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Subject: Update to Soil Action Levels for TEQ Dioxins and Recommended Soil Management Practices

1.0 Introduction

This technical memorandum presents an update to Hawai'i Department of Health (HDOH) action levels and corresponding guidance for dioxins and furans ("dioxins") in soil. This guidance serves as an addendum to the Hazard Evaluation and Emergency Response (HEER) office document *Evaluation of Environmental Hazards at Sites with Contaminated Soil and Groundwater* (EHE guidance; HDOH 2008a). A summary of the updated action levels and soil management categories is provided in Table 1. A detailed discussion of the development and support of the action levels is provided in Attachment 1 (Supplemental Information), Attachment 2 (Exposure Models) and Attachment 3 (Dietary Exposure to Dioxins).

This guidance supersedes and takes precedence over a technical memorandum on dioxins published by the HEER office in June 2008 and incorporated into the EHE guidance (HDOH 2008b). This memo also presents a modification of the HEER office soil categorization system, based on updates to dioxin action levels and a simplified approach for classification and management of dioxin-contaminated soils. The soil action levels presented herein are not promulgated regulatory standards or required cleanup levels. Alternative proposals may be presented in a site-specific risk assessment. However, the nature of the toxicity factors and exposure assumptions used to in this update are unlikely to allow significant flexibility for less stringent, site-specific action levels in the absence of institutional and/or engineering controls.

The soil action levels presented in this document are intended for comparison to soil data obtained through collection of multi-increment ("incremental") soil samples, as described in the HEER office *Technical Guidance Manual* (HDOH 2009). When combined with *Decision Unit* investigation approaches, multi-increment soil samples offer a more cost-effective and efficient approach for characterization of a targeted area or volume of soil than traditional, discrete sample approaches. Studies have shown that a small number (e.g., less than <30) of discrete samples is unlikely to adequately capture contaminant heterogeneity and small "hot spots" of elevated contaminant concentrations within a targeted area (e.g., Ramsey et. al. 2005; Jenkins et al. 2005). This can lead to an underestimate of exposure point concentrations for risk assessment purposes, as well as an underestimate of contaminant mass for *in situ* or *ex situ* treatment. Alternative soil sampling schemes should be discussed with the HEER office on a site-by-site basis.

2.0 Updated HDOH TEQ Dioxin Soil Action Levels

The updated Toxicity Equivalent (TEQ) dioxin soil action levels are as follows:

2010 HDOH TEQ Dioxin Soil Action Levels	
≤240 ng/kg	No significant risk to human health under unrestricted (e.g., residential) land use.
≤1,500 ng/kg	No significant risk to human health under commercial/industrial land use (also used as the construction/trench worker action level).

As discussed in Attachments 1-3, the development and justification of the updated soil action levels are based on the following multiple lines of evidence:

- Predominance of less-toxic forms of dioxins in soil (tetrachlorodibenzo-*p*-dioxin or TCDD, generally <<1%);
- Reduced relative bioavailability of dioxins in soil in comparison to published toxicity studies (assumed 60%);
- Uncertainty in published and proposed cancer slope factors and noncancer reference doses for TCDD;
- HDOH preference for the World Health Organization (WHO) body burden approach to evaluate potential health risks posed by chronic exposure to dioxins;
- Comparability of WHO Permissible Tolerable Intake factors for TEQ dioxins to published and draft toxicity factors for health risks published by the U.S. Environmental Protection Agency (USEPA) and other parties;
- Use of WHO Toxicity Equivalent Factors to estimate health risks from non-TCDD dioxins and furans;
- Consideration of typical dietary intake of dioxins with respect to theoretical risk posed by exposure to soil;
- Lack of a significant, added health benefit from the use of lower action levels to further reduce exposure to dioxins in soil;
- HDOH's acknowledgment that remediation of large tracts of agricultural lands where trace levels of dioxins associated with the past use of pentachlorophenol and other agricultural practices have been identified is impractical and unnecessary from a health risk perspective; and

- Recommendation to remediate localized spill areas of heavy dioxin contamination to surrounding background when feasible rather than reliance on purely risk-based action levels.

The updated action levels are used in Section 3 of this technical memorandum to redefine the soil management categories originally presented in the 2008 HEER guidance. Reduction of the soil action level for unrestricted land use from 450 ng/kg, as presented in the 2008 HEER guidance, to 240 ng/kg is not considered to be a significant change from the standpoint of potential risk to human health. HEER does not foresee the need to reopen cases closed under the 2008 action levels or require additional sampling at sites where investigations carried out under the previous guidance have already been completed. For isolated spill areas at sites where remedial action plans have not been finalized or completed, however, parties are encouraged to include *all* soil contaminated above surrounding background in remedial actions to the extent practicable (refer to Section 4).

3.0 Dioxin Soil Management Categories

Updated categories for the evaluation and management of dioxin-contaminated soil are summarized below and summarized in Table 1. These categories replace the scheme presented in the 2008 HEER guidance:

Category A Soils (natural background): Soils exhibit concentrations of TEQ dioxins <20 ng/kg, and do not appear to have been impacted by local, agricultural or industrial releases of dioxin. These soils represent "background" dioxin levels in the absence of agricultural or industrial impacts. Data on dioxins in native, un-impacted soils in Hawai‘i are limited, especially when compared to data on metals (e.g., arsenic). However, based on recent investigations overseen by HEER, the background level of TEQ dioxins in soils in Hawai‘i that have not been impacted by modern agricultural or industrial activities appears to be <20 ng/kg.

Category B Soils (minimally impacted): Soils exhibit concentrations of TEQ dioxins between 20 ng/kg and 240 ng/kg, indicating anthropogenic impacts at levels that are detectable but not considered harmful. HEER expects Category B soils to be generally associated with agricultural fields where dioxin-bearing pesticides were routinely applied in the past. Dioxin levels measured in soils in former agricultural fields range from <20 ng/kg to 100 ng/kg, and up to 200 ng/kg in some areas. HEER believes these dioxins typically represent residues of past applications of pentachlorophenol as an herbicide in sugarcane fields although burning of the fields may have also contributed. At most sites, the pentachlorophenol has degraded to below detectable levels, leaving behind a low-level residue of dioxins. For further discussion, see Section 9 in the HEER *TGM* (HDOH 2009).

Category C Soils (moderately impacted): Soils exhibit concentrations of TEQ dioxins between 240 ng/kg and 1,500 ng/kg. Category C soils are exemplified by contamination at former pesticide storage and mixing areas that included the use of pentachlorophenol and similar pesticides. Soils associated with burn pits or impacted by incinerator ash are also likely to fall into this category.

Category D Soils (heavily impacted): Soils have dioxin concentrations exceeding 1,500 ng/kg. Category D soils are exemplified by heavy contamination at former pesticide mixing areas associated with the use of pentachlorophenol. Concentrations of TEQ dioxins in soil between 10,000 ng/kg and 100,000 ng/kg are not uncommon, with concentrations up to 1,000,000 ng/kg reported at some facilities (>500 mg/kg total dioxins/furans). Pentachlorophenol is typically present at significantly lower concentrations or even below laboratory reporting limits.

4.0 Management of Dioxin-Contaminated Soils

HEER offers the following observations and recommendations for the short-term and long-term management of dioxin-contaminated soil, based on experience with past dioxin response sites.

