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Soil Guideline Values for dioxins, furans and dioxin-like PCBs in soil

Science Report SC050021 / Dioxins SGV

This technical note is one in a series that describe Soil Guideline Values (SGVs) for individual, or groups of similar, chemicals to assist in the assessment of risks from land contamination.

SGVs are an example of generic assessment criteria (Defra and Environment Agency, 2004) and can be used in the preliminary evaluation of the risk to human health from long-term exposure to chemicals in soil. Specifically, this note provides SGVs for dioxins (PCDDs), furans (PCDFs), and dioxin-like polychlorinated biphenyls (PCBs) in soil – a group of structurally related chemicals which persist in the environment and are toxic (Defra, 2002). PCDDs and dioxin-like compounds are understood to have similar mechanisms of toxicity and so are considered together when assessing potential health risks, even though they may originate from different sources.

The SGVs and the additional advice found here should be used only in conjunction with the introductory guide to the series entitled *Using Soil Guideline Values* (Environment Agency, 2009a), the framework documents *Updated technical background to the CLEA model* (Environment Agency, 2009b) and *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c), and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Dioxins, furans and dioxin-like PCBs* (Environment Agency, 2009d). Supplementary information on dioxins and dioxin-like compounds is also available (Environment Agency, 2009e).

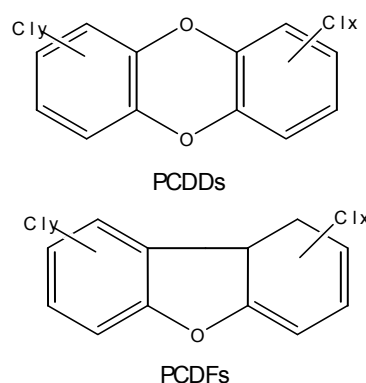
All notes in the SGV series, the introductory guide and further supplementary information can be downloaded from our website (<http://www.environment-agency.gov.uk/clea>).

Dioxins, furans and dioxin-like PCBs

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are an important group of environmental contaminants, which together form a structurally related group of 210 theoretical compounds. PCDDs and PCDFs have the general chemical formulae of $C_{12}H_{8-n}O_2Cl_n$ and $C_{12}H_{8-n}OCl_n$ respectively, with n representing the number of chlorine atoms (between one and eight) in the molecule (Environment Agency, 2007a). The generalised structures of PCDDs and PCDFs are presented in Figure 1. There are 75 different PCDD and 135 different PCDF compounds or **congeners**, depending on the number of chlorine atoms and ring substitution location.

Figure 1

Generalised structure of dioxins (PCDDs) and furans (PCDFs).



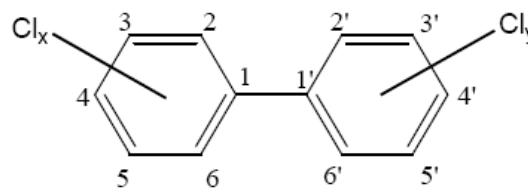
PCDDs and PCDFs can be divided into groups based on their degree of chlorination known as **homologues**, e.g. all hexachlorodibenzo-*p*-dioxins (HxCDDs) have six chlorine atoms in the molecule. Congeners containing the same number of chlorine atoms are members of the same homologous group.

Of the 210 theoretical compounds, 17 PCDDs and PCDFs have been identified as being of greatest toxicological concern (HPA, 2008) because of their similarity to the structure of the most toxic PCDD, which is 2,3,7,8-tetrachloro-*p*-dibenzodioxin (2,3,7,8-TCDD). Table 1 lists the homologous groups relevant to these PCDDs and PCDFs of toxicological concern and the abbreviations used in this report.

A number of polychlorinated biphenyls (PCBs) are also considered to possess dioxin-like toxicity and are known as 'dioxin-like PCBs' (Environment Agency, 2009d). PCBs have the general formula $C_{12}H_{10-n}Cl_n$, where n represents the number of chlorine atoms in the molecule, which can range from one to ten (Environment Agency, 2007b). Collectively, 209 PCB congeners are possible, and around 100 congeners have been reported in various commercial preparations and environmental samples (Beck *et al.*, 1996). PCBs can also be classified into homologous groups (see Table 1 for list of abbreviations used in this report). A generalised structure for PCBs is shown in Figure 2.

Figure 2

Generalised structure of biphenyl, showing chlorinated substitution position.



PCDDs and PCDFs are not produced intentionally (except in small amounts for research purposes), but are generated as by-products of combustion and as trace contaminants during the production of organochlorine compounds such as chlorophenols and chlorobenzenes (ATSDR, 1994, 1998; Fiedler, 1996; Alcock and Jones, 1997; Duarte-Davidson *et al.*, 1997; Environment Agency, 2007a).

PCBs are either oily liquids or solids; they are colourless to light yellow, tasteless and odourless (ATSDR, 2000). They are relatively insoluble in water but are freely soluble in non-polar organic solvents and biological lipids. Some PCBs are relatively volatile and may exist as a vapour in air (ATSDR, 2000). An important property of PCBs is their general inertness. PCBs resist reaction with both acids and alkalis, and are thermally stable, making them useful in a wide variety of applications including dielectric fluids in transformers and capacitors, heat transfer and hydraulic fluids, lubricants and as plasticisers in paints and plastics (IPCS, 1993, 2003).

Approximately 66,500 tonnes of PCBs were manufactured in the UK between 1954 and 1977 (Environment Agency, 2007b). They were sold and used commercially (under tradenames such as Arochlor) as complex mixtures of congeners that varied in their composition according to the manufacturer and intended use (IPCS, 1993; Environment Agency, 2007b). In response to the recognised environmental impact of PCBs, their production in the UK ceased in 1976, although the sale of PCBs in closed systems (e.g. electrical equipment) was permitted until 1986 (Defra, 2002). Harrad *et al.* (1994) estimated that, of the 40,000 tonnes of PCBs sold in the UK since 1954, only about 400 tonnes are now present in the environment with the remainder either still in use, transported away from the UK, or degraded/transformed.

Potential harm to human health

The principles behind the selection of Health Criteria Values (HCVs), and the definition of concepts and terms used, are outlined in *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c). Specific information on the toxicity of PCDDs, PCDFs and dioxin-like PCBs is reviewed in *Contaminants in soil: updated collation of toxicological data and intake values for humans. Dioxins, furans and dioxin-like PCBs* (Environment Agency, 2009d) and only a brief summary is presented here.

Table 1

Homologous groups of dioxins (PCDDs), furans (PCDFs), and PCBs considered in this report and the abbreviations used.

Homologue	Abbreviation
Dioxins (PCDDs)	
Tetrachlorodibenzo- <i>p</i> -dioxin	TCDD
Pentachlorodibenzo- <i>p</i> -dioxin	PeCDD
Hexachlorodibenzo- <i>p</i> -dioxin	HxCDD
Heptachlorodibenzo- <i>p</i> -dioxin	HpCDD
Octachlorodibenzo- <i>p</i> -dioxin	OCDD
Furans (PCDFs)	
Tetrachlorodibenzofuran	TCDF
Pentachlorodibenzofuran	PeCDF
Hexachlorodibenzofuran	HxCDF
Heptachlorodibenzofuran	HpCDF
Octachlorodibenzofuran	OCDF
Polychlorinated biphenyls (PCBs)	
Tetrachlorobiphenyl	TCB
Pentachlorobiphenyl	PeCB
Hexachlorobiphenyl	HxCB
Heptachlorobiphenyl	HpCB

Dioxin-like PCB compounds or congeners have a flat molecular structure (hence they are also referred to as 'coplanar PCBs'), with no or only one chlorine atom at an *ortho* position (i.e. at positions 2, 2', 6, or 6').

PCDDs and PCDFs are colourless solids or crystals with a low solubility in water and low volatility, although these properties vary significantly between congeners according to the degree of chlorination (ATSDR, 1994, 1998). PCDDs and PCDFs are highly lipophilic and readily partition to particles in air, water and soil.

2,3,7,8-TCDD is a proven human carcinogen although there is no convincing evidence that it possesses genotoxic potential (Environment Agency, 2009d). There have been few reported studies for other PCDDs and dioxin-like compounds.

The main non-cancer health effects induced by PCDDs and dioxin-like compounds (in either human or animal studies) are chloracne, immune system suppression, and reproductive and developmental toxicity (Environment Agency, 2009d).

The toxicity of compounds showing dioxin-like modes of action is considered additive, but the potency of such chemicals varies over orders of magnitude (Environment Agency, 2009d). The World Health Organization (WHO) has proposed toxic equivalency factors (TEFs) for 29 PCDDs and dioxin-like compounds based on comparison with 2,3,7,8-TCDD, which is considered to be the most potent congener. The TEF values for these PCDDs and dioxin-like compounds are listed in Table 2.

The WHO expert group that developed the current TEF scheme highlighted the inappropriateness of the direct application of TEF values to concentrations of dioxins and dioxin-like compounds in abiotic matrices including soil to calculate a total TEQ value for use in risk assessment (van den Berg *et al.*, 2006). It recommended that for human health risk assessments, congener-specific exposures should be considered to take into account aspects such as differences in fate, transport, and bioavailability of individual compounds.

Therefore, when assessing PCDDs, PCDFs and dioxin-like PCBs, the toxic equivalence (WHO-TEQ) of an individual compound (relative to 2,3,7,8-TCDD) is estimated by multiplying its estimated or measured exposure dose by the TEF values in Table 2. The overall toxicity of a mixture of PCDDs and dioxin-like compounds is assessed as the sum of the WHO-TEQ exposures for the individual compounds present (Environment Agency, 2009d).

Health Criteria Values (HCVs) for PCDDs, PCDFs and dioxin-like PCBs are summarised in Table 3.

