Technical Support Document for the TRIM-Based Multipathway Tiered Screening Methodology for RTR

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1. Introduction and Background

Section 112 of the Clean Air Act (CAA) directs the U.S. Environmental Protection Agency (EPA) to assess the risk remaining (i.e., residual risk) from emissions of hazardous air pollutants (HAPs) following the implementation of maximum achievable control technology (MACT) standards for emission sources. This risk assessment is a major component of EPA's Risk and Technology Review (RTR) program. As part of this program, EPA must consider additional emission standards for a source category if the current emission standards—with MACT regulations in place—do not provide an "ample margin of safety" for human health. One aspect of human health that EPA must consider under RTR is the potential for health effects resulting from exposures to persistent and bioaccumulative HAPs (PB-HAPs) via non-inhalation pathways, namely ingestion and dermal exposure. EPA's assessment for RTR focuses on specific PB-HAPs that the Office of Air Quality Planning and Standards (OAQPS) has identified as candidates for multipathway risk assessments (selection of the PB-HAPs is discussed in Section 2.2.2). These non-inhalation human health risks are considered in combination with estimated inhalation human health risks, potential ecological impacts, and other factors to support decisions about residual risk for RTR source categories. For PB-HAPs, exposures via ingestion are anticipated to be significantly higher than any dermal exposures that might occur as a result of the same emissions (see Attachment C). Consequently, a methodology has been developed to evaluate ingestion exposure and risk for PB-HAPs efficiently in the context of EPA's RTR program.

To evaluate ingestion exposures and human health risks for RTR on a source category basis, an iterative approach was developed that enables EPA to confidently screen out PB-HAP emissions unlikely to pose health risks above levels of concern (i.e., a cancer risk of 1 in 1 million or a noncancer hazard of 1.0) and to focus additional resources on sources of greater concern within the category. To estimate exposure and risk, two models are used: the Fate, Transport, and Ecological Exposure module of EPA's Total Risk Integrated Methodology (TRIM.FaTE) to model the fate and transport of pollutants released to the environment and the Multimedia Ingestion Risk Calculator (MIRC) to estimate transfer and uptake into the food chain and exposure to receptors consuming contaminated food products and soil. This approach is divided into three tiers of increasing refinement, as follows.

- Tier 1 of the approach begins by identifying the facility-level emissions of PB-HAPs within a source category and comparing them to risk-based emission thresholds. The risk-based thresholds are derived using the aforementioned models applied for a hypothetical environmental and exposure scenario, assuming ingestion of locally caught fish, locally grown produce and livestock, and local soil. This hypothetical "screening scenario" is intended to represent a situation in which the ingestion exposure is unlikely to be exceeded at any actual facility evaluated through the RTR program. The thresholds for Tier 1 are derived by estimating the emission rate that corresponds to a lifetime cancer risk of 1 in 1 million or a chronic non-cancer hazard quotient (HQ) of 1 for an individual exposed according to the characteristics associated with the screening scenario. For a facility, if the emission rate of each PB-HAP is less than the Tier 1 threshold emission rate, risks are assumed to be low and no additional multipathway screening is done. If, however, the emission rate of any PB-HAP exceeds the Tier 1 threshold emission rate, the facility can be evaluated further in Tier 2.
- In Tier 2, the actual location of the facility is used to refine some assumptions associated with the environmental scenario while maintaining the Tier 1 ingestion exposure scenario assumptions. The environmental scenario assumptions are refined by incorporating binned site-specific meteorological data and locations of fishable lakes near the facility (see below). The risk-based threshold for each PB-HAP is then adjusted for that facility

based on an understanding of how exposure concentrations estimated for the screening scenario change with meteorology and lake location. PB-HAP emissions that do not exceed the adjusted threshold are assumed to pose risks below levels of concern and no additional multipathway assessment is required. Facilities having emissions that exceed the adjusted thresholds for Tier 2 may require additional analysis.

- A Tier 3 screening assessment can be conducted on facilities that do not screen out with the Tier 2 assessment, at the discretion of the risk assessor. The Tier 3 screening approach consists of three individual assessments that further refine the Tier 2 screening scenario based on additional site-specific data and evaluations. One of the Tier 3 assessments (i.e., the lake assessment) results in the rescreening of the facility's emissions using the Tier 2 methods and using a revised lake database. The other two assessments (i.e., the plume-rise and time-series assessments) each result in an adjustment factor to be applied to the screening result reflecting the Tier 3 lake assessment. Facilities having emissions that exceed the adjusted thresholds for Tier 3 may require additional analysis.

- For facilities emitting PB-HAPs at levels that cannot be ruled out as being above levels of concern based on the screening assessments, a refined, site-specific, multipathway risk assessment can be conducted. Such an assessment would incorporate location- or facility-specific characteristics regarding the environment to which PB-HAPs are emitted, relevant exposure pathways, ingestion rates or other exposure factors, and other parameters. A range of exposure scenarios could be evaluated as part of a site-specific assessment, resulting in a range of risk estimates.

The key processes and decisions that make up this approach are summarized in Exhibit 1. In the remainder of this document, each of the tiers in the multipathway assessment approach is described in additional detail. The attachments provide a comprehensive record of the characteristics and methods associated with Tier 1 and Tier 2 assessments. If a site-specific assessment is conducted, a separate report detailing that assessment will be prepared.

1.1 Tier 1

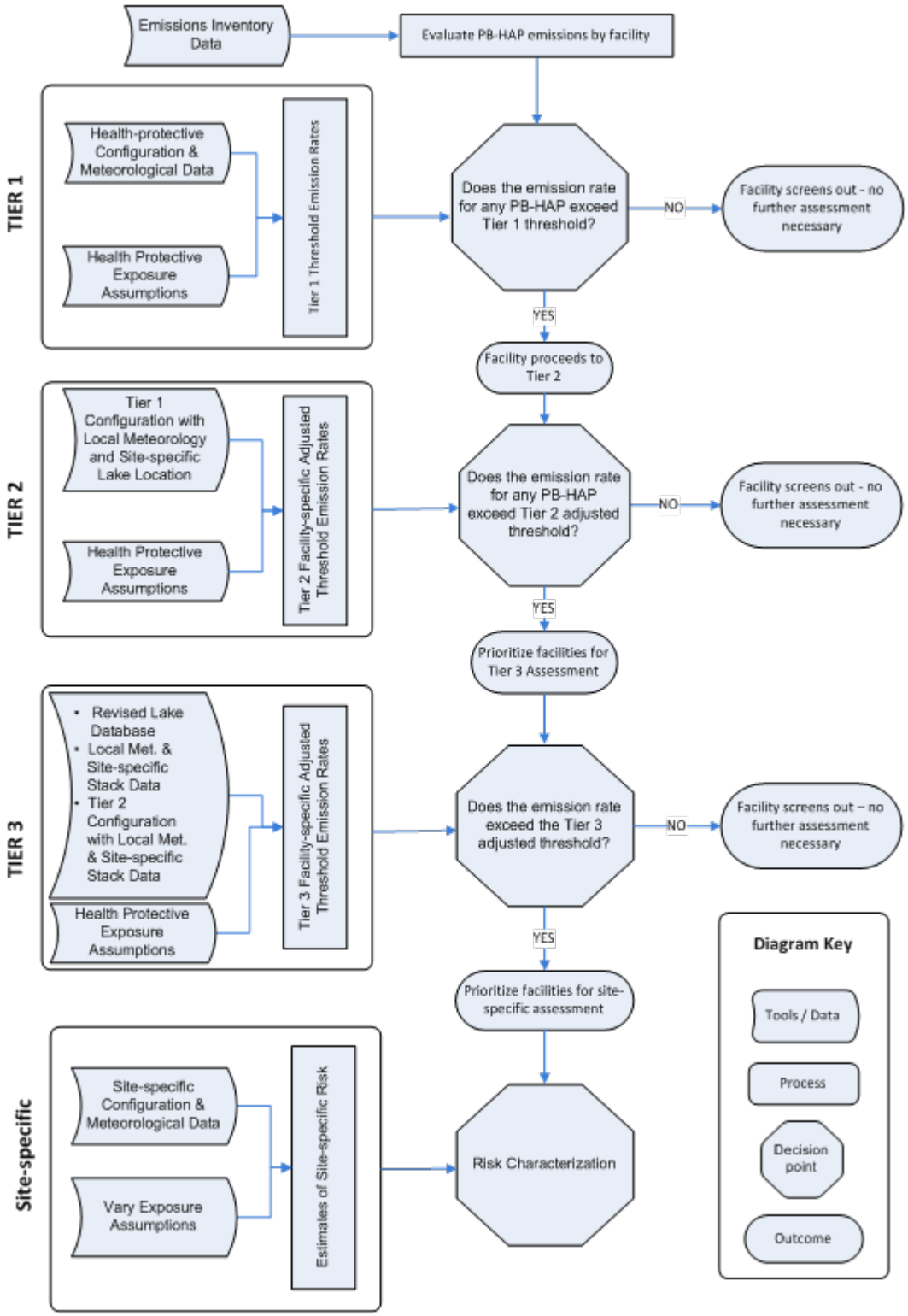
The methods used in Tier 1 are intended to enable EPA to evaluate PB-HAP emissions from multiple facilities in a source category quickly and efficiently and to remove from consideration those that are unlikely to pose risks above levels of concern, while also minimizing the possibility of EPA's failing to identify risks that exceed levels of concern. The hypothetical scenario used to estimate Tier 1 thresholds is designed to be health-protective in estimating exposures and risks; specifically, it is intended to avoid underestimating exposures to PB-HAPS that might be encountered for any location throughout the United States. The scenario also is intended to avoid grossly overestimating risk to the point where no emissions screen out (i.e., overprotective, resulting in too many "false positives").

1.1.1 Chemicals of Concern

The assessment of risk from multipathway exposures begins with a review of data for sources in a particular category to determine if emissions of any of the following PB-HAPs are reported:

- Cadmium compounds,
- Chlorinated dibenzodioxins and furans (dioxins),
- Mercury compounds, and
- Polycyclic organic matter (POM).

Exhibit 1. Conceptual Decision Tree for Evaluating Non-Inhalation Exposures for PB-HAPs



Based on current emissions, bioaccumulation potential, and toxicity considerations, emissions of these four PB-HAPs are expected to pose the majority of the non-inhalation risks to humans from air emissions at sources subject to residual risk provisions of the CAA[1] Thus, although EPA has identified nine other PB-HAPs that should be evaluated as part of residual risk assessments, the methods for multipathway assessment described here encompass only these four at this time.

If emissions of any of the four PB-HAPs listed above are reported for a facility, the emission rate for that PB-HAP is compared to the threshold emissions rate derived for that chemical using the hypothetical TRIM-based screening scenario. This threshold is the emission rate that, when input to the models used in evaluating multipathway risk for RTR, results in a specified cancer risk or non-cancer HQ threshold level of concern. For the screening scenario, threshold emission rates were calculated for a cancer risk of 1 in 1 million or an HQ of 1.0, depending on the more sensitive health effect of the PB-HAP. However, due to the hypothetical nature of the screening scenario, exceeding the threshold emissions rate by 60 times, for dioxins for example, does not imply a resulting cancer risk of 60 in 1 million. Rather, exceeding the threshold emissions rate by 60 times for dioxin implies that it is highly unlikely that the actual risk would exceed 60 in 1 million.

Important to note for dioxins and POM is that the screening methodology assesses individual congeners, taking into account differences in both the fate and transport and the toxicity among the various congeners. The details of the methods for assessing dioxins and POM are provided in Section 2.

1.1.2 Development of Emission Thresholds

Generally, the approach used to assess ingestion exposures and resulting risks for RTR has four components (Exhibit 2):

1. **Fate and transport modeling** of PB-HAPs emitted to air that partition into soil, water, and other environmental media (including fish uptake);
2. **Modeling of uptake** of PB-HAPs by farm food chain media from soil and air;
3. **Estimating ingestion exposures** in terms of average daily dose for consumption of farm food items by a hypothetical exposed human; and
4. **Calculating lifetime cancer risk estimates or chronic non-cancer HQs** for each HAP and corresponding screening threshold emission rates.

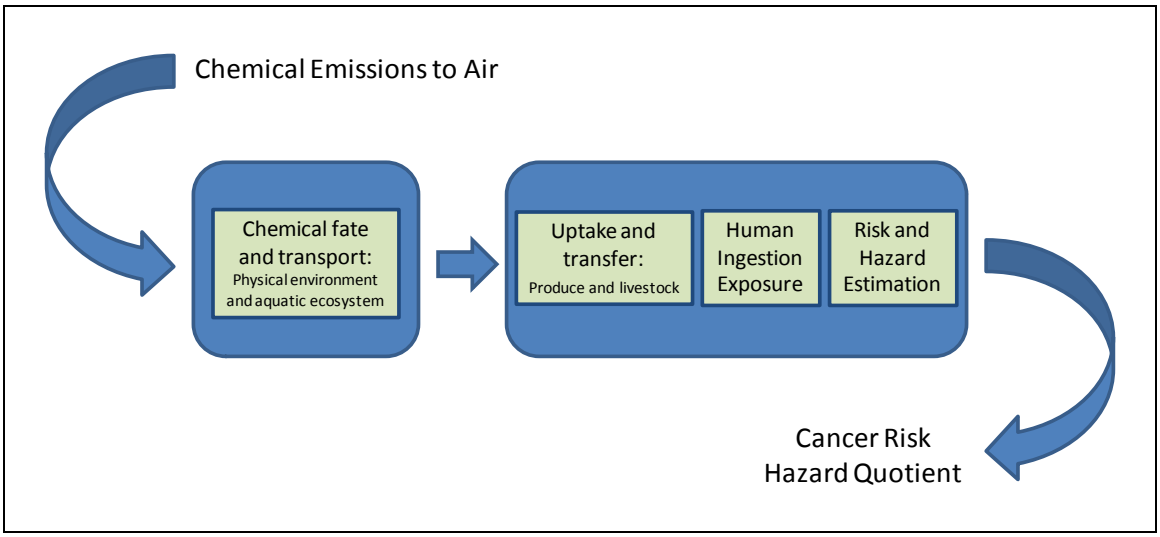
The TRIM.FaTE model is used in the first component, and the MIRC model is used to conduct calculations for the other three components.[2] To derive the emission thresholds used in Tier 1, these models are used to estimate the emission rate corresponding to a cancer risk of 1 in

[1]Potential impacts on human health from non-inhalation exposures to lead are evaluated for RTR using the National Ambient Air Quality Standard for lead, which takes into account multipathway risks.

[2] EPA's TRIM methodology was conceived as a comprehensive modeling framework for evaluating risks from air toxics. It was designed to address each of the four steps in screening ingestion risk; however, only the fate and transport module currently is available for use. For the RTR screening scenario, the Multimedia Ingestion Risk Calculator (MIRC) was constructed to complete the calculations required for estimating PB-HAP concentrations in farm food chain media, average daily ingestion doses, and cancer risks and chronic non-cancer HQs. The framework is conceptually identical to the ingestion exposure and risk analyses that TRIM intended to cover. Information about the current status of TRIM modules and documentation of modules developed thus far can be accessed on EPA's Technology Transfer Network (TTN) on the Fate, Exposure, and Risk Analysis website (http://www2.epa.gov/fera).

1 million or a noncancer HQ of 1 (depending on the PB-HAP) for each PB-HAP within the hypothetical environmental scenario, as described in more detail in the following sections.

Exhibit 2. Overview of Ingestion Exposure and Risk Screening Evaluation Method



1.1.2.1 Modeling Fate and Transport

To model chemical fate and transport in the environment when deriving emission thresholds for Tier 1, the TRIM.FaTE module of the TRIM system was used.[3] The two main components of the fate and transport modeling are (1) the modeled domain, including the meteorological data and (2) the environmental and chemical-specific properties associated with fate and transport through the environment. The hypothetical modeled domain includes a farm homestead and a fishable lake near (i.e., 2 km) an emissions source, which are assumed to be the primary food sources for exposed individuals. The spatial layout and other physical aspects of the modeled domain configuration are designed to be health-protective, which results in an ingestion exposure situation that is unlikely to be exceeded at any actual facility evaluated under the RTR program. The environmental and chemical-specific properties governing fate and transport of PB-HAPs are parameterized with either conservative (i.e., health protective) values or central-tendency values. The mix of health protective and central-tendency assumptions and parameterization is expected to result in a scenario configuration that, on average, is likely to overpredict environmental concentrations of PB-HAPs in media of interest for this evaluation. The inclusion of central-tendency values where warranted is intended to minimize the number of false positives.

Based on sensitivity analyses and model testing it is generally recognized that the spatial layout of the modeled domain (e.g., distance to a fishable lake) and the meteorological data used (or a combination of these two factors) are more influential than physical/chemical parameters in dictating the resulting chemical concentrations in air, soil, water, sediment, and fish within TRIM.FaTE. The Tier 1 assumptions about these two components of fate and transport modeling are refined with relatively more site-specific data in subsequent tiers. The spatial layout used to develop the threshold emission levels in Tier 1 and other details of the Tier 1 methodology are presented in Section 2.

[3] http://www2.epa.gov/fera

1.1.2.2 Modeling Transfer and Uptake

MIRC was developed to conduct the required calculations involving farm food chain transfer, ingestion exposure, and risk. TRIM.FaTE outputs that are used as inputs to MIRC include:

- PB-HAP concentrations in air,
- Air-to-surface deposition rates for PB-HAPs in both particle and vapor phases,
- PB-HAP concentrations in fish tissue for fish consumed, and
- PB-HAP concentrations in surface soil and root zone soil.

From these inputs, MIRC calculates the transfer and uptake of PB-HAPs through the farm food chain using algorithms based on those included in EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (EPA 2005) and biotransfer factors (e.g., soil-to-plant factors, which are the ratios of the concentrations in plants to concentrations in soil). The outputs of MIRC are PB-HAP concentrations in contaminated food items.

1.1.2.3 Estimating Ingestion Exposure

MIRC is also used to estimate exposure in terms of average daily doses (ADDs), normalized to body weight for the following exposure pathways:

- Incidental ingestion of soil
- Ingestion of homegrown produce
- Ingestion of homegrown beef
- Ingestion of milk from homegrown cows
- Ingestion of homegrown poultry/eggs
- Ingestion of homegrown pork
- Ingestion of fish
- Ingestion of breast milk (children <1 year old; dioxins only)[4]

Chemicals are modeled separately to evaluate the potential for risks, with exposures (in terms of ADD) for each PB-HAP summed across all ingestion exposure pathways. For the screening scenario used in Tiers 1 and 2, exposure characteristics were selected that result in a highly health protective estimate of total exposure. The ingestion rate for each exposure pathway listed above was set (as feasible) equal to an upper percentile value (99th percentile for fish and 90th percentile for all other food types) based on EPA's *Exposure Factors Handbook* (EPA 2011a) or other sources as appropriate. All media were assumed to be obtained from a location impacted by the modeled source. This approach results in an overestimate of total chemical exposure for a hypothetical exposure scenario. For example, the resulting total food ingestion rate is extremely high for a hypothetical consumer, with ingestion rates at the 99th percentile for fish and the 90th percentile for every other farm food type. These health protective exposure assumptions can be replaced in a site-specific assessment as appropriate (e.g., with distributions of the data for key exposure factors).

Dermal absorption of chemicals that are originally airborne is generally relatively minor and this pathway was not included in the scenario used to calculate Tier 1 emission thresholds (this topic is discussed further in Section 2 and Attachment C).

[4] Breast milk ingestion is an important exposure pathway for lipophilic compounds like dioxins and has been shown not to contribute meaningfully for exposures to mercury, cadmium, and POM. See Section 2.4.2.3 and Section 3.4 of Attachment B for full discussions of infant exposures via breast milk ingestion.

1.1.2.4 Calculating Lifetime Cancer Risk and Non-Cancer HQs

Lifetime cancer risks and the potential for chronic non-cancer effects are estimated using chemical-specific oral cancer slope factors and oral reference doses. Lifetime cancer risk estimates are calculated separately for each PB-HAP. As provided in Section 5.1 of Attachment B, age-group specific cancer risk estimates are calculated and the estimated lifetime cancer risk equals the sum of these age-group specific risks. Similarly, HQs are calculated separately for each PB-HAP and for each age group. However, as detailed in Section 5.2 of Attachment B, the HQ for the most sensitive age group is used to determine the screening threshold emission rate.

1.1.2.5 Determining Threshold Emission Rates

Tier 1 emission thresholds were calculated by conducting iterative model simulations in TRIM.FaTE and MIRC using the screening scenario described above to determine emission rates for cadmium, mercury, dioxins, and POM that correspond to a cancer risk of 1 in 1 million or a chronic non-cancer HQ of 1. Given the generally health protective nature of the scenario inputs, these thresholds are assumed to be appropriate for screening facilities emitting these PB-HAPs.

1.2 Tier 2

The Tier 1 screening approach is, by design, generic and health protective. It was constructed for quick application to a large number of facilities in a source category with the least chance of returning false negatives for risk potential. Once the Tier 1 screen is complete, however, facilities whose emissions exceed the emission screening threshold for any PB-HAP can be scrutinized further. Based on screening assessments conducted for RTR to date, many facilities might not screen out of the Tier 1 assessment for some source categories. However, conducting a full site-specific assessment of all facilities that cannot be screened out in Tier 1 would not be practical.

Site-specific values for some influential variables, however, can be determined without intensive effort during the assessment. The use of some site-specific characteristics instead of the generic characteristics used in Tier 1 can justify adjusting the threshold emission rate for a given PB-HAP at that facility, potentially screening out the facility while maintaining a high degree of confidence that risks above levels of concern have not been overlooked. In addition, using a scenario in which a fisher fishes from multiple nearby lakes, catching an amount of fish from each lake that is limited by the lake's theoretical fish productivity, creates a more site-specific approach while also maintaining health protectiveness.

In selecting the scenario characteristics to modify in Tier 2, a balance was struck between the degree of impact on the risk estimate, the ease of implementation, and the ease of obtaining relatively certain site-specific values for all facilities that might be evaluated under the RTR program. As discussed in the remainder of this section, some of these characteristics affect the PB-HAP concentrations in environmental media estimated by TRIM.FaTE. Other characteristics affect the sources of ingested fish and, potentially, the fish ingestion rates.

1.2.1.1 Site Specific Considerations

For Tier 2, location-specific data on two types of variables are taken into account:

- Meteorological characteristics, including the fraction of time the wind blows toward each farm and lake (using wind direction), wind speed, precipitation rate, and mixing height; and
- Locations of fishable lake(s) relative to the facility[5] (including the absence of a fishable lake).

For efficient Tier 2 evaluation of the impacts these parameters could have on specific facilities, a series of TRIM.FaTE simulations was performed that systematically varied the values used in the screening scenario for four of the five selected variables (lake location, wind speed, precipitation rate, and mixing height). Wind direction affects only whether the chemical mass advects toward the farms and lakes, so the effect of site-specific wind directions can be evaluated outside of the TRIM.FaTE simulations. The values of each of the four variables were changed, independent of any other changes. The values (four to six for each variable, including the original, Tier 1 scenario values) were selected using statistics on U.S. meteorological data or professional judgment to capture the expected range in the data. Four to six values were selected to result in a total number of runs that was reasonable.

Based on the TRIM.FaTE results of these simulations (and the subsequent exposure and risk characterization, conducted using MIRC), threshold adjustment factors were calculated for each unique combination of the five parameters, for each PB-HAP. These adjustment factors represent the ratio between the risk metric (i.e., cancer risk or HQ) obtained using the Tier 1 screening scenario and the risk metric obtained from the Tier 2 run. For a given facility, for each PB-HAP it emits and each nearby lake evaluated, an adjusted Tier 2 emission threshold can be estimated by dividing the Tier 1 emission threshold by the adjustment factor that best corresponds to the meteorological conditions present at the site and the location of the lake (hypothetical farms are assessed for every facility, at a constant distance from the facility). The contribution of each exposure media toward each scenario's Tier 2 risk metric (i.e., the individual contributions of fish ingestion, soil ingestion, beef ingestion, etc. toward the total Tier 2 risk metric) was included in the matrix because the Tier 2 assessment separates chemical exposure from fish ingestion from exposure from farm food chain ingestion.

To facilitate the implementation of this approach without requiring facility-specific data searches for each new source category evaluated, databases of the relevant U.S. meteorological and lake data were created that could be accessed readily during a Tier 2 evaluation. These databases are described in more detail in Section 3.4. The meteorological database is based on the same hourly meteorology data used for RTR inhalation assessments. The meteorology database includes annual summary statistics on wind direction, wind speed, precipitation, and mixing heights for more than 800 surface stations, paired with their closest upper-air station with available data, located throughout the United States (data available from the National Oceanic and Atmospheric Administration). The lake database, based on U.S. Geological Survey (USGS) data and including location and size information, consists of hundreds of thousands of water bodies classified as "Lake/Pond" or "Reservoir" but not designated for disposal, evaporation, or treatment. To focus on lakes that can support fishing of upper trophic level fish, a minimum lake surface area of 25 acres is recommended. Very large lakes and bays (i.e., those larger than 100,000 acres) are not included because their watersheds are too large and

[5]The lake size also was changed for each lake distance allowing for a constant ratio between watershed and erosion area compared with lake area within the TRIM modeling structure.

their lake dynamics are too complex to realistically model in the TRIM.FaTE system. Lakes and bays larger than 100,000 acres include the Great Lakes, the Great Salt Lake, Lake Okeechobee, Lake Pontchartrain, Lake Champlain, Green Bay, and Galveston Bay.

When the Tier 2 screening is conducted, three additional processing steps are completed for each facility and PB-HAP that will be analyzed in Tier 2 before looking up the appropriate adjustment factors. First, a proximity analysis for each lake is conducted, whereby each relevant lake within 50 km of the facility is identified and matched to its respective directional "octant" relative to the facility. For the purposes of Tier 2, a "relevant" lake meets the size and designation criteria discussed in the previous paragraph. Second, the lakes are manually evaluated to remove lakes whose names suggest uses related to disposal, evaporation, or treatment (sometimes the name indicates one of these uses while the USGS designations do not; for example, the Gavin Fly Ash Impoundment would not be included in the screening process). Third, the lakes around the facility that remain after the first two processing steps are ranked in order of highest to lowest PB-HAP concentrations in fish. These rankings are then used to refine the Tier 2 risk metric for the fisher, as discussed in the next section.

To perform Tier 2 assessments, a Microsoft® Access™ tool was created that merges Tier 1 screening results with the Tier 2 adjustment factors and the lake and meteorology information relevant to a specific facility. In the tool, each facility is matched with the same meteorology station used in RTR inhalation assessments, and the values for the four relevant meteorological parameters at that station are recorded. The distances from the facility to relevant lakes are computed in the tool as well. These five parameter values become the set of facility-specific inputs in Tier 2. Then, the Tier 2 adjustment factors are determined for each PB-HAP for the combination of these five variables. As described above, the Tier 1 screening emission threshold is then divided by the appropriate adjustment factor to obtain a revised, Tier 2 emission threshold for that PB-HAP. More information about Tier 2 assessment methods can be found in Section 3.

1.2.1.2 Refined Tier 2 Fisher Assessment

The refined fisher scenario is based on the idea that an adult fisher might travel to multiple lakes if the first lake (i.e., the lake with the highest concentrations in fish for a given PB-HAP) is unable to provide him an adequate catch to satisfy the assumed ingestion rate (i.e., 373 g/d for adults). This refined fisher assessment uses the assumption that the biological productivity limitation of each lake is 1 gram of fish (wet weight) per acre of lake; meaning that in order to fulfill the adult ingestion rate, the fisher will need to fish from 373 total acres of lakes.

In the refined fisher scenario, a fisher travels to each relevant lake in order of highest to lowest chemical concentration in fish (of a given PB-HAP) and catches fish up to the lake's assumed biological productivity limitation. A maximum travel radius of 50 km relative to the facility is used to maintain a realistic scenario. The final Tier 2 screening result for the fisher can be expressed as the sum of the screening result from each lake that is fished (which is based on the amount of fish ingested for each lake multiplied by the PB-HAP concentration in fish). If the highest-concentration lake is at least 373 acres, the ingestion rate is not altered (i.e., remains 373 g/d for adults). If the cumulative size of multiple visited lakes exceeds 373 acres, the fisher catches from the final lake only the amount of fish necessary to satisfy the ingestion rate (i.e., to reach the 373 g/d). If there are not 373 total acres of lakes, the risk reflects a reduced ingestion rate based on the cumulative lake acreage.

1.3 Tier 3

A Tier 3 screening assessment can be conducted on facilities that do not screen out with the Tier 2 assessment, at the discretion of the risk assessor. The Tier 3 screening approach consists of three individual assessments that further refine the screening scenario (beyond the refinements in Tier 2) based on additional site-specific data and evaluations. Because the Tier 3 assessment introduces additional site-specificity to the screening scenario, it requires a potentially higher level of effort than the Tier 2 assessment, but still a much lower level of effort than the full site-specific assessment (discussed in Section 1.4). One of the Tier 3 assessments (i.e., the lake assessment) potentially results in the rescreening of the facility's emissions using the Tier 2 methods described in Section 1.2 and using a revised lake dataset. The other two assessments (i.e., the plume-rise and time-series assessments) each result in an adjustment factor to be applied to the screening result reflecting the Tier 3 lake assessment. The adjustment factors of the plume-rise and time-series assessments cannot be compounded (i.e., the time-series assessment, if conducted, supplants the plume-rise assessment already conducted).

One component of the Tier 3 assessment is evaluating the fishability of the lakes used in Tier 2. The USGS dataset occasionally includes lakes that appear to be misclassified, no longer exist, or are estuarine by nature. These lakes are removed from the Tier 3 assessment after evaluating their validity using aerial imagery and other available data. These additional data sources are not used in the Tier 2 screening. Examples of lakes removed from Tier 3 source category assessments are provided in Section 4.2. If one or more lakes are removed from a facility's assessment, the facility's emissions are rescreened using the revised lake database and the Tier 2 methods described in Section 1.2. If removing a lake(s) causes the originally-fished lakes to sum to less than 373 total acres, then in the rescreening, the fisher will catch and consume fish from an additional lake(s) if available. In this situation, the Tier 3 lake assessment is conducted on the newly added lake(s), and another rescreening is conducted, and so on until no further lakes are removed or added to the assessment. The Tier 3 lake assessment is more thoroughly described in Section 4.2.

If, after the lake assessment, the Tier 3 screening result is still above a level of concern, the risk assessor may choose to conduct a plume-rise assessment. Atmospheric conditions coupled with the physical parameters of the chemical release point can cause the chemical plume to rise substantially beyond the physical release height. This process is not explicitly modeled by TRIM.FaTE but can substantially reduce ground-level chemical exposure if the plume frequently rises above the mixing height. This assessment uses a scenario in which the chemical release height varies over time due to hourly meteorological conditions and the parameters associated with the chemical release point (i.e., physical release height and diameter, exit velocity, and gas temperature). If the resulting "effective release height" is above the mixing height for a given hour, then in the TRIM.FaTE modeling system there is no chemical deposition or exposure for that hour. If this occurs across many hours, it will substantially reduce total PB-HAP exposure and reduce the screening result. The plume-rise adjustment factor—the number of hours when the effective release height remains below the mixing height, divided by the number of total modeled hours—is multiplied by the Tier 2 screening result, thus lowering the screening result. A more thorough description is described in Section 4.3.

If the Tier 3 screening result after the lake and plume-rise assessments still is above a level of concern, the risk assessor may choose to conduct a time-series assessment. This assessment utilizes hourly effective release heights (computed in the plume-rise assessment above) along with the hourly meteorology data associated with the facility (i.e., the meteorology data that was summarized and used in Tier 2). Using hourly meteorology data adds additional site-specificity compared to the summarized, binned meteorology statistics used in Tier 2. Using these data in

combination with hourly effective release heights is a more complete evaluation of hourly chemical losses due to plume rise compared with the Tier 3 plume-rise assessment described above. These time-varying release height and meteorology files are used in a run of TRIM.FaTE that also uses the facility's PB-HAP emissions and the Tier 2 spatial scenario associated with the lake being assessed. The TRIM.FaTE modeling, and subsequent exposure and risk characterization conducted using MIRC, leads directly to a screening-level cancer risk or HQ (i.e., a revised screening result). For simplicity in the software implementation of the Tiers 2 and 3 screening assessments, the result of this Tier 3 time-series assessment is converted to a time-series adjustment factor—the revised screening result divided by the screening result after the Tier 3 lake assessment. This ratio can then be multiplied by the screening result after the Tier 3 lake assessment, yielding the revised screening result accounting for the time-series assessment.