4.1 Site Characterization

Long-term management of soil with greater than 240 ng/kg TEQ dioxins (or other, approved action levels) will be required at all sites where treatment or removal of this soil is not carried out. Investigation of the site should characterize the lateral and vertical extent of soil contaminated above this action level to the extent practicable, regardless of the current land use of the site, unless otherwise approved by HEER. This includes the need to identify and include Category B soils at commercial/industrial sites in an *Environmental Hazard Management Plan* prepared for that property, even though these soils do no pose a significant health risk to site workers. This will help ensure that the soil is not inadvertently excavated and reused at a more sensitive, offsite location during future subsurface or redevelopment work (e.g., reuse as fill material for a school yard). Potential disposal and management requirements under State and USEPA hazardous waste regulations must also be evaluated and documented.

4.2 Remedial Options

Remedial options typically considered at dioxin response sites are, in order of descending preference, **treatment**, **off-site disposal**, **engineered controls** and **institutional controls**.[1] As discussed in Section 4.3, the added cost of long-term management and potential liability for inappropriate exposure or reuse of the soil in the future should be taken into consideration in the selection of a final remedy.

4.2.1 Treatment

In situ or *ex situ* thermal treatment is considered to be the state-of-the-art method for the destruction of dioxins in contaminated soils, although numerous other remedial options have also

[1] State regulations list remedial options for contaminated soils in the following order of descending preference, to the extent practicable: (a) reuse or recycling; (b) destruction or detoxification; (c) separation, concentration, or volume reduction, followed by reuse, recycling, destruction or detoxification of the residue; (d) immobilization; (e) on-site or off-site disposal, isolation, or containment at an engineered facility in accordance with applicable requirements; and (f) institutional controls or long term monitoring [Hawai‘i Administrative Rules 11-451-8(c)(2)].

been proposed (e.g., Haglund 2007, Kulkarni 2008). The number of companies and facilities that offer thermal treatment is very limited, however, and the cost of thermal treatment can far exceed the short-term costs for other remedial options. For example, the cost to excavate and ship 5,000+ tons of dioxin-contaminated soil from a former pesticide mixing area (PMA) site on O‘ahu to treatment facilities in North America was recently estimated to exceed $3,000/ton. *In situ* thermal treatment of the soil was estimated to approach $1,000/ton. The initial cost to construct an engineered cap over the soil is approximately one-tenth of the total cost for *in situ* treatment.

Treatment of Category D, dioxin-contaminated soil will, in many cases, only be feasible as part of large-scale redevelopment projects that can generate adequate capital funds for this option, e.g., by amortization of cleanup cost, concessions on the land purchase price and/or marginal increases in sales prices of new homes. Capping of the soil at currently unused sites will be necessary in many cases (see *Engineered Controls*). If so, the soil should be capped in an area that will remain accessible for possible removal or *in situ* treatment should cheaper, on-island alternatives come become available in the future (e.g., under parking lots or other open areas, versus under a permanent building). This will allow the property owner and/or responsible party to access and treat the soil in order if they so desire, in order to remove liabilities and depreciation in property value posed by continued long-term management of the soil.

4.2.2 Disposal

Disposal of dioxin-contaminated soil in a permitted landfill is a potentially cost-effective option for remediation of isolated spill areas. As discussed in Section 4.4, however, dioxin-contaminated soil must be evaluated for potential Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste restrictions prior to disposal. If the soil is determined to be a hazardous waste, then it cannot be disposed of in a local landfill. If the soil is determined to not be a hazardous waste, then it may be disposed in a municipal landfill or construction & demolition debris landfill, contingent upon acceptance by the landfill operator. Municipal landfills may also be reluctant to accept heavily contaminated soil for disposal due to worker exposure and future liability concerns.

4.2.3 Engineered Controls

The risk posed by dioxin-contaminated soils can be addressed via on-site construction of a physical barrier (a “cap”) to protect the public and the environment from exposure. Containment-based remedies require long-term maintenance and monitoring to ensure the continued integrity of the cap and effectiveness of the remedy. Protocols for long-term management should be included in an *Environmental Hazard Management Plan* prepared for the site, as described in the HEER *Technical Guidance Manual* (HDOH 2009). Specific cap designs will vary depending on site-specific conditions and redevelopment plans.

A clearly identifiable marker barrier (e.g., orange plastic construction fencing) is generally placed between the contaminated soil and the overlying clean fill material. HEER also recommends that a grid of durable, detectable (metallic) and labeled underground warning tape be placed on top of dioxin-contaminated soils as part of a long-term cap. Similar to the procedures used when burying natural gas pipelines, warning messages and contact information should be printed on the warning tape, for example: "**CAUTION – STOP DIGGING! DIOXIN-CONTAMINATED SOIL BELOW! CONTACT _____ at _____ FOR FURTHER INFORMATION**." The cost for this type of customized warning tape is approximately $200 per 1,000-foot roll; and is available from Safety Systems of Hawai'i among other vendors.

As discussed above, it is preferable that heavily contaminated soil be capped in an area that will allow access for removal or *in situ* treatment in the future should cheaper, on-island alternatives become available. For additional information, consult the HEER *Technical Guidance Manual* (HEER 2009) and contact HEER staff. HEER plans to update its capping guidance in the near future based on experience gained from current studies.

4.2.4 Institutional controls

Dioxin-contaminated sites may be addressed by the use of institutional controls (ICs) to protect the public and the environment from exposure. For example, use of the property for residences, schools, day care, medical facilities or other sensitive purposes can be restricted in a formal covenant to the deed. Excavation in contaminated areas or reuse of soil from the site without the express consent of HDOH can also be prohibited. Additional information on institutional controls is provided in the HEER *Technical Guidance Manual* (HEER 2009).

4.3 Management of Category C Soils at Commercial/Industrial Sites

Category C soils are not considered to pose health risks under commercial/industrial land use but could pose potential risks under residential or other sensitive land uses. Long-term management of these soils is therefore required if left in place at a commercial/industrial site. Specific issues associated with the long-term management of Category C soils are discussed below.

4.3.1 Include Institutional Controls in EHMPs

Category C soils can be managed in place at commercial/industrial sites with minimal engineering controls provided that care is taken to prevent offsite movement of the soils via windblown dust, storm water runoff and other processes. As discussed in above, however, a potential exists for the inadvertent excavation of these soils, transport to unrestricted/residential land use areas (e.g., schools or residential areas) and reuse of these soils as fill material in areas where the soil could then pose a health risk. Institutional controls should, therefore, be included as one part of the *Environmental Hazard Management Plan* prepared for a commercial/industrial site where Category C soils are left in place.

4.3.2 Include Soil Above Surrounding Background in Remediation of Category D Soils

From a purely risk assessment standpoint, redevelopment of a heavily contaminated site for commercial/industrial purposes only requires remediation of Category D soils, although Category C soils must be managed properly. The boundary between localized "hot spots" of heavily contaminated soil and the surrounding soils is typically very sharp, however, with a rapid drop off in contaminant concentrations to background (i.e., <20 ng/kg for non-agricultural soils and 20-100 ng/kg for former field areas). The additional area and volume of marginally impacted soil that lies at the margins of the heavily contaminated area will, in many instances, be relatively minor. The inclusion of *all* soil contaminated by the release above the surrounding background in remediation actions is therefore recommended, to the extent practicable, even though the marginally contaminated soil may not pose a significant risk to future users of the site under commercial/industrial land use.