The oral tolerable daily intake (TDI_{oral}), which is in line with the current recommendation of the UK Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT), is based on the low-dose effects of 2,3,7,8-TCDD on sperm production and morphology in the offspring of treated rats (Environment Agency, 2009d). The TDI_{oral} applies to the sum of WHO-TEQ exposure estimates for all PCDDs and dioxin-like compounds in Table 2.

Table 2

Recommended toxic equivalency factors (TEFs) according to the WHO system (van den Berg *et al.*, 2006; Environment Agency, 2009d).

Compound	WHO-TEF
PCDDs	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
PCDFs	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0003
Dioxin-like PCBs	
<i>non-ortho</i>	
3,3',4,4'-TCB (PCB-77)	0.0001
3,4,4',5-TCB (PCB-81)	0.0003
3,3',4,4',5-PeCB (PCB-126)	0.1
3,3',4,4',5,5'-HxCB (PCB-169)	0.03
<i>mono-ortho</i>	
2,3,3',4,4'-PeCB (PCB-105)	0.00003
2,3,4,4',5-PeCB (PCB-114)	0.00003
2,3',4,4',5-PeCB (PCB-118)	0.00003
2,3,4,4',5-PeCB (PCB-123)	0.00003
2,3,3',4,4',5-HxCB (PCB-156)	0.00003
2,3,3',4,4',5'-HxCB (PCB-157)	0.00003
2,3',4,4',5,5'-HxCB (PCB-167)	0.00003
2,3,3',4,4',5,5'-HpCB (PCB-189)	0.00003

Table 3

Recommended Health Criteria Values and estimated background adult intakes for PCDDs, PCDFs and dioxin-like PCBs (Environment Agency, 2009d).

Parameter	Dioxin-like compounds
TDI_{oral} , pg WHO-TEQ kg^{-1} bw day^{-1}	2
MDI_{oral} , pg WHO-TEQ day^{-1}	49

bw = bodyweight

MDI = mean daily intake

TDI = tolerable daily intake

WHO-TEQ = toxicity equivalence based on World Health Organization TEF scheme in Table 1

The adult oral mean daily intake (MDI_{oral}) from food and water combined is approximately 49 pg WHO-TEQ day^{-1} for the sum of PCDDs and dioxin-like compounds (Environment Agency, 2009d). The adult inhalation mean daily intake (MDI_{inh}) is estimated at 0.2 pg TEQ day^{-1} , and is therefore negligible in comparison with oral exposures.

No authoritative assessments of the health risks posed by inhalation or dermal exposures to PCDDs or dioxin-like compounds have been identified (Environment Agency, 2009d). There is no evidence to suggest that the toxicity of 2,3,7,8-TCDD and dioxin-like compounds is route-specific or that there is any notable first-pass metabolism following ingestion. The critical effects of exposure to PCDDs, PCDFs and dioxin-like PCBs are expected to be the same, irrespective of the route of exposure (Environment Agency, 2009d). Inhalation is likely to make only a small contribution to total exposure and therefore it is not unreasonable to also compare exposure via this route with the TDI_{oral} .

Exposure assessment

Emissions to soil

PCDDs and the dioxin-like compounds identified in Table 2 are ubiquitous in the environment and are found at very low levels in many soils and sediments due to their diffuse atmospheric deposition and persistence (ATSDR, 1998, 2000; Defra, 2002). PCDDs and PCDFs occur naturally as a result of forest fires, volcanic eruptions; they may also be formed as a by-product of some biochemical reactions such as in composts and the gut of cows (Fiedler, 1996; Defra, 2002). Lighter PCDDs and PCDFs may also be emitted to air from soils as vapour or dust particles depending on the environmental equilibrium between the air and soil compartments (Duarte-Davidson *et al.*, 1997). However, the contribution of these natural processes to total environmental emissions is considered to be low (Duarte-Davidson *et al.*, 1997; Environment Agency, 2007a). PCBs are not formed in nature, though their persistence has resulted in long-term movement between environmental compartments (Environment Agency, 2007b).

PCDDs and PCDFs are formed by the combustion of materials that contain even trace amounts of chlorine, including wood and plant matter such as straw, fossil fuels such as coal and oil, and the incineration of municipal and industrial waste (ATSDR, 1998; Defra, 2002, 2006a; Environment Agency, 2007a). Source emissions often contain a recognisable pattern or signature of PCDD and PCDF congeners and homologue groups, based on the combustion conditions (temperature, oxygen content, degree of control) and the types of material burned (Environment, 2007b). Fiedler (1996) observed a clear seasonal increase in ambient air concentrations of dioxins during the winter from monitoring in two German cities.

Since the early 1990s, successive control measures by the UK Government have resulted in a reduction of 70 per cent in aerial emissions of PCDDs and PCDFs from regulated processes including waste incineration, iron and steel manufacture, power generation and the

burning of agricultural straw (Environment Agency, 2007a). In an emissions inventory for 2004, Defra (2006a) concluded that the largest sources of PCDD and PCDF emissions were accidental fires, small waste combustion processes and agricultural waste burning (although the analysis contained considerable uncertainties).

Most PCDDs and PCDFs enter soil via atmospheric deposition and the disposal/reuse of combustion residues such as flyash and metaliferous slags (Fiedler *et al.*, 1995; Duarte-Davidson *et al.*, 1997; ATSDR, 1998; Cousins and Jones, 1998; Pless-Mulloli *et al.*, 2000; Defra, 2006a; Badreddine and François, 2009). However, they may also be formed as by-products in the manufacture of chlorinated aromatics including pesticides and other industrial chemicals such as pentachlorophenol (PCP) and *p*-chloranil, and become distributed in soil through the use of these products or disposal of wastes (Beck *et al.*, 1996; Alcock and Jones, 1997; Duarte-Davidson *et al.*, 1997; ATSDR, 1998; Defra, 2002; Vizard *et al.*, 2006). PCDDs and PCDFs are ubiquitous in the environment and, as a result, are found in urban waste waters, composts, sewage sludge, and sludge-amended soils (Wild *et al.*, 1995; Beck *et al.*, 1996; Fiedler, 1996; Duarte-Davidson *et al.*, 1997; Stevens *et al.*, 2001).

Hassanin *et al.* (2006) investigated the PCDD and PCDF concentrations in archived herbage samples taken between the mid-1800s and the present day. They observed a marked reduction in PCDD and PCDF levels over this period and a shift in the congener pattern from inefficient combustion processes associated with domestic heating using coal and wood, to the rise and then fall in congeners associated with the production and use of PCP. Over the period 1960–2004, they observed a much lower contribution from less chlorinated PCDFs and a much larger contribution from HpCDDs and OCDDs.

Small quantities of some PCBs are released during specific types of combustion, but these account for only a small proportion of the total mass emitted (Defra, 2006b). Although PCBs have not been manufactured and used in the UK for many decades, old PCB-containing electrical equipment still exists and it is estimated that 68 per cent of unintentional emissions to air are associated with such in-service appliances and their decommissioning/disposal. Lighter PCBs may also be emitted to air as a result of recycling contamination from previously polluted soils (Coleman *et al.*, 1997; Defra, 2002, 2006a). PCB emissions are estimated to have fallen by 78 per cent between 1990 and 2001, and the release of total PCBs to air in 2004 was estimated at 1,330 kg (Defra, 2006b).

It has been proposed that the environmental recycling of lighter PCBs from existing soil contamination is the most important contributor to the current atmospheric burden in the UK (Coleman *et al.*, 1997; Defra, 2002, 2006a). However, recent studies have suggested that levels in indoor air from paints and sealants may be a major source of PCBs in ambient air within large towns and cities (Harrad *et al.*, 2006; Jamshidi *et al.*, 2007; Jartun *et al.*, 2009).

Table 4

Median soil concentrations and observed relative proportions of different PCDDs, PCDFs and dioxin-like PCBs found across the UK in rural and urban locations based on median soil concentrations in ng kg⁻¹ DW for England, Northern Ireland, Scotland and Wales (Environment Agency, 2007a,b).

Compound	Median concentration in rural soils	Rural soils (per cent weight)			Median concentration in urban soils	Urban soils (per cent weight)		
	ng kg ⁻¹ DW	PCDD/Fs	PCBs	All	ng kg ⁻¹ DW	PCDD/Fs	PCBs	All
Dioxins								
2,3,7,8-TCDD	0.17	0.2		0.1	0.35	0.2		0.1
1,2,3,7,8-PeCDD	0.52	0.5		0.2	1.37	0.7		0.3
1,2,3,4,7,8-HxCDD	0.56	0.6		0.2	1.56	0.7		0.3
1,2,3,6,7,8-HxCDD	0.94	0.9		0.4	2.90	1.4		0.5
1,2,3,7,8,9-HxCDD	1.10	1.1		0.5	2.58	1.2		0.5
1,2,3,4,6,7,8-HpCDD	11.1	10.9		4.8	25.2	12.0		4.6
OCDD	60.7	59.9		26.5	104	49.5		19.1
Furans								
2,3,7,8-TCDF	0.79	0.8		0.3	2.45	1.2		0.4
1,2,3,7,8-PeCDF	0.80	0.8		0.3	2.76	1.3		0.5
2,3,4,7,8-PeCDF	1.17	1.2		0.5	4.10	2.0		0.8
1,2,3,4,7,8-HxCDF	1.34	1.3		0.6	3.57	1.7		0.7
1,2,3,7,8,9-HxCDF	0.50	0.5		0.2	1.09	0.5		0.2
1,2,3,6,7,8-HxCDF	0.95	0.9		0.4	2.59	1.2		0.5
2,3,4,6,7,8-HxCDF	1.20	1.2		0.5	3.83	1.8		0.7
1,2,3,4,6,7,8-HpCDF	8.49	8.4		3.7	24.2	11.5		4.4
1,2,3,4,7,8,9-HpCDF	0.77	0.8		0.3	1.41	0.7		0.3
OCDF	10.3	10.2		4.5	26.0	12.4		4.8
Dioxin-like PCBs								
<i>non-ortho</i>								
PCB-77	4.74		3.7	2.1	15.7		4.7	2.9
PCB-81	0.49		0.4	0.2	1.42		0.4	0.3
PCB-126	2.59		2.0	1.1	4.65		1.4	0.9
PCB-169	1.11		0.9	0.5	1.25		0.4	0.2
<i>mono-ortho</i>								
PCB-105	25.1		19.7	11.0	73.7		22.0	13.5
PCB-114	1.77		1.4	0.8	3.76		1.1	0.7
PCB-118	60.6		47.5	26.5	171		51.0	31.4
PCB-123	2.74		2.1	1.2	6.2		1.9	1.1
PCB-156	15.0		11.8	6.6	32.4		9.7	5.9
PCB-157	3.77		3.0	1.6	7.54		2.3	1.4
PCB-167	6.71		5.3	2.9	12.5		3.7	2.3
PCB-189	2.88		2.3	1.3	4.90		1.5	0.9
Total PCDDs and PCDFs	101				210			
Total dioxin-like PCBs	128				335			
Total	229				545			