1.4 Site-Specific Assessment

If, based on results of the screening assessments, a risk assessor concludes that there is a reasonable probability that individuals could be adversely affected by the facility emissions, a refined site-specific multipathway assessment might be performed. Examples of recent refined multipathway assessments include residual risk assessments of a ferroalloys production facility (EPA 2014a), petroleum refinery facility (EPA 2014b), two secondary lead smelting facilities (EPA 2011b), assessments of two coal-fired electric utility units conducted in support of EPA's utility rule (EPA 2011c), and a case study evaluation of a Portland cement facility included with other RTR materials presented to the Science Advisory Board for review (Appendix I of EPA 2009).

Whereas Tier 2 and Tier 3 assessments incorporate some site-specific and regional information on meteorology and water bodies, a refined multipathway assessment uses detailed site-specific data to parameterize more accurately (to the extent possible) each important parameter that affects pollutant fate and transport. These site-specific properties are incorporated into model scenarios configured in TRIM.FaTE and MIRC. Important site-specific data likely would include emission release height and plume buoyancy, hourly meteorology (e.g., wind flow, temperature, mixing height, and precipitation), surface compartments based on watershed and terrain data, local farms and water bodies, land use, soil properties, erosion and runoff rates, surface water and sediment properties, water transfer rates, and aquatic ecosystem information.

The outputs from the site-specific run of TRIM.FaTE (i.e., chemical concentrations in environmental media and fish) are used in MIRC to produce estimates of exposure and health risk (i.e., risk and/or HQ values). Additional analyses of the media concentrations, exposure estimates, and risk estimates for the various ingested media using a range of ingestion rates for each modeled PB-HAP allows the risk assessor to understand, based on TRIM.FaTE and MIRC, the sources and pathways of possible human health risk from emissions of PB-HAPs.

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2. Tier 1 Methodology

2.1 Introduction

As discussed in Section 1, the U.S. Environmental Protection Agency (EPA) implements a tiered approach to evaluate multipathway exposures and human health risks for the Risk and Technology Review (RTR) program. EPA's assessment for RTR focuses on persistent and bioaccumulative hazardous air pollutants (PB-HAPs) that the Office of Air Quality Planning and Standards (OAQPS) has identified as candidates for multipathway risk assessments (selection of the PB-HAPs is discussed in Section 2.2.2). In the first tier, a screen is conducted that focuses on the identity and magnitude of emissions of PB-HAPs from a given facility to determine whether a facility passes certain human health risk-based criteria. Sources that are "screened out" in the Tier 1 assessment are assumed to pose no risks to human health above levels of concern and are not considered in further assessments. For sources that do not pass the Tier 1 screen, more refined assessments, up to and including site-specific multipathway assessments, can be conducted as appropriate.

This section describes the technical basis for the first screening-level tier of EPA's multipathway human health evaluation of PB-HAP emissions from RTR sources. Specifically, the scenarios, models, configurations, and inputs used to derive screening threshold emission rates in the first tier of the approach are described in detail in the following sections.

- Section 2.2 presents an overview of how screening is conducted in Tier 1, the chemicals and exposure scenario evaluated in Tier 1, and the models and methods used to conduct the screen.
- Sections 2.3 and 2.4 present technical descriptions of the hypothetical environmental setting and the exposure modeling scenario used in Tier 1 as well as the models used in the screen.
- Section 2.5 provides a brief discussion of the screening threshold emissions for each of the chemicals assessed.

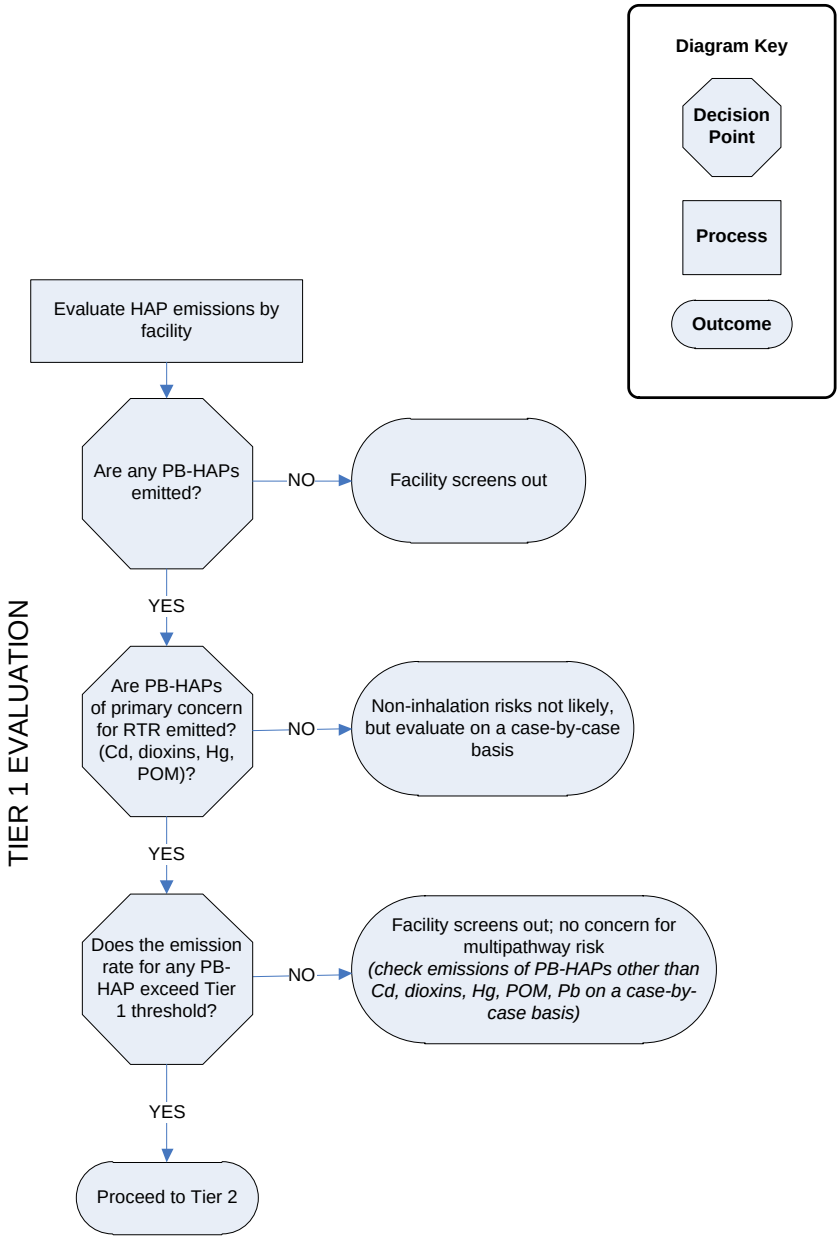
The Tier 2 and Tier 3 screening methods are discussed in Sections 3 and 4, respectively, and references cited are provided in Section 5.

2.2 Summary of Approach

2.2.1 Overview

The Tier 1 approach for evaluating non-inhalation, multipathway exposures to PB-HAPs for RTR is diagrammed in Exhibit 3. Air toxics emitted by a source under consideration are reviewed to determine, first, whether emissions are reported for any of the four PB-HAPs of concern for non-inhalation pathways. If such emissions are reported, the emission rates are compared to Tier 1 threshold-screening emission rates that have been derived using the TRIM-based Tier 1 scenario described in this document (see Exhibit 4 for threshold screening emission rates).

Exhibit 3. Conceptual Decision Tree for Tier 1 Evaluation of Non-Inhalation Exposures of PB-HAPs



The TRIM-based multipathway modeling configuration, referred to in this document as the Tier 1 scenario, forms the technical basis for determining the Tier 1 emission thresholds. The term, Tier 1 scenario, is used to refer collectively to the specific TRIM.FaTE and exposure modeling configuration described herein, including the set of assumptions and input values associated with a hypothetical watershed and the exposure and risk scenarios evaluated for this watershed. The Tier 1 scenario is a static configuration, and its primary purpose is as a modeling tool to calculate the Tier 1 emission rate thresholds for PB-HAPs of concern.

The two potential outcomes of the Tier 1 evaluation are:

- Non-inhalation exposures are unlikely to pose a human health problem (i.e., the emissions evaluated "pass" the screen); or
- Risks above the levels of concern from non-inhalation exposures cannot be ruled out.

An ideal screening approach strikes a balance between being *health-protective*—to ensure that risks above levels of concern are identified, and being *accurate*—to minimize results suggesting that additional analysis is required when in fact the actual risk is low. Typically, gains in accuracy in environmental modeling are accompanied by additional resource requirements. Stated another way, a suitable approach minimizes both false negatives and false positives. False negatives (i.e., results that suggest that the risk is acceptable when in fact the actual risk is high) can lead to inappropriate and non-protective health or environmental policy decisions. False positives (i.e., results that suggest more assessment is required when in fact the actual risk is low) can result in wasted resources by leading to additional, unnecessary analysis. For the evaluation of multipathway human health exposures to PB-HAPs, the methods for screening described in this document are intended to achieve this balance.

Because the Tier 1 evaluation enables EPA to confidently eliminate from consideration those facilities where risks from non-inhalation exposures are projected to be minimal, resources can be targeted toward those facilities that do not pass the screening test. For facilities that do not pass the Tier 1 screening, in additional tiers of analysis, some of the Tier 1 parameters are reassessed, and if appropriate, are changed to more accurately reflect site-specific characteristics. With each successive tier of the assessment, additional Tier 1 assumptions are evaluated and refined to better reflect site-specific characteristics of the facility being modeled.

The Tier 1 screening evaluation for RTR compares reported air emission rates of PB-HAPs (summed by PB-HAP for each facility) to screening threshold emission rates derived using the Tier 1 scenario. A threshold emission rate is the level that, when input to a risk model using emissions as a parameter, corresponds to a specified cancer risk or non-cancer hazard quotient (HQ) that, for the purposes of the evaluation being conducted, is assumed to be below a level of concern. Tier 1 threshold emission rates were calculated for a cancer risk of 1 in 1 million or an HQ of 1.0 and are presented in Exhibit 4.[6] Conceptually, a threshold level for the RTR multipathway screening evaluation could be obtained by back-calculating the emission rate that results in the specified cancer risk or HQ level, taking into account the exposure and fate and transport calculations included in the model. Because the models used in this assessment are not designed to run "backwards," the rates instead were derived from regression equations established following a series of TRIM.FaTE and exposure/risk model runs spanning a wide

[6]For chemicals known to cause both cancer and chronic non-cancer impacts, *and* for which acceptable quantitative dose-response values are available for both cancer and non-cancer endpoints, the endpoint that results in the lower threshold emission level is used for screening (i.e., the threshold will be based on the effect that occurs at the lower exposure level). For the set of PB-HAPs for which screening threshold levels have been derived, only chlorinated dibenzo-dioxins and -furans meet both criteria. Because the cancer dose-response value is lower than that for non-cancer effects, the screening threshold value is based on the cancer endpoint.

range of emission rates for each chemical. The estimated screening-level emission rates are verified by performing model runs using the estimated threshold emission rate to confirm that the emission rates result in a cancer risk of 1 in 1 million or an HQ of 1.0.

Exhibit 4. Emission Thresholds for Screening of Multipathway Exposures

Chemical	Screening Threshold Emission Rate (TPY)	Basis of Threshold (Type of Health Endpoint)
POM (as benzo(a)pyrene equivalents)[a]	2.58E-03	Cancer
Dioxins (as 2,3,7,8-TCDD equivalents)[a]	2.81E-09	Cancer
Cadmium	1.18E-02	Non-cancer
Mercury (as divalent mercury emissions)	3.16E-04	Non-cancer

TPY = U.S. short tons per year
[a]See Section 2.2.7 for a discussion on the derivation of equivalent emissions.

The more probable risk for each emission rate would be lower than the level corresponding to the screening threshold risk quantities in nearly all circumstances, given the health protective and hypothetical nature of the Tier 1 screening configuration. It is considered very unlikely that the estimated risk at a real site would be greater than the estimated risk for the simulated Tier 1 scenario at equivalent emission rates. This is because the Tier 1 scenario assumes, for many of the most risk influential parameters in the model, parameter values that result in high-end risk estimates. In the real world, the probability of such risk-maximizing conditions prevailing across multiple parameters is very low. For example, the Tier 1 scenario assumes a fishable lake approximately 2 km from any given facility, when in reality, a lake may be more than 50 km away. Additional conservative assumptions used in the Tier 1 screen are described in Section 2.4.4.

Tier 1 emission thresholds were developed individually for elemental and divalent mercury. Both were based on the lower of the thresholds associated with multipathway exposures to divalent mercury and methyl mercury.[7] Only speciated emissions of divalent mercury are screened because the sum of elemental mercury emissions across all National Emission Inventory (NEI) facilities is less than the elemental mercury screening threshold level. See Section 2.5.3 for a detailed discussion of mercury.

2.2.2 Chemicals of Potential Concern

EPA's assessment of multipathway human exposures for RTR focuses on PB-HAPs [8] that the Office of Air Quality Planning and Standards (OAQPS) has identified as candidates for multipathway risk assessments. OAQPS developed a list of 14 chemicals and chemical groups that are PB-HAPs based on a two-step process taking into account the following (EPA 2004a):

[7]Note that TRIM.FaTE models the transformation of mercury within the environment; thus, emissions of both divalent and elemental mercury will result in multipathway exposures to elemental mercury, methyl mercury, and divalent mercury.

[8]Although POM (polycyclic organic matter) is the name of the HAP listed in the Clean Air Act, the term "polycyclic aromatic hydrocarbons" or PAHs is used in many cases. Much of the literature regarding toxicity and fate and transport of this chemical group refers to PAHs rather than POM. In addition, the individual POM species that are of concern with respect to health risk for RTR evaluations are all PAHs (i.e., there are no POM species explicitly evaluated for RTR that do not include an aromatic ring). The terms are used interchangeably throughout this text.

- their presence on three existing EPA lists of persistent, bioaccumulative, and toxic substances, and
- a semiquantitative ranking of toxicity and bioaccumulation potential of the entire list of HAPs.

The list's development and utility in hazard identification for multipathway risk assessment are explained further in Chapter 14 and Appendix D of Volume I of EPA's *Air Toxics Risk Assessment (ATRA) Reference Library* (EPA 2004a). Exhibit 5 presents the 14 chemicals and groups that are PB-HAPs.

Exhibit 5. OAQPS PB-HAP Compounds

PB-HAP Compound[a]	Addressed by Screening Scenario?
Cadmium compounds	Yes
Chlordane	No
Chlorinated dibenzodioxins and furans	Yes
DDE (1,1-dichloro-2,2-bis(p-chlorophenyl) ethylene)	No
Heptachlor	No
Hexachlorobenzene	No
Hexachlorocyclohexane (all isomers)	No
Lead compounds	No
Mercury compounds	Yes
Methoxychlor	No
Polychlorinated biphenyls	No
Polycyclic organic matter (POM)	Yes
Toxaphene	No
Trifluralin	No

[a]Source of list: EPA (2004a).

The screening scenario described in this document is not configured for evaluating the risk potential for all 14 PB-HAPs on the list. Currently, the scenario can only be used to estimate exposures and risks quantitatively for 4 of the 14 PB-HAPs (as indicated in Exhibit 5). These four PB-HAPs are the focus of the current scenario because, based on current emissions, bioaccumulation potential, and toxicity considerations, they are expected to pose the vast majority of the non-inhalation risks to humans from air emissions at sources subject to residual risk provisions of the Clean Air Act.[9]

2.2.3 Conceptual Exposure Scenario

A conceptual exposure scenario was developed that encompasses the specific exposure routes and pathways of interest for the four PB-HAPs that are assessed in the Tier 1 assessment. Exposure routes and pathways describe the movement of air toxics from the point of release to the point where exposure occurs and generally consist of the following elements:

- Release to the environment (i.e., emissions);

[9]Potential impacts on human health from non-inhalation exposures to lead are evaluated for RTR using the National Ambient Air Quality Standard for lead, which takes into account multipathway risks. Non-inhalation exposures to the other nine PB-HAPs not addressed by the modeling scenario discussed in this report will be evaluated on an individual facility or source category basis as appropriate.

- A retention medium, or a transport mechanism and subsequent retention medium in cases involving media transfer of chemicals;
- A point of potential human contact with the contaminated medium; and
- An exposure route.

An exposure route is the particular means of entry into the body. Receptors are exposed to chemicals emitted to the atmosphere via two primary routes: either directly via inhalation, or indirectly via ingestion or dermal contact with various media that have been contaminated with the emitted PB-HAPs. (Inhalation pathways are assessed separately and are not considered in the Tier 1 assessment presented here.)

PB-HAPs can persist in the environment for long periods of time and also build up in soil and in the food chain, including fish, fruits and vegetables, and animal products (e.g., meat, dairy, eggs). For this reason, ingestion of foods grown within an area impacted by RTR sources can be an important source of exposure to PB-HAPs.

To assess risks from hazardous waste combustion facilities, EPA identified several hypothetical receptor scenarios, noting that these scenarios are considered appropriate for a broad range of situations, rather than to represent any actual scenario. These scenarios are described in EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities,* or HHRAP (EPA 2005a). In this document, EPA recommends assessment of the following hypothetical receptors: a Farmer, Farmer Child, Resident, Resident Child, Fisher, Fisher Child, Acute Receptor, and Nursing Infant. These receptors are distinguished by their pathways of exposures. EPA further notes in HHRAP that some exposure settings might warrant including additional exposure pathways; such as including exposure through fish ingestion for the farmer receptor. For the RTR screening scenario, risks are assessed for a single hypothetical receptor. Based on the guidance provided in HHRAP, a health protective exposure scenario was developed whereby the hypothetical receptor receives ingestion exposure via both the farm food chain and the fish ingestion pathways. The exposure scenario for the RTR Tier 1 assessment includes the following ingestion pathways:

- Incidental ingestion of soil,
- Ingestion of homegrown fruits and vegetables,
- Ingestion of homegrown beef,
- Ingestion of dairy products from homegrown cows,
- Ingestion of homegrown poultry and eggs,
- Ingestion of homegrown pork,
- Ingestion of locally caught fish, and
- Ingestion of breast milk (for children less than 1 year old and for dioxins only).[10]

As discussed in detail in Section 2.4.2, exposure via these pathways is assessed for adults, various age categories for children, and nursing infants (for dioxins only).

[10] Breast milk ingestion is an important exposure pathway for lipophilic compounds like dioxins and has been shown not to contribute meaningfully for exposures to mercury, cadmium, and POM. See Section 2.4.2.3 below and Section 3.4 of Attachment B for full discussions of infant exposures via breast milk ingestion.

Other non-inhalation exposure routes of possible concern for PB-HAPs discussed in HHRAP include the use of surface waters as a drinking water source and dermal exposure. These exposure routes, however, are not evaluated in the current assessment. The drinking water exposure pathway is not likely for the modeling scenario developed for this assessment because the likelihood that humans would use a lake as a drinking water source was assumed to be low.[11] Dermal absorption of chemicals that are originally airborne has been shown to a relatively minor pathway of exposure compared to other exposure pathways (EPA 2006, Cal/EPA 2000). Preliminary calculations of estimated dermal exposure and risk of PB-HAPs, presented in Attachment C, showed that the dermal exposure route is not a significant risk pathway relative to ingestion exposures.

2.2.4 Approach to Development of the Tier 1 Scenario

The TRIM-based Tier 1 scenario described in this document is used to provide a means to qualitatively estimate the potential for non-inhalation risks above the levels of concern for PB-HAPs emissions from facilities in the context of residual risk assessments conducted as part of RTR. The Tier 1 scenario used to derive the threshold emission rates is not intended to be representative of any particular situation. Rather, it was developed for the purpose of RTR to portray a hypothetical exposure scenario that will generate emissions screening levels that are health protective for any potential exposure situation that might plausibly be encountered in the United States. A range of conditions was assessed when conceptualizing and developing the screening scenario. The final configuration was chosen so that for a given individual, any potential long-term exposure levels for a given geographic region would be reasonably unlikely to exceed those of the Tier 1 configuration. These criteria were met by constructing a hypothetical scenario that would be health-protective in key aspects, including spatial orientation, meteorology, types of exposures, and ingestion rates. The overall result is a scenario that is unlikely to occur at any one location but has a high likelihood of representing the upper end of all potential exposures. This latter aspect accomplishes the goal of striking a balance between health protectiveness and the level of accuracy called for in the ideal screening approach previously discussed.

The development and application of the Tier 1 scenario for residual risk evaluations considered EPA's technical and policy guidelines presented in the *Residual Risk Report to Congress* (EPA 1999); Volumes I and II of the *Air Toxics Risk Assessment Reference Library* (EPA 2004a, 2005a); and other EPA publications. The scenario described herein is the culmination of assessments completed since 2005; it provides the basis for an efficient and scientifically defensible method for screening multipathway human health risk and provides a solid baseline from which to perform Tier 2 and Tier 3 assessments, as described in Sections 3 and 4, respectively. Nevertheless, this scenario should not be considered "final" but rather a product that can continue to evolve based on feedback from the scientific community and Agency reviewers, lessons learned as the scenario is further applied for RTR, variations in EPA's needs and requirements, and other factors.

2.2.4.1 Modeling Framework

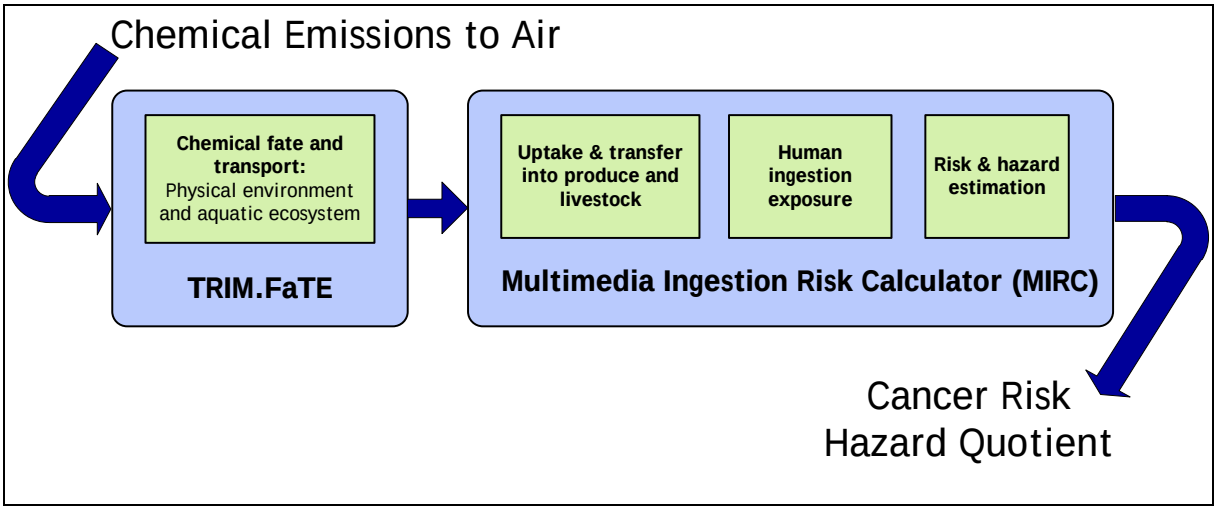
The approach for multipathway risk screening and evaluation for RTR can be divided into four steps:

[11]An exception to this generality would be reservoirs used for drinking water supplies. This situation might be worthy of additional analysis, if warranted by the characteristics of a given assessment (e.g., to estimate PB-HAP concentrations in treated drinking water derived from reservoirs).

1. Fate and transport modeling of PB-HAPs emitted to air by the source that partition into soil, water, and other environmental media (including fish[12]);
2. Modeling of transfer and uptake of PB-HAPs into farm food chain media (e.g., produce, livestock, dairy products) from soil and air, and calculation of FFC media concentrations;
3. Estimating exposures from ingestion of selected media and estimating average daily ingestion doses for a hypothetical human receptor; and
4. Calculating lifetime cancer risk estimates or chronic non-cancer HQs, as appropriate, for each PB-HAP and comparing these to selected evaluation criteria.

The relationship among these four processes is shown in Exhibit 6.

Exhibit 6. Overview of Ingestion Exposure and Risk Screening Evaluation Method



As shown in Exhibit 6, two models are used to evaluate the four steps outlined above. EPA's TRIM methodology was conceived as a comprehensive modeling framework for evaluating risks from air toxics, and the TRIM system was designed to address each of the four steps involved in screening ingestion risk.[13] Currently, however, only one component corresponding to the first step included in Exhibit 6—the fate and transport module—is available for application in an ingestion risk assessment. EPA has completed some development activities for TRIM.Expo-Ingestion and TRIM.Risk-Human Health, two additional modules that cover the other three steps. Modeling software, however, is not currently available for these modules. For the RTR screening scenario, the Multimedia Ingestion Risk Calculator (MIRC), a Microsoft® Excel™-based computing framework, was constructed to complete the calculations required for estimating PB-HAP concentrations in farm food chain media, average daily ingestion doses, and

[12]As discussed below, concentrations in fish calculated by the TRIM.FaTE model were used to estimate ingestion exposures for humans consuming fish. Modeling of fish concentrations is therefore discussed herein as part of the fate and transport modeling. Uptake of PB-HAPs into all other biotic media assumed to be ingested is modeled in the second step of the modeling framework.

[13]Information about the current status of TRIM modules and comprehensive documentation of modules developed thus far can be accessed on EPA's Technology Transfer Network (TTN) on the Fate, Exposure, and Risk Analysis website (http://www2.epa.gov/fera).

cancer risks and chronic non-cancer HQs. This framework is conceptually identical to the ingestion exposure and risk assessments that TRIM is intended to cover.

2.2.4.2 Model Configuration and Parameterization

The Tier 1 scenario is intended to reduce the possibility that EPA would underestimate potential multipathway human health risks. Although the health protective approach likely overestimates risk, EPA determined that this approach is appropriate for the purposes of an initial multipathway screening assessment. As was done with the preliminary multipathway screening for RTR conducted in 2006 (EPA 2006), exposures were modeled for a hypothetical farm homestead and fishable lake located adjacent to an emissions source. The hypothetical individual for which exposures were calculated was assumed to derive all potentially contaminated foodstuffs from adjacent locations, and many of the exposure/activity assumptions (e.g., amount of food consumed per day) were selected from the upper ends of representative exposure parameter distributions.

The physical/chemical environment represented in the screening scenario was parameterized with two types of values. One type is typical values, such as national averages. The second type is health-protective values, or values that would tend to overestimate concentrations in media driving ingestion exposures for humans, based on knowledge of exposure patterns. In general, the spatial and temporal aspects of the scenario and the components of the scenario that influence air concentrations and deposition rates (which in turn affect all other exposures) were defined to be health protective. Chemical-specific and non-chemical-specific properties of the environmental media were parameterized with either typical or health protective values; properties having greater uncertainty were assigned a greater level of health protective bias. The spatial layout of the Tier 1 scenario and the meteorological data (or a combination of these two factors) are generally more influential than physical/chemical parameters in dictating the screening model outcomes, taking into account the potential range of variation in possible values. For example, where and how the layout is spatially oriented relative to the dominant wind direction can dramatically affect the concentrations in air, thereby driving estimated concentrations of PB-HAPs in soil, water, and biota. In contrast, relatively large changes in soil characteristics within the range of possible values (e.g., organic carbon content, water content) typically result in relatively small changes in media concentrations.

The mix of health protective and central-tendency assumptions and parameterization is expected to result in a scenario configuration that, on average, is likely to overpredict environmental concentrations of PB-HAPs in media of interest for this evaluation. Given the intended application of this scenario as a screening tool, this health protective bias was deliberate, because of the desire to ensure that risks above levels of potential concern are not overlooked (i.e., to minimize false negatives). Although the inclusion of central-tendency values where warranted is intended to minimize the number of false positives, some false positives are to be expected from a screening scenario. False positives are addressed in subsequent tiers of the screening evaluation for a particular source.

2.2.5 Fate and Transport Modeling (TRIM.FaTE)

The fate and transport modeling step depicted in the first box in Exhibit 6 is implemented for RTR using the Fate, Transport, and Ecological Exposure module of the TRIM modeling system (TRIM.FaTE).[14] In developing the Tier 1 scenario, Version 3.6.2 of TRIM.FaTE was used to

[14] TRIM.FaTE is a spatially explicit, compartmental mass balance model that describes movement and transformation of pollutants over time, through a user-defined, bounded system that includes both biotic and abiotic compartments. Outputs include pollutant concentrations in multiple environmental media and biota.

model the fate and transport of emitted PB-HAPs and to estimate concentrations in relevant media. Additional information about TRIM.FaTE, including support documentation, software, and the TRIM.FaTE public reference library, is available at http://www.epa.gov/ttn/fera/.

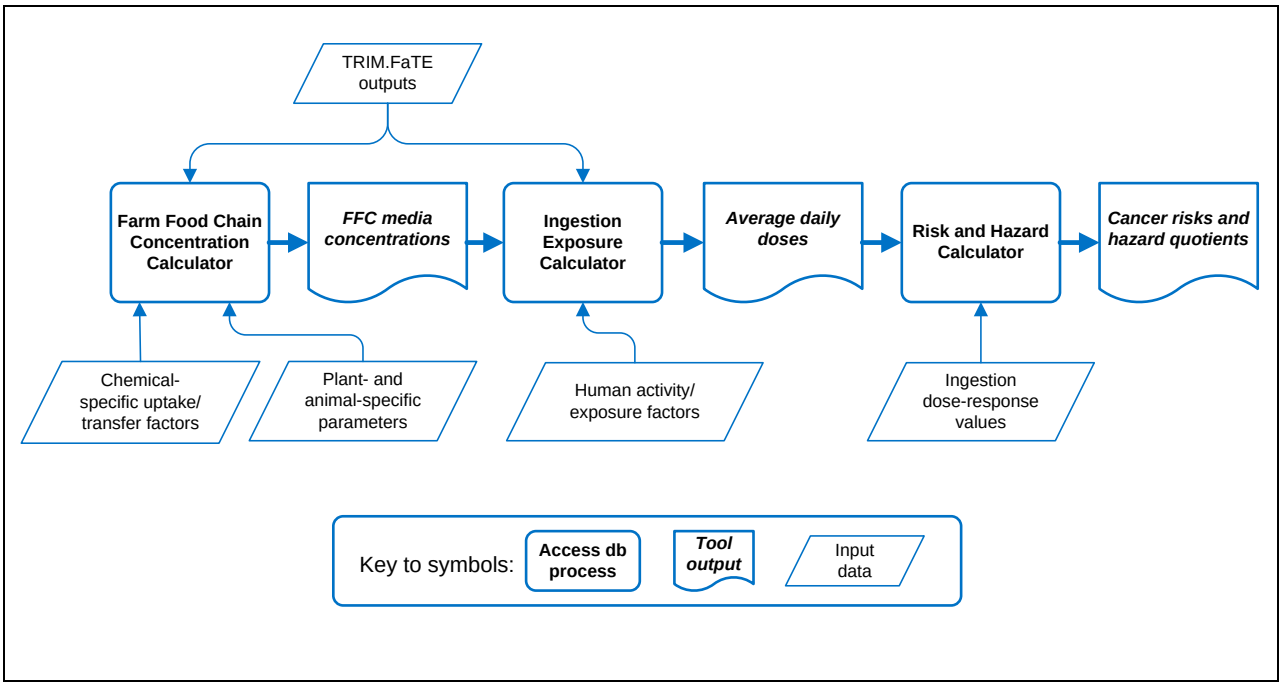
The algorithms used to model mercury species and polycyclic aromatic hydrocarbons (PAHs) are described in Volume II of the *TRIM.FaTE Technical Support Document* (EPA 2002a). A comprehensive evaluation of the performance of TRIM.FaTE for modeling mercury was documented in Volumes I and II of the T*RIM.FaTE Evaluation Report* (EPA 2002b, 2005b). Algorithms specific to the fate and transport of chlorinated dibenzo-dioxin and -furan congeners were added following the addition of those for mercury and PAHs. Documentation of the application of TRIM.FaTE for dioxin emissions is contained in the third volume of the *TRIM.FaTE Evaluation Report* (EPA 2004). More recently, the TRIM.FaTE public reference library was updated to include information on modeling for cadmium. In general, many of the algorithms and properties included in the public reference library that are used to model mercury (except for the mercury transformation algorithms) are also applicable to cadmium. Comprehensive technical documentation of TRIM.FaTE algorithms specific to cadmium has not yet been compiled; however, all chemical-specific properties used by TRIM.FaTE to model cadmium (as well as PAHs, mercury, and dioxins) are documented in Attachment A. Based on a thorough 2011 evaluation of TRIM.FaTE performance in modeling mercury's fate, transport, and transformation in the aquatic food web, a zooplankton compartment was added to TRIM.FaTE's aquatic compartment to increase the resolution and accuracy of the aquatic food web modeling. Parameterization of the TRIM.FaTE scenario used for RTR screening is described in more detail in Section 2.3.