At sites where Category D soils are to be addressed via treatment, disposal, or containment, HEER recommends that the same remedy be used for the full area and volume of soil that is clearly above background for the surrounding area to the extent practicable, for the following reasons:

1. **The added cost of addressing less contaminated soils along with heavily contaminated soils is anticipated to be relatively small.** As described above, sites characterized by isolated spill areas of highly-contaminated soils are typically sharply defined. An expansion of the boundary of the remediation area to include Category C and even Category B soils that are clearly above the surrounding background may significantly increase the long-term reliability of the remedy without an excessive increase in short-term remediation cost and decrease the cost and liability associated with long-term management of the site.

2. **Engineered and institutional controls can be more expensive than initially estimated.** Low up-front capital costs for on-site, long-term management of moderately contaminated soil can mask costs associated with long-term maintenance and oversight of controls as well as future liability associated with inappropriate onsite or offsite reuse of inadvertently exposed soil. This underestimation of the total life-cycle cost can lead to the selection of a remedy that either (1) fails due to inadequately-funded implementation, or (2) ends up exceeding the costs of other remedial options that had been deemed too expensive during the initial evaluation. Full treatment of contaminated soil will also increase the future resale and development value of the property.

Short and long-term remedial actions for sites where Category D soils are identified should be discussed with the HEER office on a site-by-site basis.

4.4 Hazardous Waste Considerations

Hazardous waste issues associated with the long-term management of dioxin-contaminated soil should be discussed with HEER staff on a site-by-site basis and incorporated into an *Environmental Hazard Management Plan* prepared for the site. The burden and feasibility of long-term management of dioxin-contaminated soil at a site can vary greatly depending on the regulatory designation of the soil as a hazardous or nonhazardous waste under RCRA Subtitle C. Dioxin-contaminated soil that is designated as a hazardous waste (see below) cannot be disposed of in any of the permitted, municipal waste landfill or construction and demolition debris landfill in Hawai‘i. The soil must instead be disposed of at an out-of-state hazardous waste facility, typically at a significantly greater cost and administrative burden. This issue should be considered in selection of a final remedy for a site.

A preliminary Land Disposal Restriction (LDR) determination under RCRA Subtitle C should be made for dioxin-contaminated soils identified in the course of a site investigation (e.g., USEPA 2005). Dioxins associated with the release of a listed waste under RCRA Subtitle C are considered to be hazardous waste at the point that the soil is excavated or “generated.” An example is dioxin-contaminated soil at a wood treatment facility that is associated with the release of pentachlorophenol. If the soil is not excavated then it is not considered to be "generated" and is therefore not subject to an LDR determination. If excavated, the soil is considered to be contaminated with a prohibited waste and must be managed in accordance with LDR restrictions.

Pesticide-contaminated soil associated with past agricultural practices is *exempt* from designation as a hazardous waste, provided that the pesticide was used as intended and containers were cleaned and disposed of in accordance with label information available at that time (40 CFR §262.70 Subpart G: Farmers; USEPA 1986, 2006). This exemption applies to both field areas and pesticide mixing areas. Dioxin-containing soil associated with these types of agricultural sites does not fall under RCRA Subtitle C regulation unless it otherwise fails a hazardous waste characteristics test for other contaminants in the soil (e.g., ignitability, corrosivity, reactivity or exceedence of Toxic Characteristics Leaching Procedure (TCLP) regulatory levels; 40 CFR §261). Note that this exemption will not generally apply to illegal dump sites where disposal of bulk pesticides (vs cleaned containers) occurred. Applicability of this exclusion should be clearly discussed in a site-specific *Environmental Hazard Management Plan* for dioxin-contaminated soil that is capped in place for long-term management, with reference made to the above documents (e.g., 40 CFR §262.70 Subpart G: Farmers; USEPA 1986, 2006) as well as other pertinent information (e.g., past use of subject site for agricultural purposes). Simple reference of this technical memorandum will not be adequate.

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Table 1. Summary of TEQ Dioxin Soil Action Levels and associated soil management categories.

Soil Management Category	Action
Category A (≤20 ng/kg)	**Background.** Within range of expected background conditions in non-agricultural and non-industrial areas. No further action required and no restrictions on land use.
Category B (>20 but ≤240 ng/kg)	**Minimally Impacted.** Exceeds expected background conditions but within range anticipated for agricultural fields. Potential health risks considered to be insignificant. Include Category B soil in remedial actions for more heavily contaminated spill areas as practicable in order to reduce exposure (e.g., outer margins of pesticide mixing areas). Offsite reuse of soil for fill material or as final cover on a decommissioned landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. For existing homes, consider measures to reduce daily exposure to soil (e.g., maintain lawn cover, ensure good hygiene, thoroughly wash homegrown produce, etc.). For new developments on large, former field areas, notify future homeowners of elevated levels of dioxin on the property (e.g., include in information provided to home buyers during property transactions).
Category C (>240 but ≤1,500 ng/kg)	**Moderately Impacted.** Typical of incinerator ash, burn pits, wood treatment operations that used pentachlorophenol (PCP), and the margins of heavily impacted, pesticide mixing areas associated with former sugarcane operations that used PCP. Restriction to commercial/industrial land use required with a formal restriction to the deed against sensitive land uses (e.g., residential, schools, day care, medical facilities, etc.) in the absence of significant institutional and engineered controls and HDOH approval. Use of soil as soil as intermediate (e.g., temporarily inactive portions) or interim (e.g., daily or weekly) cover at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions. Preparation of a site-specific, *Environmental Hazard Management Plan* (EHMP) required if soil left on site for long-term management. Removal of isolated spill areas recommended when practicable in order to minimize future management and liability concerns. This includes controls to ensure no off-site dispersion (e.g., dust or surface runoff) or inadvertent excavation and reuse at properties with sensitive land uses.
Category D (>1,500 ng/kg)	**Heavily Impacted.** Typical of former pesticide mixing areas that used PCP (e.g., sugarcane operations). Remedial actions required under any land use scenario in order to reduce potential exposure. Potentially adverse health risks under both sensitive and commercial/industrial land use scenarios in the absence of significant institutional and/or engineered controls. Disposal of soil at a regulated landfill is acceptable, pending agreement by the landfill and barring hazardous waste restrictions.

ATTACHMENT 1

SUPPLEMENTAL INFORMATION ON DEVELOPMENT AND JUSTIFICATION OF UPDATED TEQ DIOXIN ACTION LEVELS

1.0 Background Information on Dioxins

Dioxins are a group of chlorinated organic molecules whose specific members, referred to as "congeners," share similar chemical structures and mechanisms of toxicity (WHO 2001, 2002, 2006). Potential sources of dioxins in Hawai‘i include deposition of airborne dioxins originating from off-site sources, application of dioxin-bearing pesticides to agricultural fields, spills of concentrated dioxin-bearing pesticides (e.g., at pesticide mixing areas) and combustion of organic materials in the present of chlorine (e.g., incinerators, burn pits, fire training pits, building fires, forest fires, etc.). In agricultural areas, the primary source of dioxins in soils is believed to be associated with manufacturing impurities in certain chlorinated pesticides, such as 2,4,5-T and, in particular, pentachlorophenol. Data on the concentration of dioxins in soils outside of agricultural areas area are limited. HEER is currently conducting research to collect additional soil data in various types of settings throughout the state.