PCBs are deposited on soil from the atmosphere by wet and dry deposition processes (Cousins *et al.*, 1999). Pollution has also occurred as a result of their use in open applications such as in flame retardants, pesticides, surface coatings and paints, and wire insulators, and from leaks/disposal of oils and fluids from closed system equipment (ATSDR, 2000; Environment Agency, 2007b).

PCBs are ubiquitous in urban waste waters and may be found in sewage sludge and sludge-amended soils (Wild *et al.*, 1995; Beck *et al.*, 1996; Stevens *et al.*, 2001). Stevens *et al.* (2003) surveyed digested sludge from 14 UK waste water treatment plants for PCBs (excluding the non-*ortho* congeners in Table 2) and other persistent organic compounds. The mean PCB content of the mono-*ortho* dioxin-like PCBs was 12.2 $\mu\text{g kg}^{-1}$ dry weight (DW), with PCB 118 and PCB 123 making up over 80 per cent of the mass.

Retrospective analysis of archived UK soils has shown that they exhibited a sharp rise in PCB soil concentrations between about 1940 and the early 1960s, reaching a maximum during the late 1960s and early 1970s (Cousins and Jones, 1998). After this peak, PCB concentrations declined sharply to 1940s levels, a reduction that has been primarily attributed to re-volatilisation of lighter PCBs and subsequent long-range atmospheric transport (Cousins and Jones, 1998).

Profiles in soil

Source emissions of PCDDs and PCDFs have been reported to have characteristic signatures for the different congeners depending on various factors including combustion conditions and types of material burned. In the case of PCBs, the proportion of different congeners depends upon temperature and the commercial formulation or Arochlor used (ATSDR, 1998, 2002; Environment Agency, 2007a,b).

However, several studies including the UK Soil and Herbage Survey (UK SHS) have reported broadly similar congener patterns for PCDDs, PCDFs and dioxin-like PCBs for soils sampled from across the UK and between rural/urban locations (Environment Agency, 2007a,b). The loss of any clear source signature or congener profile may be the result of several different factors including:

- aerial transport and mixing processes;
- wet and dry deposition from air to soil;
- atmospheric destruction of gas phase PCDDs and PCDFs via reaction with hydroxyl radicals;
- greater persistence of higher chlorinated dioxins/furans and heavier molecular weight PCBs in soil leading to relative enrichment;
- soils acting as a long-term sink for PCDDs and dioxin-like compounds resulting in the integration of source terms over time.

Cousins and Jones (1998) observed that PCBs are very well mixed in the UK environment and that the variability in the soil levels around the UK (in the absence of a strong, local point source) is now small. They considered this to be due to a significant reduction in primary

emissions and the continuous recycling of PCBs between environmental compartments, resulting in a move towards equilibrium partitioning conditions.

The UK SHS is a comprehensive survey of the concentrations of major contaminants in soils and herbage across the UK. It found that the congener and homologue patterns for PCDDs and PCDFs observed in the national study were broadly similar across the four countries of the UK, and for rural, urban and industrial sites (Environment Agency, 2007a). The study concluded that the “broad similarity in congener/homologue profiles in urban and rural soils and herbage confirms earlier work that concluded that source congener signatures are lost relatively rapidly following emission through atmospheric weathering and the mixing of the air mass over the UK.” Similarly, the study also found that, despite the differences in PCB concentrations across land use, “PCB congener profiles in rural, urban and industrial soils and herbage were broadly similar” (Environment Agency, 2007b).¹

Table 4 presents the relative proportions of PCDDs, PCDFs and dioxin-like PCBs found in urban and rural soils based on the median soil concentrations reported for all four countries in the UK SHS study (Environment Agency, 2007a,b).

Although generic profiles have been identified in national studies such as the UK SHS (Environment Agency, 2007a,b), it is important to recognise that local and site-specific profiles can be very different and reflect more closely the source signature. These sources will be increasingly important where aerial deposition following longer-scale transport and mixing is not the primary polluting mechanism and/or where contamination is relatively recent (Duarte-Davidson *et al.*, 1997). Cachada *et al.* (2009) observed that the PCB congener profile found in urban soils from Glasgow was similar to that found in Arochlor 1254 and 1260, reflecting discrete local sources including sealants, paints and possibly leaks from electrical equipment.

Levels in soil

The UK SHS reported concentrations for individual PCDD and PCDF congeners (Environment Agency, 2007a). In urban locations, the mean concentration of the most toxic congener 2,3,7,8-TCDD was 0.5 ng kg^{-1} DW with a range from 0.03 to 2.9 ng kg^{-1} DW across England, Wales, Scotland and Northern Ireland. The most prevalent congener was OCDD with a mean of 200 ng kg^{-1} DW and a range of 2.7 to 4050 ng kg^{-1} DW. Levels in urban soils were reported to be higher than those sampled at rural locations (Environment Agency, 2007a). Table 4 presents the median soil concentrations reported by the UK SHS for individual PCDD and PCDF congeners for rural and urban locations across the UK.

¹ UK SHS also observed that rural soils were relatively enriched with lower molecular weight PCBs including PCB 18, PCB 31, PCB 49 and PCB 52 (Environment Agency, 2007b). However, they are not dioxin-like and do not appear in Table 1.

The UK SHS also reported concentrations for the 12 dioxin-like PCBs listed in Table 1 (Environment Agency, 2007b). The most prevalent congener found at urban locations was PCB-118 with a mean concentration of 285 ng kg⁻¹ DW and a range from 7.3 to 3,220 ng kg⁻¹ DW. In general, urban PCB soil concentrations were found to be twice those in rural locations (Environment Agency, 2007b). Table 4 presents the median soil concentrations reported by the UK SHS for individual dioxin-like PCBs listed in Table 1 for rural and urban locations across the UK.

The UK SHS reported mean concentrations for total PCDDs, PCDFs and dioxin-like PCBs of 930 and 1,041 ng kg⁻¹ DW for rural and urban locations respectively, based on the data for England, Northern Ireland, Scotland and Wales (Environment Agency, 2007b).

Creaser *et al.* (1989) collected soil samples from 77 locations across England, Wales and southern Scotland using a 50 km grid. They found median concentrations of PCDDs in ng kg⁻¹ DW of 7 and 155 for TCDD and OCDD respectively, and for PCDFs of 19 and 21 for TCDF and OCDF respectively. Concentrations of TCDD and TCDF were significantly higher than those found in the more recent UK SHS study.

Creaser *et al.* (1990) also investigated soil levels of PCDDs and PCDFs in four UK cities (London, Birmingham, Leeds, Sheffield) and one town (Port Talbot). They found median soil concentrations for PCDDs ranging from 40 ng kg⁻¹ DW for TCDD to 469 ng kg⁻¹ DW for OCDD, and for PCDFs ranging from 40 ng kg⁻¹ DW for OCDF to 140 ng kg⁻¹ DW for TCDF. These concentrations are much higher than those found in the UK SHS suggesting that overall levels have declined (Environment Agency, 2007a). Creaser *et al.* (1990) concluded that the higher concentrations for the more mobile congeners established the importance of local sources.

Behaviour in the soil environment

Recommended values for chemical data used in the exposure modelling of the 29 congeners listed in Table 2 can be found in *Supplementary information for the derivation of SGVs for dioxins, furans, and dioxin-like PCBs* (Environment Agency, 2009e). The report also provides information about the review and recommendations for the soil-to-plant concentration factors used and only a brief summary is presented here.

PCDDs and PCDFs are highly persistent compounds and have been detected in air, water, soil, sediments, animals and foods (Duarte-Davidson *et al.*, 1997; ATSDR, 1998). PCDDs and PCDFs partition strongly to soils and sediments where, due to their low vapour pressure, low aqueous solubility and strong sorption to organic matter, they become generally immobile (ATSDR, 1994, 1998; Wild *et al.*, 1995). Duarte-Davidson *et al.* (1997) estimated that over 99 per cent of the UK terrestrial burdens of PCDDs and PCDFs reside in soil. In general, higher chlorinated PCDDs are likely

to volatilise more slowly from soil than lower chlorinated congeners (ATSDR, 1998).

PCDDs and PCDFs have a strong affinity for lipids, as suggested by their high octanol–water partition coefficients (K_{ow}) and have been shown to bioaccumulate in both aquatic and terrestrial organisms (ATSDR, 1994, 1998; Environment Agency, 2009e). However, there is some evidence that PCDFs have a lower bioaccumulation potential in fish than might be expected from their chemical properties alone because of partial metabolism (ATSDR, 1994).