2.2.6 Exposure Modeling and Risk Characterization (MIRC)

The algorithms included in MIRC that calculate chemical concentrations in farm food chain media and ingestion exposures for hypothetical individuals were obtained from EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities,* or HHRAP (EPA 2005a).[15] These algorithms, and the required exposure factors and other parameter values, were compiled into a database. An overview of the computational processes this tool carries out and the types of input data it requires is presented in Exhibit 7. This exhibit demonstrates the general relationships between the relevant TRIM.FaTE outputs (i.e., chemical concentrations in environmental media and fish) and the ingestion exposure and risk calculations carried out using MIRC. Additional discussion of exposure and risk calculations for the Tier 1 scenario is presented in Section 2.4 and Attachment B, and all inputs required by these calculations are documented in Attachment B.

[15]The farm food chain calculations and ingestion exposure equations to be included in the TRIM.Expo software are expected to be very similar to those included in HHRAP.

Exhibit 7. Overview of Process Carried Out in the Multimedia Ingestion Risk Calculator



2.2.7 Implementation of Risk-based Emission Scaling Factors for POM and Dioxin Emissions

Two of the four PB-HAPs for which screening emission thresholds have been developed for RTR—POM and dioxins—are chemical groups comprising numerous individual entities. The members of these categories reported in NEI include both specific chemicals and groups containing multiple chemicals. For example, for POM, emissions reported in NEI include various species, such as benz[a]anthracene, 2-methylnaphthalene, and chrysene, as well as non-specific entries, such as "PAH, total." The constituents included in the POM and dioxin PB-HAP categories are grouped together not only because they are types of the "same" HAP, but also because members of these groups are assumed to have similar characteristics with respect to toxicity and behavior in the environment.

To facilitate a practical application of the multipathway screening methods for RTR, reported emissions of POM and dioxins are normalized or scaled to a single reference chemical for each group. The reference chemicals used in RTR for POM and dioxins are benzo[a]pyrene and 2,3,7,8-TCDD, respectively. These compounds were selected because they are relatively well-studied among the members of the two groups and are also among the most toxic species within each group.

Derivation of appropriate scaling factors begins with an evaluation of the basic relationship used to characterize health risk:

$$Risk \propto (Exposure\ Concentration) \times (Toxicity)$$

For a given air pollutant, the incremental exposure concentration is directly proportional to the emissions of that substance. That is, as the emissions increase, so too does the exposure to

that substance. Furthermore, toxicity is assumed to increase linearly with concentration. Consequently, emissions of one substance (e.g., chrysene) can be scaled proportional to a reference compound (e.g., benzo(a)pyrene or BaP) by applying weighting factors corresponding to the relative differences in exposure behavior and toxicity. Using the POM group as an example and BaP as the reference compound, this scaling can be expressed through an equation as follows:

$$Emiss_{PAHi:BaP} = Emiss_{PAHi} \times EEF_{PAHi:BaP} \times TEF_{PAHi:BaP}$$

where:

$Emiss_{PAHi:BaP}$	=	Risk-weighted emissions of PAH_i (weighted according to cancer risk relative to BaP for oral exposures)
$Emiss_{PAHi}$	=	Emission rate of PAH_i
$EEF_{PAHi:BaP}$	=	Exposure equivalency (weighting) factor accounting for difference in relative oral exposure between PAH_i and BaP
$TEF_{PAHi:BaP}$	=	Toxicity equivalency (weighting) factor accounting for difference in relative toxicity via oral route between PAH_i and BaP

In combination, the product of the EEF and TEF for a given substance is considered to be a "risk equivalency factor" for the purposes of RTR evaluations that enables scaling of emissions of a given substance for a given exposure scenario.

The TEF for each PAH and dioxin species can be calculated on the basis of relative toxicities. Toxicities were not evaluated separately for RTR but are based on analyses conducted by EPA elsewhere. For PAHs, oral toxicity values for individual species have been derived following the same approach used to develop inhalation toxicity values. For dioxins, TEFs are based on the relative toxicities developed by EPA recently and are ultimately based on the values developed by the World Health Organization (van den Berg et al. 2006). Refer to Section 4 of Attachment B for more information on these values.

The EEFs can be calculated directly for each individual chemical that can be modeled in TRIM.FaTE and MIRC. TRIM.FaTE is configured for 14 POM congeners and 17 dioxin/furan congeners. For these substances, EEFs were calculated directly using the modeling approach and parameterization scheme for the Tier 1 scenario described in this document. Several other POM and dioxin emissions, however, are reported in the NEI. For these, exposure surrogates must be assigned after evaluating the correlation between chemical properties of the POM or dioxin congener and exposure quantified as lifetime average daily dose. The specific calculations for EEFs and exposure surrogates for each chemical group are discussed in the sections that follow.

2.2.7.1 Calculation of Scaling Factors for POM Congeners

The calculated EEFs, TEFs, and total REFs for the 14 POM congeners that are configured in TRIM.FaTE, plus 15 others not configured in TRIM.FaTE, are shown in Exhibit 8. To determine appropriate exposure surrogates for chemicals not parameterized in TRIM.FaTE, EPA evaluated the relationships between chemical-specific properties (e.g., K_{ow} and Henry's law constant, k_h) and intermediate modeled values (e.g., deposition, soil concentration) and exposure in terms of lifetime average daily dose (LADDs) where the average daily doses (ADDs) for the youngest two age groups were adjusted by the age-dependent adjustment factors (ADAFs) to account for the mutagenic mode of action of PAHs. The correlation between K_{ow} and exposure is stronger than for any other chemical-specific property. Exposure

surrogates were thus identified for each congener by calculating Total Lifetime Average Daily Dose (Age Adjusted) for each based on the congener's K_{ow} and the power regression of the modeled PAHs. Exhibit 9 shows that as K_{ow} increases, so too does exposure.

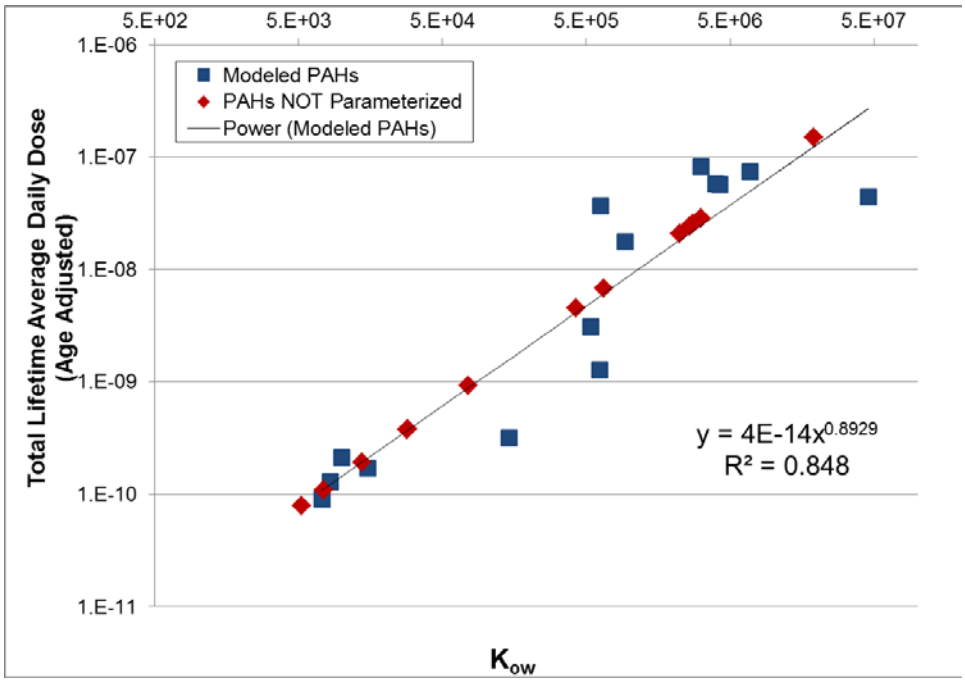
Exhibit 8. Exposure, Toxicity, and Risk Equivalency Factors Relative to BaP for POM Congeners Currently Evaluated in Tiers 1 and 2 Assessments

Chemical	Fully Parameterized in TRIM.FaTE?	Exposure Equivalency Factor (EEF)	Toxicity Equivalency Factor (TEF)[a]	Risk Equivalency Factor (REF)
Dibenzo(a,i)pyrene	n	27.5	16.4	452
7,12-Dimethylbenz(a)anthracene	Y	5.4	34.2	186
3-Methylcholanthrene	n	4.3	3.0	12.9
Dibenz(a,h)anthracene	Y	8.0	0.6	4.5
Benzo(k)fluoranthene	Y	18.0	0.2	3.0
Benzo(a)pyrene	Y	1.0	1.00	1.00
Benzo(b)fluoranthene	Y	11.4	0.2	1.9
Indeno(1,2,3-cd)pyrene	Y	4.5	0.2	0.7
PAH, total	n	5.1	0.07	0.3
Polycyclic Organic Matter	n	5.1	0.07	0.3
Benzo(g,h,i)perylene	Y	4.3	0.07	0.3
Benzo(e)pyrene	n	4.5	0.07	0.3
Retene	n	3.7	0.07	0.3
Dibenzo(a,j)acridine	n	0.78	0.2	0.1
Perylene	n	1.2	0.07	0.08
Benzo(a)anthracene	Y	0.09	0.16	0.01
Chrysene	Y	0.25	0.02	0.004
2-Acetylaminofluorene	n	0.005	1.4	0.01
Fluoranthene	Y	0.04	0.07	0.003
Acenaphthylene	Y	0.04	0.07	0.003
2-Chloronaphthalene	n	0.03	0.07	0.002
Fluorene	Y	0.03	0.07	0.002
Acenaphthene	Y	0.02	0.07	0.002
1-Methylnaphthalene	n	0.02	0.07	0.001
2-Methylnaphthalene	Y	0.02	0.07	0.001
Carbazole	n	0.01	0.003	0.00003
Anthracene	n	0.06	0[b]	0
Phenanthrene	n	0.06	0[b]	0
Pyrene	n	0.15	0[b]	0

[a]TEFs are calculated as the ratio of the cancer slope factor (CSF) for each specific POM congener to the CSF for benzo(a)pyrene. Dose response values, including CSFs, that are used in the screening assessment are discussed in Section 4 of Attachment B.
[b]Weight of evidence evaluations indicated that the available data were adequate to determine that three PAHs (anthracene, phenanthrene, and pyrene) were not carcinogenic (EPA 2010a),

For POMs reported as unspeciated groups (i.e., "PAH, total" and "Polycyclic Organic Matter") EPA assigned surrogates with K_{ow} values near the upper end of the range of all of the K_{ow} values, corresponding to an exposure near the upper end of the range (log K_{ow} = 6.5). This assignment is assumed to be health protective and likely will not under predict exposure.

Exhibit 9. Relationship between Exposure and K_{ow} for POM Congeners



It is worthy of noting that naphthalene is not included in the POM category for the RTR multipathway (i.e., non-inhalation) analyses. Naphthalene is listed individually as a HAP under Section 112(b) of the Clean Air Act. POM also is listed as a HAP under Section 112(b) and is defined as organic compounds with more than one benzene ring and a boiling point greater than or equal to 100° C (see http://www.epa.gov/ttn/atw/orig189.html). While naphthalene is a POM, as defined in the Clean Air Act, unlike the other POM chemicals modeled in the multipathway assessment, naphthalene is short-lived in environmental media due to its tendency to volatilize and biodegrade and, consequently, will not build up in environmental media over time (ATSDR 2005). Additionally, based on a log Kow of 3.29, it has a moderate affinity for lipids and will undergo short-term bioaccumulation in tissues; however, biochemical processes lead to its biodegradation and elimination. For the reasons stated above, and to avoid a less accurate and less meaningful estimate of media concentrations and multipathway risk, EPA is not including naphthalene in its multipathway risk assessment.

2.2.7.2 Calculation of Scaling Factors for Dioxin Congeners

The calculated EEFs, TEFs, and REFs for the 17 dioxin congeners that are configured in TRIM.FaTE are presented in Exhibit 10. Although there are many dioxins reported in the NEI other than the 17 configured for TRIM.FaTE, to date, none of them have been included in emissions datasets that have been screened. Therefore, no surrogate EEF's have been developed for dioxins. In future screening assessments, if surrogate EEFs are needed, an approach similar to that used for POM will be used to develop surrogate EEFs for dioxins.

Many facilities report dioxins as "Dioxins, Total, without Individual Isomers Reported," "Dioxins," or as "2,3,7,8-TCDD TEQ," and in these cases, we do not adjust or scale the emissions. That is, we assume that they behave like and possess the toxic characteristics of TCDD. This approach could be improved by obtaining information on the speciation of dioxin emissions for each facility or an average speciation profile that could be assumed to apply to all facilities in a source category.

Exhibit 10. Exposure and Toxicity Equivalency Factors Relative to TCDD for Modeled Dioxin Congeners

Chemical	Exposure Equivalency Factor (EEF)	Toxicity Equivalency Factor (TEF)[a]	Risk Equivalency Factor (REF)
PentaCDD, 1,2,3,7,8-	3.8	1	3.8
TetraCDD, 2,3,7,8-	1	1	1
Dioxins, Total, w/o Indiv. Isomers Rptd.	1	1	1
Dioxins	1	1	1
2,3,7,8-TCDD TEQ	1	1	1
HexaCDD, 1,2,3,4,7,8-	1.6	0.1	0.2
PentaCDF, 2,3,4,7,8-	0.4	0.3	0.1
HexaCDD, 1,2,3,6,7,8-	1.0	0.1	0.1
HexaCDF, 1,2,3,7,8,9-	0.5	0.1	0.05
HexaCDF, 1,2,3,6,7,8-	0.5	0.1	0.05
HexaCDD, 1,2,3,7,8,9 -	1.0	0.04	0.04
HexaCDF, 1,2,3,4,7,8-	0.3	0.1	0.03
HexaCDF, 2,3,4,6,7,8-	0.2	0.1	0.02
PentaCDF, 1,2,3,7,8-	0.4	0.03	0.01
TetraCDF, 2,3,7,8-	0.1	0.1	0.01
HeptaCDD, 1,2,3,4,6,7,8-	1.0	0.01	0.01
HeptaCDF, 1,2,3,4,6,7,8-	0.2	0.01	0.002
HeptaCDF, 1,2,3,4,7,8,9-	0.2	0.01	0.002
OctaCDD, 1,2,3,4,6,7,8,9-	1.1	0.0003	0.0003
OctaCDF, 1,2,3,4,6,7,8,9-	0.2	0.0003	0.0001

[a] Values from Van den Berg et al. (2006), except for 1,2,3,7,8,9-hexaCDD, which is calculated based on the ratio of the IRIS-based CSF for 1,2,3,7,8,9-hexaCDD to the IRIS-based CSF for 2,3,7,8-TCDD. Dose response values, including CSFs, that are used in the screening assessment are discussed in Section 4 of Attachment B.

2.3 Description of Environmental Modeling Scenario

As described in Section 2.2.4.2, the physical configuration of the RTR Screening Scenario was designed to encompass the upper end of potential long-term PB-HAP exposures, and the environmental and chemical-specific properties were parameterized with either health protective or central-tendency values. Information regarding the scenario configuration and important aspects of the parameterization process, justifications for selecting particular property values, and model uncertainties is presented in the sections that follow. Comprehensive documentation of TRIM.FaTE property values for this scenario is provided in Attachment A.

2.3.1 Chemical Properties

The general chemical/physical properties that TRIM.FaTE requires, such as Henry's law constant, molecular weight, and melting point, were obtained from peer-reviewed and standard reference sources. Numerous other chemical-specific properties are related more specifically to

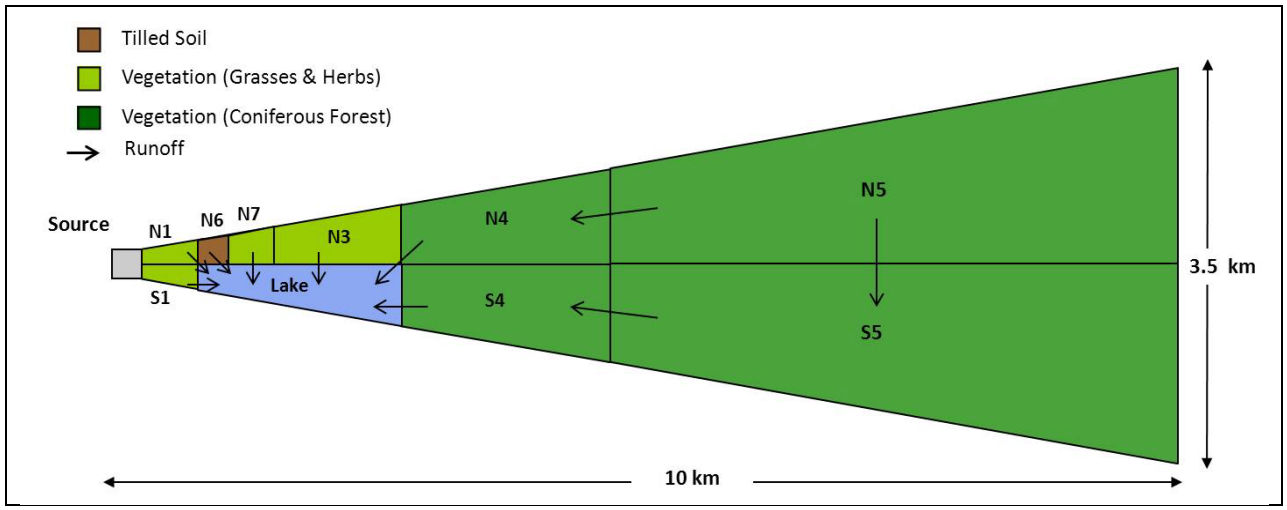
a particular abiotic or biotic compartment type; these properties are discussed generally in the sections that follow and are documented in Attachment A.

2.3.2 Spatial Layout

For the purpose of estimating media concentrations, the TRIM.FaTE scenario is intended to represent a farm homestead and a fishable lake (and its surrounding watershed) located near the emissions source of interest. A diagram of the surface parcel layout is presented in Exhibit 11. The source parcel is parameterized as a square with sides of 250 m, which is assumed to be a fair estimation for the size of a relatively small-to-medium facility at the fence line. With a predominant wind direction toward the east, the modeled layout is generally symmetric about an east-west line and is wedge-shaped to reflect Gaussian dispersion of the emission plume.

A lateral, downwind distance of 10 km was established for the watershed included in the scenario. Based on the results of dispersion modeling, the location of the maximum air concentration and deposition rate is expected to occur relatively close to the facility (probably within a few hundred meters, with the exact location varying with stack height and other parameters) and well within a 10-km radius. Additionally, deposition rates for the PB-HAPs for which this screening scenario is applicable is expected to decrease by about two orders of magnitude relative to the predicted maximum rate within a 10-km radius. Extending the modeling layout beyond a 10-km downwind distance would increase the amount of deposition "captured" by the modeled watershed, but the incremental chemical mass expected to accumulate in the watershed diminishes rapidly with distance. In addition, the impact of this additional deposited mass on ingestion exposures is expected to be negligible.[16] Given these conditions, a downwind length of 10 km was determined to be appropriate for the screening scenario.

Exhibit 11. TRIM.FaTE Surface Parcel Layout



[16]Mass deposited at the outer edge of the watershed is expected to result in only a very small increase in estimated exposure via fish consumption by increasing the chemical mass transported to the lake through erosion and runoff. The distance from these more distant locations to the lake would attenuate transport of chemical mass by erosion and runoff, dampening the effect of including additional deposition beyond 10 km. (Other exposure pathways largely would be unaffected; the soil concentrations used to calculate exposures for the farm food scenario are derived from soil parcels located close to the source and unaffected by deposition to the far reaches of the watershed.)

The north-south width of the wedge-shaped watershed was set based on the observed behavior of chemicals emitted to the ambient air. If meteorological stability is known or can be assumed, the lateral spread of the plume (σ_y, measured from the centerline) at a certain distance from the source can be estimated using the Pasquill-Gifford curves. Turner (1970) derived the equations for these curves, which can be found in the Industrial Source Complex 3 Dispersion Model Manual (among other sources).[17] For a relatively neutral atmosphere (stability class D), σ at 10km is about 550 m using this estimation. In a Gaussian distribution, about 99.6 percent of the plume spread area is contained within 3σ of the median line. Therefore, the plume σ was set at 3 times 550 m, or approximately 1.75 km from the centerline at a distance of 10 km. The plume width for these conditions is expected to be about twice this distance, or 3.5 km. These dimensions were used to define the dimensions of the overall air and surface parcel layouts for the screening scenario.

The surface (land and surface water) modeling area was initially divided into five pairs of parcels the areas of which increase with distance from the source, which approximately corresponds to the spatial gradient that is expected in the downwind direction from the source. The second north parcel from the source was divided further into two parts; one of them tilled soil (Parcel N6) to represent agricultural conditions and the other (Parcel N7) untilled to represent pasture.

The depth of the surface soil compartments was set to 1 cm, except for Parcel N6, for which the depth was set to 20 cm to simulate the effect of tillage. Characteristics of the soil layers (e.g., organic carbon content, air and water content, and subsoil depth) generally were set to represent typical or national averages as summarized by McKone et al. (2001).

The overall shape and boundaries of the air parcel layout mirror those of the surface parcel layout. A single air parcel (N2) overlies surface Parcels N6 and N7, and the air over the lake is divided into air Parcels S2 and S3 (mirroring the analogous parcels on the north side of the lake).

2.3.3 Watershed and Water Body Parameterization

Properties associated with the watershed soil and lake determine how pollutants in the system are transported through and accumulate in various media compartments. These properties describe the physical characteristics of the environmental media included in the modeled region, as well as the assumed connections and relationships between media types and modeled spatial components that in turn affect chemical transport via water runoff, ground infiltration, deposition of suspended sediments in the water column, and other processes. This section presents the justification for setting the key properties of the soil, water, and sediment compartments. Also discussed are some of the chemical properties related to watershed and waterbody processes (chemical-specific compartment properties in TRIM.FaTE) and the configuration of terrestrial plants included in the scenario.

2.3.3.1 Water Balance

Water-related properties of the lake and related watershed characteristics (e.g., runoff rates from each surface soil compartment) were set so that a simplified water balance is achieved. Although TRIM.FaTE maintains a chemical mass balance, the model does not calculate or maintain media mass balances (e.g., for water) except where specified in certain formulas. For the Tier 1 scenario, the parameters were set to satisfy two equations relating water volume. The first equation maintains a balance of water entering and leaving the terrestrial portion of the scenario:

[17] http://www.epa.gov/scram001/userg/regmod/isc3v2.pdf

[total precipitation] = [evapotranspiration] + [total runoff]

In this equation, total runoff is equal to the sum of overland runoff to the lake and seepage to the lake via groundwater.

The second equation describes the volumetric balance of transfers of water to and from the lake:

[total runoff] + [direct precipitation to the lake] = [evaporation from the lake surface] + [outflow from the lake]

Note that TRIM.FaTE actually uses only some of these properties (e.g., precipitation rate and surface runoff, but not evapotranspiration). The water characteristics assumed for the Tier 1 scenario are meant to represent a relatively wet and moderately warm location in the United States (USGS 1987). Following are the assumptions for this scenario:

- 35 percent of the total precipitation leaves the scenario through evapotranspiration.
- 25 percent of total precipitation infiltrates into the groundwater and eventually flows into the lake.
- 40 percent of total precipitation contributes to overland runoff.

For these calculations, the source parcel was considered to be outside the watershed and therefore was not included in the water balance. The evaporation rate from the lake was assumed to be 700 mm/yr based on data reported by Morton (1986) for various lakes. The runoff rate was defined to be spatially constant and temporally constant (i.e., it is not linked to precipitation events) throughout the modeled domain. Based on these assumptions, the outflow of water from the lake is about 18 million m^3/yr, which translates to a volumetric turnover rate of about 12.2 lake volumes per year.

Other quantitative water body and watershed characteristics TRIM.FaTE uses are listed in Attachment A.

2.3.3.2 Sediment Balance

A simplified balance of sediment transfers between the watershed and the lake was also maintained for the screening scenario via the parameterization of sediment-related properties. As with water, the model does not internally balance sediment mass; these calculations were performed externally for the purposes of setting parameter values. The sediment balance maintained is described by the following equation, where terms represent mass of sediment:

[total surface soil transfers to the lake via erosion] = [removal of sediment from the water column via outflow] + [sediment burial]

where the second term (removal of sediment from the water column via outflow) is accounted for in TRIM.FaTE by lake flushing rate and the third term (sediment burial) is the transfer of sediment from the unconsolidated benthic sediment compartment to the consolidated sediment layer.

To maintain the sediment balance, erosion rates were calculated for each surface soil compartment using the universal soil loss equation (USLE, Wischmeier and Smith 1978), assuming a relatively high rate of erosion. The total suspended sediment concentration is

assumed to remain constant in TRIM.FaTE, and the flushing rate of the lake (calculated via the water balance approach described above) was then used to estimate the removal of sediment from the modeling domain via lake water outflow. The difference between these sediment fluxes was taken to be the sediment burial rate. The sediment burial rate is the rate at which sediment particles in the unconsolidated benthic sediment layer are transported to the consolidated sediment, where the particles can no longer freely interact with the water column.

In TRIM.FaTE, the consolidated sediment layer is represented with a sediment sink; as with all sinks in TRIM.FaTE, chemical mass sorbed to buried sediment that is transported to the sink cannot be returned to the modeling domain. The burial rate is a formula property calculated by the model according to the difference between user-specified values for sediment deposition velocity (from the water column to the benthic sediment) and sediment resuspension velocity (back into the water column from the benthic sediments). These formula properties assume a constant volume of particles in the sediment layer (because the densities for benthic and suspended sediment particles were defined to the same value, the mass of particles in the sediment is also constant).

For the Tier 1 scenario described here, the average sediment delivery rate (i.e., transfer of sediment mass from watershed surface soil to the lake due to erosion) for the entire watershed was estimated to be about 0.0036 kg/m^2-day, based on calculations using the USLE. The HHRAP documentation notes that using the USLE to calculate sediment load to a lake from the surrounding watershed sometimes leads to overestimates (EPA 2005a). For the Tier 1 scenario, however, this approach was considered to be appropriate in that health protective assumptions are a goal of the screening scenario.[18] Surface soil compartments adjacent to the lake are linked directly to the lake for the purposes of estimating erosion and runoff transfers (see layout in Exhibit 11). Erosion and runoff from the source parcel are linked directly to a sink and do not enter the Tier 1 scenario lake. The transport of sediment to the lake via overland is thus assumed to be efficient. Note that erosion from parcels not directly adjacent to the lake is assumed to be somewhat attenuated, effected by using a lower sediment delivery ratio in the USLE.

Using the calculated surface soil erosion rates for the scenario, the total average daily sediment load to the lake from the watershed is about 16,600 kg/day. About 15 percent of this load is removed from the lake via outflow of suspended sediments (based on a calculated flush rate of 12.2 volume turnovers per year) with the remainder of the sediment input to the lake transferred to the sediment burial sink.

2.3.4 Meteorology

Meteorological properties used in TRIM.FaTE algorithms include air temperature, mixing height, wind speed and direction, and precipitation rate. These properties, which can vary significantly among geographic locations, and seasonally and hourly for a single location, greatly influence the chemical concentrations predicted in media of interest. Because the screening scenario is intended to be generally applicable for any U.S. location, and to minimize the frequency of false negatives, a health protective configuration was used. The meteorology of the screening scenario was defined to ensure that (when used in combination with the selected spatial layout) the maximum exposures that might be encountered for the scenarios of interest would be encompassed (i.e., consumption of home-grown farm foodstuffs and self-caught fish, with all farm foods and fish obtained from locations impacted by chemicals emitted from the local

[18]Based on sensitivity analysis, a higher erosion rate will both increase surface water concentrations and decrease surface soil concentrations; the relative impact on resulting concentrations, however, will be proportionally greater in the waterbody.

source). Ensuring that the meteorological parameters were not overly protective of health, such as *always* having the wind blow toward the location of interest, however, was also important to avoid too many false positives.

The meteorological data for the screening scenario are intended to be representative of a location with a low wind speed, a wind direction that strongly favors the watershed, and a relatively high amount of total precipitation falling on the watershed. The values used were based on actual data trends for U.S. locations as specified in Exhibit 12 but an artificial data set was compiled for this assessment (for example, temporally variable meteorological parameters were made to vary only on a daily basis). This simplified approach allowed for greater control (relative to selecting a data set for an actual location) so that desired trends or outcomes could be specified. Also, using a meteorological data set with values varying on a daily basis rather than a shorter period (such as hourly, which is the typical temporal interval for meteorological measurements) reduced required model run time. Meteorological inputs are summarized in Exhibit 12.

The sensitivity of modeled PB-HAPs to changes in these meteorological variables was tested. Lower wind speeds and mixing heights affected concentrations the most. This sensitivity is not unexpected because lower wind speeds should increase pollutant deposition onto the soil and lower mixing heights should reduce the volume through which pollutants disperse. The wind speed used for the screening scenario was 2.8 m/s, the 5th percentile of the annual averages among 239 stations; by comparison, the mean annual average wind speed is approximately 4 m/s in the contiguous United States). The mixing height (mean heights from 4 states) used was 710 m (the 5th percentile of annual averages among all 40 states in the SCRAM database).

Exhibit 12. Summary of Key Meteorological Inputs

Meteorological Property	Selected Value	Justification
Air temperature	Constant at 298 Kelvin	Recommended default value listed in HHRAP (EPA 2005a). Value is similar to the mean daily June temperature in much of the U.S. Southern Plains and Southeast.[a]
Mixing height	Constant at 710 m	Value is 5th percentile of annual average mixing heights for 75 U.S. locations, using data obtained from EPA's SCRAM Web site.[b] Value is the approximate U.S. median for periods without precipitation, based on data compiled by Holzworth (1972). Value is conservative compared to the 1- to 2-km typical mid-latitude daytime value (Stull 1988).
Wind direction	Blows from source parcel into scenario domain (west to east) 3 days per week; during other times does not blow into domain	A wind direction that favors the location of interest (for example, a watershed downwind of a source of concern) will tend to result in more emitted mass accumulating in the location of interest. For much of the U.S. mid-Atlantic and western regions, the wind tends to favor the eastward direction.[a] Among the NCDC 1981–2010 normalized wind vector data, the average wind direction had a strong eastward component at over one-third of the stations.[c] For the hypothetical RTR scenario, a more extreme example of this pattern is represented by conditions in Yakima, Washington, where the wind blows eastward approximately 40 percent of the time based on a review of wind direction data compiled by the National Weather Service (NCDC 1995). This pattern was approximated in the RTR scenario with a configuration in which the modeled domain is downwind of the source 3 out of 7 days.
Horizontal wind speed	Constant at 2.8 m/sec	Set to 5th percentile of annual average speed for 239 stations across the contiguous United States (about 50 years of data per station). Value is similar to the annual average wind speeds of

Meteorological Property	Selected Value	Justification
		many areas of the U.S. east coast and west coast.[a]
Precipitation frequency	Precipitation occurs 3 days per week; wind direction blows into domain 2 of these days	This value was selected so that two-thirds of the total precipitation occurs when the domain is downwind of the modeled source. This pattern approximates that for rainy U.S. locations, where precipitation occurs 35–40% of the time (Holzworth 1972). These locations include parts of the U.S. Northeast and Northwest.[a]
Total Precipitation	1.5 m/yr	Assumed to represent rainy conditions for the United States. This annual precipitation amount is experienced in parts of the U.S. Deep South and parts of the U.S. northwest coast.[a] Conditional precipitation rate (rainfall rate when precipitation is occurring) is 9.59 mm/d, which is similar to conditions in many areas along the U.S. east coast and in the Midwest and Plains.[a]

[a]National Climatic Data Center CliMaps (NCDC-CliMaps) (2007). https://www.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl.
[b]Support Center for Regulatory Atmospheric Modeling; http://www.epa.gov/ttn/scram/.
[c]National Climatic Data Center 1981-2010 Climate Normals; http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

2.3.5 Aquatic Food Web

The aquatic food web is an important part of the screening scenario because the chemical concentrations modeled in fish are used to calculate human ingestion exposure and risks associated with eating contaminated local fish. A biokinetic approach to modeling bioaccumulation in fish is used in the RTR screening scenario. The primary producers (first trophic level) in the TRIM.FaTE aquatic ecosystems are algae and macrophytes in the water column and detritus in the sediments (the latter simulated as sediment particles). Zooplankton feed on algae in the water column, while benthic invertebrates, represented as a single compartment, consume detritus that settles to the sediment compartment. In the water column, small young-of-the-year fish and minnows feed on zooplankton and phytoplankton. The small fish are in turn consumed by larger or “pan” fish (e.g., bluegills, white perch), which are in turn consumed by the top consumers (e.g., gar, pickerel). The invertebrates in the sediments of the benthic environment support small bottom-feeding fish (young-of-the-year fish for many species), which in turn are consumed by larger bottom-feeding fish (e.g., catfish). For TRIM.FaTE to provide reasonable predictions of the distribution of a chemical across biotic and abiotic compartments in aquatic systems, the biomass of the aquatic biotic compartments must represent all biota in the system and the distribution of biomass among the trophic levels and groups must be as realistic as possible.