The risk to human health posed by exposure to dioxins is evaluated based on 17 specific dioxin congeners: 7 polychlorinated dibenzo-p-dioxins (PCDDs) and 10 polychlorinated dibenzofurans (PCDFs). The majority of the published literature on dioxin toxicity is limited to 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD, USEPA 2010), considered to be the most toxic of the 17 congeners studied. The World Health Organization (WHO) assigns toxicity values, referred to as "Toxicity Equivalence Factors (TEFs)," to specific congeners relative to the toxicity of TCDD (WHO 2006). The reported concentration of each congener in a sample is multiplied by its respective TEF to calculate a "Toxicity Equivalent (TEQ)" concentration. The TEQ concentrations for individual congeners are then added together to obtain a total TEQ concentration for the sample. The U.S. Environmental Protection Agency (USEPA) and HEER office recommend the use of WHO's TEFs to calculate TEQ dioxin levels for use in human health risk assessments or for comparison to risk-based action levels (USEPA 2009a, HDOH 2009a).

2.0 2008 HEER Dioxin Guidance

Soil action levels published by the HEER office in 2006 and 2008 were based on potential excess cancer risk posed by long-term, direct exposure to dioxins in soil (HDOH 2008a,b). Noncancer health risks were not specifically considered but were presumed to be less significant than cancer risks. The soil action levels were based on the USEPA Regional Screening Levels (RSLs; USEPA 2009b), adjusted to a target excess cancer risk of 10^{-4} (i.e., one in ten thousand; see Attachment 2). Action levels based on a more conservative cancer slope factor published by the Minnesota Department of Health were also developed.

Cancer slope factors published by USEPA and other agencies for dioxins are not fully accepted by the toxicology community and considered by others to be excessively conservative (e.g., Cole et. al 2003, Hayes and Aylward 2003, NAS 2006). Confidence in the slope factors is considered to be low (see Section 4.4). A target excess cancer risk of 10^{-4} was therefore deemed appropriate (refer to Attachment 2).

The 2008 HEER action levels were used to define three categories of soil each for unrestricted (e.g., “residential”) and commercial/industrial land use scenarios. Specific guidance was then presented for the management of soil in each category. The final action levels and soil categories were defined as follows:

2008 HEER TEQ Dioxin Soil Categories		
Category	**Unrestricted/Residential Land Use [1]**	**Commercial/Industrial Land Use**
Category 1 [2]	<42 ng/kg	<170 ng/kg
Category 2 [3]	42 to ≤450 ng/kg	170 to ≤1,800 ng/kg
Category 3 [3]	>450 ng/kg	>1,800 ng/kg

Notes:
1. Includes schools, day care centers, medical facilities and other related sensitive land uses.
2. Action levels based on Minnesota Department of Health cancer slope factors.
3. Action levels based on California EPA cancer slope factors.

No further action was recommended for Category 1 soils under the noted land use. Efforts to minimize exposure (e.g., lawn maintenance) were recommended for Category 2 soils if the soil was associated with widespread, trace-level dioxin contamination in former agricultural fields. Removal or capping of small isolated “hot spots” of Category 2 soils to surrounding, background levels was recommended when feasible in order to minimize exposure, but not considered necessary from a purely health-risk standpoint. Removal or capping of Category 3 soils was recommended. Long-term management of soil at commercial/industrial sites that exceeded the upper action level for unrestricted/residential land use of 450 ng/kg TEQ dioxins was recommended to ensure that the soil was not inappropriately excavated and reused offsite in the future.

3.0 Basis of 2010 Updates to Dioxin Soil Action Levels

This technical memorandum updates the 2008 soil action levels for TEQ dioxin to take into account World Health Organization (WHO) Permissible Tolerable Intake factors for potential cancer and noncancer health risks. Exposure assumptions and model parameters used to develop the earlier action levels are otherwise identical. HDOH considers the WHO factors to be more defensible (e.g., lowest uncertainty factor) and appropriate for use in Hawaiʻi in comparison to alternative factors, including cancer slope factors published by USEPA and other agencies, as well as noncancer toxicity factors published by the US Agency for Toxic Substances and Disease Registry (ATSDR) and more recently by USEPA.

A discussion of alternative toxicity factors is provided for comparison. The final, updated soil action levels fall within the range of action levels that could be developed by use of the alternative toxicity factors. A detailed discussion of model equations and assumptions used to generate the action levels is provided in Attachment 2.

3.1 Use of WHO PMTI Factors to Develop Soil Action Levels

This update incorporates the use of WHO Permissible Tolerable Monthly Intake (PTMI) factors (WHO 2001, 2002) to develop alternative soil action levels for TEQ dioxins. The WHO PTMI is intended to limit the long-term, body burden of TEQ dioxins to levels that are not believed to be associated with significant cancer or noncancer health risks. WHO concluded that body burden is a more appropriate measure of potential health risks than is a traditional approach based on daily dose, although the two parameters are closely related.

In 1998 WHO published a Tolerable *Daily* Intake (TDI) range for bioavailable TEQ dioxins of 1 to 4 picograms per kilogram of body weight per day (1-4 pg/kg-day; WHO 1998). The ATSDR published an identical range of TEQ dioxin "Minimal Risk Levels" in the same year (ATSDR 1998, 2008). WHO subsequently published an updated, Permissible *Monthly* Tolerable Intake (PTMI) factor range for TEQ Dioxins of 40 to 100 pg/kg-month, after further review of available studies (WHO 2001, 2002). The PTMI of 100 pg/kg-month is based on a No Observed Effects Level (NOEL, power model) for an equivalent human monthly intake (EHMI) of 330 pg/kg per month, adjusted by safety factor of 3.2 to account for inter-individual differences in toxicokinetics among humans (rounded downward to a value of 100). The PTMI of 40 pg/kg-month is based on a Lowest Observed Effects Level (LOEL, linear model) for an equivalent human monthly intake (EHMI) of 423 pg/kg per month, adjusted by safety factor of approximately 9.6 to account for both use of a LOEL (vs NOEL) and inter-individual differences in toxicokinetics (rounded downward to a value of 40).

The WHO PTMI levels were divided by a factor of 30.4 days/month in order to generate an equivalent, tolerable *daily* intake range of 1.3 pg/kg-day to 3.3 pg/kg-day and allow their use in risk-based models for development soil action levels (see Attachment 2). WHO presents monthly, rather than daily, intake ranges to emphasize that the PMTI range is applicable to long-term exposure only, and is well below levels that could pose immediate health effects. As stated in the WHO document:

> "The PTMI is not a limit of toxicity and does not represent a boundary between safe intake and intake associated with a significant increase in body burden or risk. Long-term intakes slightly above the (upper range of the) PTMI would not necessarily result in adverse health effects but would erode the safety factor built into the calculations of the PTMI."

The more rigorous, NOEL-based PMTI of 100 pg/kg-month (3.3 pg/kg-day) was selected for calculation of final dioxin soil action levels. The adjusted factor was incorporated into the USEPA Regional Screening Level (RSL) models for noncancer health risks. This generated a soil action level 240 ng/kg for unrestricted (e.g., residential) land use and 2,800 ng/kg for commercial/industrial land use (see Attachment 2). The calculated action level for unrestricted land use was retained for use in this guidance (refer to Sections 2 and 3 in main text). As discussed in the following section, the commercial/industrial action level was reduced by a factor of 1.9 to 1,500 ng/kg in order to limit theoretical exposure to dioxins in soil to approximately

50% of the estimated dietary intake for adults (refer also to Attachment 2). The HEER office believes that the final soil action levels are appropriate and practicable for screening of dioxin-contaminated sites in Hawaiʻi.