Most biological and abiotic transformation and degradation processes for PCDDs are slow, with photolysis in sunlight being the most rapid (ATSDR, 1998). This is illustrated by the relatively shorter half-life of 2,3,7,8-TCDD in surface soils (9–15 years) compared with 25–100 years in the sub-surface (ATSDR, 1998). McLachlan *et al.* (1996) observed that over 50 per cent of the PCDDs and PCDFs present in a sludge-amended soil in 1972 were still present in 1990, and that the uniform reduction in all homologues was indicative of physical loss of material.

The organic carbon content of soil is considered to be the most important factor governing the extent of adsorption of PCDDs and PCDFs (ATSDR, 1994, 1998; Cousins and Jones, 1998; Fan *et al.*, 2006). The range of organic carbon–water partition coefficients (K_{oc} values) reported for PCDDs and PCDFs indicate that most congeners will be strongly bound to organic matter (Wild *et al.*, 1995; Environment Agency, 2009e). Mobility of PCDDs and PCDFs may be increased by co-solvency and/or through the transport of dissolved organic matter /mobilised particulates in water and air (Orazio *et al.*, 1992; ATSDR, 1994, 1998; Dougherty *et al.*, 1994).

The primary mechanisms by which PCDDs and PCDFs enter the food chain are by atmospheric wet and dry deposition on foliar and soil surfaces from the vapour phase and particulate matter (Müller *et al.*, 1993, 1994; ATSDR, 1994, 1998; Eduljee and Gair, 1996; Smith and Jones, 2000). Hülster and Marschner (1993) noted that, under certain circumstances, contamination of crops by soil particles can also be an important pathway for accumulation. Root uptake of PCDDs via the soil solution is likely to be a relatively minor pathway because of the strong sorption of PCDDs within soil and their relatively low aqueous solubility (ATSDR, 1998; Meneses *et al.*, 2002; Schumacher *et al.*, 2006; Environment Agency, 2009e). However, the exception appears to be plants from the Cucurbitaceae family including zucchini and pumpkin, where the release of root exudates is one possible explanation of their behaviour (ATSDR, 1998; Smith and Jones, 2000; Environment Agency, 2009e).

PCB behaviour in soil systems will depend on the extent of chlorination and the degree of ring substitution at the *ortho*-position (ATSDR, 2000). More highly chlorinated PCBs and those with few (if any) substitutions at the *ortho*-position, including the dioxin-like PCBs in Table 2, tend to have the lowest volatility and solubility – and the highest K_{ow} and K_{oc} values – within the group suggesting

they are more persistent and immobilised by soil and sediments (Harrad *et al.*, 1994; Wild *et al.*, 1995; ATSDR, 2000). PCBs are strongly sorbed by soil organic matter as a result of their low water solubility and high K_{ow} values (Wild *et al.*, 1995; Cousins *et al.*, 1999; ATSDR, 2000; Meijer *et al.*, 2003; Environment Agency, 2007b). However, Doick *et al.* (2005) suggested that the mineral fraction of soil may be more important in PCB sequestration than earlier work had indicated.

PCBs can be degraded in soils under both aerobic and anaerobic conditions (ATSDR, 2000; Environment Agency, 2007b). Although PCBs have a relatively low volatility, this is still an important transport process for PCBs in the environment and contributes significantly to their recycling between soil, air and water (ATSDR, 2000; Environment Agency, 2007b). However, PCBs with fewer chlorines in the *ortho* substitution position more readily condense from the atmosphere than other PCBs (ATSDR, 2000).

It has been reported that volatilisation of PCBs from soil depends on ambient temperature, organic matter content, soil moisture and the equilibrium position between soil and air (Cousins and Jones, 1998; Halsall *et al.*, 1999; ATSDR, 2000). Air–soil exchange may be the key process that controls the soil concentration of persistent chemicals such as PCBs with evidence that, in the past few decades, soil has been both a sink and a source for PCBs in the UK atmosphere (Cousins and Jones, 1998). Co-evaporation with water is considered an important process for increasing the volatilisation of PCBs from soils and sediments. Since the production and new use of PCBs ceased, the soil has become a major reservoir for these compounds and an important source for releasing PCBs into the atmosphere (Harrad *et al.*, 1994; ATSDR, 2000).

PCBs have been shown to bioaccumulate in aquatic and terrestrial organisms with those in the penta-, hexa-, and hepta- homologous groups demonstrating the highest potential (ATSDR, 2000; Environment Agency, 2007b). Plant uptake of PCBs is primarily through vapour-to-plant transfer for the lighter PCBs and aerial dry deposition for hepta- and octa- homologous groups (ATSDR, 2000; Environment Agency, 2007b). Plant uptake via the root system is generally negligible, although it may be significant for highly chlorinated PCBs through direct contact and especially so for those plants such as carrot with a lipid-rich epidermal layer (ATSDR, 2000; Environment Agency, 2007b).

PCDDs, PCDFs and dioxin-like PCBs have been reported to accumulate in fat-rich foods including fish, meat, eggs and dairy produce (Travis and Hattemer-Frey, 1991; Wild *et al.*, 1995; ATSDR, 1998, 2000; Harnly *et al.*, 2000). Lake *et al.* (2005) observed higher concentrations of PCDDs and dioxin-like compounds in cow's milk on farms where the pasture land was prone to flooding, and where chemical concentrations in soil and herbage were elevated. Several studies have investigated the accumulation of dioxins and dioxin-like compounds in eggs and poultry, with probable transfer mechanisms including contaminated feed and inadvertent soil ingestion during foraging (Schuler *et al.*,

1997; Harnly *et al.*, 2000; Pless-Mullooli *et al.*, 2001; Waegeneers *et al.*, 2009).

Dermal absorption of PCDDs and PCDFs is not expected to be significant. Roy *et al.* (2008) investigated dermal absorption of radiolabelled 2,3,7,8-TCDD by human skin *in vitro* from a soil consisting of 15 per cent sand, 68 per cent silt, 17 per cent clay and 0.8 per cent soil organic matter (SOM). After taking into account exposure duration and the amount of soil adhered to the skin, they concluded that dermal absorption was around 1.9 per cent. This is consistent with the dermal absorption fraction (ABS_d) of 0.03 recommended by USEPA (2004a) for TCDD and other dioxins. The ABS_d applies to soils with an organic matter content of less than 10 per cent (USEPA, 2004a) and has been used here in the derivation of SGVs.

Wester *et al.* (1993) studied the *in vitro* percutaneous absorption of the PCB mixtures Arochlor 1242 and 1254 applied in soil. They detected around 2.6 per cent PCBs in the human skin samples after the soil was removed and the skin sample washed with soap and water. Mayes *et al.* (2002) investigated dermal absorption of radiolabelled Arochlor 1260 from soil by Rhesus monkeys and concluded that the factor controlling percutaneous absorption was soil organic matter content. Roy *et al.* (2009) investigated *in vitro* percutaneous absorption of radiolabelled 3,3',4,4'-TCB (PCB 77) in human skin. After 24 hours, the total amount of PCB 77 absorbed was 1.3 per cent – a similar but lower amount than observed by Wester *et al.* (1993), although there were clear methodological differences. The US Environmental Protection Agency (USEPA) recommended an ABS_d value of 0.14 applicable to Arochlors 1254/1242 and other PCBs based on the study by Wester *et al.* (USEPA, 2004b). This value has been used in the derivation of SGVs.

A review of the literature found no data that could be used to provide a generalised soil-to-dust transport factor for PCDDs, PCDFs and dioxin-like PCBs. Franzblau *et al.* (2009) investigated a number of homes in Michigan with high concentrations of PCDDs, PCDFs and dioxin-like PCBs in house dust, concluding that in only two of 20 cases was soil from around the home the likely source of house dust contamination. Vorhees *et al.* (1999) found no correlation between PCB concentrations in soil and house dust in 34 homes surrounding New Bedford Harbor, Massachusetts. In the absence of a contaminant-specific soil-to-dust transport factor, the default value of $0.5 \text{ g g}^{-1} \text{ DW}$ has been used.

SGVs and site-specific assessments

Soil Guideline Values (SGVs) for dioxins (PCDDs), furans (PCDFs) and dioxin-like PCBs are presented according to land use in Table 5. These are applicable to soils where the profile of individual PCDDs and dioxin-like compounds is consistent with a generic pattern observed widely across the UK. Worksheets are provided in Appendix 1 to allow the assessment of soils where the congener profile is different from this pattern.

For residential and allotment land uses, SGVs are based on estimates representative of exposure of young children because they are generally more likely to have higher exposures to soil contaminants. Further information on the default exposure assumptions used in the derivation of SGVs can be found in *Updated technical background to the CLEA model* (Environment Agency, 2009b).

The SGVs and the worksheets in Appendix 1 (see below) are based on comparing the sum of the individual congener-specific exposures, adjusted for relative toxicity to 2,3,7,8-TCDD using the WHO-TEF scheme, with the group TDI_{oral}. This is consistent with both the Hazard Index approach described in Environment Agency (2009c), which is applicable where two or more compounds share a common mode of toxic action, and the recommendations of the WHO expert group that produced the current TEF scheme (van den Berg *et al.*, 2006).

For each congener i , the average daily exposure from soil (ADE _{i}) was calculated using Equation 1.

Equation 1

$$ADE_i = C_i \times EF_i \times TEF_i$$

Where

ADE _{i}	Average daily exposure from soil, pg WHO-TEQ kg ⁻¹ bw day ⁻¹
C _{i}	Soil concentration, ng kg ⁻¹ DW
EF _{i}	Exposure factor, pg kg ⁻¹ BW day ⁻¹ per ng kg ⁻¹ DW soil
TEF _{i}	Toxic equivalency factor, pg WHO-TEQ pg ⁻¹
i	is the specific PCDD, PCDF, or dioxin-like PCB congener

The exposure factor (EF _{i}) for each congener was estimated using the CLEA software. EF _{i} is the sum of the average exposure from soil for all relevant pathways per unit concentration of the congener in soil according to the standard land-use scenario (Environment Agency, 2009b). The fate and transport of each congener was modelled separately using the physical-chemical data reported in the supplementary information (Environment Agency, 2009e). EF _{i} assumes that there is a linear relationship between exposure and soil concentration, which is applicable at levels below the soil saturation limit using the CLEA software.