To support the development of a relatively generic freshwater aquatic ecosystem in which to model bioaccumulation in fish, a literature search, review, and analysis was conducted (ICF 2005). This research demonstrated that the diversity of species and food webs across U.S. aquatic ecosystems is substantial, reflecting the wide range of sizes, locations, and physical/chemical attributes of both flowing (rivers, streams) and low-flow water bodies (ponds, lakes, reservoirs). In general, lentic bodies of water (lakes and ponds) can accumulate higher levels of contaminants in both sediments and biota than lotic systems (rivers, streams). Also, that initial research (ICF 2005) suggests that a lake of at least 60 hectares (ha) or 150 acres could support higher trophic level predatory fish, with some fraction of their diet comprising smaller fish.

The RTR Tier 1 scenario includes a generic aquatic ecosystem with a 47-hectare (116-acre) lake. Although slightly smaller than the size suggested by the previous review (ICF 2005), a 47-ha lake is large enough to support higher trophic level fish given appropriate conditions (e.g., high productivity given a sufficient nutrient base and average temperature and growing season). Also, this size was compatible with the overall size of the defined watershed in the screening

scenario. The fish types, biomass, diet fractions, and body weights recommended for fish compartments for the Tier 1 scenario are listed in Exhibit 13. Biomass is based on an assumption that the total fish biomass (wet-weight) for the aquatic ecosystem is 5.7 grams per square meter (g_w/m^2, ICF 2005). That assumption yields health protective (i.e., higher) estimates of chemical concentrations in fish than would the assumption of higher standing biomass and fish productivity.

In general, the food web implemented in the Tier 1 scenario is consistent with aquatic food webs that support trophic level 4 fish (to maximize bioaccumulation), and is intended to be generally health protective.

Exhibit 13. Aquatic Biota Parameters for the TRIM.FaTE Screening Scenario

TRIM.FaTE Compartment Type	Organisms Represented by Compartment	Biomass		Diet	Average Body Weight (kg)
		Areal density (g_w/m^2)	Fraction of Total Fish Biomass		
Algae	green algae, diatoms, blue-green algae	7.95	–	Autotrophic	–
Zooplankton	crustaceans, rotifers, protozoans	6.36	–	100% algae[a]	5.7 E−8
Macrophyte	hydrilla, milfoil	500	–	–	–
Water column planktivore	young-of-the-year, minnows	2.0	35.1%	100% zooplankton	0.025
Water column omnivore	bluegill, white perch	0.5	8.8%	100% water column planktivore	0.25
Water column carnivore	largemouth bass, walleye	0.2	3.5%	100% water column omnivore	2.0
Benthic invertebrate	aquatic insect larvae, crustaceans, mollusks[b]	20	–	detritus in sediments	0.000255
Benthic omnivore	small catfish, rock bass	2.0	35.1%	100% benthic invert.	0.25
Benthic carnivore	large catfish, sculpins	1.0	17.5%	50% benthic invert. 50% benthic omniv.	2.0
Total Fish Biomass[c]		**5.7**			

[a]Algae is modeled as a phase of surface water in TRIM.FaTE.
[b]Benthic invertebrates include aquatic insects (e.g., nymphs of mayflies, caddisflies, dragonflies, and other species that emerge from the water when they become adults), crustaceans (e.g., amphipods, crayfish), and mollusks (e.g., snails, mussels).
[c]Total fish biomass does not include algae, macrophytes, zooplankton, or benthic invertebrates.

2.3.6 Using TRIM.FaTE Media Concentrations

The Tier 1 scenario outputs include average PB-HAP concentrations and deposition rates for each year and for each parcel of the model scenario. In each surface parcel, deposition rates to the soil are provided as are soil concentrations for the surface, root, and vadose zones and grass or leaf concentrations as appropriate for the plants. For each air parcel, air concentrations are provided. For the lake, surface water concentrations and concentrations in the various levels of the aquatic food chain are provided. For the ingestion exposure calculations, some concentrations are used to calculate direct exposure (e.g., soil ingestion),

and some are used to perform the farm food chain concentration calculations in the various media that humans can ingest.

The locations that determine exposures were selected to be health protective. Decisions regarding which TRIM.FaTE outputs to use in calculating exposures for the Tier 1 scenario assume exposure at locations very close to the modeled source. These locations are predicted to have amongst the highest media concentrations consistent with the specified spatial layout, thereby resulting in higher exposures to the emitted chemicals. These assumptions are summarized in Exhibit 14.

Exhibit 14. Spatial Considerations – TRIM.FaTE Results Selected for Calculating Farm Food Chain Media Concentrations and Receptor Exposures

TRIM.FaTE Output Used in Exposure Calculations	Representative Compartment
Concentration in air, for uptake by plants via vapor transfer	Air compartment in air Parcel N2 (air over tilled soil)
Deposition rates, for uptake by farm produce	Deposition to surface soil compartment in surface Parcel N6 (tilled soil)
Concentration in surface soil, for incidental ingestion by humans and farm animals	Surface soil compartment in surface Parcel N1 (untilled soil, closest to facility)
Concentration in soil, for uptake by farm produce and animal feed	Surface soil compartment in surface Parcel N6 (tilled soil)
Concentration in fish consumed by fisher	Water column carnivore compartment in lake (50% of fish consumed) and benthic carnivore in lake (50% of fish consumed)

TRIM.FaTE can output instantaneous chemical concentrations for a user-specified time step and also can be configured to calculate temporal averages (e.g., annual averages). For the Tier 1 scenario, the model is set up to output results on a daily basis, largely because daily is the smallest time step over which input data change (i.e., wind direction and precipitation rate). Daily concentration results were averaged to obtain annual average concentrations. The default assumption is annual average concentrations for media during the fiftieth year of emissions.

For the chemicals modeled in this scenario, long-term concentrations in environmental media will be relatively constant at 50 years. Aside from mercury, chemicals modeled for RTR approach steady state before 50 years. And, although mercury concentrations do not achieve steady state after 50 years in the modeled screening scenario configuration, the rate of change in mercury concentrations shows a decreasing trend.

2.4 Description of Exposure and Risk Modeling Scenario

This section describes the approach for modeling chemical concentrations in farm food chain (FFC) media (Section 2.4.1); estimating human exposures associated with ingestion of FFC media, incidental ingestion of soil, ingestion of fish, and infant consumption of breast milk (Section 2.4.2); and calculating human health screening risk metrics associated with these exposure pathways (Section 2.4.3). All of these calculations are conducted using MIRC. For this multipathway screening evaluation, partitioning of PB-HAPs into FFC media is modeled with MIRC, not as a part of the TRIM.FaTE modeling. Consequently, processes and inputs related to estimating chemical levels in FFC media are summarized in this section and discussed in detail in Attachment B.

2.4.1 Calculating Concentrations in Farm Food Chain Media

As was shown in Exhibit 7, MIRC was compiled to calculate concentrations of PB-HAPs in foodstuffs that are part of the farm food chain. The FFC media included in this screening scenario include:

- exposed and protected fruit,
- exposed and protected vegetables,
- root vegetables,
- beef,
- dairy products,
- pork, and
- poultry and eggs.

The algorithms used in MIRC were obtained from EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (HHRAP; EPA 2005a). These algorithms model the transfer of concentrations of PB-HAPs in FFC media using biotransfer factors. Environmental media concentrations (i.e., the chemical source terms in these algorithms) are obtained from TRIM.FaTE. As noted in Section 1.1.2.2, the TRIM.FaTE outputs included as inputs to MIRC are the following:

- PB-HAP concentrations in air;
- air-to-surface deposition rates for PB-HAPs in both particle and vapor phases;
- PB-HAP concentrations in fish tissue for water column carnivores and benthic carnivores; and
- PB-HAP concentrations in surface soil and root zone soil.

In general, plant- and animal-specific parameter values, including chemical-specific transfer factors for FFC media, were obtained from the Hazardous Waste Companion Database included in HHRAP (EPA 2005a). Attachment B provides parameter values used in MIRC for the Tier 1 assessment.

2.4.2 Ingestion Exposure

MIRC was used to estimate ingestion rates as ADDs, normalized to body weight for a range of exposure pathways. Exposure pathways included are incidental ingestion of soil, consumption of fish, produce, farm animals and related products, and ingestion of breast milk by infants. The ingestion exposure pathways included in the screening evaluation and the environmental media through which these exposures occur are summarized in Exhibit 15.

2.4.2.1 Exposure Scenarios and Corresponding Inputs

Specific exposure scenarios are developed by defining the ingestion activity patterns (i.e., estimating how much of each medium is consumed and the fraction of the consumed medium that is grown in or obtained from contaminated areas) and the characteristics of the hypothetical human exposed (e.g., age and body weight). MIRC computes exposure doses and risks for each ingestion pathway separately, enabling the pathway(s) of interest for each PB-HAP to be determined. Data related to exposure factors and receptor characteristics were obtained primarily from EPA's *Exposure Factors Handbook* (EPA 2011).

Exhibit 15. Summary of Ingestion Exposure Pathways and Routes of Uptake

Ingestion Exposure Pathway	Medium Ingested	Intermediate Exposure Pathway – Farm Animals[a]	Environmental Uptake Route	
			Medium	Process[b]
Incidental ingestion of soil	Untilled surface soil	N/A	Surface soil	Deposition; transfer via erosion and runoff [c]
Consumption of fish	Fish from local water body	N/A	Fish tissue	Direct uptake from water and consumption of food compartments modeled in TRIM.FaTE[c]
Consumption of breast milk[d]	Breast milk	N/A	Breast milk	Contaminant ingested by mother partitions to breast milk
Consumption of produce	Aboveground produce, exposed fruits and vegetables	N/A	Air Air Soil	Deposition to leaves/plants Vapor transfer Root uptake
	Aboveground produce, protected fruits and vegetables	N/A	Soil	Root uptake
	Belowground produce	N/A	Soil	Root uptake
Consumption of farm animals and related food products	Beef	Ingestion of forage	Air Air Soil	Direct deposition to plant Vapor transfer to plant Root uptake
		Ingestion of silage		
		Ingestion of grain	Soil	Root uptake
		Ingestion of soil	Soil	Ingestion from surface
	Dairy (milk)	Ingestion of forage	Air Air Soil	Direct deposition to plant Vapor transfer to plant Root uptake
		Ingestion of silage		
		Ingestion of grain	Soil	Root uptake
		Ingestion of soil	Soil	Ingestion from surface
	Pork	Ingestion of silage	Air Air Soil	Direct deposition to plant Vapor transfer to plant Root uptake
		Ingestion of grain	Soil	Root uptake
		Ingestion of soil	Soil	Ingestion from surface
	Poultry	Ingestion of grain	Soil	Root uptake
		Ingestion of soil	Soil	Ingestion from surface
	Eggs	Ingestion of grain	Soil	Root uptake
		Ingestion of soil	Soil	Ingestion from surface

[a]Calculation of intermediate exposure concentrations were required only for the farm animal/animal product ingestion pathways.
[b]Process by which HAP enters medium ingested by humans.
[c]Modeled in TRIM.FaTE.
[d]The consumption of breast milk exposure scenario is discussed in Section 2.4.2.3.

For the Tier 1 scenario described here, exposure characteristics that would result in a highly health protective estimate of total exposure were selected. The ingestion rate for each medium was set at high-end values (equal to the 90th percentile values for all food types except for fish, which was set at 99th percentile values). All media were assumed to be obtained from locations impacted by the modeled source. Although this approach could result in an overestimate of

total chemical exposure for a hypothetical exposure scenario (for example, note that the total food ingestion rate that results is extremely high for a hypothetical consumer with ingestion rates in the upper percentile for every food type), it was selected to avoid underestimating exposure for any single farm food type. The exposure characteristics selected for the Tier 1 scenario are summarized in Exhibit 16.

Exhibit 16. Overview of Exposure Factors Used for RTR Multipathway Screening[a,b]

Exposure Factor	Selection for Screening Assessment
Age group evaluated	Infants under 1 year (breast milk only) Children 1–2 years of age Children 3–5 years of age Children 6–11 years of age Children 12–19 years of age Adult (20–70 years)
Body weight (BW; varies by age)	Weighted mean of national distribution or recommended value
Ingestion rate (IR) for farm produce and animal products other than fish (varies by age and medium)	90th percentile of distribution of consumers who produce own food
Ingestion rate for fish	For adults, 99th percentile *as-prepared* ingestion rate representative of subsistence fisher woman. For children, based on 99th percentile, *as-prepared*, consumer-only, national ingestion rates – adjusted.
Exposure frequency (EF)	365 days/year
Exposure duration	Lifetime, for estimating cancer risk; varies by chemical for chronic non-cancer evaluation
Fraction contaminated (FC) (varies by media consumed)[c]	1
Cooking loss[d]	Assumed to be "typical"; varies depending on food product (see Attachment B). Cooking losses were not considered for fish consumption because intake rates represent "as prepared" values.
Food preparation/cooking adjustment factor for fish[e]	Mercury = 1.5 Cadmium = 1.5 Dioxin = 0.7 PAH = 1.0

[a]Data for exposure characteristics are presented in Attachment B. Exposure parameter values were based on data obtained primarily from the *Exposure Factors Handbook* (EPA 2011). See Attachment B for details.
[b]Exposure factor inputs are used in calculating ADD estimates for each exposure pathway. ADD equations for each pathway evaluated in this screening assessment are provided in Attachment B.
[c]Fraction contaminated represents the fraction of food product that is derived from the environment included in the screening scenario (e.g., produce grown on soil impacted by PB-HAPs). This parameter is defined separately for each FFC medium; however, for the Tier 1 scenario, all ingested media are assumed to be impacted.
[d]Cooking loss inputs were included to simulate the amount of a food product that is not ingested due to loss during preparation or cooking, or after cooking.
[e]Because "as consumed," fish consumption rates are used with whole-fish concentrations, adjustments might be appropriate to adjust the fish tissue concentrations to reflect concentrations after food preparation. See Attachment B, Section 6.4.4 for additional discussion.

2.4.2.2 Calculating Average Daily Doses

MIRC calculates chemical-specific ADDs normalized to body weight (mg PB-HAP per kg of body weight per day). Equations used to calculate ADDs were adapted from the algorithms provided in the technical documentation of EPA's *Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Modeling System* (EPA 2003), which derived much of its input data

from the *Exposure Factors Handbook* (EPA 2011). The ingestion exposure modeling approach embodied by 3MRA is conceptually similar to that presented in HHRAP. A discussion of exposure dose estimation and the equations to calculate ADDs for each ingestion pathway are provided in Attachment B.

2.4.2.3 Infant Ingestion of Breast Milk

A nursing mother exposed to contaminants by any ingestion pathway described above can pass the contaminants to her infant through breast milk (ATSDR 1998). The nursing infant's exposure can be estimated from the levels of chemical concentrations in the breast milk, which in turn can be estimated based on the mother's chemical intake.

Reports of bioaccumulation of lipophilic compounds such as polychlorinated biphenyls (PCBs), polychlorinated dibenzofurans (PCDFs), and dioxins are prevalent in the scientific literature. Due to their high lipophilicity, these compounds partition almost exclusively to the milk fat of breast milk rather than the aqueous phase (EPA 1998). PCBs, PCDFs, and PCDDs are the most documented groups of contaminants found in breast milk. Other compounds with lower octanol-water partition coefficients, such as phenol, benzene, halobenzenes, and PAHs, are found in both the milk fat and the aqueous phase of breast milk. Heavy metals such as arsenic, lead, cadmium, and mercury have been found in the aqueous phase of the breast milk. However, given their chemical and physical characteristics (and the impact such qualities have on partitioning within the body and pharmacokinetics), substances that do not partition as strongly to the lipophilic phase of breast milk tend to be of lower concern with regard to exposures to nursing infants. Because of the greater concern with regard to dioxins for this exposure pathway, it is the only PB-HAP included in the breast milk exposure pathway for RTR at this time. This approach is consistent with the risk assessment procedures included in EPA's Human Health Risk Assessment Protocol (EPA 2005a).

Exposure via the breast milk consumption pathway is estimated in MIRC for dioxins only. This pathway is included in computing total exposure for developing the screening threshold for dioxins. In the absence of congener-specific data, dioxin congeners were assumed to manifest the same tendency to accumulate in breast milk as 2,3,7,8-TCDD.

2.4.3 Calculating Risk

MIRC was used to calculate excess lifetime cancer risk and non-cancer hazard (expressed as the hazard quotient or HQ) using the calculated ADDs and ingestion dose-response values. Chemical dose-response data include cancer slope factors (CSFs) for ingestion and non-cancer oral RfDs. The CSFs and RfDs for the PB-HAPs included in the Tier 1 scenario are presented in Exhibit 17 and are discussed in more detail in Attachment B. Equations used to estimate cancer risk and non-cancer hazard also are provided in Attachment B.

Exhibit 17. Dose-response Values for PB-HAPs Addressed by the Screening Scenario

PB-HAP	CSF ([mg/kg-day]$^{-1}$)	Source	RfD (mg/kg-day)	Source
Inorganics				
Cadmium compounds (as Cd)	not available		1E−3	IRIS
Elemental mercury	not available		not available	
Divalent mercury	not available		3E−4	IRIS
Methyl mercury	not available		1E−4	IRIS
Organics				
Benzo[a]pyrene[a]	7.3	IRIS	not available	
2,3,7,8-TCDD	1.5E+5	EPA ORD	7E−10	IRIS

Source: EPA (2007).
CSF = cancer slope factor; RfD = reference dose; IRIS = EPA's Integrated Risk Information System; Cal/EPA = California Environmental Protection Agency; EPA ORD = EPA's Office of Research and Development
[a]For consistency with the overall approach for dose-response assessment of PAHs, the CSF listed in IRIS for benzo[a]pyrene ([7.3 mg/kg-day]$^{-1}$) was adjusted due to its mutagenic mode of action as discussed below (see also Attachment B).

Estimated individual cancer risks for the PAHs included in the screening scenario were adjusted upward to account for the mutagenic cancer potency of these compounds during childhood, as specified by EPA in supplemental guidance for cancer risk assessment (EPA 2005c). Specifically, cancer potency for PAHs is assumed to be tenfold greater for the first 2 years of life and threefold greater for the next 14 years. These factors were incorporated into a time-weighted total increase in potency over a lifetime of 70 years. The cancer potency adjustment for chemicals with a mutagenic mode of action is discussed in Attachment B.

2.4.4 Summary of Tier 1 Assumptions

As emphasized previously, the screening scenario created for evaluating PB-HAP emissions from RTR facilities is intended to be health protective to prevent underestimating risk. The scenario also is intended to avoid grossly overestimating risk to the point where no emissions screen. The overall degree to which the scenario is health protective is the sum of the multiple assumptions that affect the outputs of the fate and transport, exposure, and risk modeling. Exhibit 18 summarizes important characteristics that influence exposure and risk estimates for this scenario and indicates the general degree of health protectiveness associated with the values for each assumption. Although this summary does not provide a quantitative estimate of the output uncertainty or the degree to which exposures and risks estimated using the scenario would be overestimated, it does demonstrate qualitatively that the scenario generally overestimates exposure and thus favors a health-protective risk output.

Exhibit 18. Summary of RTR Tier 1 Screening Scenario Assumptions

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
General Spatial Attributes			
Farm location	375 m from source; generally downwind	Health Protective	Location dictates soil and air concentrations and deposition rates used to calculate chemical levels in farm produce.
Lake location	375 m from source; generally downwind	Health Protective	Location dictates where impacted fish population is located.

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
Surface soil properties	Typical values or national averages	Neutral	Based on existing EPA documentation and other references.
Size of farm parcel	About 4 ha	Health Protective	Relatively small parcel size results in higher chemical concentration.
Size of lake	47 ha; about 3 m average depth	Health Protective	Lake is large enough to support an aquatic ecosystem with higher trophic-level fish, but is relatively small and shallow (thus increasing surface area-to-volume ratio).
Meteorological Inputs			
Total precipitation	1.5 m/yr	Health Protective	Intended to represent rainy U.S. location; set to highest state-wide average for the contiguous United States.
Precipitation frequency (with respect to impacted farm/lake)	2/3 of total precipitation fall on farm/lake and watershed	Health Protective	Most of total precipitation occurs when the farm/lake are downwind of the source.
Wind direction	Farm/lake are downwind 40% of the time	Health Protective	Farm/lake located in the predominantly downwind direction. Temporal dominance of wind direction based on data from Yakima, Washington, where wind is predominantly from the west.
Wind speed	2.8 m/sec	Health Protective	Low wind speed (5th percentile of long-term averages for contiguous United States); increases net deposition to lake/watershed.
Air temperature	298 K	Neutral	Typical for summer temperatures in central and southern United States.
Mixing height	710 m	Health Protective	Relatively low long-term average mixing height (5th percentile of long-term averages for contiguous United States); increases estimated air concentration.
Watershed and Water Body Characteristics			
Evaporation of lake surface water	700 mm/yr	Neutral	Based on sensitivity analyses, value is not expected to under- or overestimate concentration in surface water.
Surface runoff into lake	Equal to 40% of total precipitation	Health Protective	Based on typical water flow in wetter U.S. locations; higher runoff results in greater transfer of chemical to lake.
Surface water turnover rate in lake	About 12 turnovers per year	Neutral	Consistent with calculated water balance; reasonable in light of published values for small lakes. Might overestimate flushing rate if water inputs are also overestimated. Note that after evapotranspiration, remaining water volume added via precipitation is assumed to flow into or through lake.

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
Soil erosion from surface soil into lake	Varies by parcel; ranges from 0.002 to 0.01 kg/m^2-day	Neutral	Erosion rates calculated using the universal soil loss equation (USLE); inputs to USLE were selected to be generally conservative with regard to concentration in the pond (i.e., higher erosion rates were favored). Might underestimate erosion for locations susceptible to high erosion rates. Note that higher erosion increases concentration in lake (and fish) but decreases levels in surface soil (and farm products).
Aquatic food web structure and components	Multilevel; includes large, upper trophic-level fish	Health Protective	Inclusion of upper trophic-level fish and absence of large-bodied herbivore/detritivore fish favor higher concentrations of bioaccumulative chemicals and result in higher concentrations in consumed fish. Linear food-chain maximizes concentration of bioaccumulative chemicals in higher trophic-level fish.
Parameters for Estimating Concentrations in Farm Food Chain Media			
Fraction of plants and soil ingested by farm animals that is contaminated	1.0 (all food and soil from contaminated areas)	Health Protective	Assumes livestock feed sources (including grains and silage) are derived from most highly impacted locations.
Soil- and air-to-plant transfer factors for produce and related parameters	Typical (see Attachment B for details)	Neutral	Obtained from peer-reviewed and standard EPA reference sources.
Biotransfer factors for efficiency of uptake by animal of chemical in food/soil	Typical (see Attachment B for details)	Neutral	Obtained from peer-reviewed and standard EPA reference sources.
Bioavailability of chemicals in soil (for soil ingested by animals)	1.0 (relative to bioavailability of chemical in plant matter)	Health Protective	Probably overestimates bioavailability in soil; many chemicals are less bioavailable in soil than in plants.
Ingestion Exposure Assumptions			
Ingestion rates for all farm produce/livestock types	Person obtains all food sources from local farm; ingestion rate is 90th percentile of rates for home-produced food items	Health Protective	All food derived from impacted farm; total food ingestion rate would exceed expected body weight-normalized ingestion rates (prevents underestimating any individual food type).
Fish ingestion rate	Adult: 373 g/day Child age groups: 1 to 2: 108 g/day 3 to 5: 159 g/day 6 to 11: 268 g/day 12 to 19: 331 g/day	Health Protective	The adult rate is the 99th percentile value for adult females from Burger (2002) and is considered representative of subsistence fishers. Rates for children are based on the 99th percentile, consumer-only fish ingestion rates from EPA 2002. Rates were adjusted

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
			to be representative of the age groups used in the screening scenario. See Attachment B for a detailed discussion.
Exposure frequency	Consumption of contaminated food items occurs 365 days/yr	Health Protective	All meals from local farm products.
Body weight	Mean of national distribution	Neutral	Note that this does not affect the body-weight-normalized rates for produce and animal products.
Other Chemical-Specific Characteristics			
General chemical properties used in fate and transport modeling (Henry's law, K_{ow}, etc.)	Varies	Neutral	Obtained from peer-reviewed sources; intended to be representative of typical behavior and characteristics.
"General" physical properties (plant matter density, aquatic life biomass, algal growth rate, etc.)	Varies	Neutral	Obtained from peer-reviewed sources; intended to be representative of typical behavior and characteristics.
Dose-response values	Varies	Neutral to Health Protective	Values used are those determined to be appropriate for risk assessment by OAQPS; values are developed to be health protective.

2.5 Evaluation of Screening Scenario

2.5.1 Introduction

The screening scenario developed for assessing multipathway human health risk for EPA's Risk and Technology Review has been subjected to a series of evaluations. As described previously the major PB-HAP categories of concern for this assessment are cadmium compounds (Section 2.5.2), mercury compounds (Section 2.5.3), dioxins (Section 2.5.4), and POM (Section 2.5.5). The scenario evaluations were focused primarily on assessing the behavior of these HAP categories in the environment, the accumulation of these chemicals in ingestible food products, and the predominant pathways of human exposure.

2.5.2 Cadmium Compounds

Some of the largest anthropogenic sources of cadmium to air are facilities that process, mine, or smelt cadmium-zinc ores or cadmium-zinc-lead ores, coal- and oil-fired boilers, other urban and industrial facilities, phosphate fertilizer manufacturing facilities, road dust, and municipal sewage sludge incinerators (ATSDR 2008).

2.5.2.1 Behavior in the Environment

Once emitted into the environment, airborne cadmium particles can be transported over long distances before being deposited. Cadmium has been observed to partition primarily to soil when released to the environment (ATSDR 2008). The mobility of cadmium in soil depends

strongly on soil pH, clay content, and availability of organic matter—factors that determine whether the cadmium is dissolved or sorbed in surface soil. In general, cadmium adsorbs to soil particles in the surface layers of the soil profile, but to a lesser degree than many other heavy metals (HSDB 2005). Cadmium also binds strongly to organic matter, rendering the metal relatively immobile in some soils. Nonetheless, some plants still can take up cadmium efficiently, thus providing an entry point for cadmium into the food chain (ATSDR 2008).

Cadmium also enters surface waters, which can occur via atmospheric deposition, runoff and erosion, or wastewater streams. Most cadmium compounds entering the water column are quickly removed through adsorption to organic matter in sediment or to other suspended compounds. Cadmium that remains in the water column is expected to exist primarily in the dissolved state where it is available for uptake by aquatic organisms.

Freshwater fish accumulate cadmium primarily through direct uptake of the dissolved form through the gills and secondarily through the diet, which plays a variable role in total cadmium uptake (Reinfelder et al. 1998; Chen et al. 2000; Saiki et al. 1995). Although some biomagnification of cadmium has been reported for aquatic food chains in saltwater systems, biomagnification in freshwater systems appears to be present only at lower trophic levels (Chen et al. 2000) and in narrowly defined niches (e.g., plankton/macroinvertebrate food chains; Croteau et al. 2005). Biomagnification factors (BMFs) of less than 1 generally have been reported for fish at higher trophic levels, indicating that cadmium concentrations generally biodiminish from lower to higher trophic levels (Chen et al. 2000; Mason et al. 2000).

For the RTR screening scenario, the partitioning behavior modeled in TRIM.FaTE was consistent with the behavior of cadmium expected in the natural environment.

2.5.2.2 Concentrations in Ingestible Products

Most non-inhalation exposure to cadmium outside of occupational settings is through dietary intake. Available data indicate that cadmium accumulates in plants, aquatic organisms, and terrestrial animals, offering multiple ingestion exposure pathways (ATSDR 2008). Actual cadmium levels in ingestible products, however, varies based on type of food, agricultural and cultivation practices, atmospheric deposition rates, characteristics of environmental media, and presence of other anthropogenic pollutants. Meat and fish generally contain lower amounts of cadmium overall, but cadmium can be highly concentrated in certain organ meats, such as kidney and liver (ATSDR 2008). In a study of cadmium concentrations in 14 food groups (including prepared foods), meat, cheese, and fruits generally contained low levels of cadmium (ATSDR 2008).

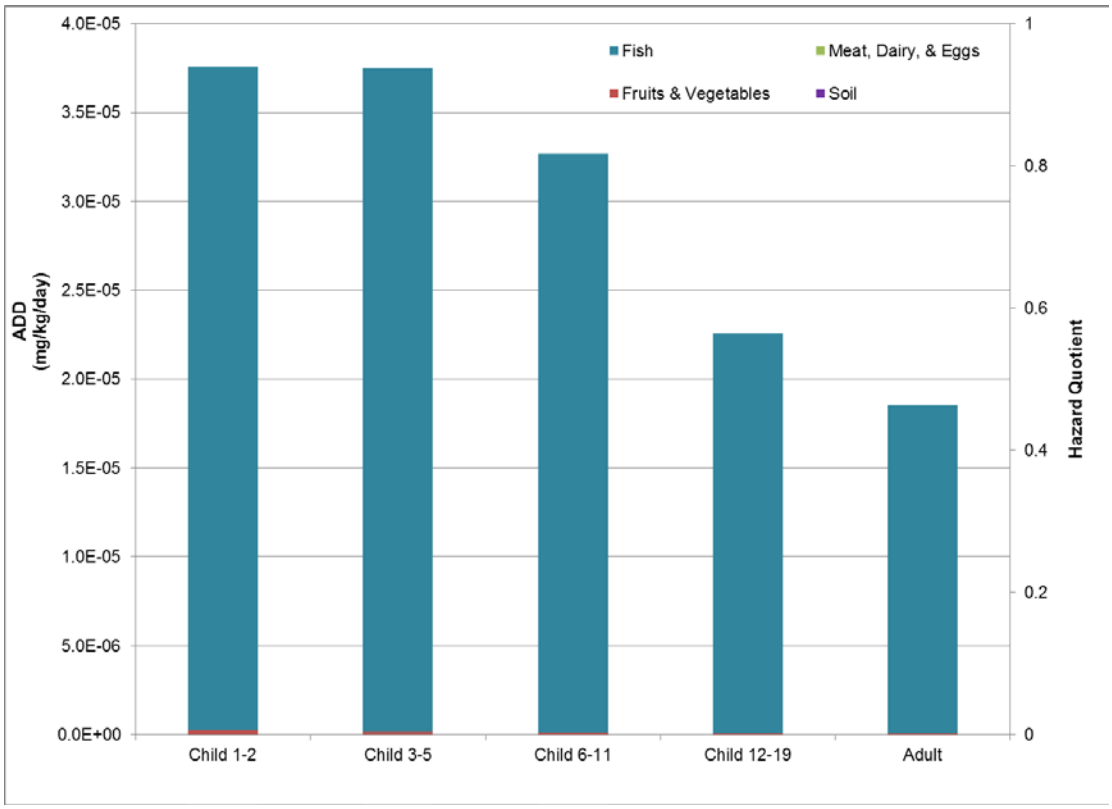
For the RTR screening scenario, the cadmium concentrations output by MIRC were consistent with reported values in all ingestible media products. The products with higher reported cadmium levels in the literature, including soil, plants, and fish, also contained the higher modeled concentrations.