Note that the WHO PTMI assumes a 50% bioavailability of TEQ dioxins in food (see footnote to Table 14, WHO 2002). This is similar to estimates of average dioxin bioavailability in soil, as recently reviewed by the Washington Department of the Environment (Washington DOE 2007a,b). In the absence of site-specific data, further adjustment of the WHO PTMI and soil action levels presented in the main text of this guidance based on assumed dioxin bioavailability in soil is not recommended.

3.2 Comparison of Dietary Exposure

A comparison of WHO PTMI factors to typical dietary exposure to TEQ dioxins is useful in order to put potential exposure to dioxins in soil at the action levels noted in perspective. The WHO estimates the mean, dietary intake of TEQ dioxins to be 15 to 160 pg/kg-month at the 90th percentile of mean lifetime exposure (WHO 2002). This equates to a daily dietary exposure of 0.5 to 5 pg/kg-day, or up to 75 pg/day for a 15 kg child and 350 pg/day for a 70 kg adult (default body weights typically used in human health risk assessments).

As summarized in Attachment 3, dietary intake of TEQ dioxins for Pacific-Asian diets heavy in fish and vegetables is estimated to range from 66 pg/day for children (4.4 pg/kg-day for a 15 kg child) and to 102 pg/day adults (1.5 pg/kg-day for a 70 kg adult), respectively. Food of animal origin is estimated to contribute to approximately 80% of overall human exposure to dioxins (USEPA 2010). Other studies have indicated a minimal contribution of TEQ dioxins from soil with respect to dietary intake (e.g., Kimbrough et al 2010).

For comparison, the HDOH soil action level for unrestricted (e.g., residential) land use of 240 ng/kg equates to a theoretical, TEQ dioxin average daily dose of approximately 23 pg/day for a 15 kg child and 12 pg/day for a 70 kg adult (assuming a soil ingestion rate of 200 mg/day for children and 100 mg/day for adults, a bioavailability of 50% and the additional exposure factors noted in Attachment 2). This represents approximately 35% of the estimated dietary exposure for a 15 kg child (USEPA default body weight for children, as averaged for ages 1-6; refer to Attachment 2).

The HDOH soil action level for commercial/industrial land use of 2,800 ng/kg equates to a theoretical, TEQ dioxin average daily dose of approximately 96 pg/day for a 70 kg adult. This is approximately equal to the estimated dietary exposure of adults to TEQ dioxins. As an added measure of safety, however, HEER decided to reduce the soil action level to 1,500 ng/kg in order to limit the theoretical exposure to dioxins in soil to 50 pg/day or approximately 50% of the estimated dietary exposure (added safety factor of 1.9; refer to Attachment 2). Actual exposure to dioxins in soil for both children and adults is likely to be much lower than exposure predicted by the models due to the conservative nature of the exposure factors assumed in the models.

3.3 Comparison to 2009 USEPA RSLs Adjusted for Relative Bioavailability

The 2009 USEPA Regional Screening Levels (RSLs; USEPA 2009b) do not consider the relative bioavailability of dioxins in soil (i.e., relative bioavailability of dioxins in soil in comparison to bioavailability of dioxins in laboratory-based studies). Guidance published by the Washington Department of Ecology (DOE) was used to adjust the USEPA RSLs for comparison to WHO-based action levels (Washington DOE 2007a,b; see Attachment 2). Washington DOE presents the following rationale for use of a gastrointestinal absorption adjustment (bioavailability) factor in the calculation of soil screening levels for cancer risk concerns:

- Available evidence suggests that soil-bound dioxins/furans are less bioavailable than dioxins/furans used to assess the health risks from bioassays, epidemiological studies or studies used to assess the toxicity of dioxins/furans in foods and drinking water.

- Although there is uncertainty in assigning congener-specific bioavailability estimates, the available evidence suggests that the higher-chlorinated dioxin/furan congeners (hexa-, hepta-, octa-) are less well absorbed and less bioavailable than the lower-chlorinated congeners (tetra- and penta-).

- Within a range of uncertainty and variability, available evidence suggests that congener-specific differences in bioavailability should be considered when evaluating the toxicity and assessing the risks for mixtures of dioxins/furans.

Based on a review of published studies, Washington DOE (2007a) recommended a default relative bioavailability 0.7 for the tetra- and penta-chlorinated dioxin/furan congeners, and 0.4 for the less available (but usually more abundant) hexa-, hepta-, and octa-chlorinated congeners (i.e., bioavailability in soil *relative* to the bioavailability in the food used in the animal studies, estimated to be between 80% ad 90%; USEPA 2010). Final guidance published by Washington DOE recommended a weighted, relative bioavailability or gastrointestinal absorption fraction for TEQ dioxins of 0.6, based on typical mixtures of dioxin/furan congeners identified in soil (Washington DOE 2007b). This was consistent with the default, relative bioavailability of TEQ dioxins in soil recommended by a majority of other State and international agency guidance reviewed by Washington DOE. Assuming a bioavailability of dioxins in the food used in animal studies of 80% to 90%, this equates to an ultimate bioavailability of dioxins in soil of approximately 50%, similar to the bioavailability of dioxins assumed in the WHO PMTI factors (refer to Section 3.1).

An internal HEER review of dioxin/furan congener soil data from former sugarcane operations in Hawai‘i indicated an average mixture of 2% tetra- and penta- dioxin/furan congeners and 98% hexa-, hepta-, and octa- congeners, with a worst-case instance of 20% tetra- and penta-dioxin/furan congeners and 80% hexa-, hepta-, and octa- congeners. Applying Washington DOE’s approachTo dioxin data from former sugarcane fields and pesticide mixing area in Hawai‘i, HEER calculated TEQ dioxin bioavailability factors from 0.41 (average) to 0.46

(worst-case). This suggests that the default, relative bioavailability of 0.6 published by the Washington DOE is adequately for modification of the USEPA RSLs.

Modification of the 2009 USEPA RSLs for relative bioavailability applies only to the incidental ingestion portion of the soil action level models. As indicated in Attachment 2, a separate absorption factor is used for dermal exposure. Relative bioavailability is not considered for inhalation of particulates. The latter two exposure pathways are relatively minor in comparison to incidental ingestion. Adjustment of the incidental ingestion portion of the soil model to reflect a relative bioavailability 0.6 and use of a target, excess cancer risk of 10^{-4} yields modified RSLs of 650 ng/kg and 2,400 ng/kg for unrestricted/residential land use and commercial/industrial land use respectively.

The updated TEQ dioxin soil action level for unrestricted land use presented in the main text (240 ng/kg) is more conservative than the USEPA RSL adjusted for relative bioavailability and a target excess cancer risk of 10^{-4}. The updated action level for commercial/industrial land use (1,500 ng/kg) is also lower than the adjusted RSL.

3.4 Comparison to 2009 USEPA TEQ Dioxin PRGs (Draft)

USEPA recently published a draft document entitled *Recommended Interim Preliminary Remediation Goals (PRGs) for Dioxin in Soil at CERCLA and RCRA Sites* (USEPA 2009a). Although the final PRGs are similar to the updated HDOH soil action levels presented above, the HEER office considers the approach presented in this technical memorandum to be more applicable for use in Hawai‘i.

The USEPA draft guidance proposes to retract screening levels for TEQ dioxins published in 1998 for use at CERCLA and RCRA sites, including the often cited screening levels of 1 µg/kg TEQ dioxins for residential soils and 5 to 20 µg/kg for commercial/industrial soils (USEPA 1998). The HEER office had previously discounted use of these action levels in Hawai‘i, after concluding that they may not be adequately protective of human health in some circumstances.