In the derivation of the SGVs, C _{i} is estimated from the relative contribution of each congener at the median soil concentration to the total concentration of PCDDs and dioxin-like compounds in soils from urban locations in

the UK SHS (see Table 4 and nearby text box). In the worksheets in Appendix 1, C _{i} is specified by the user as a representative soil concentration from observed or measured data.

Using generic representative estimates of congener concentrations from UK soils in setting SGVs

The SGVs for PCDDs, PCDFs and dioxin-like PCBs apply to the sum of the soil concentrations for the individual congeners/compounds in Table 2. It was therefore necessary in deriving an SGV for a mixture of the 29 compounds in Table 2 to make an assumption about the relative proportions of different congeners in the mixture (within the soil) in order to estimate congener-specific soil concentrations.

The SGVs are derived assuming a generic profile or congener pattern that was based on the results of the UK SHS for urban soils, using the median concentrations for each congener from the combined data for England, Northern Ireland, Scotland and Wales (Environment Agency, 2007a,b). The contribution from each congener in terms of per cent weight is presented in Table 4.

It is clear that in most cases, PCDDs/PCDFs and dioxin-like PCBs originate from different primary sources. The UK SHS observed a common congener soil profile within PCDDs/PCDFs and dioxin-like PCBs respectively (Environment Agency, 2007a and 2007b). Although the survey did not examine whether there was a common profile across the group of dioxins and dioxin-like compounds as a whole, it is considered reasonable to conclude that the median soil concentrations from the UK SHS of all PCDDs and dioxin-like compounds represent a common generic profile because:

- Contamination was observed to occur from a common secondary source (the UK air mass) after mixing and transport
- Soil represents a sink for these compounds and therefore over long periods is an effective integrator of different sources

It is also important to note that the effect of this assumption on the SGVs in this report is low, primarily because of the lower general prevalence and much lower toxicity of the dioxin-like PCBs relative to the PCDD/PCDF congeners.

The soil concentration for an individual congener/compound is estimated by multiplying the total soil concentration by the weight fraction for the specific congener (ng ng⁻¹). For example, assuming a total soil concentration of 100 ng kg⁻¹ DW, the weight fraction for 2,3,7,8-TCDD from Table 3 is 0.001 (0.1/100), resulting in an estimated congener concentration of 0.1 ng kg⁻¹ DW for 2,3,7,8-TCDD.

The Hazard Index (HI) for PCDDs, PCDFs, and dioxin-like PCBs was calculated using Equation 2.

Equation 2

$$HI = \frac{\sum ADE_i}{TDSI}$$

Where

HI Hazard Index all congeners
 ADE_i Average daily exposure from soil, pg WHO-TEQ kg⁻¹ bw day⁻¹
 TDSI Tolerable Daily Soil Intake for PCDDs, PCDFs, and dioxin-like PCBs, pg WHO-TEQ kg⁻¹ bw day⁻¹
i is the specific PCDD, PCDF, or dioxin-like PCB congener

SGVs should be compared directly (i.e. not adjusted for toxic equivalence, as this has been taken into account in the derivation of the SGV) with the sum of the congener-specific soil concentrations of all 29 compounds listed in Table 2. Such a comparison is valid only where the relative concentrations of individual congeners is consistent with the assumed profile or pattern used to derive the SGVs (see text box for further discussion). This pattern or profile will depend on contamination source, deposition history, and the effects of weathering / aging in soil.

The SGVs are based on the generic pattern or profile for PCDDs, PCDFs, and dioxin-like PCBs, which was consistently observed for rural and urban soils by the UK SHS (Environment Agency, 2007a and 2007b). This profile reflects input from general diffuse pollution over many years rather than contamination from a relatively recent or specific point source and assumes that:

- there is no strong local or on-site signature
- contamination has resulted primarily from aerial deposition, following transport and mixing of different sources in the regional air mass
- soil aging and weathering has resulted in the integration of different source terms in soil and a relative enrichment in more inert / immobile congeners

In many cases, it will not be appropriate to apply the SGVs to a suspected contaminated site, especially where the preliminary risk assessment has highlighted a potential on-site source such as made ground or a leak from electrical equipment. The reason for this is that the relative proportions of the individual congeners within the soil may be quite different from the generic profile assumed in the derivation of the SGVs. Often the risk to human health from PCDDs and dioxin-like compounds in soil depends on the relative concentrations of the lower chlorinated congeners to the higher chlorinated congeners because the former generally have greater environmental mobility and higher human toxicity.

Where the site-specific congener pattern or profile is not similar to that presented in Table 4, the worksheets in

Appendix 1 are available.² The worksheets can be used by an assessor to estimate the total exposure, adjusted for toxic equivalence, from the sum of individual congener-specific exposures based on soil concentrations for the 29 congeners in Table 2. The worksheets do not assume a common congener pattern or profile but require representative site-specific data for each congener to be entered separately. The worksheets cannot be used to derive an SGV but enable a site-specific comparison of total exposure from soil (pg WHO-TEQ kg⁻¹ BW day⁻¹) for the critical receptor with the TDSI.

Analytical limits of detection³ for speciated PCDD and PCDF congeners range from 0.3 to 3.8 ng kg⁻¹ DW, and for speciated PCBs between 1.8 and 12.7 ng kg⁻¹ DW. Individual congeners have different analytical limits because of instrument sensitivity and also due to the inherent levels of the different congeners used in blanks and reference materials. Corresponding analytical limits of quantification⁴ range from 1.5 to 20 ng kg⁻¹ DW for PCDDs and PCDFs, and between 9 and 64 ng kg⁻¹ DW for PCBs. MCERTS⁵ accredited analytical methods for PCDDs, PCDFs and dioxin-like PCBs in soil and herbage are available.

Table 5

The Soil Guideline Values for PCDDs, PCDFs and dioxin-like PCBs presented in this table should only be used in conjunction with the information contained in this briefing note and with an understanding of the exposure and toxicological assumptions contained in *Updated technical background to the CLEA model* (Environment Agency, 2009b), *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c) and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Dioxins, furans and dioxin-like PCBs* (Environment Agency, 2009d).

Land use	Soil Guideline Value (µg kg ⁻¹ DW) ^{1,2,3,4}
	Sum of PCDDs, PCDFs and dioxin-like PCBs
Residential	8
Allotment	8
Commercial	240

Notes: ¹ Figures are rounded to one or two significant figures
² Based on a sandy loam soil as defined in Environment Agency (2009b) and 6 per cent SOM.
³ Based on an assumed soil profile for urban soils.
⁴ SGV should be compared with sum of the soil concentrations of all congeners in Table 2.

² The worksheets assume the same exposure scenario as used for the SGV for the residential, allotment, and commercial land-uses. They are also available in electronic form from our website (<http://www.environment-agency.gov.uk/clea>).

³ The amount of a substance that can be detected, but not quantitatively measured

⁴ Amount present of a substance that can be quantitatively measured

⁵ Environment Agency's Monitoring Certification Scheme

Table 6

Contribution to total exposure ($\text{pg kg}^{-1} \text{ BW day}^{-1}$) for the relevant pathways as calculated by the CLEA software for each homologous group according to the standard land use scenarios and a generic soil profile. These figures do not take into account toxic equivalence to 2,3,7,8-TCDD.

Compound ¹	Contribution to total soil exposure (%) ²														
	Residential					Allotments					Commercial				
	soil ingestion	consumption of homegrown produce	dermal contact	inhalation of dust	inhalation of vapour	soil ingestion	consumption of homegrown produce	dermal contact	inhalation of dust	inhalation of vapour	soil ingestion	consumption of homegrown produce	dermal contact	inhalation of dust	inhalation of vapour
Dioxins															
TCDD	71.2	17.6	11.0	0.2	<0.1	13.7	84.2	2.1	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
PeCDD	71.5	17.3	11.0	0.2	<0.1	14.0	83.9	2.1	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
HxCDD	75.9	12.2	11.7	0.2	<0.1	19.5	77.6	2.9	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
HpCDD	83.0	4.0	12.8	0.3	<0.1	43.0	50.6	6.4	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
OCDD	85.1	1.5	13.1	0.3	<0.1	62.6	28.1	9.3	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
Furans															
TCDF	73.3	15.2	11.3	0.2	0.1	16.0	81.6	2.4	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
PeCDF	73.4	15.1	11.3	0.2	<0.1	16.0	81.6	2.4	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
HxCDF	77.2	10.7	11.9	0.2	<0.1	21.9	74.8	3.3	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
HpCDF	82.7	4.3	12.8	0.3	<0.1	41.1	52.7	6.1	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
OCDF	84.1	2.7	13.0	0.3	<0.1	51.9	40.4	7.7	<0.1	<0.1	94.7	NA	4.7	0.6	<0.1
Dioxin-like PCBs															
TCB	57.4	1.0	41.3	0.2	<0.1	46.6	20.9	32.5	<0.1	<0.1	80.8	NA	18.7	0.5	<0.1
PeCB	57.6	0.8	41.5	0.2	<0.1	49.3	16.4	34.3	<0.1	<0.1	80.8	NA	18.7	0.5	<0.1
HxCB	57.7	0.7	41.5	0.2	<0.1	50.1	15.0	34.9	<0.1	<0.1	80.8	NA	18.7	0.5	<0.1
HpCB	57.7	0.7	41.5	0.2	<0.1	50.4	14.5	35.1	<0.1	<0.1	80.8	NA	18.7	0.5	<0.1

Notes: ¹ See Table 1 for complete list of abbreviations.