2.5.2.3 Average Daily Dose (ADD)

To determine the media most relevant to exposure and risk, the ingestion exposure factors must be considered in addition to the estimated media concentrations (i.e., a higher concentration for a particular medium does not necessarily mean higher risk). In Exhibit 19, the contributions of ingestion exposure pathways to the average daily dose (ADD) (and thus the HQ) for the different age categories are presented. As shown in the exhibit, fish ingestion is the dominant exposure pathway across all age categories, accounting for nearly 100 percent of the ADD for all groups. The combined contribution from all other exposure pathways accounts for less than 0.7 percent of the total ADD for all age groups. Most of the additional exposure was from

ingestion of fruits and vegetables. The highest ADD corresponds to children aged 1–2 years; thus, the exposure corresponding to this group was used to determine the emission threshold for cadmium. In other words, the threshold emissions rate for cadmium is set at the level where the HQ for this age category is equal to 1.0.

Exhibit 19. Estimated Contributions of Modeled Food Types to Cadmium Ingestion Exposures and Hazard Quotients



2.5.3 Mercury Compounds

Some of the largest anthropogenic sources of mercury to air are facilities that process, mine, or smelt mercury ores; industrial/commercial boilers; fossil fuel combustion activities (primarily coal); cement production facilities; other urban and industrial facilities; and medical and municipal waste incinerators (ATSDR 1999). These facilities can emit a mixture of elemental and divalent mercury, mostly in the gaseous phase, with some divalent forms in particle-bound phases (EPA 1997).

2.5.3.1 Behavior in the Environment

Once emitted into the environment, mercury undergoes changes in form and species as it moves through environmental media. Elemental mercury is the most prevalent species of mercury in the atmosphere. Due to the long residence time of elemental mercury in the atmosphere, this compound is relatively well distributed, even on a global scale.

Divalent mercury is removed from the atmosphere at a faster rate than elemental mercury, and it can be transferred to the surface near the emission source via wet or dry deposition where it appears to adsorb tightly to soil particles (EPA 1997) or dissolved organic carbon. Divalent mercury in soil also can be methylated by microbes or reduced to elemental mercury and revolatilized back into the atmosphere. Most divalent mercury from atmospheric deposition will

remain in the soil profile, however, in the form of inorganic compounds bound to soil organic matter. Although this complexing behavior with organic matter significantly limits mercury transport, the ability of mercury to form these complexes greatly depends on soil conditions such as pH, temperature, and soil humic content. For example, mercury strongly adsorbs to humic materials and sesquioxides in soil at pH > 4 and in soils with high iron and aluminum content (ATSDR 1999). Small amounts of mercury in soil can be transported to surface water via runoff or leaching.

Mercury could also enter the water column through atmospheric fallout. Once in the water body, divalent mercury can be methylated through microbial activity. In addition, divalent and methyl mercury can be further reduced to elemental mercury, which can volatilize and reenter the atmosphere. Solid forms of inorganic mercury compounds could adsorb to particulates in the water column or partition to the sediment bed (EPA 1997).

The solubility of mercury in water depends on the species and form of mercury present as well as properties of the water such as water pH and chloride ion concentration (ATSDR 1999). Low pH favors the methylation of mercury in the water column, typically performed by sulfur-reducing bacteria in anaerobic conditions. Methyl mercury is typically of greatest concern because it readily bioaccumulates and efficiently biomagnifies in aquatic organisms. A considerable amount (25–60 percent) of both divalent mercury compounds and methyl mercury is strongly bound to particulates in the water column (EPA 1997). The remaining mercury is dissolved. Most of the elemental mercury produced as a result of reduction of divalent mercury volatilizes back into the atmosphere.

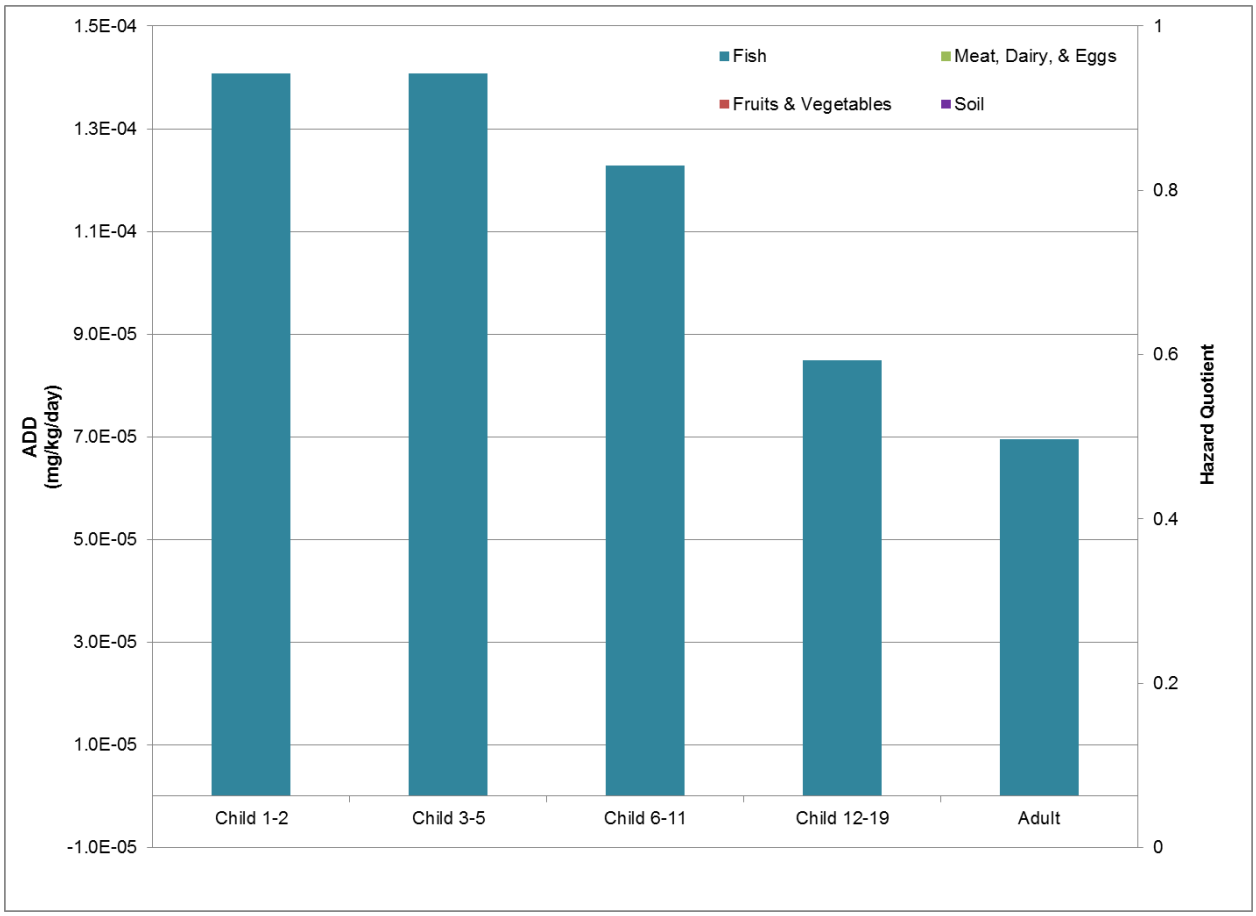
For the screening scenario, the partitioning behavior modeled in TRIM.FaTE generally was consistent with trends noted in the literature. Divalent mercury was the most prevalent species in modeled surface soil, surface water, and sediment compartments, while methyl mercury was the dominant species in fish.

2.5.3.2 Concentrations in Ingestible Products

Available data indicate that mercury bioaccumulates in plants, aquatic organisms, and terrestrial animals, providing multiple ingestion exposure pathways (EPA 1997; ATSDR 1999). Low levels of mercury are found in plants, with leafy vegetables containing higher concentrations than potatoes, grains, legumes, and other vegetables and fruits (ATSDR 1999; EPA 1997). Cattle demethylate mercury in the rumen and, therefore, store very little of the mercury they ingest by foraging or consuming silage or grain. Thus, mercury content in meat and cow's milk is low (ATSDR 1999). Concentrations of methyl mercury in fish are generally highest in larger, older specimens at the higher trophic levels (EPA 1997).

Although data on mercury in foods other than fish are not abundant in the literature, total mercury concentrations output by MIRC were generally consistent with the reported values that were available. The exposure pathways that most influenced the mercury HQs in the model are presented in Exhibit 20. As shown, the dominant exposure pathway for all age groups is ingestion of fish. Relative to divalent mercury, methyl mercury concentrations in fish were very high (approximately 95 percent of total mercury).

Exhibit 20. Estimated Contributions of Modeled Food Types to Methyl Mercury Ingestion Exposures



2.5.3.3 Average Daily Dose

In Exhibit 20, the contributions of ingestion exposure pathways to the ADD (and thus the HQ) for methyl mercury across the different age categories are presented. As shown, fish is the dominant exposure pathway across all age categories, accounting for nearly 100 percent of the ADD for each group. The combined contribution of all other exposure pathways accounts for less than 1 percent of the total ADD for all age groups. The high degree of exposure to methyl mercury through fish ingestion is attributed to the ease with which this compound bioaccumulates and biomagnifies in fish and to the health protective ingestion assumptions used in the screening scenario. The highest ADD corresponds to children aged 1–2 years; thus, the exposure corresponding to this group was used to determine the emission threshold for mercury.

2.5.4 Dioxins

Incineration and combustion processes are believed to be the primary emission sources for chlorinated dioxins (ATSDR 1998). The five stationary source categories that generate the vast majority of 2,3,7,8-TCDD emissions in the United States are municipal waste incineration, medical waste incineration, hazardous waste kilns from Portland cement manufacturing, secondary aluminum smelting, and biological incineration.

2.5.4.1 Behavior in the Environment

Dioxins emitted to the atmosphere can be transported long distances in vapor form or bound to particulates, depositing in soils and water bodies in otherwise pristine locations far from the source. Although airborne dioxins are susceptible to wet and dry deposition, most dioxins emitted to the atmosphere through incineration/combustion processes are not deposited close to the source (ATSDR 1998).

In soil, dioxins strongly adsorb to organic matter and show very little vertical movement, particularly in soils with a high organic carbon content (ATSDR 1998). Most dioxins deposited in soil are expected to remain buried in the soil profile, with erosion of contaminated soil particles the only significant mechanism for transport to water bodies.

The dry deposition of dioxins from the atmosphere to water bodies is another important transport process. Because of the hydrophobic nature of dioxins, most dioxins entering the water column are expected to adsorb to suspended organic particles or partition to bed sediment, which appears to be the primary environmental sink for this chemical group (EPA 2004c). Although dioxins bound to aquatic sediment primarily become buried in the sediment compartment, some resuspension and remobilization of congeners can occur if sediments are disturbed by benthic organisms (ATSDR 1998).

Bioaccumulation factors (BAFs) in fish are high as a result of the lipophilic nature of chlorinated dioxins. Although the processes by which freshwater fish accumulate dioxins are not well understood, both fish and invertebrates bioaccumulate congeners that have partitioned to sediment or have become suspended in water (EPA 2004c). Because most dioxins in the aquatic environment are adsorbed to suspended particles, however, direct uptake from the water is unlikely to be the primary route of exposure for most aquatic organisms at higher trophic levels (ATSDR 1998). At lower trophic levels, the primary route of exposure appears to be through uptake of water in contaminated sediment pores, and the primary route of exposure in the higher trophic levels appears to be through food chain transfer. Following ingestion, some fish can slowly metabolize certain congeners, such as 2,3,7,8-TCDD, and release the polar metabolites in bile. This process ultimately might limit bioaccumulation at higher trophic levels (ATSDR 1998).

For the RTR screening scenario, the partitioning behavior modeled in TRIM.FaTE was consistent with the behavior of 2,3,7,8-TCDD expected in the natural environment. Also of note is that dioxins readily partition into breast milk due to the lipophilic nature of these compounds.

2.5.4.2 Concentrations in Ingestible Products

The primary source of non-inhalation exposure to dioxins outside of occupational settings is through dietary intake, which accounts for more than 90 percent of daily dioxin exposure (ATSDR 1998). Available data indicate that dioxins concentrate in plants, aquatic organisms, and animals, offering multiple ingestion exposure pathways. Actual congener levels in ingestible products, however, can vary based on type of food, agricultural and cultivation practices, atmospheric deposition rates, characteristics of environmental media, and presence of other anthropogenic pollutants. Dioxins appear to enter the terrestrial food chain primarily through vapor-phase deposition onto surfaces of plants, which are then consumed by larger animals. Another major source of exposure to dioxins is through ingestion of contaminated soil by animals.

Observed trends indicate that meat, dairy, and fish consumption are the dominant exposure pathways, comprising 90 percent of dioxin dietary intake (ATSDR 1998). Consistent with the literature, the modeled concentration of 2,3,7,8-TCDD in the fish compartment for the screening

scenario was at least one order of magnitude greater than concentrations in the other compartments. Among the compartments with the lowest concentrations were fruits and vegetables, which do not readily accumulate 2,3,7,8-TCDD.

Ingestion of breast milk during infancy and fish ingestion contribute to over 97 percent of lifetime dioxin exposure for 2,3,7,8-TCDD in the screening scenario. Daily intakes of 2,3,7,8-TCDD from cow's milk, produce, and fish have been reported in the literature to comprise 27 percent, 11 percent, and 10 percent, respectively, of the total daily intake in the general population. Some studies note that specific subpopulations, such as subsistence farmers and fishers, however, might have very different exposure profiles in which fish, meat, and dairy drive congener exposure (ATSDR 1998). Given the subsistence diet modeled in the RTR screening scenario, the high exposure from consumption of fish is appropriate within the context of this assessment.

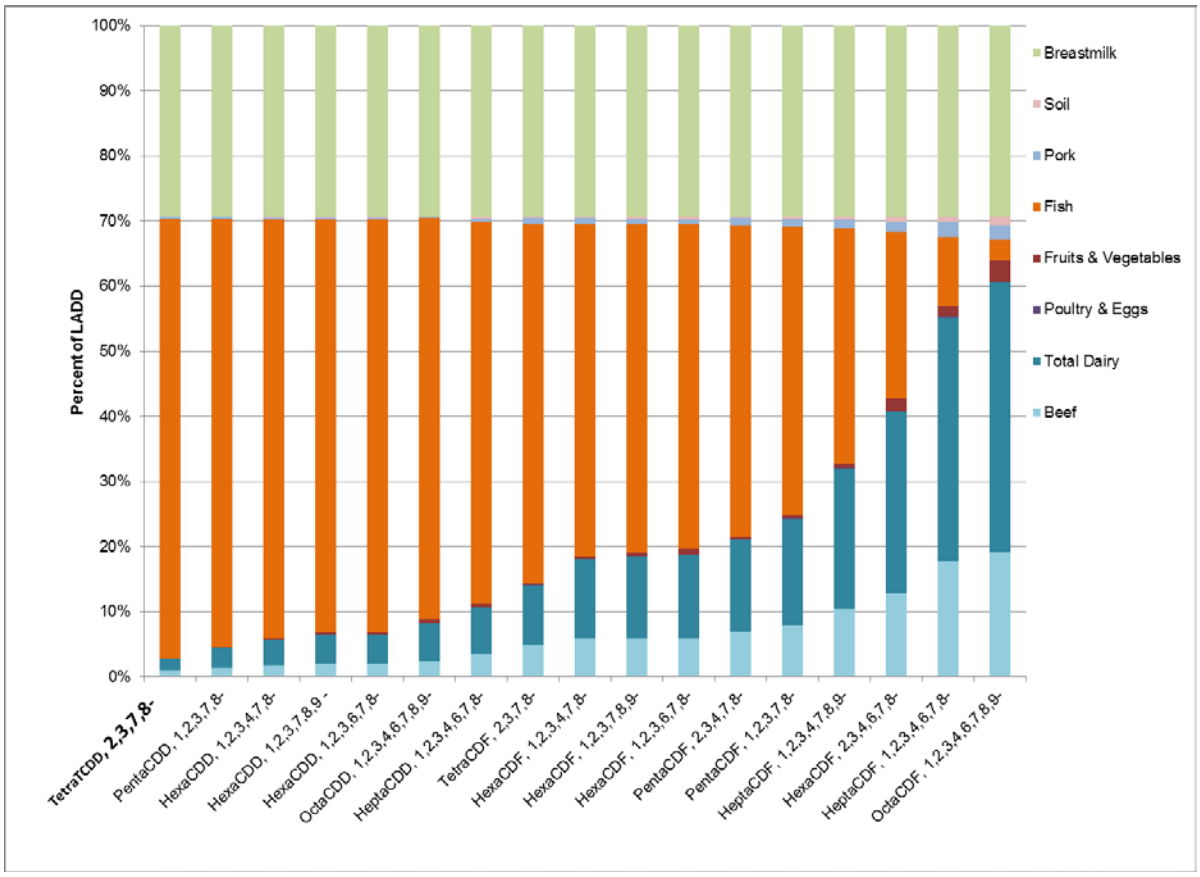
2.5.4.3 Lifetime Average Daily Dose (LADD)

The contributions of ingestion exposure pathways to the lifetime average daily dose (LADD) (and thus lifetime cancer risk) for the modeled dioxin congeners are presented in Exhibit 21. Based on the modeling methodology and assumptions used, exposures via the breast milk pathway consistently account for approximately 30 percent of the lifetime exposure for all congeners, while exposure via fish, soil, and the various farm food chain pathways is highly variable across congeners. This variability can be explained in part by differences in the physiochemical properties that drive the environmental transport processes of these congeners (e.g., K_{ow}, molecular weight). The differences are also likely attributed to differences in the congener-specific half-life in abiotic media and the degree to which the congener is metabolized in biotic media.

2.5.5 Polycyclic Aromatic Hydrocarbons

PAHs can enter the atmosphere as a result of a variety of combustion processes, both natural and anthropogenic. Stationary emission sources account for approximately 80 percent of total annual PAH emissions. Although the primary source of stationary source PAH emissions is thought to be residential wood burning, other processes such as power generation; incineration; coal tar, coke, and asphalt production; and petroleum catalytic cracking are also major contributors (ATSDR 1995).

Exhibit 21. Estimated Contributions of Modeled Food Types to Dioxin Ingestion Exposures



2.5.5.1 Behavior in the Environment

PAHs emitted to the atmosphere can travel long distances in vapor form or attached to particles, or they can deposit relatively close to an emission source via wet or dry deposition onto water, soil, and vegetation. In the atmosphere, PAHs are found primarily in the particle-bound phase, and atmospheric residence time and transport distances are highly influenced by climatic conditions and the size of the particles to which they are bound (ATSDR 1995).

As a result of sustained input from anthropogenic sources, PAHs are ubiquitous in soil. High molecular weight PAHs, such as benzo(a)pyrene, strongly adsorb to organic carbon in soil, indicating that adsorption to soil particles will limit the mobility of these compounds following deposition to soil (ATSDR 1995).

Most PAHs enter the water column directly through atmospheric deposition (ATSDR 1995). Following deposition onto surface waters, approximately two-thirds of PAHs adsorb strongly to sediment and suspended particles, while only small amounts revolatilize back to the atmosphere (ATSDR 1995). Aquatic organisms can accumulate PAHs via uptake from water, sediment, or food. Although fish and other organisms readily take up PAHs from contaminated food (e.g., aquatic insects, other benthic invertebrates, smaller fish), biomagnification generally does not occur because many organisms can rapidly metabolize PAHs (ATSDR 1995). As a result, concentrations of PAHs have generally been observed to decrease with increasing trophic levels (ATSDR 1995). Due to this ability to metabolize PAHs, BAFs in fish are not expected to be especially high. Sediment-dwelling organisms can experience increased

exposure to PAHs through association (e.g., direct uptake, consumption) with contaminated sediment (ATSDR 1995).

For the screening scenario, the partitioning behavior of benzo(a)pyrene is generally consistent with trends reported in the literature.

2.5.5.2 Concentrations in Ingestible Products

The primary source of non-inhalation exposure to benzo(a)pyrene outside of occupational settings is through dietary intake. Exposure can depend on the origin of the food (higher values are often recorded at contaminated sites) and the method of food preparation (higher values have been reported for food that is smoked or grilled). PAHs have been observed to bioaccumulate in aquatic organisms and terrestrial animals through uptake of contaminated water, soil, and food. These compounds are readily metabolized by higher trophic level organisms, including humans, however, so biomagnification is not considered to be significant (ATSDR 1995). Plants accumulate PAHs primarily through atmospheric deposition, but chemical concentrations tend to be below detection levels. PAHs in meat have been observed at concentrations below detection levels up to higher concentrations when the meat is smoked. Similar concentrations have been reported for fish, with smoked fish concentrations sometimes quadruple those found in terrestrial animals. Because PAH concentrations are highest in products that are smoked or grilled, most of the available data for benzo(a)pyrene in food is for products that have been prepared using these processes. As a result, reported values might be significantly higher than those output by MIRC.

For the RTR screening scenario, concentrations output by MIRC were generally lower than the reported ranges for benzo(a)pyrene in ingestible products. This trend is likely the result of background exposure in reported measurements and available data that are skewed toward concentrations in highly contaminated products. Considering these mitigating factors, the RTR screening scenario output concentrations are within the range of plausible values for PAHs in ingestible products.

2.5.5.3 Lifetime Average Daily Dose

The contributions of ingestion exposure pathways to the LADD (and thus lifetime cancer risk) for various PAHs are presented in Exhibit 22. As shown, the variability in the driving exposure pathways across PAHs is significant, with fish, beef, dairy, fruits, and vegetables comprising between 90 and 99 percent of exposure for different PAHs.

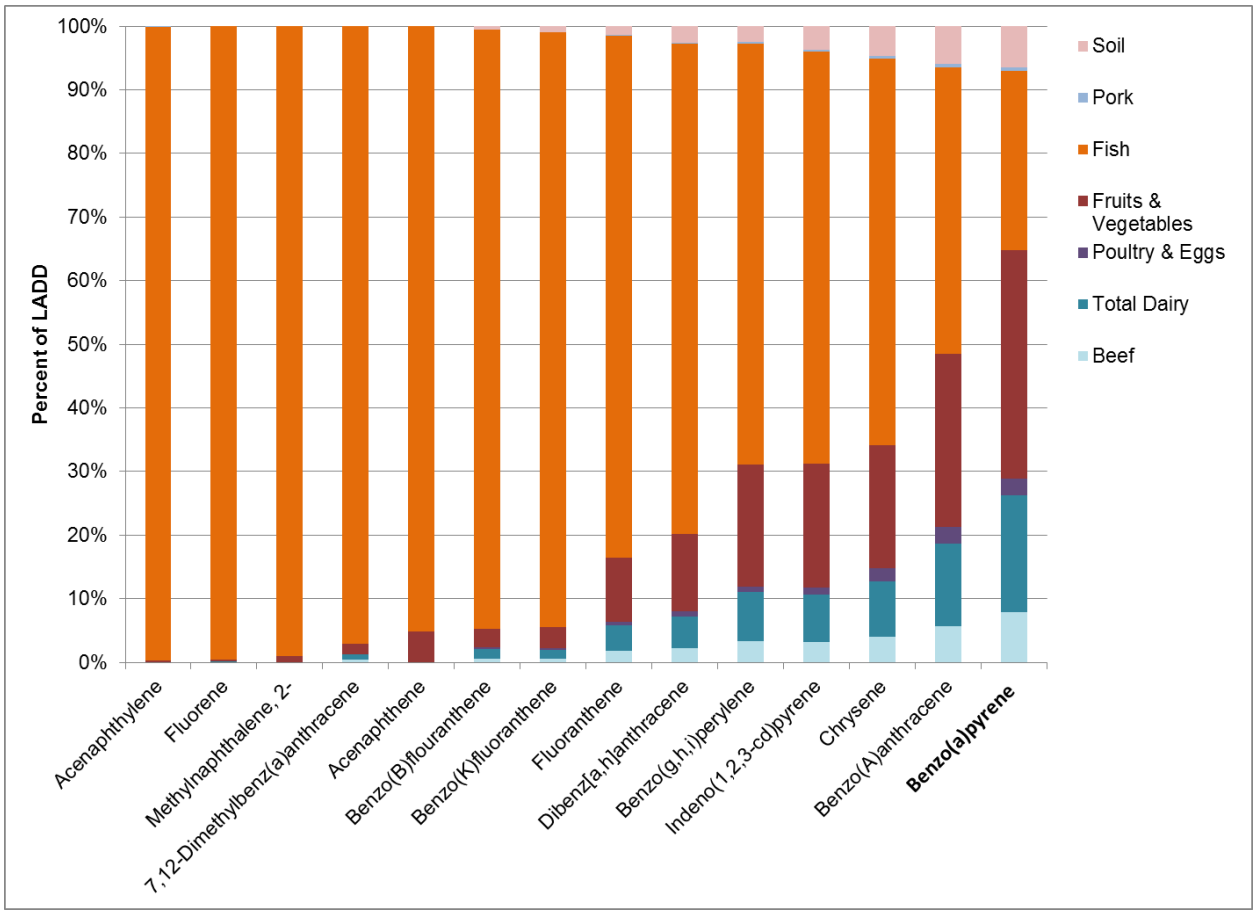
This variability can be accounted for in part by differences in the physiochemical properties that drive the environmental fate and transport processes of these PAHs (e.g., K_{ow}, molecular weight, chemical structure), differences in the PAH-specific half-life in abiotic media, and the degree to which the PAHs are metabolized in biotic media. The variability in exposure pathways is consistent with information provided in the literature.

2.5.6 Summary

This assessment provides a summary of the fate and transport processes and the major routes of exposure for the PB-HAP categories of interest to EPA's RTR Program, as modeled in TRIM.FaTE. In general, the modeled behavior of the compounds is consistent with data found in the literature.

This assessment reveals that fish ingestion is a major route of exposure for cadmium, mercury, dioxins, and PAHs. For organics (i.e., dioxins and PAHs), the farm-food-chain also is a major route of exposure, with beef and dairy contributing significantly to the LADD.

Exhibit 22. Estimated Contributions of Modeled Food Types to PAH Ingestion Exposures



3. Tier 2 Methodology

3.1 Overview of Approach

The Tier 1 screening scenario is, by design, generic and health-protective. It was constructed to allow for quick application to a large number of facilities in a source category with a minimal chance of returning false negatives for risk. Based on screening assessments conducted for RTR to date, many facilities might not screen out of the Tier 1 assessment for some source categories. Because the Tier 1 screen uses numerous health-protective assumptions, the assessment must be refined to determine whether the facility is actually expected to pose a risk above levels of concern.

One way to refine the risk estimates is to conduct a site-specific assessment where the Tier 1 model values and layout are replaced with site-specific values and layouts wherever possible. However, this approach would not be feasible given the resource intensive nature of a site-specific assessment and the number of facilities that might not screen out of the Tier 1 assessment in some source categories.

As an intermediate approach, we instead refine our Tier 1 screening estimates to Tier 2 screening estimates. This is done by replacing some of the more health-protective assumptions in a Tier 1 screen with more site-appropriate values. Specifically, for Tier 2, the following parameter values are varied from their Tier 1 values:

- Meteorological characteristics, including the fraction of time the wind blows in the direction of each farm and lake (using wind direction), the wind speed, the precipitation rate, and the mixing height; and
- Locations of fishable lake(s) relative to the facility (including the absence of a fishable lake).

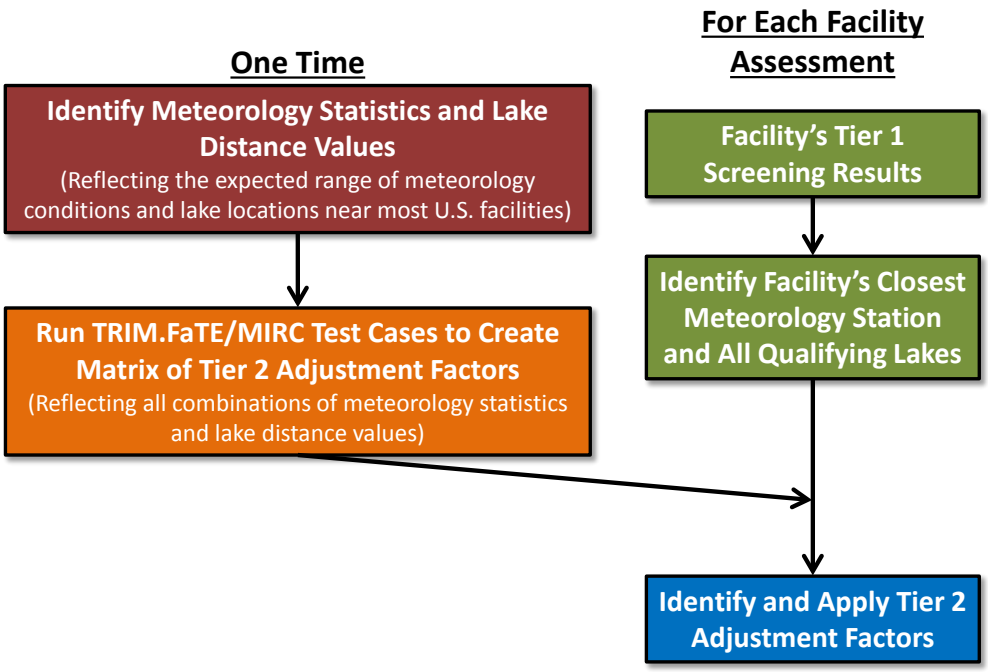
In addition, a refined fisher scenario is used to model risks associated with nearby lakes. The refined fisher scenario is based on the idea that an adult fisher might fish from multiple lakes if the first (i.e., highest-concentration) lake is unable to provide him an adequate catch to satisfy the assumed ingestion rate (i.e., 373 g/d for adults). This assessment uses the assumption that the biological productivity limitation of each lake is 1 gram of fish per acre of water: meaning that in order to fulfill the adult ingestion rate, the fisher will need to fish from 373 total acres of lakes.

In selecting the fate and transport variables listed above to include in Tier 2 adjustments, a balance was struck between: 1) the degree of impact on the potential risk estimate; 2) the ease of implementation in TRIM.FaTE; and 3) the ease of obtaining site-specific values on a facility-by-facility basis. Because of the expected variability in exposure parameters amongst any population living around a given facility, the exposure parameters pertaining to farm ingestion pathways remain fixed at their health-protective Tier 1 levels. However, the fish ingestion rates might vary on a site-specific level using the refined fisher scenario based on the availability of lakes to fish.

Tier 2 screening assessments are performed for those facilities that do not screen out during the Tier 1 assessment. The overall implementation of Tier 2 is shown in Exhibit 23. The starting point (shown in green) is the ratio of the facility emission rate for the PB-HAP of concern to the Tier 1 threshold for that PB-HAP. Next, the facility-specific estimates of the Tier 2 meteorological and lake-location parameters listed above must be gathered for each facility (shown in red). Then, the associated TRIM.FaTE and MIRC risk estimates must be calculated (shown in orange). Because of the volume of facilities that need to be evaluated in Tier 2, the implementation focuses on estimating refined risk using pre-calculated databases (discussed

below) rather than gathering the input data and performing TRIM.FaTE and MIRC modeling separately for each facility.

Exhibit 23. Basic Process for Implementing Tier 2



First, databases of the relevant U.S. meteorological and lake data were created that can be accessed during a Tier 2 evaluation (shown in red in the figure). These meteorological and lake data are discussed in more detail in Section 3.5. The meteorological database includes annual-average summary statistics on wind direction, wind speed, and precipitation for more than 800 surface stations paired with their closest upper-air stations located throughout the United States. These surface data cover year 2011 and are the same AERMOD-ready data used by EPA OAQPS for RTR inhalation modeling. As discussed below, in most cases the 2011 precipitation data were not used, and instead, the 30-year average annual precipitation data for each station were used. The database of lakes, available from ESRI® and based on U.S. Geological Survey data, includes information on the location, size, use or type designation, and name (if available) of all lakes in the United States. To focus on lakes that can support angling of upper trophic level fish, lakes used for disposal, evaporation, or treatment were excluded, and only lakes greater than 25 acres in area are included. Lakes larger than 100,000 acres in area are not included because the sizes of their watersheds and the complexity of their lake dynamics are not feasible to model with the TRIM.FaTE modeling system.

In parallel to the meteorological and lake data collection, a series of TRIM.FaTE simulations was performed that systematically varied the values for four of the five selected fate and transport variables (shown in orange in the figure, consisting of lake location, wind speed, precipitation rate, and mixing height). Wind direction affects only whether the chemical mass advects toward the farm and lake, so the effect of site-specific wind directions can be evaluated outside TRIM.FaTE simulations. These simulations do not simulate specific facilities; instead, four or five alternative values for each of the four variables were selected using statistics on U.S. meteorological data or professional judgment to capture the expected range in the facility data. TRIM.FaTE simulations were performed for every possible combination of these variable values to enable the estimation of appropriate site-specific threshold adjustment factors for scenarios with the corresponding characteristics. Based on the TRIM.FaTE results of these

simulations (and the subsequent exposure and risk characterization, conducted using MIRC), a matrix of Tier 2 threshold adjustment factors was calculated, with each element of the matrix corresponding to a unique combination of values from each of the selected variables. The contribution of each exposure media toward each scenario's Tier 2 risk metric (i.e., the individual contributions of fish ingestion, soil ingestion, beef ingestion, etc. toward the total Tier 2 risk metric) was included in the matrix because the Tier 2 assessment separates chemical exposure from fish ingestion from exposure from farm food chain ingestion.