As an alternative, the draft USEPA document proposes use of the 1998 ATSDR Minimal Risk Level (MRL) to develop TEQ dioxin soil screening levels or “Preliminary Remediation Goals” (“PRGs”). The ATSDR document presents an MRL range for TEQ dioxins of 1 to 4 pg per kilogram bodyweight per day (pg/kg-day), identical to guidance published by the World Health Organization the same year (see above). This equates to an exposure of 15 to 60 pg/day for a 15 kg child (average child bodyweight used in noncancer risk assessments) or 60 to 280 pg/day TEQ dioxins for a 70kg adult (lifetime average bodyweight used in cancer risk assessments). Exposures below these levels are assumed to not pose a significant health risk. Note that the upper limit of the ATSDR MRL range is slightly less conservative than the range proposed by WHO (WHO 2002; see above).

Using the models and exposure assumptions presented in the draft guidance with the ATSDR MRL range for TEQ dioxins of 1 to 4 pg/kg-day yields a soil screening level range of 72 to 290 ng/kg for residential land use and 850 to 3,400 ng/kg for commercial/industrial land use. This is comparable to the range of screening levels generated by use of the WHO PTMI guidance as described above and in the main text of this document. The draft USEPA document proposed a TEQ dioxin “Preliminary Remediation Goal” (PRG) of 72 ng/kg for residential soil and 950 ng/kg for commercial/industrial, based on use of the low end of the ATSDR MRL range, or 1 pg/kg-day. These action levels do not consider the relative bioavailability of dioxins in soil (see Section 3.2). Adjusting for a relative bioavailability of 0.6 would yield correlative PRGs of 120 ng/kg and 1,600 ng/kg, respectively. While the HEER office does not disagree that soils with concentrations of TEQ dioxins below the proposed PRGs levels do not pose a significant health risk, HEER feels that the PRGs are too conservative to be useful for initial screening purposes in Hawai‘i. As discussed above, the HEER office also prefers use of the more recent, WHO PTMI guidance over the 1998 ATSDR guidance.

The draft USEPA document also notes that the proposed PRGs fall within the range of screening levels that would be generated using cancer slope factors published by the USEPA in the 1980s and a risk range of 10^{-6} to 10^{-4} (e.g., 4.5 to 450 ng/kg for residential soil and 18 to 1,800 ng/kg; based on the current USEPA RSLs; USEPA 2009b). Note that identical, noncancer screening levels for TEQ dioxins were calculated as part of the 2009 USEPA RSL guidance but ultimately not selected as the final RSLs, since the screening level for cancer concerns assumes a target risk of 10^{-6}.

As discussed below, HEER prefers to focus on remediation of *localized* areas of dioxin-contaminated soil (e.g., pesticide mixing areas) to meet the surrounding area background concentrations *as practicable* on a site-by-site basis, rather than deferring to a purely risk-based soil action level. Remediation of minimally impacted soils in large, former agricultural fields to natural background concentrations (e.g., <20 ng/kg) is considered to be impracticable and, from the standpoint of risk and added health benefit, unnecessary. This is supported by consideration of dietary intake of dioxins and furans, which is estimated to exceed the hypothetical intake associated with long-term exposure to soils with concentrations of TEQ dioxins at or below the updated action levels.

3.5 Comparison to 2010 USEPA TCDD Toxicity Review (Draft)

USEPA recently released a draft review of published literature on the health effects of tetrachlordibenzonedioxin (TCDD) and related compounds (USEPA 2010). USEPA focused on two studies of human exposure to TCDD to develop a draft, noncancer reference dose. A Lowest Observed Adverse Effects Level (LOAEL) of 20 pg/kg-day exposure to TCDD was ultimately selected for development of an oral reference dose (RfD).

The selected LOAEL of 20 pg/kg-day is well above the WHO Permissible Tolerable Intake of 3.3 pg/kg-day used to develop soil action levels in this technical memorandum (refer to Section 3.2). In the draft document, however, USEPA reduces the LOAEL by an uncertainty factor of ten due to the lack of a No Observed Adverse Effects Level (NOAEL) for TCDD. The LOAEL is further reduced by a factor of three to account for human inter-individual variability, for a total uncertainty factor of thirty. The document then proposes a final, draft, TCDD reference dose of 0.7 pg/kg-day.

The selected WHO tolerable intake factor of 3.3 pg/kg-day exceeds the final RfD of 0.7 pg-kg-day selected by USEPA in it's draft document. The WHO factor falls near the low end of the RfD and LOAEL low-risk range of TCDD exposure identified in the draft review, however (0.70 pg/kg-day to 20 pg/kg-day). Adjustment of the draft USEPA RfD to take into account a reduced relative bioavailability of dioxins in soil would further reduce the difference between action levels derived by either method. For example, use of the draft RfD in the USEPA RSL models would yield soil action levels of approximately 50 ng/kg and 600 ng/kg for residential and commercial/industrial land use, respectively (refer to Attachment 2). Adjustment for a relative bioavailability of dioxins in soil of 0.6 (see Section 3.2) yields action levels of 85 ng/kg and 1,000 ng/kg, respectively.

The draft USEPA document also presents an oral slope factor range of 1.1 x 10^{5} (mg/kg-day)$^{-1}$ to 1.6 x 10^{6} (mg/kg-day)$^{-1}$ for possible use in cancer risk assessments, depending on the selected target risk. As discussed above, the 2009 USEPA RSLs for 2,3,7,8 dioxins is based on a slope factor of 1.3 x 10^{5} (mg/kg-day)$^{-1}$. Use of a more conservative slope factor would (e.g., 7.8 x 10^{5} (mg/kg-day)$^{-1}$ based on target risk of 10^{-4}) would reduce the RSL by a factor of approximately six. As discussed above, the cancer slope factors incorporate a relatively high degree of uncertainty and confidence in their use to develop meaningful soil action levels is low.

HDOH does not feel that use of an RfD or cancer slope factor that equates to an exposure below anticipated dietary intake to derive soil action levels is practical. At this time, and in consideration of the multiple lines of evidence summarized in Section 2 of the main text, HDOH considers the WHO PTMI factors to be the most technically supportable and appropriate values for development of direct-exposure soil action levels for use in Hawai‘i.

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ATTACHMENT 2

EQUATIONS AND ASSUMPTIONS FOR DERIVATION OF TEQ DIOXIN SOIL ACTION LEVELS

1.0 Introduction

A summary of models and assumptions used to develop for human health, direct-exposure concerns is presented below. For addition information on the models, refer to the USEPA document *Screening Levels for Chemical Contaminants* (USEPA 2009). See also Appendix 1 of the HEER *EHE Guidance* (HDOH 2008b).

2.0 TEQ Dioxin Toxicity Factors and Bioavailability

The WHO Permissible Tolerable Monthly Intake (PTMI) upper limit of 100 pg/(kg-month) is used to calculate noncancer soil action levels (WHO 2002). The PTMI is converted to a Permissible Tolerable *Daily* Intake (PTDI) level of 3.3 pg/(kg-day) for use in the noncancer equations. Although not necessarily applicable, a default Hazard Quotient of 1.0 is also assumed in the equations. A Cancer Slope Factor (CSF) of 1.3E+05 $(mg/kg\text{-}day)^{-1}$ and an Inhalation Unit Risk Factor (IURF) of 38 $(\mu g/m^3)^{-1}$ were selected for calculation of cancer-based soil action levels (USEPA 2009; CSF adopted from CalEPA). Action levels are based on a target excess cancer risk of 10^{-4}.