² All values have been rounded to one decimal place.

NA = not applicable (this exposure pathway is not included in the generic land use)

Many analytical laboratories will report PCDD, PCDF, and dioxin-like PCB results in terms of one of the toxicity equivalency (TEQ) or TEF schemes. It is important that speciated soil concentration data used in the worksheets in Appendix 1 or used for comparison with the SGVs in Table 5 has not previously been adjusted for TEQ.

Further risk evaluation

The SGVs in Table 5 and the worksheets in Appendix 1 are based on a consideration of the total systemic exposure via the oral, dermal and inhalation routes. Although the degree of absorption of PCDDs and dioxin-like compounds by the human body might be as much as a factor of two higher by the inhalation route relative to the oral route, the former makes a negligible contribution to total exposure for the standard land use scenarios. Therefore, all pathways of exposure have been compared with the TDI_{oral} .

Table 6 presents the estimated contribution via each exposure pathway to total soil exposure according to homologous group for PCDDs, PCDFs and dioxin-like PCBs according to land use. It should be noted that these data have not been adjusted for toxicity and so, whilst useful for understanding the importance of different pathways, should not be used in isolation to evaluate risk-driving pathways. The data show that:

- the pattern of exposure for PCDDs and PCDFs is similar, with the contribution to total exposure from soil ingestion and dermal contact increasing with the degree of chlorination;
- the contribution to total exposure from the consumption of homegrown produce decreases with increasing chlorination and is much lower overall for dioxin-like PCBs compared with PCDDs and PCDFs;
- dioxin-like PCBs have a similar exposure pattern irrespective of the degree of chlorination with a much higher contribution from dermal pathways;
- soil ingestion is the most important pathway for all land use scenarios for dioxin-like PCBs and, for residential and commercial land uses only, also for PCDDs and PCDFs;
- dermal exposure makes a significant contribution to total exposure for dioxin-like PCBs for the residential and allotment land use scenarios;
- consumption of homegrown produce is the most important pathway for the allotment scenario for the lower chlorinated PCDDs and PCDFs only;
- inhalation of dust and vapours makes a negligible contribution to exposure for all land use scenarios.

Exposure to PCDDs and dioxin-like compounds from non-soil sources including the diet and ambient air is high relative to the TDI_{oral} and, for a young child, there is the possibility that non-soil exposure exceeds 50 per cent of the TDI (Environment Agency, 2009d). In deriving the SGVs and in setting the TDSI in the worksheets in Appendix 1, a minimum of 50 per cent of the TDI_{oral} is reserved for exposure from soil sources. At representative soil concentrations equal to or greater than the SGV, the total exposure from soil and non-soil sources will potentially exceed the TDI for some individuals (Environment Agency, 2009b).

Table 7

Contribution to total toxicity-adjusted soil exposure ($\text{pg WHO-TEQ kg}^{-1} \text{ BW day}^{-1}$) at a soil concentration equal to the SGV according to the congener/ compound profile for urban soils as set out in Table 3.

Compound ^{1,3}	Contribution to total soil exposure, after adjustment using WHO-TEF scheme (%) ²		
	Residential	Allotments	Commercial
Dioxins			
2,3,7,8-TCDD	5.8	7.7	5.6
1,2,3,7,8-PeCDD	22.7	29.6	22.0
1,2,3,4,7,8-HxCDD	2.4	2.4	2.5
1,2,3,6,7,8-HxCDD	4.5	4.5	4.6
1,2,3,7,8,9-HxCDD	4.0	4.0	4.1
1,2,3,4,6,7,8-HpCDD	3.6	1.8	4.0
OCDD	0.4	0.2	0.5
Furans			
2,3,7,8-TCDF	4.0	4.6	3.9
1,2,3,7,8-PeCDF	1.3	1.6	1.3
2,3,4,7,8-PeCDF	19.9	23.2	19.7
1,2,3,4,7,8-HxCDF	5.5	4.9	5.7
1,2,3,7,8,9-HxCDF	1.7	1.5	1.7
1,2,3,6,7,8-HxCDF	4.0	3.6	4.2
2,3,4,6,7,8-HxCDF	5.9	5.3	6.1
1,2,3,4,6,7,8-HpCDF	3.5	1.8	3.9
1,2,3,4,7,8,9-HpCDF	0.2	0.1	0.2
OCDF	0.1	–	0.1
Dioxin-like PCBs			
PCB-126	9.6	2.9	8.7
PCB-169	0.8	0.2	0.7
PCB-118	0.1	–	0.1

Notes: ¹ See Table 1 for complete list of abbreviations.
² All values have been rounded to one decimal place.
³ Only compounds that contribute at least 0.1 per cent for any of the land use scenarios are included in this table.

In the urban soils investigated by the UK SHS (see Table 4), the compounds/congeners with the highest contribution to total PCDD, PCDF and dioxin-like PCB content were PCB 118, OCDD and PCB 105, which together made up 64 per cent by weight. However, these compounds also have low TEF values and a much reduced contribution to total exposure from soil reported as $\text{pg WHO-TEQ kg}^{-1} \text{ bodyweight (BW) day}^{-1}$.

Table 7 shows contribution to total soil exposure after adjusting for toxicity equivalency (TEQ) ⁶ at a total soil concentration equal to the relevant SGV according to the generic urban soil profile. The contribution to total

⁶ The estimated exposure and not the soil concentration for each congener is multiplied by the TEF according to the WHO TEF scheme in Table 2

toxicity-adjusted soil exposure for PCB 118, OCDD and PCB 105 ranges from only 0.2 to 0.6 per cent. 1,2,3,7,8-PeCDD and 2,3,4,7,8-PeCDF together make the highest contributions to total toxicity-adjusted soil exposure, between 41.7 and 52.8 per cent depending on land use scenario. By comparison, these two congeners contributed only one per cent by weight to the total soil concentration estimated from UK SHS data (see also Table 4).

Other site-specific factors

The most important assumption in the derivation of the SGVs in Table 5 is the use of a generic urban soil profile based on the UK SHS data. As noted previously, this assumption may not hold for many contaminated sites where soil contamination has been identified as being of concern because of current or previous site-use.

The generic profile for individual congeners is applicable to soils contaminated by diffuse aerial pollution. The assumed profile and SGVs may not be applicable where a preliminary risk assessment or desk study suggests that contamination may have arisen from a highly localised, probably on-site, source (e.g. leaks from old transformer equipment) or the disposal of solid and liquid wastes including sewage sludge.⁷ In these cases, a site-specific generic risk assessment should be carried out using the appropriate worksheet found in Appendix 1 where representative values for the observed soil concentrations for each congener/compound can be entered directly.

Another critical assumption is the use of a linear relationship between soil concentration and exposure to derive congener-specific exposure factors (EF_i). The CLEA software assumes simple linear chemical partitioning between soil, water, air and plants. It is based primarily on observed behaviour at low chemical concentrations in soil (Environment Agency, 2002). The approach depends on a number of limiting assumptions, notably that the chemical concentration in the soil cannot exceed saturation (Environment Agency, 2009b). The CLEA software calculates theoretical saturation limits for a chemical based on its aqueous solubility and volatility. In the case of PCDDs, PCDFs and dioxin-like PCBs, the saturation limits range from 58.5 mg kg⁻¹ DW for OCDF to 4,900 mg kg⁻¹ DW for PCB 189. In many cases, these levels are one or more orders of magnitude higher than soil concentrations likely to pose a minimal risk to health.

As observed in Table 6, the most important exposure pathways for the residential and commercial land uses are direct soil ingestion and dermal contact with soil. Further discussion of these pathways can be found in Environment Agency (2009b).

Inhalation of dust and vapours is indicated as being negligible. This is consistent with the findings of other studies. Paustenbach *et al.* (1991) concluded that "inhalation will rarely, if ever, be a significant route of exposure to TCDD-contaminated soil."

The generic conceptual exposure models used to derive SGVs (as described in Environment Agency, 2009b) assume that:

- the source term is infinite; and
- the source term is not itself reduced by biological or chemical degradation.

Assessors undertaking a Detailed Quantitative Risk Assessment (DQRA) (Defra and Environment Agency, 2004) may wish to consider the applicability of these assumptions on a site-specific basis. Although actual half-lives of a chemical in soil are site-specific, many studies have found PCDDs, PCDFs and dioxin-like PCBs to be highly persistent in soils (Orazio *et al.*, 1992; Fiedler, 1996; McLachlan *et al.*, 1996; ATSDR, 1998, 2000).

Consumption of homegrown produce is the most important pathway for the allotment scenario, although the accumulation potential for dioxins and dioxin-like compounds in fruits and vegetable is generally low.

The phytoavailability of PCDDs, PCDFs and dioxin-like PCBs to garden produce depends on a number of complex factors. The soil-to-plant concentration factors used in the derivation of the SGVs are calculated from generic algorithms (detailed in Environment Agency, 2009b) for a generic scenario; the only exception is the factors for PCDDs and PCDFs for herbaceous fruit, which have been taken from the literature (Environment Agency, 2009e). No data were available to estimate plant uptake of PCDDs and PCDFs by shrub fruits or of dioxin-like PCBs by herbaceous and shrub fruits (Environment Agency, 2009e).

Assessors undertaking a DQRA could also carry out further investigation (including the sampling and chemical analysis of edible parts of fruits and vegetables) to determine site-specific plant concentration factors and to ascertain the level of PCDDs and dioxin-like compounds in the edible portions of fruits and vegetables. The sampling and chemical analysis of edible parts of fruits and vegetables is unlikely to be an easy task and the assessor will need to be careful to distinguish between local soil contamination and ongoing aerial deposition from non-soil sources.