These TRIM.FaTE and MIRC simulations are used to estimate part of the Tier 2 threshold adjustment factors. Wind direction is the other part of the Tier 2 threshold adjustment factors. The wind direction adjustment for a given facility is the ratio of the frequency that winds blow toward the Tier 1 farm and lake (43 percent of the time) and the frequency that winds blow toward the facility-specific farm and lake in Tier 2. These Tier 2 threshold adjustment factors are multiplied by each other and represent the ratio between the risk metric (i.e., cancer risk or HQ) obtained using the Tier 1 screening scenario and the risk metric obtained from the Tier 2 TRIM.FaTE runs. For a given facility, an adjusted Tier 2 ratio (emissions compared to the emission threshold) can be estimated by dividing the Tier 1 emission ratio (the output of the Tier 1 screen) by the adjustment factor that best corresponds to the meteorological conditions present at the site and the presence and location of lakes at the site:

$$\textit{Tier 2 Ratio} = \textit{Tier 1 Ratio} \div \textit{Tier 2 Adjustment Factor}$$

Matrices of threshold adjustment factors from the TRIM.FaTE and MIRC simulations were separately developed for the four PB-HAPs that currently have screening emission thresholds in the Tier 1 process: benzo(a)pyrene (BaP, representative of PAHs), cadmium, divalent mercury and 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD, representative of dioxins). The wind direction threshold adjustment factors were irrespective of chemical (specific only to the facility). In implementing the Tier 2 process, a risk equivalency approach was used to convert speciated emissions of PAHs and dioxins into BaP and TCDD equivalents, respectively, similar to the Tier 1 screening approach.

Finally, to implement the Tier 2 screen, a Microsoft® Access™ tool was created that includes the database of meteorological data and lake data as well as the Tier 2 adjustment factors for the combinations of variables simulated in the Tier 2 TRIM.FaTE simulations. In the tool, each facility is matched with the same surface meteorological station used in the RTR inhalation risk assessment, and the values for the four relevant parameters at that station are recorded (wind speed, wind direction, precipitation rate, and mixing height). The tool also facilitates the identification of all qualifying lakes in the area surrounding the facility and their distances and directions relative to the facility. These five values become the set of facility-specific parameters. The threshold adjustment factor corresponding to this set of site-specific data is then estimated using the matrix of adjustment factors and the wind direction adjustment. Wind direction values are used as-is with no rounding or binning. If one of the four facility matrix variables (wind speed, precipitation rate, mixing height, or lake location) is between two of the computed levels available for that variable in the simulation matrix, the more health-protective of the two levels is selected (i.e., the level that resulted in the smaller adjustment to the Tier 1 exposure). The Tier 1 screening emission threshold for a PB-HAP is then divided by the appropriate adjustment factors to obtain an updated Tier 2 emission threshold for that PB-HAP at that facility. A facility then screens out in Tier 2 if the emissions are below the Tier 2 threshold for the fisher scenario and for the farmer scenario.

3.2 Selection of Site-Specific Characteristics for the Tier 2 Assessment

The screening scenario used to derive Tier 1 thresholds incorporates assumptions regarding meteorological conditions, the spatial configuration of the hypothetical exposure setting, physical parameters of the environment, and chemical-specific parameters that result in generally health-protective results. In Tier 2, selected assumptions used in the fate and transport modeling conducted using TRIM.FaTE are modified to reflect more site-specific information for the facilities being evaluated.[19] To determine which scenario characteristics should be incorporated into the Tier 2 assessment, the following issues were considered for TRIM.FaTE model parameters:

- How sensitive are the modeled risks to a specific user-input model parameter (e.g., wind direction, wind speed)?
- Do the plausible values for a given parameter span a large range when comparing different RTR facility locations?
- Which site-specific characteristics can be found easily and reliably for facilities with emissions exceeding Tier 1 thresholds?
- In general, is the uncertainty associated with the parameter high or low?
- How complicated or time-consuming is the incorporation of a given parameter (e.g., wind speed) into the screening scenario set-up?

Attachment D provides an exhibit showing all the TRIM.FaTE variables considered for the Tier 2 assessment. These variables were evaluated qualitatively using the criteria above to determine whether the variable was of high, medium, or low priority. The following five “high priority” variables were selected for implementation in the current Tier 2 assessment:

- Wind direction (the percent of time the wind blows toward the lake and farm),
- Wind speed,
- Precipitation,
- Mixing height, and
- Location of fishable lakes relative to the facility.

These parameters were judged to represent a balance between range of potential variability, ease of implementation within the modeling scheme used for RTR, and ease of obtaining site-specific values with a relatively high level of confidence.

3.3 Estimation of Adjustment Factors for Selected Site-Specific Parameters

The purpose of including site-specific detail for a facility evaluated in Tier 2 is to develop a more realistic estimate of risk associated with facility emissions. This purpose is achieved within the assessment by generating revised emission thresholds of potential concern specific to a given PB-HAP on a facility-by-facility basis. However, instead of performing full-fledged, site-specific model runs for each facility that does not “screen out” in Tier 1, a set of generally applicable threshold adjustment factors for each PB-HAP was developed based on a set of model runs.

[19] Only TRIM.FaTE parameters were considered for inclusion in Tier 2 adjustments because of the difficulty in identifying substantial ***location-related*** differences in values for exposure factors (and other inputs to MIRC). The exposure characteristics used in MIRC are considered to be generally consistent across different locations and facilities.

For each PB-HAP, these runs corresponded to unique combinations of values for wind speed, precipitation rate, mixing height, and lake location (wind direction is assessed separately). These adjustment factors were based on a set of runs in which the values for these parameters were varied systematically. The wind direction adjustment factor is the ratio of the frequency that winds blow toward the lake and farm in the Tier 1 screening scenario (43 percent) and the frequency that winds blow toward the facility's farm and lake in Tier 2, with a separate wind direction adjustment factor for each directional octant (i.e., separate factors for the farm and lakes in the northern octant, the farm and lakes in the northeastern octant, etc.). The appropriate adjustment factors are then applied to the Tier 1 threshold for that PB-HAP when evaluating a facility in Tier 2.

The analyses conducted to select the parameters to derive the threshold adjustment factors are described in this section. Section 3.3.2 also describes the development of appropriate "bins" for the selected parameters. These bins correspond to the subset of parameter values for which adjustment factors were calculated, based on the anticipated range of plausible values for facilities evaluated in RTR.

3.3.1 Selection Values for Variables of Interest

For each site-specific parameter that is assessed in the Tier 2 assessment, other than wind direction, adjustment factors were estimated that correspond to a set of four to six particular values for the parameter. The adjustment factor for wind direction directly relates Tier 1 and site-specific Tier 2 wind direction frequencies, with respect to the directions of the lake and farm. These individual adjustment factors can then be multiplied for a particular variable combination to get an overall adjustment factor. To facilitate this, bins were created for each parameter of interest and a relevant range of values, with the exception of wind direction (as described below, representative bins were not necessary for this parameter). The rationale for selecting the range for each bin for each parameter of interest is described below.

Wind Direction: Within the context of the hypothetical exposure scenario used in Tier 1 (and under actual conditions), when the frequency with which the wind blows towards the modeled domain (i.e., where the hypothetical farm and lake are located) increases, greater pollutant deposition will occur over and around the farm and lake. The percentage of time the wind blows toward the farm and lake is therefore positively correlated with ingestion exposure and risk. In the screening scenario used to estimate Tier 1 thresholds, the wind is assumed to blow toward the modeled domain 3 days a week, or 43 percent of the time. This assumption is intended to approximate an unusually consistent long-term wind pattern and is representative of wind direction patterns in Yakima, Washington (where the wind blows eastward approximately 40 percent of the time, based on a review of wind direction data compiled by the National Weather Service).

In the model runs to develop the Tier 2 bins, this factor was changed to 1, 2, and 4 days per week, corresponding to 14 percent, 29 percent, and 57 percent of the time. This range of values was chosen to obtain a good understanding of the impact of wind direction on risk for the range of wind direction patterns likely to be present at real facilities. Review of these results indicated that, within this modeling scenario, estimated ingestion exposure varies directly with percentage of time the wind blows toward the farm and lake. Given the exactly linear nature of the relationship observed in model results obtained from these runs, the adjustment of the threshold for wind direction in Tier 2 is a direct, linear adjustment **using the actual site value** rather than an incremental, bin-based approach. In other words, the Tier 1 threshold is adjusted for wind direction in direct proportion to the difference between conditions for the actual facility location and the wind direction parameters included in the Tier 1 screening scenario (i.e., blowing toward the lake/farm 43 percent of the time on average).

Wind Speed: Although the impact of wind speed on non-inhalation risks also is likely to depend on configurational parameters such as the location of farms and lakes, in general it is reasonable to assume that higher wind speeds lead to more rapid chemical transfer out of the modeled domain, allowing less time for chemical deposition and, therefore, less total near-field deposition and a lower exposure and risk. The Tier 1 screening assessment assumed a wind speed of 2.8 m/s, corresponding to the 5th percentile (i.e., slower) of annual average speed for the contiguous United States (distribution was based on data from a climate publication from the National Oceanic and Atmospheric Administration [NOAA], which used data from over 200 stations nationwide).[20] This value is similar to the annual average wind speeds of the U.S. Deep South.[21] In the model runs to develop the Tier 2 threshold adjustment factors, we calculated the change to exposure resulting from increasing this value to 3.5 m/s, 4 m/s, and 5 m/s (values also shown in Exhibit 24; 5 m/s is the 88th percentile in the NOAA data). Based on these values, the bins used to classify wind speed are: 2.8–3.5 m/s, 3.5–4 m/s, 4–5 m/s and above 5 m/s. In all modeled cases, increasing the wind speed while maintaining constant lake location, wind direction, mixing height, and precipitation led to Tier 2 estimations of high-end risk or hazard that were smaller than that of Tier 1. To ensure that the approach is health-protective, a facility was assigned the lower end value of the bin into which it was placed. Facilities with wind speeds less than 2.8 m/s were assumed to have a wind speed of 2.8 m/s.

Precipitation: Higher levels of precipitation over the modeled domain are expected to increase non-inhalation risks by increasing particulate and gaseous wet deposition near-field to the source. The screening scenario used in Tier 1 assessment assumed an annual precipitation rate of 1,500 mm/year. This level of annual precipitation was estimated to represent rainy conditions in the U.S., such as parts of the U.S. Deep South and parts of the U.S. Northwest Coast[22]. Though the rate was an estimate, it does correspond to approximately the 95th percentile (i.e., higher rate) precipitation in the National Climatic Data Center's (NCDC) 30-year (1981–2010) data from U.S. stations.[23] To estimate adjustment factors in the Tier 2 assessment, model simulations were conducted with the parameter value set to three lower values (i.e., 1,187 mm/year, 924 mm/year and 512 mm/year; values also shown in Exhibit 24), corresponding to the 75th, 50th and 25th percentiles, respectively, of the NCDC data. Locations with lower precipitation levels were assumed to have a minimum precipitation of 512 mm/year. Based on these levels, the bins used to classify precipitation were: 0-512 mm/year, 512-924 mm/year, 924-1,187 mm/year, 1,187-1,500 mm/year, and above 1,500 mm/year. In nearly all modeled cases, decreasing the precipitation rate while maintaining constant lake location, wind speed, wind direction, and mixing height led to Tier 2 estimations of high-end risk or hazard that were smaller than that of Tier 1. To be health-protective, a facility was assigned the upper end value of the bin in which it was placed. Facilities with precipitation levels above 1,500 mm/year were assumed to experience precipitation of 1,500 mm/year.

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[20] http://ols.nndc.noaa.gov/plolstore/plsql/olstore.prodspecific?prodnum=C00095-PUB-A0001#TABLES – this website is updated yearly, so its current data may not match the data used to develop wind speeds for screening analyses.

[21] National Climatic Data Center CliMaps (NCDC-CliMaps) (2007).

[22] National Climatic Data Center Historical Climate Series (NCDC-HCS) (2007).

[23] http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html

Exhibit 24. Lake Distance and Meteorological Parameter Values for which Adjustment Factors were Developed in Tier 2[a,b]

Parameter	Value
Wind Speed (m/s)	**2.8**
	3.5
	4
	5
Precipitation (mm/yr)	512
	924
	1,187
	1,500
Mixing Height (m)	**710**
	865
	1,097
	1,537
Lake Distance (km)	No lake
	2
	5
	10
	20
	40

[a]Bold indicates the value is equal to the value used in Tier 1.
[b]Wind direction is not shown here because its effect on modeled exposure and risk in TRIM.FaTE is linear.

Mixing Height: Greater mixing heights can dilute the concentration of pollutants in air, resulting in lower deposition and other transfer rates from air to surfaces and consequently also lower ingestion exposures. The Tier 1 screening assessment assumed a mixing height of 710 meters. This value is the 5th percentile (i.e., lower) of annual average mixing heights for 463 U.S. locations, based on data obtained from EPA's SCRAM Web site.[24] To estimate adjustment factors in the Tier 2 assessment, model simulations were conducted with the parameter value set to three larger values (i.e., 865 m, 1,079 m, and 1,537 m; values also shown in Exhibit 24). These values correspond to North Little Rock, Arkansas; Boise, Idaho; and Tucson, Arizona; and they are intended to encompass the range of annual average mixing heights experienced in different parts of the United States. Based on these levels, the following bins were selected for categorization of mixing height: 710–865 m, 865–1,079 m, 1,079–1,537 m, and above 1,537. In all modeled cases, increasing the mixing heights while maintaining constant lake location, wind direction, wind speed, and precipitation rate led to Tier 2 estimations of high-end risk or hazard that were smaller than that of Tier 1. To be health-protective, a facility was assigned the lower end value of the bin into which it was placed. Facilities with mixing heights above 1,537 m and those below 710 m were assumed to have mixing heights of 1,537 m and 710 m, respectively.

Lake Location: Moving the lake included in the hypothetical Tier 1 scenario to a location farther from the actual source in the modeled domain will reduce modeled (TRIM.FaTE) deposition to the lake and its watershed and consequently reduce exposures associated with

[24]Support Center for Regulatory Atmospheric Modeling; http://www3.epa.gov/scram001/

the fish consumption pathway. For the scenario modeled in Tier 1, the center of the lake was situated approximately 2 km from the source. To estimate lake location adjustment factors for use in Tier 2, we completed a series of model runs in which the lake was located 5 km, 10 km, 20 km, and 40 km from the source, as well as runs with no lake (values also shown in Exhibit 24). Accordingly, the bins used to classify lake location relative to the facility are: no lake, 2–5 km, 5–10 km, 10–20 km, 20–40 km, and 40–50 km (lakes farther than 50 km are not considered). To be health-protective, a facility was assigned the lower end value of the bin into which it was placed. A facility with a lake closer than 2 km was assumed to have a lake at 2 km.

In resituating the lake at these alternative locations, we maintained ratios consistent with those included in the Tier 1 screening scenario for (1) lake area to total land area in the modeled domain, (2) runoff watershed area to lake area, and (3) erosion watershed area to lake area. Exhibit 25 provides a diagram of the TRIM.FaTE layout in each of the alternate lake location simulations except no-lake. We used a “thin” lake shape (i.e., downwind width much smaller than the cross-wind length) that minimized the potential effect of declining deposition with distance from stack that might affect lakes that are long in the downwind direction. By controlling for these potentially confounding effects, we could isolate the effect of lake location on risk appropriately. Moving the lakes to increasing distances from the stack required expansion of the modeled domain. Maintaining the same overall ratio of land area to lake area in each domain resulted in scenarios with increasingly large lakes, with surface area increasing with distance from the source. This approach also was taken for reasons of modeling convenience (i.e., taking into account resource requirements associated with reconfiguring the TRIM.FaTE spatial layout). The changes in lake size between these four runs are not expected to have a substantial independent effect on exposure and risk because the effect of increased lake size is offset by greater total deposition and runoff. Furthermore, the lake depth was not changed, which might be as important a parameter as lake surface area in determining the chemical concentrations in the water column and sediment. As noted above, we set up the configurations to ensure that the lakes in the different scenarios received runoff and erosion from equivalent watersheds on a per surface area basis.

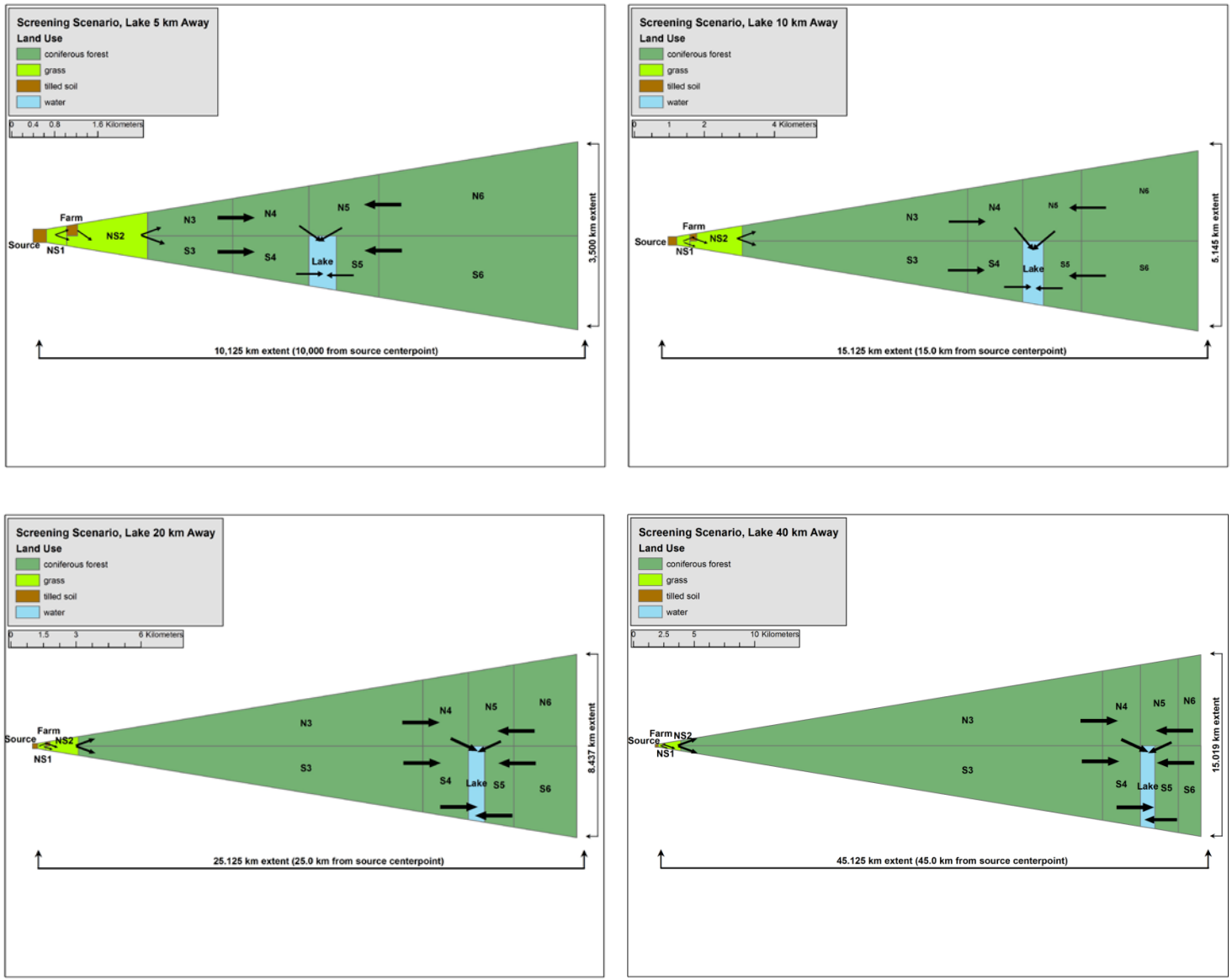
3.3.2 Estimation of Adjustment Factors

Adjustment factors were estimated for each variable described above and applied as divisors to the Tier 1 emissions thresholds. The resulting Tier 2 emissions thresholds are used to assess whether facilities with corresponding configurations carry some potential for significant multipathway health risks by comparing their actual emissions to the Tier 2 thresholds.

3.3.2.1 General Approach

The core principle in the estimation of adjustment factors is the assumption of direct proportionality of risk and emissions in the modeling approach used for RTR involving TRIM.FaTE and MIRC. Although not strictly present across all variations due to feedback mechanisms and other processes encompassed by the TRIM.FaTE model, a generally linear relationship between risk and emissions has been observed across model simulations conducted for RTR. This suggests that the ratio of total estimated exposures (and consequently risks) obtained for the screening scenario and any alternative configuration could be used as an adjustment factor to scale emissions for that specific alternative configuration. The risk in the alternative configuration following such a scaling of emissions would be equal to the risk in the screening scenario (which in Tier 1 was set at a risk level of 1E−6 incremental lifetime cancer risk or an incremental HQ of 1, depending on the toxic effect of the chemical in question).

Exhibit 25. Layouts for Tier 2 TRIM.FaTE Simulations Using Alternate Distances Between the Facility and the Fishable Lake[a]



[a]The no-lake scenario is not shown.

To account for potential interactions between the chosen Tier 2 variables, matrix adjustment factors were estimated by performing TRIM.FaTE runs for each unique combination of the specified variable values (that is, all permutations of the selected values for the wind speed, precipitation, mixing height, and lake location). Adjustment factors for each configuration were then estimated as the ratio of risks in the Tier 1 assessment to the estimated risk for the particular TRIM.FaTE configuration. This approach results in a large matrix of adjustment factors and has the advantage of accounting for all possible interaction effects between the variables. The contribution of each exposure media toward each scenario's Tier 2 risk metric (i.e., the individual contributions of fish ingestion, soil ingestion, beef ingestion, etc. toward the total Tier 2 risk metric) was included in the matrix because the Tier 2 assessment separates chemical exposure from fish ingestion from exposure from farm food chain ingestion.

The adjustment factor for wind direction is handled separately. Based on TRIM.FaTE test runs, the fraction of the time the wind blows in the direction of the farm and lake was observed to have a direct, linear effect on the resulting risk estimates. For this reason, it was not necessary to include this variable in the TRIM runs conducted to create the matrix of adjustment factors, as described above. Instead, the adjustment factor is calculated with a linear factor that divides the Tier 1 value (0.43, or 43% of the time in the direction of the farm and lake) by the site-specific facility value, as follows:

$$\textit{Adjustment Factor}_{\textit{Wind Direction}} = 0.43 \,/\, (\textit{fraction of time wind blows towards domain})$$

The adjustment factor for wind direction is then multiplied by the matrix adjustment factor discussed above to obtain a consolidated threshold adjustment factor that accounts for all the five variables considered in Tier 2.

3.3.2.2 Incorporation of the Risk Equivalency Approach

The adoption of a risk-equivalency approach to convert speciated emissions of PAHs and dioxins to BaP and TCDD equivalents, respectively, in Tier 1 required the development of risk equivalency factors (REFs) for each reported species in these groups. The REFs for PAHs and dioxins represent the ratio of the risk posed by a particular species to the risk posed by BaP and TCDD, respectively, at equivalent emissions rates in a given scenario.

The REFs can be represented as the product of exposure equivalency factors (EEFs) and toxicity equivalency factors (TEFs). For the PAHs, this can be expressed as:

$$REF_{PAH} = EEF_{PAH} \times TEF_{PAH}$$

The EEFs for PAHs represent the ratio of the exposure to a particular species to the exposure to BaP (and similarly for dioxins and TCDD) at equivalent emission rates. These ratios are thus specific to the TRIM.FaTE layout and input assumptions. The TEFs for PAHs and dioxins represent the ratio of the oral cancer slope factor (CSF) for a particular species to the CSF for BaP and TCDD, respectively, and are the same in Tier 1 and in Tier 2.

The EEFs depend on the TRIM.FaTE configuration, including layout and meteorological input values. For example, the exposure profile (i.e., how the different ingestion pathways contribute to total exposure and risk) is different for each PAH. For a PAH where fish is a dominant driver of risk, moving the lake will have a large effect on the overall risk; however, if produce is the dominant driver of risk, moving the lake will have a much smaller effect on overall risk. Thus, for Tier 2, EEFs were recomputed for each of the representative scenarios modeled in Tier 2 separately for the PAH species currently evaluated (some based on direct TRIM.FaTE modeling, others 15 based on K_{ow}-based regression estimates) and the dioxin species currently

evaluated (most based on direct TRIM.FaTE modeling, and a small number assumed to behave like TCDD).

The following mathematical formulas demonstrate how the Tier 2 adjustment factors are estimated for the PAH and dioxin species. The formulas presented below are for a representative PAH species, but they are also applied to dioxin species.

For a given PAH congener emitted at a rate E_{PAH} at a facility, the risk-equivalent BaP emission level can be expressed as:

$$E_{BAP\ EQIV} = E_{PAH\ SPECIES} \times EEF_{PAH\ SPECIES} \times TEF_{PAH\ SPECIES}$$

Then, the Tier 1 screening result is estimated by comparing the risk-equivalent BaP emissions to the BaP emission threshold:

$$Ratio_{TIER\ 1_PAH\ SPECIES} = \frac{E_{TIER\ 1_BAP\ EQUIV}}{Threshold_{TIER\ 1_BAP}}$$

If the ratio is less than 1, the facility "screens out" of the Tier 1 assessment. Similarly, for Tier 2, the ratio of risk-equivalent BaP emissions to the Tier 2 BaP threshold may be expressed as:

$$Ratio_{TIER\ 2_PAH\ SPECIES} = \frac{E_{TIER\ 2_BAP\ EQUIV}}{Threshold_{TIER\ 2_BAP}}$$

Using the definition of the risk-equivalent BaP emissions, this can be re-expressed for a given PAH species as:

$$Ratio_{TIER\ 2_PAH\ SPECIES} = \frac{E_{PAH\ SPECIES} \times EEF_{TIER\ 2_PAH\ SPECIES} \times TEF_{PAH\ SPECIES}}{Threshold_{TIER\ 2_BAP}}$$

This expression may be further reconfigured, after some algebraic rearrangement, in terms of the Tier 1 ratio as:

$$Ratio_{TIER\ 2_PAH\ SPECIES} = Ratio_{TIER\ 1_PAH\ SPECIES} \times \frac{Threshold_{TIER\ 1_BAP}}{Threshold_{TIER\ 2_BAP}} \times \frac{EEF_{TIER\ 2_PAH\ SPECIES}}{EEF_{TIER\ 1_PAH\ SPECIES}}$$

$$Tier\ 2\ Adjustment\ Factor_{PAH\ SPECIES} = \frac{Threshold_{TIER\ 1_BAP}}{Threshold_{TIER\ 2_BAP}} \times \frac{EEF_{TIER\ 2_PAH\ SPECIES}}{EEF_{TIER\ 1_PAH\ SPECIES}}$$

These equations simply state that to adjust the Tier 1 threshold to a Tier 2 threshold for a particular PAH species, the adjustment factor must include the ratio of the BaP Tier 1 and 2 thresholds (as is true for cadmium, mercury, and TCDD, as discussed above) *and* the ratio of the EEFs for the particular PAH species in Tier 2 and Tier 1. This additional EEF factor is needed to account for the fact that the EEFs are different for each Tier 2 TRIM.FaTE configuration.

Finally, the ratio of total BaP equivalents contributed by all PAH species at a given facility to the BaP Tier 2 threshold may be expressed, by summing the above expression, as:

$$Ratio_{TIER\ 2_ALL\ PAHs} = \sum^{ALL\ PAHs} Ratio_{TIER\ 1_PAH\ SPECIES} \times \frac{Threshold_{TIER\ 1_BAP}}{Threshold_{TIER\ 2_BAP}} \times \frac{EEF_{TIER\ 2_PAH\ SPECIES}}{EEF_{TIER\ 1_PAH\ SPECIES}}$$

If the ratio of total BaP equivalents contributed by all PAH species to the BaP Tier 2 threshold is greater than 1, the facility would not have screened out of the Tier 2 assessment for the PAH group.

3.3.2.3 Refined Fisher Scenario

The refined fisher scenario is based on the idea that an adult fisher might fish from multiple lakes if the first (i.e., highest-concentration) lake is unable to provide an adequate catch to satisfy the assumed ingestion rate (i.e., 373 g/d for adults). This assessment uses the assumption that the biological productivity limitation of each lake is 1 gram of fish per acre of water: meaning that in order to fulfill the adult ingestion rate, the fisher will need to fish from 373 total acres of lakes (see Attachment E for further discussion on lake productivity).

Under the refined fisher scenario, a fisher fishes from each surrounding lake in order of highest chemical concentration in fish to lowest concentration and catches fish up to the biological productivity limit. A maximum travel radius is used to maintain a realistic scenario. The total screening result to the fisher can be expressed as the sum of all screening results for each lake (which is based on the ingestion rate and fish concentration for each respective lake).

A 50 km radius of lakes is used to maintain a realistic scenario. Depending on the model configuration, very large modeling configurations put a strain on computing resources, and TRIM.FaTE can crash if the domain is very large or if the domain is divided into too many compartments. In most scenarios, the vast majority of chemical deposition occurs across distances smaller than 50 km, so the added computing resources needed to model a domain larger than 50 km will usually not be offset by additional, substantial chemical deposition and exposure. Indeed, wind speeds must exceed 13 m/s (approximately 29 mph) sustained across an hour in order for the chemical plume to travel farther than 50 km; those wind speeds are unlikely to occur across the many days or weeks needed to substantially affect chronic exposure. In addition, a 50-km limit also puts a reasonable constraint on the domain of lakes for the fisher scenario.

In order for the Tier 2 screening to remain health protective, it is assumed that the fisher visits lakes in order of highest to lowest with respect to risk. If the first lake is 373 acres or greater, the fisher will only travel to that lake. If the acreage is smaller than 373 acres, then the fisher will travel to the next highest risk lake, and continues to travel to subsequent lakes until a total acreage of 373 acres is achieved, or until all qualifying lakes have been visited.

The associated risk for each lake is then scaled by the total adult ingestion rate (equations 1 and 2).

$$(1)\ Scaled\ T2\ Fish\ risk = T2\ Fish\ risk\ \times \left(\frac{Lake\ SA(acs)}{373\ acs}\right)$$

Equation 1: Scaled fish risk for each lake 1 to n-1

$$(2)\ Scaled\ T2\ risk = T2\ Fish\ risk\ \times \left(\frac{373\ acs - \sum(SAs\ of\ Previously\ Visited\ Lakes\ (acs))}{373\ \text{acs}}\right)$$

Equation 2: Scaled fish risk for nth lake

The risk associated with each lake visited is then summed together for a final risk (equation 3).

$$(3)\ Total\ Scaled\ T2\ Fish\ risk = (\text{Eq. 2}) + \sum(\text{Eq. 1})$$

Equation 3: Total fish risk for scenario

If the total acreage of fishable lakes surrounding the facility fails to exceed 373 acres, then the risk for each lake is found using equation 1, and the total risk is the sum of all scaled risks (equation 4).

$$(4)\ Total\ Scaled\ T2\ Fish\ risk = \sum(\text{Eq. 1})$$

Equation 4: Total fish risk if total acreage of lakes does not reach 373 acres

3.4 Preparing National Databases of Lake and Meteorological Data

To facilitate the effective application of the Tier 2 screening procedures, databases were prepared containing national-scale information about lakes (locations and sizes) and meteorological data at available surface stations (including wind direction, wind speed, precipitation, and estimated mixing height). The development and content of these two databases are discussed in the following sections.