The equations incorporate an additional Gastrointestinal Absorption Factor (GIABS) to adjust for the bioavailability of dioxins and furans in soil, as necessary. A default GIABS for dioxins and furans of 0.6 is assumed for soils (Washington DOE 2007a,b). This is used to adjust the incidental ingestion exposure portion of the cancer-based action level (see Table 1 and Equations 1 and 3). An assumed bioavailability of 0.5 is directly incorporated into the WHO PTMI; further adjustment of bioavailability for exposure to soil is therefore not warranted (GIABSnc = 1; see Table 1 and Equations 2 and 4).

3.0 Soil Action Levels Models

Human exposure assumptions are summarized in Table 1. With the exceptions noted, parameter values in Table 1 were taken directly from the USEPA Regional Screening Level (RSL) guidance document (USEPA 2009). Parameter values for the construction/trench worker exposure scenario are discussed in more detail in Appendix 1. Tables 2 and 3 summarize equations and parameter values used to develop the RSL Particulate Emission Factor and physiochemical constants assumed in the models for TEQ dioxins.

Carcinogenic risks under unrestricted/residential exposure scenarios were calculated using the following age-adjusted factors. Definition of terms and default parameter values used in the equations are presented in Tables 1, 2, and 3.

1) Ingestion [(mg·yr)/kg·d)]:

$$IFS_{adj} = \frac{ED_c \ x \ IRS_c}{BW_C} + \frac{(ED_r - ED_c) \ x \ IRS_a}{BW_a}$$

2) Dermal Contact [(mg·yr)/kg·d)]:

$$SFS_{adj} = \frac{ED_c \ x \ AF_c \ x \ SA_c}{BW_C} + \frac{(ED_r - ED_c) \ x \ AF_a \ x \ IRS_a}{BW_a}$$

3) Inhalation [(m^3·yr)/kg·d)]:

$$InhF_{adj} = \frac{ED_c \ x \ IRA_c}{BW_C} + \frac{(ED_r - ED_c) \ x \ IRA_a}{BW_a}$$

Direct exposure equations for soil are summarized as follows:

Equation 1: Combined Exposures to Carcinogenic Contaminants in Residential Soil

$$C(mg/kg) = \frac{TR \ x \ AT_c}{EF_r \left[\left(\frac{IFS_{adj} \ xGIABSc \times CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{SF_{adj} \ x \ ABS \ x \ CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{InhF_{adj} \ x \ CSF_i}{PEF} \right) \right]}$$

Equation 2: Combined Exposures to Noncarcinogenic Contaminants in Residential Soil

$$C(mg/kg) = \frac{THQ \times BW_c \times AT_n}{EF_r \times ED_c \ \left[\left(\frac{1}{RfD_o} \times \frac{IRS_c \times GIABSnc}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_o} \times \frac{SA_c \times AF_c \ x \ ABS}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_i} \times \frac{IRA_c}{PEF} \right) \right]}$$

Equation 3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil

$$C(mg/kg) = \frac{TR \times BW_a \times AT_c}{EF_o \times ED_o \ \left[\left(\frac{IRS_o \times GIABSc \times CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{SA_a \times AF_a \times ABS \times CSF_o}{10^6 \, mg/kg} \right) + \left(\frac{IRA_a \times CSF_i}{PEF} \right) \right]}$$

Equation 4: Combined Exposures to Noncarcinogenic Contaminants in Industrial Soil

$$C(mg/kg) = \frac{THQ \times BW_a \times AT_n}{EF_o \times ED_o \ \left[\left(\frac{1}{RfD_o} \times \frac{IRS_o \times GIABSnc}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_o} \times \frac{SA_a \times AF_a \times ABS}{10^6 \, mg/kg} \right) + \left(\frac{1}{RfD_i} \times \frac{IRA_a}{PEF} \right) \right]}$$

Equation 5: Derivation of Particulate Emission Factor (residential & occupational)

$$PEF\,(m^3/kg) \quad = \quad Q/C \;x\; \frac{3600s/h}{0.036 \times (1-V)\,(U_m/U_t)^3 \times F(x)}$$

The USEPA RSL models incorporate a Volatilization Factor (VF) for emission of volatile chemicals to outdoor air. Volatile chemicals are defined as having a Henry's Law Constant of >1.0E-05 (atm·m^3)/mol and a molecular weight of <200 g/mol. Dioxin/furan mixtures do not meet this definition. The VF term in the soil equations is therefore replaced with the Particulate Emission Factor (PEF) term for non-volatile chemicals.

4.0 Calculated Soil Action Levels

4.1 Unadjusted Action Levels

Based on the models and model assumptions described above and in Table 1, a TEQ dioxin soil action level of 240 ng/kg is generated for unrestricted (e.g., residential) land use. This action level was retained for use in the final guidance (refer to Table 1 in the main text). A preliminary soil action level of 2,800 ng/kg is generated for commercial/industrial land use. As described below, this action level was adjusted by an additional safety factor of 1.9 in order to minimize exposure to dioxins in soil to approximately 50% of the estimated dietary exposure.

4.2 Adjustment of Commercial/Industrial Soil Action Level

The HDOH soil action level for commercial/industrial land use of 2,800 ng/kg equates to a theoretical exposure to TEQ dioxins of approximately 96 pg/day for a 70 kg adult (refer to Section 3.2 in main text). This is approximately equal to the estimated dietary exposure of adults to TEQ dioxins. As an added measure of safety, however, HEER decided to reduce the soil action level to 1,500 ng/kg in order to limit the theoretical exposure to dioxins in soil to 50 pg/day or approximately 50% of the estimated dietary exposure (added safety factor of 1.9). Actual exposure to dioxins in soil for both children and adults is likely to be much lower than exposure predicted by the models due to the conservative nature of the exposure factors assumed in the models.