Potential exposure to contaminated meat and eggs is not considered within the CLEA software (Environment Agency, 2009b). However, some allotment holders and residential gardeners may choose to keep animals, including goats, rabbits, and poultry. PCDDs and dioxin-like compounds are known to bioaccumulate in meat and dairy produce and, where applicable, these may be an important exposure pathway. As part of a preliminary risk assessment for dioxins and dioxin-like compounds, the assessor should consider whether this pathway needs to be taken into account in any subsequent assessment. Although site-specific sampling of dairy produce including milk and eggs is possible, further risk assessment may also involve additional generic modelling and use of literature bioconcentration factor (BCF) values as part of a DQRA.

⁷ The fit of the generic profile to actual site data can also be compared to consider the appropriateness of using the SGV.

In circumstances where the worksheets in Appendix 1 indicate that the TDSI may be exceeded or where the SGV is exceeded, assessors may wish to adjust for the site-specific measured organic matter content (SOM). A higher SOM will reduce the availability of PCDDs, PCDFs and dioxin-like PCBs for either plant uptake or dermal absorption.⁸ SGVs are based on a SOM content of six per cent. At a lower SOM, they may not be sufficiently protective.

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The CLEA Guidance incorporates the following

- 1) *Science Report SC050021/SR2: Human health toxicological assessment of contaminants in soil.*
- 2) *Science Report SC050021/SR3: Updated technical background to the CLEA model.*
- 3) *Science Report SC050021/SR4: CLEA Software (Version 1.05) Handbook.*
- 4) *CLEA Software version 1.05 (2009)*
- 5) *Toxicological reports and SGV technical notes*

The CLEA Guidance can help suitably qualified assessors to estimate the risk that a child or adult may be exposed to a soil concentration on a given site over a long period of exposure that may be a cause for concern to human health. The CLEA Guidance does not cover other types of risk to humans, such as fire, suffocation or explosion, or short-term and acute exposures. Nor does it cover risks to the environment or the pollution of water.

The CLEA Guidance is non-statutory. It does not purport to interpret the policies or procedures of the Environment Agency and shall not operate as a statutory licence, waiver, consent or approval from the Environment Agency. Nothing in the CLEA Guidance shall prejudice, conflict with or affect the exercise by the Environment Agency of its statutory functions, powers, rights, duties, responsibilities, obligations or discretions arising or imposed under the Environment Act 1995 or any other legislative provision enactment, bye-law or regulation.

The CLEA Guidance describes the soil concentrations above which, in the opinion of the Environment Agency, there may be concern that warrants further investigation and risk evaluation for both threshold and non-threshold substances. These levels are a guide to help assessors estimate risk. It does not provide a definitive test for telling when risks are significant.

Regulators are under no obligation to use the CLEA Guidance.

Appendix 1

This Appendix contains a series of worksheets for comparing the total soil exposure with the TDI_{oral} based on measured concentrations of individual congeners for PCDDs, PCDFs and dioxin-like PCBs. There are separate worksheets for each of the standard land use scenarios described in *Updated technical background to the CLEA model* (Environment Agency, 2009b) and a blank worksheet for user-defined exposure scenarios. These worksheets are also available from our website (<http://www.environment-agency.gov.uk/clea>) in electronic format for use with Microsoft® Excel.

The worksheets require users to enter the representative site concentration for each congener/compound in Table 2 in $ng\ kg^{-1}\ DW$. The worksheet can then be used to calculate the congener/compound-specific soil exposure, adjusted in terms of relative toxicity to 2,3,7,8-TCDD using WHO-TEF values. The sum of all toxicity-adjusted soil exposures ($pg\ WHO-TEQ\ kg^{-1}\ BW\ day^{-1}$) is then compared with the oral tolerable daily soil intake (TDI_{oral}) in $pg\ WHO-TEQ\ kg^{-1}\ BW\ day^{-1}$. A Hazard Index of ≤ 1 means that the combined soil exposure from the 29 PCDDs and dioxin-like compounds in Table 2 is unlikely to pose a significant risk to health.

User defined land use scenarios

The CLEA Software (Version 1.05) has been used to calculate the exposure factor⁹ to convert the soil concentration of a specified congener/compound into an estimate of the soil-derived average daily exposure (ADE). The data for the standard land use scenarios have been pre-entered on the appropriate worksheet and users need only to enter the individual congener soil concentrations to be able to calculate the total exposure for all congener/compounds.

For user-defined land use scenarios, the exposure factors for each congener/compound must be calculated using the CLEA software and the data transferred to the worksheet. The following guidelines are provided to assist users to do this.

Physical-chemical data for all PCDDs, PCDFs and dioxin-like PCBs must be added to the CLEA software. These data can be found in *Supplementary information for estimating human exposure to dioxins, furans and dioxin-like PCBs from soil* (Environment Agency, 2009e). Toxicological data is not used in subsequent calculations but is required to ensure that the CLEA software operates correctly. For this purpose only, therefore, assume that for each congener, the TDI_{oral} is $2\ pg\ WHO-TEQ\ kg^{-1}\ BW\ day^{-1}$ and that oral, dermal and inhalation exposure pathways should be compared with this TDI. For each congener, also assume that the MDI_{oral} is $49\ pg\ WHO-TEQ\ day^{-1}$.

Set up the exposure scenario in the CLEA software. General guidelines for this can be found in the *CLEA Software (Version 1.05) Handbook* (Environment Agency, 2009f).

When selecting the 29 PCDDs, PCDFs and dioxin-like PCBs on the *Select Chemicals* worksheet tab, subsequent steps will be easier if the same list order is used as shown in the worksheets in this Appendix.

For each chemical, specify a soil concentration of $1E-06\ mg\ kg^{-1}\ DW$ (equivalent to $1\ ng\ kg^{-1}\ DW$) on the *Select Chemicals* worksheet tab.

On the Microsoft® Excel menu:

- Select Tools>Sheet>Unhide and choose the worksheet *ADE Calculations* (if not already visible).
- Select worksheet *ADE Calculations* and find the columns entitled *Soil ADE by HCV* (i.e. columns HE and HF).

The data needed for the worksheet are in the column entitled *Oral ADE* in $mg\ kg^{-1}\ BW\ day^{-1}$ (column HE). Select the data in this column and copy them to the clipboard. If your chemical list is in the same order as the worksheets in this Appendix, then the data can be copied directly into the user-defined worksheet column D using the Paste Special function to insert only the value in each cell.

The worksheet is now ready to use by entering the site-specific soil concentrations for individual congeners/compounds.

⁹ The exposure factor is the sum of the estimated average daily exposure for the relevant exposure pathways derived for a fixed soil concentration of $1\ ng\ kg^{-1}\ DW$ for each congener. The critical assumption is that for soil concentrations less than the lower saturation limit, the relationship between exposure and soil concentration is linear.

PCDDs, PCDFs and dioxin-like compounds worksheet for a residential land use scenario

For each congener/compound, enter the site-specific representative soil concentration in the respective grey box. Calculate the soil exposure for each congener/compound, giving the result in the respective yellow box. Calculate the sum of soil exposure from all compounds, giving the result in the yellow box below. The Hazard Index is the ratio of the total soil exposure to the oral TDSI.

Substance	Soil concentration ng kg ⁻¹ DW		Exposure factor pg kg ⁻¹ BW day ⁻¹ per ng kg ⁻¹ DW soil		TEF		Soil average daily exposure pg WHO-TEQ kg ⁻¹ BW day ⁻¹
2,3,7,8-TCDD		x	1.04E-02	x	1	=	
1,2,3,7,8-PeCDD		x	1.04E-02	x	1	=	
1,2,3,4,7,8-HxCDD		x	9.78E-03	x	0.1	=	
1,2,3,6,7,8-HxCDD		x	9.78E-03	x	0.1	=	
1,2,3,7,8,9-HxCDD		x	9.78E-03	x	0.1	=	
1,2,3,4,6,7,8-HpCDD		x	8.94E-03	x	0.01	=	
OCDD		x	8.72E-03	x	0.0003	=	
2,3,7,8-TCDF		x	1.01E-02	x	0.1	=	
1,2,3,7,8-PeCDF		x	1.01E-02	x	0.03	=	
2,3,4,7,8-PeCDF		x	1.01E-02	x	0.3	=	
1,2,3,4,7,8-HxCDF		x	9.61E-03	x	0.1	=	
1,2,3,7,8,9-HxCDF		x	9.61E-03	x	0.1	=	
1,2,3,6,7,8-HxCDF		x	9.61E-03	x	0.1	=	
2,3,4,6,7,8-HxCDF		x	9.61E-03	x	0.1	=	
1,2,3,4,6,7,8-HpCDF		x	8.97E-03	x	0.01	=	
1,2,3,4,7,8,9-HpCDF		x	8.97E-03	x	0.01	=	
OCDF		x	8.82E-03	x	0.0003	=	
PCB-77		x	1.29E-02	x	0.0001	=	
PCB-81		x	1.29E-02	x	0.0003	=	
PCB-126		x	1.29E-02	x	0.1	=	
PCB-169		x	1.29E-02	x	0.03	=	
PCB-105		x	1.29E-02	x	0.00003	=	
PCB-114		x	1.29E-02	x	0.00003	=	
PCB-118		x	1.29E-02	x	0.00003	=	
PCB-123		x	1.29E-02	x	0.00003	=	
PCB-156		x	1.29E-02	x	0.00003	=	
PCB-157		x	1.29E-02	x	0.00003	=	
PCB-167		x	1.29E-02	x	0.00003	=	
PCB-189		x	1.29E-02	x	0.00003	=	
Total average daily soil exposure (pg WHO-TEQ kg ⁻¹ BW day ⁻¹)							
TDSI (pg WHO-TEQ kg ⁻¹ BW day ⁻¹)							1.0
Hazard Index							

TDSI = tolerable daily soil intake
TEF = Toxicity Equivalence Factor

This worksheet is also available in electronic format at <http://www.environment-agency.gov.uk/clea>

PCDDs, PCDFs and dioxin-like compounds worksheet for an allotment land use scenario

For each congener/compound, enter the site-specific representative soil concentration in the respective grey box. Calculate the soil exposure for each congener/compound, giving the result in the respective yellow box. Calculate the sum of soil exposure from all compounds, giving the result in the yellow box below. The Hazard Index is the ratio of the total soil exposure to the oral TDSI.