3.4.1 Processing Lake Data for Tier 2 Assessment

The lake database was built using a geospatial file (U.S. Water Bodies) provided by ESRI® for their ArcGIS™ products.[25] Because this geospatial file excluded water bodies in Alaska, Puerto Rico, and the U.S. Virgin Islands, it was augmented with water body information (directly from the USGS National Hydrography Dataset) for those other locations. The data generally have an estimated horizontal accuracy of 50 m. For the Tier 2 assessment, we focused on the hundreds of thousands of water bodies classified as “Lake/Pond” or “Reservoir” but not designated for disposal, evaporation, or treatment. We refer to these water bodies simply as “lakes” in the remainder of this document. The approximately 100,000 other water bodies (classified as canal/ditch, ice mass, inundation area, playa, stream/river, swamp marsh, or unclassified) were not included. In a more subjective step during the processing of the lake database for a specific source category (when Tier 2 is run “operationally”), the lake names (when provided) are scrutinized manually, and lakes are removed from the assessment when their names suggest industrial or treatment use (e.g., wastewater treatment ponds, sludge ponds, fly ash ponds, paper mill ponds, sewage pools, etc.). In this respect, the lake dataset is never truly final; lake names are scrutinized each time a new set of facilities is assessed using the Tier 2 methods and tools, which can lead to the permanent removal of some lakes from the dataset.

Early in the process of compiling this database, we encountered the question: “What size water body qualifies as a ‘lake’ for the purposes of this assessment?” The Tier 2 assessment must focus on lakes large enough to support relatively intensive angling pressure to be compatible

[25] Specifically, the geospatial file in the ESRI® Data & Maps 2009 Data Update for ArcGIS™ version 9.3.1. It was derived by the United States Geological Survey (USGS), EPA, and ESRI® from the USGS National Hydrography Dataset (USGS 2012).

with the assumed exposure scenario. To estimate the relationship between high fish consumption rates, harvest rates, and lake size, the following five key assumptions were made. Information and citations to peer-reviewed literature that support these assumptions are provided in Attachment E. Note that in the TRIM.FaTE model screening scenario, water-column carnivores (WCCs) are modeled as trophic level 4 (TL4) fish (e.g., pickerel, largemouth bass), with all of their diet consisting of smaller "prey" or "pan" fish in the water column that are simulated as trophic level 3 (TL3). The benthic carnivores (BCs) in TRIM.FaTE are modeled to represent an intermediate trophic level between 3 and 4, i.e., TL3.5. The BCs (e.g., catfish) obtain half of their diet from TL2 (benthic invertebrates that feed on detritus at the sediment surface) and half from TL3 fish in the benthic environment. For the screening scenario, we assume that fishers consume fish biomass in a ratio of 50:50 from the BC and WCC compartments, respectively. Together, these two fish compartments are referred to as piscivorous fish.

1. Piscivorous fish, when present, comprise approximately 21 percent of the standing biomass of fish. BC fish represent 17.5 percent of the standing fish biomass in natural lakes; WCC fish account for 3.5 percent of this total fish biomass. Thus, WCC (or TL4) fish represent the limiting compartment for fish harvesting and consumption.
2. Humans can harvest 10 percent of any single fish compartment without threatening the population due to overharvesting.
3. The minimum viable effective population size for a single fish species is at least 50 adult fish for a local population to survive over the short term (e.g., more than a decade).
4. Only 33 percent of the fish caught for consumption is edible fillet muscle. A 0.33 edible fraction is used to estimate total fish biomass associated with human consumption.
5. A total fish standing biomass of 40 g wet weight/m^2 represents an approximate upper bound for natural ponds and lakes in the United States.

Using the above assumptions and a series of equations (see Attachment E), the maximum fish ingestion rates as a function of standing biomass and lake size were estimated. Exhibit 26 presents these findings, where the grey shading indicating when WCC fish would probably not be present, the white (unshaded) cells represent combinations of lake size and productivity that could sustain the listed fish ingestion rates over some time, and the yellow cells represent likely long-term sustainability associated with more than 500 adult WCC fish in the lake (see Exhibit notes).

The Tier 2 assessment is intended to retain most of the health-protective attributes of the screening scenario used in Tier 1 so that no facilities of potential concern erroneously "pass" the screen. For a given facility, the smaller the lake size threshold, the greater the number of lakes and the greater the probability that a lake is closer to the facility. Lakes closer to a facility will result in higher chemical concentrations in fish compared with lakes farther from the facility. Thus, Exhibit 26 was used to determine the smallest lake size that would support a TL4 population. At the assumed upper-limit standing fish biomass of 40 g ww/m^2, this corresponds to 25 acres (the first "white" box when moving from smaller to larger lakes).

The fish ingestion rate supported by a 25-acre lake is not as high as the adult ingestion rate used in the Tier 1 and Tier 2 assessments (i.e., 373 g ww fillet per day). Exhibit 26 indicates that at a total fish biomass productivity of 40 g ww/m^2, the maximum sustainable fish harvest from the WCC compartment would correspond to an ingestion rate of only 26 g/day for those fish, with an additional 26 g/day from the benthic carnivores (which are not the limiting population), for a total of 52 g per day. However, to be health protective and to ensure that small lakes that might be more highly contaminated than estimated by the TRIM.FaTE screens were

not eliminated, we selected 25 acres as the “cutoff” for the minimum size for an actual lake near a facility to be included in the Tier 2 assessment. In addition, larger lakes (larger than 100,000 acres) were not considered since they cannot be readily modeled in TRIM.FaTE. For the purposes of proximity matching lakes to emitting facilities, the location of each lake is identified as the geographic centroid inside the lake.

It should be noted that an individual lake as small as 25 acres could be stocked annually at a rate adequate to support the assumed fish ingestion rate. For stocked fish, however, we would have to assume that when introduced to the lake, the fish were uncontaminated by the chemicals of interest. Moreover, the period over which accumulation of chemical from the lake could occur would be roughly three to six months (fishing season) for the majority of the fish stocked as adults (i.e., at approximately 2 kg), instead of several years for fish hatched in the lake.

To place an upper bound on the radial distance from the source up to which lake-derived risks need to be assessed, we took into account the limitations of TRIM.FaTE. We limited the lake analysis to an outward radial bound of 50 km from the stack. For facilities with no lakes within 50 km, lake-derived risk is assumed 0.

Exhibit 26. Maximum Fish Ingestion Rate (g/day) Associated with Sustainable Fishing[a]

Standing Biomass (g ww/m^2)[b]	Size of Pond or Lake (acres)															
	1	2	3	4	5	7.5	10	15	25	35	50	75	100	150	200	400
2	0	0	0	0	0	0	1	1	1	2	3	4	5	8	10	20
3	0	0	0	0	0	1	1	1	2	3	4	6	8	12	15	31
4	0	0	0	0	1	1	1	2	3	4	5	8	10	15	20	41
5.7	0	0	0	1	1	1	1	2	4	5	7	11	15	22	29	58
10	0	1	1	1	1	2	3	4	6	9	13	19	26	38	51	102
15	0	1	1	2	2	3	4	6	10	13	19	29	38	58	77	154
20	1	1	2	2	3	4	5	8	13	18	26	38	51	77	102	205
30	1	2	2	3	4	6	8	12	19	27	38	58	77	115	154	307
35	1	2	3	4	4	7	9	13	22	31	45	67	90	134	179	359
40	1	2	3	4	5	8	10	15	26	36	51	77	102	154	205	410
50	1	3	4	5	6	10	13	19	32	45	64	96	128	192	256	512
60	2	3	5	6	8	12	15	23	38	54	77	115	154	231	307	615
70	2	4	5	7	9	13	18	27	45	63	90	134	179	269	359	717
80	2	4	6	8	10	15	20	31	51	72	102	154	205	307	410	820
90	2	5	7	9	12	17	23	35	58	81	115	173	231	346	461	922
100	3	5	8	10	13	19	26	38	64	90	128	192	256	384	512	1025
110	3	6	8	11	14	21	28	42	70	99	141	211	282	423	563	1127
120	3	6	9	12	15	23	31	46	77	108	154	231	307	461	615	1229
130	3	7	10	13	17	25	33	50	83	117	166	250	333	499	666	1332

[a]Dark gray shading indicates insufficient population size for TL4 (WCC) fish (<50 adults) to be sustainable for more than a decade; yellow-shaded cells indicate the likelihood to provide long-term sustainable fish populations with at least 500 TL4 adult fish present; white area indicates medium-term sustainability.
[b]Represents the standing biomass of TL4 fish. At the upper-limit standing biomass of 40 g ww/ m^2 estimated for natural lakes, 25 acres could support a water-column TL4 fish population, but would provide for no more than 26 grams of fillet per day for a single fisher over a full year.

3.4.2 Processing Meteorological Data for Tier 2 Assessment

In addition to the lake database, a database of U.S. surface stations with complete data was created, so that each source category facility can be paired with the closest meteorological station data. This process of pairing dozens or hundreds of facilities with meteorological data is not unprecedented. In their report to the Science Advisory Board (SAB) on the 1996 NATA, EPA described pairing each facility with the closest meteorological station in an inventory of over 350 meteorological stations nationwide, creating an average facility-to-station distance of less than 50 km in the 1996 NATA (EPA 2001b). In a separate 2009 report to the SAB on the RTR program, EPA described using 158 meteorological stations to choose from nationwide, with a standard practice of selecting the station nearest to each facility unless the facility provides onsite meteorological data (EPA 2009). Using 156 petroleum refineries as a sample data set, the average facility-to-station distance was 72 km. In both instances, the SAB accepted this matching as standard practice when modeling large numbers of sources, although they recommended providing high-level siting maps (e.g., meteorological stations overlaid with terrain gradients or regional climate regimes) to qualify some of the uncertainties related to meteorological data in air dispersion modeling (EPA 2001a; EPA 2010b). The current effort builds on this practice but increases the number of available meteorological stations as described below.

3.4.2.1 Sources of Meteorological Data

To construct a database of meteorological statistics for all available U.S. surface stations for use in multipathway screening assessments, EPA started with the same U.S. meteorology dataset used in RTR inhalation assessments. RTR inhalation assessments use data from 824 ASOS (Automated Surface Observing System) stations that record hourly and sub-hourly measurements. These data represent the year 2011, and the surface stations are paired with their closest, regularly-reporting upper-air stations. This number of stations is far greater than the 350 and 158 stations, respectively, used in the 1996 NATA report (EPA 2001b) and the 2009 RTR report (EPA 2009).

The 2011 precipitation measurements reflect 2011 weather conditions, and, like any other year, some areas of the country experienced rainfall that was significantly less than normal, and some areas received much more rainfall than normal. To reduce this bias in precipitation data, we used average annual precipitation data from the 1981−2010 National Climatic Data Center 30-year normal dataset wherever possible. If 30-year normal precipitation data were not available for a station, as was the case for a few stations in the dataset, we used the ASOS precipitation data as-is.

3.4.2.2 Coverage of Meteorological Stations Compared with Facility Locations

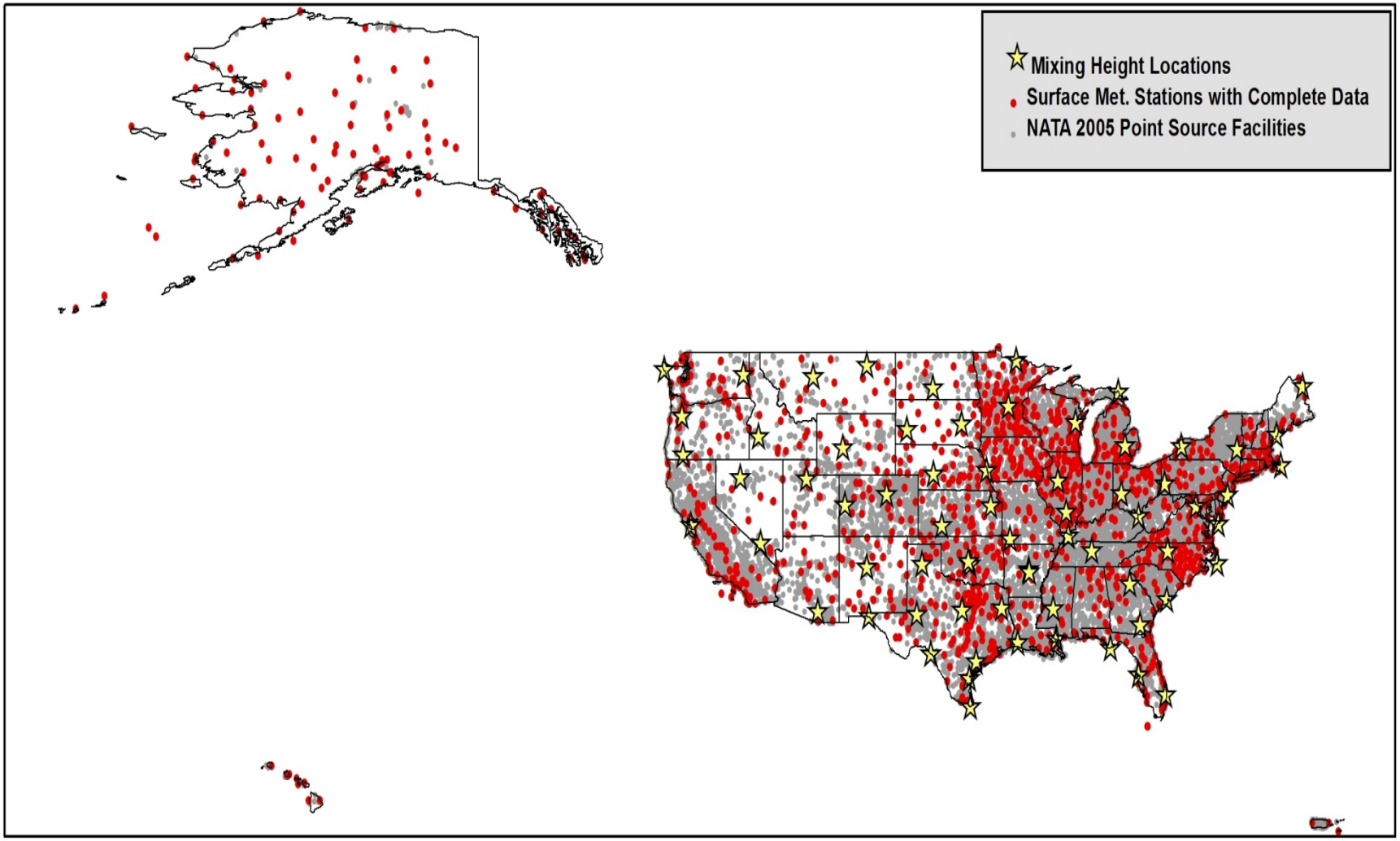
Exhibit 27 shows the proximity of the evaluated meteorology sites to the locations of U.S. point source facilities from the 2005 NATA. Generally, the spatial density of the surface meteorological stations in this dataset was similar to the spatial density of the 2005 NATA facilities. That is, the density tends to be greatest in the Great Lakes region, along the East and West Coasts, and in the Southern Plains, and tends to be lowest in the Rockies (except Colorado) and Northern Plains.

3.4.2.3 Data Processing

To facilitate application of the meteorological data to the Tier 2 assessment, EPA gathered wind information in directional octants that could be linked to the direction of the relevant lakes (see Introduction and Section 3.5). EPA divided the periphery around a meteorological station into eight octants representing the direction toward which the wind was blowing:

N: >337.5 to 22.5 degrees
NE: >22.5 to 67.5 degrees
E: >67.5 to 112.5 degrees
SE: >112.5 to 157.5 degrees
S: >157.5 to 202.5 degrees
SW: >202.5 to 247.5 degrees
W: >247.5 to 292.5 degrees
NW: >292.5 to 337.5 degrees

Exhibit 27. The Locations of Meteorological Stations and Point Source Facilities[a]



[a]The 2005 NATA was the most recent, comprehensive, finalized dataset of nationwide point source emitters of hazardous air pollutants, and it is used here only for illustrative purposes. The 2005 NATA used a meteorological dataset different from the one used in this report.

A software program was developed to calculate the following statistics for each of these stations:

- Number of hourly observations,
- Number of hours with calm winds or missing winds,
- Percentage of time the wind blows into each octant (after excluding missing wind hours),
- Median wind speed blowing into each octant,
- Median mixing height used (if heat flux > 0, convective mixing height was used, otherwise mechanical mixing height was used), and
- Average annual precipitation (irrespective of wind octant and preferring 30-year normal data if available).

Total annual precipitation data in the 2011 meteorological data included anomalies (relative to normal conditions) in areas that experienced extreme drought conditions or large rainfall surpluses. To address this, the 30-year (1981-2010) average annual precipitation was used instead.[26]

The choice of using median values for wind speed and mixing height was based on a comparison of median and mean values. For nearly all stations, the median value was smaller than the mean value; because smaller values are more health protective, we selected the median statistic for all stations.

3.5 Implementation of Tier 2 Assessment

The Tier 2 screening assessment is conducted using a Microsoft® Access™ tool that was developed specifically for this purpose. Similar to the Tier 1 screening assessment tool, the Tier 2 tool was created so that facilities that do not screen out during the Tier 1 assessment can be screened concurrently, if desired.

The Tier 2 tool requires three inputs to run: the results of the Tier 1 screening assessment, a list of facilities to model, associated meteorology stations that can be matched to using a proximity analysis, and the matrix of adjustments factors that are used to adjust the Tier 1 screening thresholds to the Tier 2 screening levels. The matrix is used to standardize the scenario based on the chemical and on the lake distance and meteorology characteristics of the assessed facility (refer to Section 3.3 for a discussion of these adjustment factors).

The tool contains procedures that match each facility to all lakes within a user-defined radius (currently 50 km) that are within user-defined size limitations (currently 25 acres to 100,000 acres), and based on water body type (e.g., they are not waste disposal or treatment facilities, retention ponds, etc.). In addition, each facility is matched to the same meteorology station used in RTR inhalation assessments, which is usually the nearest meteorology station; when the meteorology station match is not known from the RTR inhalation assessment, the tool conducts a proximity analysis. The tool allows the user to review matching lakes and exclude ones that are not considered suitable for modeling (e.g., based on names indicating industrial, waste, or treatment purposes, as discussed in Section 3.4.1.) Any excluded lakes are recorded by the tool so that they are omitted from subsequent screening assessments.

[26] 30-year average annual precipitation was obtained from the National Climatic Data Center (NCDC). http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html.

Per facility and PB-HAP, the tool evaluates the screening result at each lake and hypothetical farm. For each lake, the initial calculations produce screening results consistent with the full screening scenario ingestion rate (i.e., 373 g/day for adults, regardless of assumed lake fish productivity), and then additional calculations adjust the screening results for the lakes based on the initial screening results and areas of the lakes (see Section 3.3.2.3). Each modeling scenario consists of a farm and a lake (or, in some cases, no lake). Although the distance from the facility to the modeled farm remains fixed for each octant, the location of the lake affects chemical concentrations in some farm food chain media due to modeled runoff and erosion patterns that are directed mostly toward the lake. Therefore, there can be multiple different farm screening results in the same octant for the same facility, each corresponding to a different lake-distance scenario. The tool identifies the largest farm screening result from all scenarios evaluated for a facility. The tool presents the final Tier 2 screening results for the fisher and farmer separately, including results specific to individual farm food chain media, for each chemical, and then summed together for each PB-HAP group.

The tool also can incorporate the results of Tier 3 assessments. Since the tool allows the user to manually exclude lakes, if any lakes are removed from the assessment in Tier 3, those lakes can be removed in the tool and the Tier 2 screening can be repeated with the revised lake database. If Tier 3 plume-rise or time-series assessments are conducted, the resulting Tier 3 adjustment factors can be entered into the tool and it will update the Tier 2 screening results to produce Tier 3 screening results.

The tool outputs several results tables, including an intermediate table that provides information on each lake and farm, including the fish ingestion and screening-level risk associated with each lake. The final screening results for each facility and PB-HAP group are also output. A summary table identifies the facilities exceeding the Tier 2 emission screening threshold of each PB-HAP group (separately for the fisher and farmer) and the largest screening results. All intermediate and final results tables present the Tier 1 and Tier 2 screening results side-by-side for comparison. Exhibit 28 through Exhibit 30 provide screen shots of tool output tables.

Exhibit 28. Example of the Summary Output Table from Tier 2 Tool[a]

Src Cat Info				Tier 1			Tier 2					
Src Cat	PB-HAP Grp	Num Facil in Src Cat (Emitting Any HAI	Num Facil Emitting this Gr	Num Facil SV ≥ 2	Facil with Largest S	Largest S	Num Facil Fisher SV ≥ 2	Num Facil Farmer SV ≥ 2	Facil with Largest Fisher SV	Largest Fisher S	Facil with Largest Farmer SV	Largest Farmer
[redacted]	Cadmium	12	12	6	[redacted]	3.E+01	0	0	[redacted]	1.E+00	[redacted]	3.E-01
	Dioxin	13	13	13		2.E+02	12	12		4.E+01		2.E+01
	Mercury (methyl)	13	13	9		1.E+01	0	0		1.E+00		8.E-04
	PAH	13	13	13		2.E+03	10	9		6.E+01		1.E+02
	PAH + Dioxin	13	13	13		2.E+03	13	12		7.E+01		2.E+02
	Cadmium	13	13	7		3.E+01	1	0		2.E+00		4.E-01
	Dioxin	14	14	14		3.E+02	13	13		5.E+01		2.E+01
	Mercury (methyl)	14	14	9		1.E+01	1	0		2.E+00		8.E-04
	PAH	14	14	14		4.E+03	11	11		3.E+02		2.E+02
	PAH + Dioxin	14	14	14		5.E+03	14	14		4.E+02		2.E+02

[a] The screen shot examples shown in this section are for actual facilities in actual source categories; however their source categories, NEI IDs, and coordinates have been altered or masked so the data are not linked to specific facilities. “SV” means “screening value”, which is the ratio of emissions to emission screening threshold.

Exhibit 29. Example of the Facility Output Table from Tier 2 Tool[a, b]

Facil Info						Tier 1			
Src Cat	NEI ID	Lat	Long	Met WBAN	PB-HAP Grp	SV	Fisher S	Farmer SV	Farmer SV, Soil
[redacted]				94725	Mercury (methyl	2.E+00	2.E-01	2.E-04	3.E-05
				94725	Dioxin	8.E+01	6.E+00	4.E+00	4.E-02
				94725	Cadmium	1.E+00	9.E-02	8.E-03	2.E-04
				94725	PAH	2.E+01	9.E-01	2.E+00	1.E-01
				13880	Dioxin	1.E+02	3.E+01	4.E+00	5.E-02
				13880	Cadmium	3.E+00	9.E-01	2.E-02	4.E-04
				13880	Mercury (methyl	5.E+00	1.E+00	3.E-04	5.E-05
				13880	PAH	4.E+01	6.E+00	2.E+00	2.E-01
				94239	Mercury (methyl	2.E+00	3.E-01	1.E-04	2.E-05
				94239	PAH	2.E+01	9.E-01	1.E+00	7.E-02
				94239	Dioxin	1.E+02	1.E+01	6.E+00	7.E-02
				94239	Cadmium	9.E-01	9.E-02	5.E-03	9.E-05
				94725	PAH	2.E+03	6.E+01	1.E+02	1.E+01
				94725	Cadmium	8.E-01	4.E-02	6.E-03	1.E-04
				94725	Dioxin	2.E+02	1.E+01	2.E+01	2.E-01
				94725	Mercury (methyl	5.E-01	2.E-02	4.E-05	6.E-06
				03937	Dioxin	2.E+00	5.E-01	8.E-02	1.E-03
				03937	Cadmium	2.E-02	6.E-03	2.E-04	4.E-06
				03937	Mercury (methyl	7.E-01	2.E-01	6.E-05	1.E-05

[a] The screen shot examples shown in this section are for actual facilities in actual source categories; however their source categories, NEI IDs, and coordinates have been altered or masked so the data are not linked to specific facilities. "SV" means "screening value", which is the ratio of emissions to emission screening threshold.

[b] Only a portion of the table is shown. Individual farm ingestion media are in the table but only "soil" is displayed for space reasons.

Exhibit 30. Example of the Lake Assessment Output Table from Tier 2 Tool[a,b]

Facil Info			Tier 1		Lake Info					
Src Cat	NEI ID	PB-HAP Grp	SV	Oct	Name	Object ID (USGS	Size (acres	Facility-Lake Dist (km)	Lat	Long
[redacted]		Cadmium	2.E+00	N	[redacted]		40	3.1	[redacted]	
		Cadmium	2.E+00	N			42	5.2		
		Cadmium	2.E+00	NE			59	33.2		
		Cadmium	2.E+00	NE			54	32.5		
		Cadmium	2.E+00	NE			44	33.0		
		Cadmium	2.E+00	NE			44	28.8		
		Cadmium	2.E+00	NE			42	36.9		
		Cadmium	2.E+00	SW			72	23.5		
		Cadmium	2.E+00	E			27	21.7		
		Cadmium	2.E+00	E			27	30.6		
		Cadmium	2.E+00	E			32	22.9		
		Cadmium	2.E+00	E			30	22.7		
		Cadmium	2.E+00	N			32	47.3		
		Cadmium	2.E+00	N			62	45.9		
		Cadmium	2.E+00	N			32	45.1		
		Cadmium	2.E+00	N			27	46.5		
		Cadmium	2.E+00	N			54	49.8		
		Cadmium	2.E+00	NE			94	41.8		

r 2						
Stationary Fisher Approach		Traveling Fisher Assessment				
SV Angler (Stationary Angler)	SV Farmer	Traveling Fisher Order n/a = fisher did not visit in original screening	Travel Fisher Fraction Ingestion (based on lake size	Add'l Lake Assessments	Plume Rise Adj Factors	Time Series Adj Factor
4.E-01	3.E-03	1	0.105996783	TRUE	0.690	0.690036379
4.E-01	8.E-03	2	0.112621582	TRUE	0.690	0.690036379
2.E-01	8.E-03	3	0.158995174	TRUE	0.690	0.690036379
2.E-01	8.E-03	4	0.145745576	TRUE	0.690	0.690036379
2.E-01	8.E-03	5	0.119246381	TRUE	0.690	0.69003533
2.E-01	8.E-03	6	0.119246381	TRUE	0.690	0.69003533
2.E-01	8.E-03	7	0.112621582	TRUE	0.690	0.69003533
1.E-01	7.E-03	8	0.125526542	TRUE	0.690	0.69003533
9.E-02	5.E-03	n/a	0	TRUE	0.69	0.690036379
9.E-02	5.E-03	n/a	0	TRUE	0.69	0.690036379
9.E-02	5.E-03	n/a	0	TRUE	0.69	0.690036379
9.E-02	5.E-03	n/a	0	TRUE	0.69	0.690036379
7.E-02	8.E-03	n/a	0	TRUE	0.69	0.690036441
7.E-02	8.E-03	n/a	0	TRUE	0.69	0.690035444
7.E-02	8.E-03	n/a	0	TRUE	0.69	0.690035444
7.E-02	8.E-03	n/a	0	TRUE	0.69	0.690035444
7.E-02	8.E-03	n/a	0	TRUE	0.69	0.690035444
8.E-02	8.E-03	n/a	0	TRUE	0.69	0.690035444

[a] The screen shot examples shown in this section are for actual facilities; however their source categories, NEI IDs, and coordinates have been altered or masked so the data are not linked to specific facilities. Only a portion of the table might be shown. The headers "Stationary Fisher" and "Traveling Fisher" are shorthand references to the initial fisher scenario (i.e., catches and consumes 373 g/d per lake, regardless of lake area) and the refined fisher scenario (i.e., assumes a 1 g/acre/d lake productivity), respectively. "SV" means "screening value", which is the ratio of emissions to emission screening threshold.

[b] The table displayed reflects a Tier 3 Screening Assessment having been conducted. In a Tier 2 Screening Assessment, the Add'l Lake Assessment, Plume Rise Adj Factors, and Time Series Adj Factors would not be shown.

4. Tier 3 Methodology

4.1 Overview of Approach

Tier 3 screening consists of a set of assessments that can be conducted, at the discretion of the risk assessor, on facilities that do not screen out with the Tier 2 assessment. The Tier 3 screening approach consists of three individual assessments that further refine the screening scenario (beyond the refinements in Tier 2) based on additional site-specific data and evaluations. The assessments introduce additional site-specificity to the screening scenario, requiring a potentially higher level of effort than the Tier 2 assessment, but still a much lower level of effort than the full site-specific assessment. The first of the Tier 3 assessments (i.e., the lake assessment) results in the rescreening of the facility's emissions using the Tier 2 methods and using a revised lake database. The Tier 3 plume-rise assessment, which only needs to be conducted if facilities do not screen out with the Tier 3 lake assessment, results in an adjustment factor to be applied to the screening result of the Tier 3 lake assessment. The Tier 3 time-series assessment, which only needs to be conducted if facilities do not screen out with the Tier 3 plume-rise assessment, directly models in TRIM.FaTE and MIRC the effects of plume rise as well as hourly meteorology conditions, resulting in modeled screening-level risk values that replace the screening values of the Tier 3 plume-rise assessment.

The remainder of this section discusses each of these assessments.

4.2 Lake Assessment

Other than verifying a facility's emission rates, one of the simplest assessments that can be conducted (beyond the Tier 2 methods) is to assess the existence, the potential purpose, the accessibility and fishability, and the suitability of lakes for the models and methods used in Tier 2. The full USGS dataset of lakes and reservoirs nationwide that is used in Tier 2 does not contain information on lake accessibility or fishability. In addition, it occasionally identifies a lake that no longer exists (e.g., has evaporated or been drained) or it uses a classification that might not accurately reflect the lake's purpose or type. Aerial and street-view imagery and internet searches can be used to quickly ascertain if an assessed lake actually exists, if it is likely not fished (e.g., appears swampy or covered in algae), if it is likely used for industrial or waste disposal/treatment purposes, and/or if it is adjacent to or connected to a river or saltwater body (estuaries, rivers, and saltwater areas are not ideal for the assessment models and methods).

For example, the blue outline in Exhibit 31 identifies a lake from the USGS dataset that originally qualified for Tier 2 based on the information provided in that dataset, but aerial imagery shows it is likely evaporated or drained. Similarly, the outline in Exhibit 32 identifies a lake that originally qualified, but aerial imagery shows that it is directly adjacent to an industrial facility and likely used only for on-site industrial purposes.

For facilities undergoing Tier 3 screening, all lakes are assessed from which the fisher catches and consumes fish according to the refined Tier 2 fisher methods discussed in Section 3. All lakes meeting the criteria discussed in the previous paragraphs are permanently removed from the screening assessment so that they are no longer used in any screening assessment. If a lake is removed from the facility's assessment, it might be necessary for the hypothetical fisher to catch and consume fish from additional lake(s) in order to fish a total of 373 acres in order to satisfy the fisher ingestion rate 373 g-fish/d. In this case, additional lakes that were not fished previously are evaluated, using the methods discussed in Section 3, in descending order of initial Tier 2 fisher screening result and lake area.

If any lakes are removed from the screening, the screening assessment is conducted again (using the Tier 2 methods) with the revised lake dataset. Although this additional lake assessment is conducted based on the Tier 2 screening results of a particular set of facilities, lakes removed during that assessment could affect the screening results of other facilities in the source category beyond that original set. This can happen if an assessed facility is within 50 km of another assessed facility, whereby removing a lake could affect the screening results of both facilities. It should be noted, however, that screening results across different facilities are not summed.

Exhibit 31. Example of Lake Removed from Screening—Likely Evaporated or Drained

Note: Aerial imagery from ESRI World Imagery (2014).

Exhibit 32. Example of Lake Removed from Screening—Likely an Industrial Lake

Note: Aerial imagery from ESRI World Imagery (2014).

4.3 Plume-rise Assessment

If a facility's emissions do not screen out with the Tier 3 lake assessment, a Tier 3 plume-rise assessment may be conducted. In Tiers 1 and 2, all chemicals are emitted inside the mixing layer and are available for ground-level exposure. This is because the mixing height (held static) is never less than 710 m, while the physical emission source height (also held static) is always inside the mixing layer; therefore, the chemical plume is always inside the mixing layer. In reality, the physical height of an emission source, in combination with the temperature and velocity of the chemical plume as it leaves the source, can cause some of the chemical plume to reach areas above the mixing layer. In TRIM.FaTE modeling, the chemical mass deposited above the mixing layer (i.e., the model's upper-air layer) is unavailable for ground-level exposure (i.e., the upper-air layer functions as a chemical sink). Many RTR emission sources are physically taller than the actual, hourly-varying mixing height during some hours, and hot exit gas temperatures (i.e., buoyancy) and/or high exit gas velocities (i.e., momentum) can further elevate the chemical plume well above the source height and mixing layer.

