{\text{Intake Factor}_{dust}(7x10^{-9})\times TRV_I(0.143(mg/m^3)^{-1})} = 10000(mg/kg)$$

Calculation for Ingestion of BaP via Home-grown Produce

As discussed in Appendix A, the potential for the uptake of BaP into plants is considered to be limited and hence this pathway has not been considered in the calculation of the HIL A.

Calculation of the Residential HIL from all Exposure Pathways

The final HIL is calculated by combining the pathway-specific HILs calculated above using Equation 2 (for the complete pathways of exposure) (as rounded):

$$HIL\,(mg/kg) = \frac{1}{\left[\frac{1}{HIL_{ingestion}}\right]+\left[\frac{1}{HIL_{dermal}}\right]+\left[\frac{1}{HIL_{dust}}\right]} = \frac{1}{\frac{1}{5.6}+\frac{1}{4.6}+\frac{1}{10000}} = 2.5\,mg/kg = 3\,mg/kg \text{ (rounded to 1 s.f.)}$$

Equation 2

Based on these calculations, the HIL A for BaP = 3 mg/kg for the scenario presented.

3.2 Bibliography

EA 2009, *Updated technical background to the CLEA model,* Science report SC050021/SR3, Environment Agency, Bristol, UK.

MfE 2011, *Toxicological intake values for priority contaminants in soil*, New Zealand Ministry for the Environment, Wellington, New Zealand.

US EPA 1996, *Soil Screening Guidance: Technical Background Document*, EPA/540/R-95/128, United States Environmental Protection Agency, Washington, DC, USA.

US EPA 2002, *Supplemental guidance for developing soil screening levels for Superfund sites*, OSWER 9355.4-24, United States Environmental Protection Agency, Washington, DC, USA.

US EPA, 2005, *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposures to Carcinogens*. EPA/630/R-03/003F, United States Environmental Protection Agency, Washington, DC, USA.

WHO 2011, *Guidelines for drinking-water quality, 4th edn*, World Health Organization, Geneva, available from http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html .