Practical Issues Associated with Deriving Cleanup Goals Using the TEQ Approach

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The use of the toxic equivalency (TEQ) approach for evaluating the potential risks associated with mixtures of 2,3,7,8-substituted dioxins and furans (CDDs/CDFs) and selected polychlorinated biphenyl (PCB) congeners has been gaining momentum over the past 25 years due to the fact that there is limited or no information available on the carcinogenic potential of most of those congeners. Only a few of the dioxin/furan congeners have been evaluated using cancer bioassays. While cancer bioassays have been conducted using commercial mixtures of PCBs, these may or may not be representative of the mixtures that persist in the environment after weathering. In the wake of limited information about the carcinogenic potential of individual constituents, the TEQ approach is often used to estimate the carcinogenic potential of combinations of congeners that have been detected in the environment. Much attention has been paid to the scientific supportability of the TEQ approach, due to assumptions about the use of non-cancer endpoints as indicators of carcinogenicity, additivity of congeners, similarities in dose response curves for congeners and endpoints, and the magnitude of the cancer slope factor for 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), which forms the toxicological basis for the approach.

Little attention has focused, however, on the practical implications of the TEQ approach when attempting to use it to develop health protective cleanup goals. Difficulties in applying the approach for this purpose arise from the substantial limitations in empirical data concerning the differences in food chain transfer and bioaccumulation of the individual congeners, which are important considerations when attempting to backcalculate cleanup goals. It is often the case for these congeners that while the primary route of exposure is through the food chain (e.g., consumption of fish or beef), the source of these congeners is another medium (e.g., sediment or soil). While the risks that are unacceptable are the result of the mixture of congeners in the fish tissue, often the mixture in those tissues is not the same as the congener mixture in the source medium due to the fact that congeners have variable tendencies to move through the food web and bioaccumulate. As a result, some congeners in the source medium are not detected in the fish tissue and the proportion of the congeners in the fish tissue is not the same as the proportion of congeners found in the source material. This differential transfer and bioaccumulation grows more complicated with each step along a food chain.

Because there are few congener-specific data on food chain transfer, it is assumed that all congeners have the same bioavailability and potential for transfer as TCDD. Empirical evidence indicates, however, that this is not the case. The bioavailability and transfer of congeners differ substantially, as demonstrated in reported average background levels in U.S. sediments and freshwater fish, as reported by the United States Environmental Protection Agency (USEPA)[1]. The fraction of CDD/CDFs in sediment represented by TCDD was 0.043% (Table 1). However, the fraction of TCDD reported in freshwater fish was 1.6% percent of the total CDD/CDF concentration, higher by a factor of 37. At the same time, octachlorodibenzofuran (OCDF) represented 14% of the total CDD/CDF concentration in sediment but did not tend to bioaccumulate in the fish (0% of total CDD/CDF). When combining these congeners to estimate total TEQ in sediment and fish, the background total TEQ concentration in sediment was 4.4 parts per trillion (ppt) while the background total TEQ concentration in fish tissue was 0.65 ppt, providing a fish TEQ/sediment TEQ ratio of 0.15. However, the fish/sediment TEQ ratios for the individual congeners ranged from 0 to 0.58 (Table 1). OCDD represented 66% of the total CDD/CDF concentration and 2.7% of the total TEQ concentration in sediment, but only represented 0.28 percent of the total TEQ concentration in the fish. Thus while it readily bioaccumulates in fish tissue, it does not contribute substantially to the toxicity of the mixture in the fish.

Differing transfer and uptake of individual congeners can be an issue when conducting a risk assessment, but the impact of this can be reduced through the collection of specific data at the point of exposure (e.g., in fish tissue or other food products), rather than modeling transfer through the food chain. These measured concentrations can be adjusted by relevant Toxic Equivalency Factors (TEFs) to provide a reasonable estimate of toxicity at the exposure point. However, these same uncertainties cannot be easily accommodated when attempting to work backward, from an acceptable exposure point concentration at the point of contact to the appropriate cleanup goal at the source. For example, the source of dioxin/furan congeners in a river system may be soil but the primary human exposure point may be from the consumption of fish from the river. To calculate a soil cleanup goal, it is necessary to work backward through the food chain to identify an acceptable concentration in soil. This backcalculation needs to consider the differential adsorption to soil particles that are transported by runoff, the weathering of soil before it reaches the river, volatilization of selected congeners, weathering once in sediment, and uptake by insects, benthic invertebrates, lower trophic level fish, upper trophic level fish, and humans. At each stage of this process, the congener profiles may be altered.