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TABLE 1. HUMAN EXPOSURE PARAMETER DEFINITIONS AND DEFAULT VALUES

Symbol	Definition (units)	Value	Units	References (see USEPA 2002 for full references)
CSFo	Cancer slope factor, oral	1.3E+05	$(mg/(kg·d))^{-1}$	USEPA 2009 (references California EPA 2008)
CSFi	Cancer slope factor, inhaled	38	$(ug/m^3)^{-1}$	USEPA 2009 (references California EPA 2008)
RfDo	Reference dose, oral	3.3E-09	mg/(kg·d)	WHO 2002, see text
RfDi	Reference dose, inhaled	-	mg/(kg·d)	-
TRr/o	Target cancer risk – residential or occupational exposure scenario	1.0E-04	Unitless	HDOH, see text
THQ	Target hazard quotient	1.0	Unitless	See text
BWa	Body weight, adult	70	Kg	USEPA 2009
BWc	Body weight, child	15	Kg	USEPA 2009
ATc	Average time, cancer risk	25,550	D	USEPA 2009
ATn	Average time, noncancer risk	ED × 365	d	USEPA 2009
SAar	Exposed surface area, adult residential	5.7E+03	cm^2/d	USEPA 2009
SAaw	Exposed surface area, adult occupational	3.3E+03	cm^2/d	USEPA 2009
SAc	Exposed surface area, child	2.8E+03	cm^2/d	USEPA 2009
AFar	Adherence factor, adult residential	0.07	mg/cm^2	USEPA 2009
AFaw	Adherence factor, occupational	0.20	mg/cm^2	USEPA 2009
AFc	Adherence factor, child	0.20	mg/cm^2	USEPA 2009
ABS	Skin absorption, chemical specific	0.03	unitless	USEPA 2009
IRAa	Inhalation rate, adult	20	m^3/d	USEPA 2009
IRAc	Inhalation rate, child	10	m^3/d	USEPA 2009
IRSa	Soil ingestion, adult	100	mg/d	USEPA 2009
IRSc	Soil ingestion, child	200	mg/d	USEPA 2009
IRSo	Soil ingestion, occupational	50	mg/d	USEPA 2009
GIABSc	Gastrointestinal Absorption Adjustment Factor, cancer risk	0.6	unitless	Washington DOE 2007b, see text
GIABSnc	Gastrointestinal Absorption Adjustment Factor, noncancer risk	1.0	unitless	No adjustment; 50% dioxin bioavailability assumed in food (WHO 2002), see text
EFr	Exposure frequency, residential	350	d/yr	USEPA 2009
EFo	Exposure frequency, occupational	250	d/yr	USEPA 2009
EDr	Exposure duration, residential	30	yr	USEPA 2009
EDc	Exposure duration, child	6	yr	USEPA 2009
EDo	Exposure duration, occupational	25	yr	USEPA 2009
IFSadj	Ingestion factor, soil	114	(mg·yr)/(kg·d)	USEPA 2009
SFSadj	Skin contact factor, soil	361	(mg·yr)/(kg·d)	USEPA 2009
InhFadj	Inhalation factor	11	$(m^3·yr)/(kg·d)$	USEPA 2009
PEFres/oc	Particulate emission factor, residential/occupational exposure scenarios	1.32E+09	m^3/kg	USEPA 2009

Primary Reference: USEPA *Screening Levels for Chemical Contaminants* (USEPA 2009).

TABLE 2. PARTICULATE EMISSION FACTOR PARAMETER DEFINITIONS AND DEFAULT VALUES - RESIDENTIAL/OCCUPATIONAL SCENARIOS

Parameter	Definition	Default Value	Units
PEF *	Particulate emission factor	1.316E+09	m^3/kg
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source	90.80	$g/(m^2 \cdot s)$ per kg/m^3
V	Fraction of vegetative cover	0.5	unitless
Um	Mean annual windspeed	4.69	m/s
Ut	Equivalent threshold value of windspeed at 7 m	11.32	m/s
F(x)	Function dependent on Um/Ut derived using Cowherd (1985)	0.194	unitless

* Equivalent to an airborne dust concentration, in mg/m^3, of (1,000,000 mg / 1 kg) / PEF = 0.0007 mg/m^3.

TABLE 3. DEFAULT PHYSIOCHEMICAL PARAMETERS FOR TEQ DIOXINS (USEPA 2009)

Parameter	Default Value	Units
Molecular weight	3.56E+02	g/mol
Koc	2.57E+05	l/kg
Solubility in water	1.2E-04	mg/l
Henry’s Law Constant	2.2E-06	$(atm \cdot m^3)/mol$
Henry’s Law Constant	9.0E-05	unitless

ATTACHMENT 3

ESTIMATED DIETARY INTAKE OF TEQ DIOXIN FOR PACIFIC-ASIAN DIETS (see main text for full references)

Table 1. Estimated food consumption for a Pacific-Asian diet.

Food Group	Child (Ave 6mo-5yr) [1]Consumption (g/d)	Child (Ave 6mo-5yr) Percent of Total	Mean Population [1]Consumption (g/d)	Mean Population Percent of Total
Cereals & Cereal Products	**166**	**32%**	**364**	**43%**
Rice & Products	122	23%	303	58%
Corn and Products	17	3%	31	6%
Other Cereals and Products	27	5%	30	6%
Starch Roots and Tubers	**8**	**2%**	**19**	**4%**
Sugars and Syrups	**15**	**3%**	**24**	**5%**
Fats and Oils	**6**	**1%**	**18**	**3%**
Fish, Meat & Poultry	**95**	**18%**	**185**	**35%**
Fish and Products	57	11%	104	20%
Meat and Products	27	5%	61	12%
Poultry and Products	11	2%	20	4%
Eggs	**8**	2%	**13**	**2%**
Milk and Products	**179**	**34%**	**49**	**9%**
Whole Milk	158	30%	35	7%
Milk Products	21	4%	14	3%
Dried Beans, Nuts & Seeds	**4**	**1%**	**10**	**2%**
Vegetables	**13**	**2%**	**111**	**21%**
Green Leafy & Yellow	10	2%	31	6%
Other Vegetables	3	1%	80	15%
Fruits	**31**	**6%**	**54**	**10%**
Vitamin C-rich Fruits	4	1%	12	2%
Other Fruits	27	5%	42	8%
Total Food Consumption:	525		847	

Combined Food Groups	Consumption (kg/day) Child	Consumption (kg/day) Mean
[1]**Fuits & Vegetables**	0.237	0.582
Dairy	0.179	0.049
[2]**Meat**	0.044	0.099
Fish	0.057	0.104
Eggs	0.008	0.013
Total:	0.525	0.847

1. Including cereals and cereal products, starch roots and tubers, dried beans, nuts and seeds.

2. Including fats, oil & poultry.

Reference: FNRI, 2003, The 6th National Nutrition Survey: Food, Philippine Department of Science and Technology, Nutrition and Research Institute, http://www.fnri.dost.gov.ph/index.php?option=content&task=view&id=1130

1. Raw as purchased (rice and cereals presumably dry weight).

Table 2. Estimated dietary intake of TEQ dioxins based on a typical Asian-Pacific diet (see also Table 1).

		[4]Child (6mo-5yr)			[5]Mean Population		
Food Group	**[1]TEQ Dioxins (pg/kg)**	**[2]Daily Dose (pg/d)**	**[3,4]Daily Intake (pg/Kg-d)**	**Percent TEQ Dioxins Contribution**	**[1]Daily Intake (pg/d)**	**[3,5]Daily Dose (pg/Kg-d)**	**Percent TEQ Dioxins Contribution**
Fruits and Vegetables	40	9.5	0.63	14%	23.3	0.33	23%
Dairy	100	17.9	1.19	27%	4.9	0.07	5%
Meat	130	5.7	0.38	9%	12.9	0.18	13%
Fish	560	31.9	2.13	48%	58.2	0.83	57%
Eggs	170	1.4	0.09	2%	2.2	0.03	2%
Total:		66	4.43	100%	102	1.45	100%

1. WHO, 2002, Safety Evaluation of Certain Food Additives and Contaminants: WHO Technical Report Series, Fifty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives, WHO Technical Report Series 909, http://whqlibdoc.who.int/trs/WHO_TRS_909.pdf. Data for North America (vegetable data from Europe).

2. Calculated as: Daily Food Group Consumption (refer to Table 1; converted to kg/day) multiplied by the noted Food Group TEQ Dioxins concentration (converted to pg/kg).

3. Calculated as: Estimated Daily Intake in pg/day divided by assumed weight in Kg.

4. Assumed Child Weight = 15 Kg (default in USEPA risk assessment guidance; e.g., USEPA 2009b).

5. Assumed Mean Population Weight =70 Kg (default in USEPA risk assessment guidance; e.g., USEPA 2009b).

Figure 1. Summary of estimated TEQ dioxin intake based on a Pacific-Asian diet [based on data reported by WHO for dioxin in food (WHO 2002)]