Substance	Soil concentration ng kg ⁻¹ DW		Exposure factor pg kg ⁻¹ BW day ⁻¹ per ng kg ⁻¹ DW soil		TEF		Soil average daily exposure pg WHO-TEQ kg ⁻¹ BW day ⁻¹
2,3,7,8-TCDD		x	1.45E-02	x	1	=	
1,2,3,7,8-PeCDD		x	1.42E-02	x	1	=	
1,2,3,4,7,8-HxCDD		x	1.03E-02	x	0.1	=	
1,2,3,6,7,8-HxCDD		x	1.03E-02	x	0.1	=	
1,2,3,7,8,9-HxCDD		x	1.03E-02	x	0.1	=	
1,2,3,4,6,7,8-HpCDD		x	4.65E-03	x	0.01	=	
OCDD		x	3.19E-03	x	0.0003	=	
2,3,7,8-TCDF		x	1.25E-02	x	0.1	=	
1,2,3,7,8-PeCDF		x	1.25E-02	x	0.03	=	
2,3,4,7,8-PeCDF		x	1.25E-02	x	0.3	=	
1,2,3,4,7,8-HxCDF		x	9.12E-03	x	0.1	=	
1,2,3,7,8,9-HxCDF		x	9.12E-03	x	0.1	=	
1,2,3,6,7,8-HxCDF		x	9.12E-03	x	0.1	=	
2,3,4,6,7,8-HxCDF		x	9.12E-03	x	0.1	=	
1,2,3,4,6,7,8-HpCDF		x	4.85E-03	x	0.01	=	
1,2,3,4,7,8,9-HpCDF		x	4.85E-03	x	0.01	=	
OCDF		x	3.85E-03	x	0.0003	=	
PCB-77		x	4.28E-03	x	0.0001	=	
PCB-81		x	4.28E-03	x	0.0003	=	
PCB-126		x	4.05E-03	x	0.1	=	
PCB-169		x	3.98E-03	x	0.03	=	
PCB-105		x	4.05E-03	x	0.00003	=	
PCB-114		x	4.05E-03	x	0.00003	=	
PCB-118		x	4.05E-03	x	0.00003	=	
PCB-123		x	4.05E-03	x	0.00003	=	
PCB-156		x	3.98E-03	x	0.00003	=	
PCB-157		x	3.98E-03	x	0.00003	=	
PCB-167		x	3.98E-03	x	0.00003	=	
PCB-189		x	3.96E-03	x	0.00003	=	
Total average daily soil exposure (pg WHO-TEQ kg ⁻¹ BW day ⁻¹)							
TDSI (pg WHO-TEQ kg ⁻¹ BW day ⁻¹)							1.0
Hazard Index							

TDSI = tolerable daily soil intake

TEF = Toxicity Equivalence Factor

This worksheet is also available in electronic format at <http://www.environment-agency.gov.uk/clea>

PCDDs, PCDFs and dioxin-like compounds worksheet for a commercial land use scenario

For each congener/compound, enter the site-specific representative soil concentration in the respective grey box. Calculate the soil exposure for each congener/compound, giving the result in the respective yellow box. Calculate the sum of soil exposure from all compounds, giving the result in the yellow box below. The Hazard Index is the ratio of the total soil exposure to the oral TDSI.

Substance	Soil concentration ng kg ⁻¹ DW		Exposure factor pg kg ⁻¹ BW day ⁻¹ per ng kg ⁻¹ DW soil		TEF		Soil average daily exposure pg WHO-TEQ kg ⁻¹ BW day ⁻¹
2,3,7,8-TCDD		x	4.75E-04	x	1	=	
1,2,3,7,8-PeCDD		x	4.75E-04	x	1	=	
1,2,3,4,7,8-HxCDD		x	4.75E-04	x	0.1	=	
1,2,3,6,7,8-HxCDD		x	4.75E-04	x	0.1	=	
1,2,3,7,8,9-HxCDD		x	4.75E-04	x	0.1	=	
1,2,3,4,6,7,8-HpCDD		x	4.75E-04	x	0.01	=	
OCDD		x	4.75E-04	x	0.0003	=	
2,3,7,8-TCDF		x	4.75E-04	x	0.1	=	
1,2,3,7,8-PeCDF		x	4.75E-04	x	0.03	=	
2,3,4,7,8-PeCDF		x	4.75E-04	x	0.3	=	
1,2,3,4,7,8-HxCDF		x	4.75E-04	x	0.1	=	
1,2,3,7,8,9-HxCDF		x	4.75E-04	x	0.1	=	
1,2,3,6,7,8-HxCDF		x	4.75E-04	x	0.1	=	
2,3,4,6,7,8-HxCDF		x	4.75E-04	x	0.1	=	
1,2,3,4,6,7,8-HpCDF		x	4.75E-04	x	0.01	=	
1,2,3,4,7,8,9-HpCDF		x	4.75E-04	x	0.01	=	
OCDF		x	4.75E-04	x	0.0003	=	
PCB-77		x	5.57E-04	x	0.0001	=	
PCB-81		x	5.57E-04	x	0.0003	=	
PCB-126		x	5.57E-04	x	0.1	=	
PCB-169		x	5.57E-04	x	0.03	=	
PCB-105		x	5.57E-04	x	0.00003	=	
PCB-114		x	5.57E-04	x	0.00003	=	
PCB-118		x	5.57E-04	x	0.00003	=	
PCB-123		x	5.57E-04	x	0.00003	=	
PCB-156		x	5.57E-04	x	0.00003	=	
PCB-157		x	5.57E-04	x	0.00003	=	
PCB-167		x	5.57E-04	x	0.00003	=	
PCB-189		x	5.57E-04	x	0.00003	=	
Total average daily soil exposure (pg WHO-TEQ kg ⁻¹ BW day ⁻¹)							
TDSI (pg WHO-TEQ kg ⁻¹ BW day ⁻¹)							1.3
Hazard Index							

TDSI = tolerable daily soil intake
TEF = Toxicity Equivalence Factor

This worksheet is also available in electronic format at <http://www.environment-agency.gov.uk/clea>

PCDDs, PCDFs and dioxin-like compounds worksheet for a user defined land use scenario

For each congener/compound, enter the site-specific representative soil concentration and the calculated exposure factor from the CLEA software in the respective grey box.

Calculate the unit corrected exposure factor and the soil exposure for each congener/compound, giving the result in the respective yellow box.

Calculate the sum of soil exposure from all compounds, giving the result in the yellow box below.

Also calculate the oral TDSI for the age classes considered.

The Hazard Index is the ratio of the total soil exposure to the oral TDSI.

Substance	Soil concentration		Exposure factor			TEF		Soil average daily exposure pg WHO-TEQ kg ⁻¹ BW day ⁻¹
	ng kg ⁻¹ DW	mg kg ⁻¹ BW day ⁻¹ per ng kg ⁻¹ DW soil			pg kg ⁻¹ BW day ⁻¹ per ng kg ⁻¹ DW soil			
2,3,7,8-TCDD	x (	x (	x 1E+09	=	)	x 1	=	
1,2,3,7,8-PeCDD	x (	x (	x 1E+09	=	)	x 1	=	
1,2,3,4,7,8-HxCDD	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,6,7,8-HxCDD	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,7,8,9-HxCDD	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,4,6,7,8-HpCDD	x (	x (	x 1E+09	=	)	x 0.01	=	
OCDD	x (	x (	x 1E+09	=	)	x 0.0003	=	
2,3,7,8-TCDF	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,7,8-PeCDF	x (	x (	x 1E+09	=	)	x 0.03	=	
2,3,4,7,8-PeCDF	x (	x (	x 1E+09	=	)	x 0.3	=	
1,2,3,4,7,8-HxCDF	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,7,8,9-HxCDF	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,6,7,8-HxCDF	x (	x (	x 1E+09	=	)	x 0.1	=	
2,3,4,6,7,8-HxCDF	x (	x (	x 1E+09	=	)	x 0.1	=	
1,2,3,4,6,7,8-HpCDF	x (	x (	x 1E+09	=	)	x 0.01	=	
1,2,3,4,7,8,9-HpCDF	x (	x (	x 1E+09	=	)	x 0.01	=	
OCDF	x (	x (	x 1E+09	=	)	x 0.0003	=	
PCB-77	x (	x (	x 1E+09	=	)	x 0.0001	=	
PCB-81	x (	x (	x 1E+09	=	)	x 0.0003	=	
PCB-126	x (	x (	x 1E+09	=	)	x 0.1	=	
PCB-169	x (	x (	x 1E+09	=	)	x 0.03	=	
PCB-105	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-114	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-118	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-123	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-156	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-157	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-167	x (	x (	x 1E+09	=	)	x 0.00003	=	
PCB-189	x (	x (	x 1E+09	=	)	x 0.00003	=	

Total average daily soil exposure (pg WHO-TEQ kg⁻¹ BW day⁻¹)

TDSI (pg WHO-TEQ kg⁻¹ BW day⁻¹)

Hazard Index

TDSI = tolerable daily soil intake
TEF = Toxicity Equivalence Factor

This worksheet is also available in electronic format at <http://www.environment-agency.gov.uk/clea>