In an attempt to correct for this when developing the water quality criteria for the Great Lakes, the USEPA developed Bioaccumulation Equivalency Factors (BEFs).[2] These BEFs were based on an estimated biota-sediment accumulation factor (BSAF) for each congener, compared with the BSAF for TCDD. The TEF for the congener was then weighted by the BEF to yield a total toxic equivalency (TE) that simultaneously considered the differential uptake and toxicity of the congeners.

This approach is theoretically reasonable but is difficult to implement on a general basis because the magnitudes of the measured BSAFs upon which it is based are affected by the distribution of the congeners between the sediment and water, the relationship of the food web to the water/sediment, the length of the food web, and metabolic transformation rates of each congener within the food web. Uptake is also affected by the type and amount of organic carbon in an ecosystem, the character and temperature of the water body, and the lipid content, age, lifespan, migratory pattern and feeding behavior of the fish.[3,4,5] Because many of these factors vary widely among different ecosystems and fish species, the BSAFs developed for a particular fish species in one ecosystem may not be appropriate for another fish species or ecosystem. Thus these factors may vary widely among sites and species, making it extremely difficult to develop a reliable set of generic BEFs to use in backcalculating cleanup goals for sediment based on acceptable exposure levels in fish.

Similar issues arise when attempting to develop cleanup goals based on potential exposures via the terrestrial food web. Congeners may be detected in agricultural soils that are used to graze or provide feed for beef cattle and may bioaccumulate to unacceptable levels in the meat of those animals. In this case, it is necessary to develop a cleanup goal for soil that will reduce potential risks. However, there are many transfer steps that lead to the final concentrations measured in the meat. These may include direct ingestion of soil, dust transfer to consumed forage or silage, vapor transfer to plant material, weathering of congeners during storage, ingestion by the cattle of different dietary mixes, and metabolism and elimination by the cattle. There is a variable tendency of individual congeners to transfer or accumulate at each of these stages. While the congeners that are present in the soil that is directly ingested by the cow reflect the source material, this is often not the case for the other food products consumed by them because some congeners have a greater tendency to volatilize, degrade, and bioaccumulate than do others, resulting in different congener profiles at each stage.

Evaluating a single stage of this process demonstrates the high level of uncertainty in predicting uptake/transfer. Table 2 provides a comparison of the congeners present in grass grown on floodplain soil containing PCBs.[6] The average total PCB concentration for the listed congeners is higher in soil than in grass by a factor of 121 and the calculated total TEQ concentration associated with the soil itself is higher, by a factor of 23, than the measured total TEQ concentration in the grass. This would indicate that a potential grass/soil bioaccumulation factor for the entire mixture might be 0.0083, if based on total concentration, or 0.045 if based on total TEQ. In addition, the contribution of each congener to the total TEQ of the mixture varies substantially. PCB 126 represents only 0.03% of the total PCB concentration in the soil, but provids 48% of the TEQ concentration in soil. Similarly, PCB 126 represents 0.19% of the total PCB concentration measured in grass but 54% of the total TEQ concentration in grass. Overall, the grass/soil ratio for total TEQ is 0.045 but the ratios for individual congeners range from zero to 0.29.

The uptake of congeners is substantially affected by the organic carbon content in soil and the surface area of the plant material. Thus even if site-specific soil-to-grass uptake factors are calculated, they are not necessarily representative of uptake that occurs in other plant materials. The amount of uptake by different types of plants grown on identical soils varies, as shown in the data collected by Sawhney and Hankin.[7] These authors reported that while Aroclor 1260 constituted 88% of the total Aroclors in the soil, it only represented 27% of the total Aroclors measured in turnip leaves. Conversely, while Aroclor 1248 constituted only 0.49% of the total Aroclors in the soil, it represented 13% and 32% of the total Aroclors in beet leaves and turnip leaves, respectively. Thus uptake even by similar types of plant material (e.g., above ground broad leaf vegetation) is not consistent among plant types. Since beef cattle are likely to consume a variety of materials with different potentials to take up the individual congeners, it becomes nearly impossible to determine what the appropriate congener-specific bioaccumulation factor should be in backcalculating an acceptable cleanup goal.

The World Health Organization (WHO)[8] recognized the limitations of the TEQ approach when attempting to relate it to abiotic media such as soil and sediment. These authors recommended that this approach not be applied to abiotic media due to the fact that TEFs are based on food chain exposure and are not well explained in those media. This is because the bioavailability of these congeners is highly dependent upon the level of organic carbon and the degree of weathering that has occurred. While this caution is appropriate, it does not consider the fact that if one is to use the TEQ approach to evaluate risks and calculate appropriate cleanup goals when the source of the material is an abiotic medium, such as soil or sediment, there really is no alternative but to apply those TEQ to the abiotic medium. There is no other way to determine what acceptable cleanup goals for the source material might be based on the calculated risk.

To resolve these uncertainties, it will be necessary to conduct additional research to map the movement of the different congeners through various food chains and increase the available body of scientific knowledge concerning their tendencies to transfer and bioaccumulate within food webs. Once this information becomes more available and complete, it will be possible to develop cleanup goals for individual congeners rather than make assumptions about entire mixtures. This will allow more realistic and health protective cleanup goals to be developed while reducing the uncertainties associated with them.

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Table 1. Comparison of Mean Background Concentrations in Sediment and Fish Tissue in the United States

		Sediment			Freshwater Fish			Ratio of Fish TEQ/ Sediment TEQ Conc.
Dioxin/Furan Congener	**WHO TEF[8]**	**Conc. (ppt)**	**Fraction Total CDD/CDF Conc. In Sediment**	**TEQ (ppt)**	**Conc. (ppt)**	**Fraction In Fish**	**TEQ (ppt)**	
2,3,7,8-TCDD	1	0.26	0.00043	0.26	0.149	0.016	0.15	0.58
1,2,3,7,8-PeCDD	1	0.95	0.0016	0.95	0.251	0.028	0.25	0.26
1,2,3,4,7,8-HxCDD	0.1	1.8	0.0030	0.18	0.145	0.016	0.015	0.083
1,2,3,6,78,-HxCDD	0.1	4.7	0.0078	0.47	0.256	0.028	0.026	0.055
1,2,3,7,8,9-HxCDD	0.1	4.1	0.0068	0.41	0.199	0.022	0.020	0.049
1,2,3,4,6,7,8-HpCDD	0.01	100.6	0.17	1.0	1.135	0.12	0.011	0.011
OCDD	0.0003	400.5	0.66	0.12	5.893	0.65	0.0018	0.015
2,3,7,8-TCDF	0.1	1.6	0.0026	0.16	0.696	0.077	0.070	0.44
1,2,3,7,8-PeCDF	0.03	0.91	0.0015	0.027	0	0	0	0
2,3,4,7,8-PeCDF	0.3	1.5	0.0025	0.45	0.365	0.040	0.11	0.24
1,2,3,4,7,8-HxCDF	0.1	1.9	0.0031	0.19	0	0	0	0
1,2,3,6,7,8-HxCDF	0.1	0.003	0.0000050	0.00030	0	0	0	0
1,2,3,7,8,9-HxCDF	0.1	0.02	0.000033	0.0020	0	0	0	0
2,3,4,6,7,8-HxCDF	0.1	1.7	0.0028	0.17	0	0	0	0
1,2,3,4,6,7,8-HpCDF	0.01	0.01	0.000017	0.00010	0	0	0	0
1,2,3,4,7,8,9-HpCDF	0.01	2.1	0.0035	0.021	0	0	0	0
OCDF	0.0003	83	0.14	0.025	0	0	0	0
Total		**605.4**		**4.4**	**9.1**		**0.65**	**0.15**

Based on data provided by USEPA (2000): Tables 3-19 and 3-27

Table 2. Comparison of Concentrations in Soil and Grass Grown in a Floodplain Area

		Soil			Grass			Ratio of Grass TEQ/ Soil TEQ Conc.
Congener	**WHO TEF[8]**	**Ave. Conc. (ppt)**	**Fraction Conc. In Soil**	**TEQ (ppt)**	**Ave. Conc. (ppt)**	**Fraction Conc. In Grass**	**TEQ (ppt)**	
PCB 77	0.0001	830	0.00070	0.083	36.4	0.0037	0.00364	0.044
PCB 81	0.0003	211	0.00018	0.063	ND	0	0	0
PCB 126	0.1	365	0.00031	37	18.2	0.0019	1.82	0.050
PCB 169	0.03	150	0.00013	4.5	43.3	0.0044	1.30	0.29
PCB 105	0.00003	52100	0.044	1.6	524	0.053	0.016	0.010
PCB 114	0.00003	0	0	0	ND	0	0	0
PCB 118	0.00003	114000	0.096	3.4	1440	0.15	0.043	0.013
PCB 123 (149/123)	0.00003	866000	0.73	26	6480	0.66	0.19	0.0075
PCB 156	0.00003	53400	0.045	1.6	431	0.044	0.013	0.0081
PCB 157 (201/157/173)	0.00003	49600	0.042	1.5	346	0.035	0.010	0.0070
PCB 167	0.00003	32000	0.027	0.96	328	0.033	0.0098	0.010
PCB 189	0.00003	14200	0.012	0.43	152	0.016	0.0046	0.011
Total		**1182856**		**77**	**9801**		**3.4**	**0.044**

Based on data provided by USEPA (2005)