The Tier 3 plume-rise methodology utilizes methods summarized by Seinfeld and Pandis (1998) to estimate how often a facility's emissions reach the upper-air sink, which decreases availability for ground-level exposure. The methods to estimate the amount of chemical lost to the upper-air sink require use of the facility's corresponding hourly meteorology data (e.g., air temperature and vertical temperature gradient, wind speed, and atmospheric stability), the mass of the PB-HAP emitted from each source, the physical characteristics of the sources (i.e., release height, inside diameter at the release point, and exit gas temperature and velocity), and an estimate of the size of the facility. The facility size is a necessary component because the emission plume can continue to rise as it travels laterally away from the emission source, and the height the plume reaches must be assessed as it leaves the facility area (where it is assumed the public is not exposed to the emissions) and enters areas where people could be exposed.

For each relevant emission source, estimates of the hourly effective release height (i.e., sum of actual release height and plume rise) are compared to the hourly mixing height to determine the mass of chemical remaining in the mixing layer. The mass of chemical remaining in the mixing layer, summed across the sources, is compared to the total emitted mass of the chemical. This results in an adjustment factor expressing the fraction of emissions remaining in the mixing layer after accounting for release height and plume rise. For the lake or hypothetical farm being assessed, the Tier 2 methods already account for how often the plume is bowing toward the lake or farm (i.e., direct chemical deposition can only occur when wind blows the plume toward those media); therefore, in the Tier 3 plume-rise assessment, the calculations of total mass emitted and mass remaining in the mixing layer are limited to only the times when winds blow toward the lake or farm. That is, the plume-rise adjustment factor is calculated as [number of hours when winds blow toward the lake or farm AND the emitted mass remains in the mixing layer] ÷ [number of hours when winds blow toward the lake or farm]. This final plume-rise adjustment factor is then applied to the Tier 2 screening results.

4.4 Assessment of Time-series Meteorology and Effective Release Heights

If a facility's emissions do not screen out with the Tier 3 plume-rise assessment, a Tier 3 time-series meteorology assessment may be conducted. As discussed in Section 3, the Tier 2 screening results are based on the average meteorological conditions prevailing at the facility being assessed. The use of time-series meteorology data, which captures hour-by-hour changes in each of the assessed meteorological parameters instead of using constant average values, increases the accuracy of the estimates of potential risk by accounting for potential

statistical interactions between the meteorology parameters and by improving the method of accounting for mass advected into the modeling domain.

As noted above, Tier 2 screening results also are based on a static emission release height that is always within the mixing layer. Including hourly effective release heights along with hourly meteorology data further increases the accuracy of the screening results.

Furthermore, in the Tier 2 assessment, the emission screening thresholds for PAHs and dioxins correspond to BaP and TCDD, respectively, and a facility's emissions of the individual congeners are related to those surrogates using Risk Equivalency Factors (REFs; see Section 2.2.7) based on comparisons of toxicity and of fate and transport behavior in TRIM.FaTE. Therefore, PAH and dioxin congeners other than BaP and TCDD are assessed indirectly in the Tiers 1 and 2 screening assessments, though modeled directly in the TRIM.FaTE and MIRC model runs that used derive the equivalency factors.

For a facility undergoing a Tier 3 time-series assessment, a new TRIM.FaTE model run is conducted using the facility's emission rate of the chemical of concern, the time-series meteorological and plume-rise data developed for the Tier 3 plume-rise assessment, and the Tier 2 spatial scenario that best matches the lake or farm being assessed (e.g., the lake or farm corresponding to screening values above levels of concern in Tier 2). All other model settings are unchanged from the Tier 2 assessment. Modeling is repeated for each chemical and lake or farm of concern. This results in a screening-level risk value for each lake or farm. The screening-level risk associated with each lake is multiplied by the percent of daily ingested fish caught from the lake (i.e., the 1 g-fish/d/acre methods discussed in Section 3.3.2.3); summing those products across all modeled lakes results in the screening-level fisher risk (i.e., fisher screening result) associated with the evaluated PB-HAP emitted by the facility.

5. References

ATSDR (Agency for Toxic Substances and Disease Registry). 1995. Toxicological profile for polycyclic aromatic hydrocarbons. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

ATSDR. 1998. Toxicological profile for chlorinated dibenzo-p-dioxins. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

ATSDR. 1999. Toxicological profile for Mercury. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

ATSDR. 2008. Toxicological profile for Cadmium. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Burger, J. 2002. Daily consumption of wild fish and game: Exposures of high end recreationists. *International Journal of Environmental Health Research* 12:343-354.

Cal/EPA (California Environmental Protection Agency) Office of Environmental Health Hazard Assessment (OEHHA). 2000. Air Toxics Hot Spots Program Risk Assessment Guidelines; Part IV, Exposure Assessment and Stochastic Analysis Technical Support Document. Section 6, Dermal Exposure Assessment. September. Available at: http://www.oehha.ca.gov/air/hot_spots/pdf/chap6.pdf.

Chen, C.Y., R.S. Stemberger, B. Klaue, J.D. Blum, P.C. Pickhardt, and C.L. Folt. 2000. Accumulation of heavy metals in food web components across a gradient of lakes. Limnology and Oceanography 45(7): 1525-1536.

Croteau, M., S.N. Luoma, and A.R. Stewart. 2005. Trophic transfer of metals along freshwater food webs: Evidence of cadmium biomagnification in nature. Limnology and Oceanography 50(5):1511-1519.

EPA 1997. Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment. EPA-452/R-97-005. Office of Air Quality Planning and Standards and Office of Research and Development. December.

EPA 1998. Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions. National Center for Environmental Assessment. Cincinnati, OH. EPA-600/6-90/003. December.

EPA 1999. Short Sheet: IEUBK Model Soil/Dust Ingestion Rates. EPA-540-F-00-007; OSWER-9285.7-33. Washington, D.C.: Office of Solid Waste and Emergency Response; December. Available at: http://www.epa.gov/superfund/lead/products/ssircolo.pdf.

EPA 2001a. NATA – Evaluating the National-scale Air Toxics Assessment, 1996 DATA – An SAB Advisory. U.S EPA Science Advisory Board. EPA-SAB-EC-ADV-02-001. 12/2001.

EPA 2001b. National-scale Air Toxics Assessment for 1996, Draft for EPA Science Advisory Board Review. EPA Office of Air Quality Planning and Standards. EPA-453/R-01-003. 01/18/2001.

EPA 2002a. Total Risk Integrated Methodology: TRIM.FaTE Technical Support Document. Volume II: Description of Chemical Transport and Transformation Algorithms. EPA-453/R-

02-011b. Office of Air Quality Planning and Standards: Research Triangle Park, NC. September.

EPA 2002b. Evaluation of TRIM.FaTE, Volume I: Approach and Initial Findings. EPA-453/R-02-0012. Office of Air Quality and Planning Standards: Research Triangle Park, NC. September.

EPA 2003. Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Modeling System, Volume II: Site-based, Regional, and National Data. SAB Review Draft. EP-530/D-03-001b. Office of Research and Development, Athens, GA, and Research Triangle Park, NC, and Office of Solid Waste, Washington, DC. July. Available at: http://www3.epa.gov/epawaste/hazard/wastetypes/wasteid/hwirwste/risk03.htm#vol3.

EPA 2004a. Air Toxics Risk Assessment Reference Library; Volume 1 – Technical Resource Document, Part III, Human Health Risk Assessment: Multipathway Chapter 14, Overview and Getting Started: Planning and Scoping the Multipathway Risk Assessment. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available at: http://www2.epa.gov/sites/production/files/2013-08/documents/volume_1_reflibrary.pdf.

EPA 2004b. Evaluation of TRIM.FaTE Volume III: Model Comparison Focusing on Dioxin Test Case. EPA-453/R-04-002. Available at: http://www2.epa.gov/sites/production/files/2014-01/documents/eval_rept_vol3_2005.pdf.

EPA 2004c. Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Volume 2: Properties, Environmental Levels, and Background Exposures. Dioxin Reassessment, NAS Review Draft. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/P-00/001Cb. Available at: http://www.epa.gov/ncea/pdfs/dioxin/nas-review/.

EPA 2005a. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (including the Hazardous Waste Companion Database of chemical-specific parameter values). U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. EPA-530-R-05-006. September.

EPA 2005b. Evaluation of TRIM.FaTE, Volume II: Model Comparison Focusing on Mercury Test Case. EPA-453/R-05-002. Office of Air Quality and Planning Standards: Research Triangle Park, NC. July.

EPA 2005c. Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. EPA-630/R-03-003F. Risk Assessment Forum: Washington, DC. March.

EPA 2006. Risk and Technology Review (RTR) Assessment Plan. Office of Air and Radiation. November 20, 2006. Available at: http://www.epa.gov/sab/panels/consul_risk_and_tech_assessment_plan.htm.

EPA 2007. Prioritized Chronic Dose-Response Values for Screening Risk Assessments (Table 1). Office of Air Quality Planning and Standards; June 12, 2007. Available at: http://www.epa.gov/ttn/atw/toxsource/summary.html.

EPA 2009. Risk and Technology Review (RTR) Risk Assessment Methodologies: For Review by the EPA's Science Advisory Board with Case Studies – MACT I Petroleum Refining Sources and Portland Cement Manufacturing. EPA Office of Air Quality Planning and Standards. EPA-452/R-09-006. 06/2009.

EPA 2010a Development of a Relative Potency Factor (RPF) Approach for Polycyclic Aromatic Hydrocarbon (PAH) Mixtures (External Review Draft). Washington, DC, EPA/635/R-08/012A February. Available at: http://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=194584.

EPA 2010 Review of EPA's draft entitled, "Risk and Technology Review (RTR) Risk Assessment Methodologies: For Review by the EPA's Science Advisory Board with Case Studies – MACT I Petroleum Refining Sources and Portland Cement Manufacturing." EPA Science Advisory Board. EPA-SAB-10-007. 05/07/2010.

EPA 2011a Exposure Factors Handbook: 2011 edition. National Center for Environmental Assessment, Washington, DC; EPA/600/R-09/052F. Available from the National Technical Information Service, Springfield, VA, and online at http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=522996.

EPA 2011b Human Health Multipathway Residual Risk Assessment for the Secondary Lead Smelting Source Category. Draft Report. Prepared by ICF International for EPA Risk and Exposure Assessment Group. 02/15/2011.

EPA 2011c Technical Support Document: Case Study Analyses of Potential Local-scale Human Health Risks Associated with Mercury Emissions from Electric Utility Steam-generating Units. Draft. Prepared by ICF International for EPA Office of Air Quality Planning and Standards. 02/17/2011.

EPA 2014a Technical Support Document: Human Health Multipathway Residual Risk Assessment for the Ferroalloys Production Source Category. Draft. Prepared by ICF International for EPA Office of Air Quality Planning and Standards. 02/21/2014.

EPA 2014b Technical Support Document: Human Health Multipathway Residual Risk Assessment for the Petroleum Refineries Sector. Draft. Prepared by ICF International for EPA Office of Air Quality Planning and Standards. 01/31/2014.

ESRI (Environmental Systems Research Institute). 2014. World Imagery. Accessed June 03, 2014. Available at: http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9.

Hazardous Substances Data Bank (HSDB). 2005. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 06/23/2005]. Cadmium Compounds; Hazardous Substances Databank Number: 6922. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB.

Holzworth, G.C. 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States," AP-101, January 1972, U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina.

ICF (ICF International). 2005. Memorandum: TRIM.FaTE Screening Scenario: Aquatic Food Web Analysis; submitted to Deirdre Murphy and Terri Hollingsworth, U.S. EPA, from Margaret McVey and Rebecca Kauffman, ICF Consulting. October 18.

Mason R.P., J. Laporte, and S. Andres. 2000. Factors controlling the bioaccumulation of mercury, methylmercury, arsenic, selenium, and cadmium by freshwater invertebrates and fish. Archives for Environmental Contamination and Toxicology 38(3):283-97.

McKone, T.E., A. Bodnar, and E. Hertwich. 2001. Development and evaluation of state-specific landscape data sets for multimedia source-to-dose models. University of California at Berkeley. Supported by U.S. Environmental Protection Agency (Sustainable Technology

Division, National Risk Management Research Laboratory) and Environmental Defense Fund. July. LBNL-43722.

Morton, F.I. 1986. Practical estimates of lake evaporation. Journal of Climate and Applied Meteorology 25:371-387.

NCDC (National Climatic Data Center). 1995. Hourly United States Weather Observations (HUSWO) 1990-1995.

National Climatic Data Center. (2007). Cimate Maps of the United States (CLIMAPS). Available online at https://www.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl.

National Climatic Data Center (NCDC). (2012) Quality Controlled Local Climatological Data. Available online at https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/quality-controlled-local-climatological-data-qclcd.

Reinfelder, J.R., N.S. Fisher, S.N. Luoma, J.W. Nichols, and W.-X. Wang. 1998. Trace element trophic transfer in aquatic organisms: A critique of the kinetic model approach. The Science of the Total Environment 219: 117-135.

Saiki, M.K., D.T. Castleberry, T.W. May, B.A. Martin, and F.N. Bullard. 1995. Copper, cadmium, and zinc concentrations in aquatic food chains from the upper Sacramento River (California) and selected tributaries. Arch. Environ. Contam. Toxicol. 29:484-491.

Seinfeld, J.H., and S.N. Pandis. 1998. Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, Wiley-Interscience, New York, pp. 931–933.

Stull, R.B. 1988. An Introduction to Boundary Layer Meteorology. Kluwer Academic Publishers, The Netherlands. 452 pp.

Turner, D.B. 1970. Workbook of Atmospheric Dispersion Estimates. PHS Publication No. 999-AP-26. U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio.

USGS (U.S. Geological Survey). (2012) National Hydrography Dataset. Available online at http://nhd.usgs.gov/.

USGS (U.S. Geological Survey). 1987. National Water Summary 1987 – Hydrologic Events and Water Supply and Use. USGS Water-Supply Paper 2350. J.E. Carr, E.B. Chase, R.W. Paulson, and D.W. Moody, Compilers.

Van den Berg, M., L.S. Birnbaum, M. Denison, M. DeVito, W. Farlans, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L.. Haws, M. Rose, S. Safe, D. Schrenk, C. Tohyama, A. Tritscher, J. Tuomisto, M. Tysklind, N. Walker, and R.E. Peterson. 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. Toxicol Sci. 93(2): 223-41.

Wischmeier, W.H., and D. Smith. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA-ARS Agriculture Handbook No. 537, Washington, D.C. 58 pp.

Attachment A. TRIM.FaTE Inputs

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Exhibits, Attachment A

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Exhibit A-2. Meteorological Inputs for the TRIM.FaTE Screening Scenario A-2
Exhibit A-3. Air Parameters for the TRIM.FaTE Screening Scenario A-3
Exhibit A-4. Soil and Groundwater Parameters for the TRIM.FaTE Screening Scenario A-4
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Exhibit A-27. Dioxin Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario A-43

This attachment provides tables of the modeling inputs for the TRIM.FaTE screening scenario. Exhibit A-1 presents runtime settings for TRIM.FaTE. Exhibit A-2 and Exhibit A-3 present meteorological and air parameters, respectively, entered into the model. Exhibit A-4. , Exhibit A-5, and Exhibit A-6 present the parameters for soil and groundwater, runoff assumptions, and the USLE (universal soil loss equation) erosion parameters, respectively, for the screening scenario. Exhibit A-7 and Exhibit A-8 present terrestrial parameters. Exhibit A-9 through Exhibit A-11 present lake parameters, and Exhibit A-12 through Exhibit A-27 present parameters specific to the chemicals modeled in the scenario.

Exhibit A-1. TRIM.FaTE Simulation Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Start of simulation	date/time	1/1/1990, midnight	Consistent with met data.
End of simulation	date/time	1/1/2040, midnight	Consistent with met data set; selected to provide a 50-year modeling period.
Simulation time step	hr	1	Selected value.
Output time step[a]	hr	4	Selected value.

[a]Output time step is set in TRIM.FaTE using the scenario properties "simulationStepsPerOutputStep" and "simulationTimeStep."

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Exhibit A-2. Meteorological Inputs for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Meteorological Inputs			
Air temperature	degrees K	298	USEPA 2005.
Horizontal wind speed	m/sec	2.8	5th percentile annual average value for contiguous United States, calculated from 30 yrs of annual normal temperature values.
Vertical wind speed	m/sec	0.0	Assumption; vertical wind speed not used by any of the algorithms in the version of the TRIM.FaTE library used for screening.
Wind direction	degrees clockwise from N (blowing from)	3-days-on 4-days-off	On is defined as time during which wind is blowing into the model domain. A conservative estimate of time during which wind should blow into the modeling domain was determined by evaluating HUSWO; it was concluded that a conservative estimate would be approximately 42% of the time.
Rainfall rate	m^3[rain]/m^2 [surface area]-day	varies daily	1.5 m/yr is the maximum statewide 30-year (1971-2000) average for the contiguous United States, excluding Rhode Island because of extreme weather conditions on Mt. Washington. Data obtained from the National Climatic Data Center at https://www.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl. The precipitation frequency was 3-days-on:4-days-off based on data from Holzworth, 1972.
Mixing height (used to set air VE property named “top”)	m	710	5th percentile annual average mixing heights (calculated from daily morning and afternoon values), for all stations on SCRM (40 state, 70 stations).
isDay_SteadyState_forAir	unitless	--	Value not used in current dynamic runs (would need to be reevaluated if steady-state runs are needed).
isDay_SteadyState_forOther	unitless	--	

Exhibit A-3. Air Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Atmospheric dust load	kg[dust]/m^3[air]	6.15E-08	Bidleman 1988
Density of air	g/cm^3	0.0012	USEPA 1997b
Dust density	kg[dust]/m^3[dust]	1,400	Bidleman 1988
Fraction organic matter on particulates	unitless	0.2	Harner and Bidleman 1998

Exhibit A-4. Soil and Groundwater Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Surface Soil Compartment Type			
Air content	volume[air]/volume[compartment]	0.28	McKone et al. 2001.
Average vertical velocity of water (percolation)	m/day	8.22E-04	Assumed to be 0.2 times average precipitation for site.
Boundary layer thickness above surface soil	m	0.005	Thibodeaux 1996; McKone et al. 2001 (Table 3).
Density of soil solids (dry weight)	kg[soil]/m^3[soil]	2600	Default in McKone et al. 2001 (Table 3).
Thickness - untilled[a]	m	0.01	McKone et al. 2001 (p. 30).
Thickness - tilled[a]	m	0.20	USEPA 2005.
Erosion fraction	unitless	varies[b]	See Exhibit 5.
Fraction of area available for erosion	m^2[area available]/m^2[total]	1	Assumption ; area assumed rural.
Fraction of area available for runoff	m^2[area available]/m^2[total]	1	Assumption ; area assumed rural.
Fraction of area available for vertical diffusion	m^2[area available]/m^2[total]	1	Assumption ; area assumed rural.
Fraction sand	unitless	0.25	Assumption.
Organic carbon fraction	unitless	0.008	U.S. average in McKone et al. 2001 (Table 16 and A-3).
pH	unitless	6.8	Assumption.
Runoff fraction	unitless	varies[b]	See Exhibit A-5.
Total erosion rate	kg [soil]/m^2/day	varies[b]	See Exhibit A-6.
Total runoff rate	m^3[water]/m^2/day	1.64E-03	Calculated using scenario-specific precipitation rate and assumptions associated with water balance.
Water content	volume[water]/volume[compartment]	0.15	McKone et al. 2001
Root Zone Soil Compartment Type			
Air content	volume[air]/volume[compartment]	0.25	McKone et al 2001 (Table 16).
Average vertical velocity of water (percolation)	m/day	8.22E-04	Assumed as 0.2 times average precipitation for New England in McKone et al. 2001.
Density of soil solids (dry weight)	kg[soil]/m^3[soil]	2,600	McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.25	Assumption.

Exhibit A-4. Soil and Groundwater Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Root Zone Soil Compartment Type, continued			
Thickness - untilled[a]	m	0.79	McKone et al. 2001 (Table 16 - U.S. average).
Thickness - tilled[a]	m	0.6	Adjusted from McKone et al. 2001 (Table 16).
Organic carbon fraction	unitless	0.008	McKone et al. 2001 (Tables 16 and A-3, U.S. average).
pH	unitless	6.8	Assumption.
Water content	volume[water]/volume[compartment]	0.15	McKone et al. 2001
Vadose Zone Soil Compartment Type			
Air content	volume[air]/volume[compartment]	0.22	McKone et al. 2001 (Table 17).
Average vertical velocity of water (percolation)	m/day	8.22E-04	Assumed as 0.2 times average precipitation for New England in McKone et al. 2001.
Density of soil solids (dry weight)	kg[soil]/m^3[soil]	2,600	Default in McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.35	Assumption.
Thickness[a]	m	1.4	McKone et al. 2001 (Table 17).
Organic carbon fraction	unitless	0.003	McKone et al. 2001 (Tables 16 and A-3, U.S. average).
pH	unitless	6.8	Assumption.
Water content	volume[water]/volume[compartment]	0.21	McKone et al. 2001 (Table 17 - national average).
Groundwater Compartment Type			
Thickness[a]	m	3	McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.4	Assumption.
Organic carbon fraction	unitless	0.004	Assumption.
pH	unitless	6.8	Assumption.
Porosity	volume[total pore space]/volume[compartment]	0.2	Default in McKone et al. 2001 (Table 3).
Density of solid material in aquifer	kg[soil]/m^3[soil]	2,600	Default in McKone et al. 2001 (Table 3).

[a]Set using the volume element properties file.
[b]See separate tables (Exhibit A-5 and Exhibit A-6) for erosion/runoff fractions and total erosion rates.

Exhibit A-5. Runoff Assumptions for the TRIM.FaTE Screening Scenario

Originating Compartment	Destination Compartment	Runoff/Erosion Fraction
SurfSoil_Source	SurfSoil_N1	0.0
	SurfSoil_S1	0.0
	sink	1.0
SurfSoil_N1	SW_Pond	1.0
	SurfSoil_Source	0.0
	SurfSoil_N6	0.0
	SurfSoil_S1	0.0
	sink	0.0
SurfSoil_S1	SW_Pond	1.0
	SurfSoil_Source	0.0
	SurfSoil_N1	0.0
	sink	0.0
SurfSoil_N6	SW_Pond	1.0
	SurfSoil_N1	0.0
	SurfSoil_N7	0.0
	sink	0.0
SurfSoil_N7	SW_Pond	1.0
	SurfSoil_N6	0.0
	SurfSoil_N3	0.0
	sink	0.0
SurfSoil_N3	SW_Pond	1.0
	SurfSoil_N7	0.0
	SurfSoil_N4	0.0
	sink	0.0
SurfSoil_N4	SW_Pond	1.0
	SurfSoil_N3	0.0
	SurfSoil_N5	0.0
	SurfSoil_S4	0.0
	sink	0.0
SurfSoil_S4	SW_Pond	1.0
	SurfSoil_N4	0.0
	SurfSoil_S5	0.0
	sink	0.0
SurfSoil_N5[a]	SW_Pond	0.0
	SurfSoil_N4	0.5
	SurfSoil_S5	0.5
	sink	0.0
SurfSoil_S5[a]	SW_Pond	0.0
	SurfSoil_N5	0.0
	SurfSoil_S4	1.0
	sink	0.0

[a]Assumes that N5 is higher ground than S5, and half of the runoff flows into N4, and the other half into S5. Assumes all runoff from S5 flows into S4.

Exhibit A-6. USLE Erosion Parameters for the TRIM.FaTE Screening Scenario

Soil Parcel	Area	Rainfall/Erosivity Index	Soil Erodibility Index	Length-Slope Factor	Land Use	Cover Mgmt Factor	Supporting Practices Factor	Unit Soil Loss		Sediment Delivery Ratio[a]	Calculated (Adjusted) Erosion Rate
Code	m^2	R (100 ft-ton/ac)	K (ton/ac/(100 ft-ton/acre))	LS (USCS)	type	C (USCS)	P	A (ton/ac/yr)	A ($kg/m^2/d$)	SDR[a]	$kg/m^2/d$
N1	5.8E+04	300	0.39	1.5	grass	0.1	1	17.55	0.010779	0.533	0.005740
N6	4.1E+04	300	0.39	1.5	crops	0.2	1	35.1	0.021557	0.557	0.012014
N7	7.3E+04	300	0.39	1.5	grass	0.1	1	17.55	0.010779	0.518	0.005580
N3	3.5E+05	300	0.39	1.5	grass	0.1	1	17.55	0.010779	0.385	0.004151
N4	2.0E+06	300	0.39	1.5	forest	0.1	1	17.55	0.010779	0.309	0.003331
N5	6.7E+06	300	0.39	1.5	forest	0.1	1	17.55	0.010779	0.196	0.002116
S1	5.8E+04	300	0.39	1.5	grass	0.1	1	17.55	0.010779	0.533	0.005740
S4	2.0E+06	300	0.39	1.5	forest	0.1	1	17.55	0.010779	0.309	0.003331
S5	6.7E+06	300	0.39	1.5	forest	0.1	1	17.55	0.010779	0.196	0.002116

[a]Calculated using SDR = $a * (AL)^{-b}$; where *a* is the empirical intercept coefficient (based on the size of the watershed), AL is the total watershed area receiving deposition (m^2), and *b* is the empirical slope coefficient (always 0.125).

Exhibit A-7. Terrestrial Plant Placement for the TRIM.FaTE Screening Scenario

Surface Soil Volume Element	Surface Soil Depth (m)	Coniferous Forest	Grasses/ Herbs	None
Source	0.01			x
N1	0.01		x	
N6	0.20 (tilled)			x
N7	0.01		x	
N3	0.01		x	
N4	0.01	x		
N5	0.01	x		
S1	0.01		x	
S4	0.01	x		
S5	0.01	x		

Exhibit A-8. Terrestrial Plant Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Coniferous[a]		Grass/Herb[a]	
		Value Used	Reference	Value Used	Reference
Leaf Compartment Type					
Allow exchange	1=yes, 0=no	1	-	Seasonal[b]	-
Average leaf area index	m^2[leaf]/ m^2[area]	5.0	Harvard Forest, dom. red oak and red maple, CDIAC website	5.0	Mid-range of 4-6 for old fields, R.J. Luxmoore, ORNL.
Calculate wet deposition interception fraction (Boolean)	1=yes, 0=no	0	Assumption.	0	Assumption.
Correction exponent, octanol to lipid	unitless	0.76	From roots, Trapp 1995.	0.76	From roots, Trapp 1995.
Degree stomatal opening	unitless	1	Assumed value of 1 for daytime (stomatal diffusion is turned off at night using a different property, IsDay).	1	Assumed value of 1 for daytime (stomatal diffusion is turned off at night using a different property, IsDay).
Density of wet leaf	kg/m^3	820	Paterson et al. 1991.	820	Paterson et al. 1991.
Leaf wetting factor	m	3.00E-04	1E-04 to 6E-04 for different crops and elements, Muller and Prohl 1993.	3.00E-04	1E-04 to 6E-04 for different crops and elements, Muller and Prohl 1993.
Length of leaf	m	0.01	Assumption.	0.05	Assumption.
Lipid content	kg/kg wet weight	0.00224	European beech, Riederer 1995.	0.00224	European beech, Riederer 1995.
Litter fall rate	1/day	0.0021	value assumes 1st-order relationship and that 99% of leaves fall over 6 years	Seasonal[c]	-
Stomatal area normalized effective diffusion path length	1/m	200	Wilmer and Fricker 1996.	200	Wilmer and Fricker 1996.
Vegetation attenuation factor	m^2/kg	2.9	Grass/hay, Baes et al. 1984.	2.9	Grass/hay, Baes et al. 1984.
Water content	unitless	0.8	Paterson et al. 1991.	0.8	Paterson et al. 1991.
Wet deposition interception fraction	unitless	0.2	Calculated based on 5 years of local met data, 1987-1991.	0.2	Calculated based on 5 years of local met data, 1987-1991.
Wet mass of leaf per soil area	kg[fresh leaf]/m^2[area]	2.0	Calculated from leaf area index, leaf thickness (Simonich and Hites, 1994), density of wet foliage.	0.6	Calculated from leaf area index and Leith 1975.
Particle on Leaf Compartment Type					
Allow exchange	1=yes, 0=no	1	-	Seasonal[b]	-

Exhibit A-8. Terrestrial Plant Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Coniferous[a]		Grass/Herb[a]	
		Value Used	Reference	Value Used	Reference
Particle on Leaf Compartment Type, continued					
Volume particle per area leaf	m^3[leaf particles]/m^2[leaf]	1.00E-09	Based on particle density and size distribution for atmospheric particles measured on an adhesive surface, Coe and Lindberg 1987.	1.00E-09	Based on particle density and size distribution for atmospheric particles measured on an adhesive surface, Coe and Lindberg 1987.
Root Compartment Type – Nonwoody Only					
Allow exchange	1=yes, 0=no			Seasonal[b]	-
Correction exponent, octanol to lipid	unitless			0.76	Trapp 1995.
Lipid content of root	kg/kg wet weight			0.011	Calculated.
Water content of root	kg/kg wet weight			0.8	Assumption.
Wet density of root	kg/m^3			820	Soybean, Paterson et al. 1991.
Wet mass per soil area	kg/m^2			1.4	Temperate grassland, Jackson et al. 1996.
Stem Compartment Type – Nonwoody Only					
Allow exchange	1=yes, 0=no			Seasonal[b]	-
Correction exponent, octanol to lipid	unitless			0.76	Trapp 1995.
Density of phloem fluid	kg/m^3			1,000	Assumption.
Density of xylem fluid	kg/cm^3			900	Assumption.
Flow rate of transpired water per leaf area	m^3[water]/m^2[leaf]			0.0048	Crank et al. 1981.
Fraction of transpiration flow rate that is phloem rate	unitless			0.05	Paterson et al. 1991.
Lipid content of stem	kg/kg wet weight			0.00224	Leaves of European beech, Riederer 1995.
Water content of stem	unitless			0.8	Paterson et al. 1991
Wet density of stem	kg/m^3			830	Assumption.
Wet mass per soil area	kg/m^2			0.24	Calculated from leaf and root biomass density.

[a]See Exhibit A-7 for assignment of plant types to surface soil compartments.
[b]Begins March 9 (set to 1), ends November 7 (set to 0). Nationwide 80th percentile.
[c]Begins November 7, ends December 6; rate = 0.15/day during this time (value assumes 99 percent of leaves fall in 30 days).

Exhibit A-9. Surface Water Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Algae carbon content (fraction)	unitless	0.465	APHA 1995.
Algae density in water column	g[algae]/L[water]	0.0025	Millard et al. 1996 as cited in ICF 2005.
Algae growth rate	1/day	0.7	Hudson et al. 1994 as cited in Mason et al. 1995b.
Algae radius	um	2.5	Mason et al. 1995b.
Algae water content (fraction)	unitless	0.9	APHA 1995.
Average algae cell density (per volume cell, not water)	g[algae]/m^3[algae]	1,000,000	Mason et al. 1995b, Mason et al. 1996.
Boundary layer thickness above sediment	m	0.02	Cal EPA 1993.
Chloride concentration	mg/L	8.0	Kaushal et al. 2005.
Chlorophyll concentration	mg/L	0.0029	ICF 2005.
Depth[a]	m	3.18	WI DNR 2007 - calculation based on relationship between drainage basin and lake area size.
Dimensionless viscous sublayer thickness	unitless	4	Ambrose et al. 1995.
Drag coefficient for water body	unitless	0.0011	Ambrose et al. 1995.
Flush rate	1/year	12.17	Calculated based on pond dimensions and flow calculations.
Fraction Sand	unitless	0.25	Assumption.
Organic carbon fraction in suspended sediments	unitless	0.02	Assumption.
pH	unitless	7.3	Assumption.
Suspended sediment deposition velocity	m/day	2	USEPA 1997b.
Total suspended sediment concentration	kg[sediment]/m^3[water column]	0.05	USEPA 2005.
Water temperature	degrees K	298	USEPA 2005.

[a]Set using the volume element properties named "top" and "bottom."

Exhibit A-10. Sediment Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Depth[a]	m	0.05	McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.25	Assumption.
Organic carbon fraction	unitless	0.02	McKone et al. 2001 (Table 3).
Porosity of the sediment zone	volume[total pore space]/volume[sediment compartment]	0.6	USEPA 2005.
Solid material density in sediment	kg[sediment]/m^3[sediment]	2,600	McKone et al. 2001 (Table 3).
pH	unitless	7.3	Assumption.
Sediment resuspension velocity	m/day	6.69E-05	Calculated from water balance model.

[a]Set using the volume element properties named "top" and "bottom."

Exhibit A-11. Aquatic Animals Food Chain, Density, and Mass for the TRIM.FaTE Screening Scenario

Aquatic Biota (Consuming Organism)	Fraction Diet								Biomass (kg/m^2)	Body Weight (kg)	Reference
	Algae	Zooplankton	Benthic Invertebrate	Water Column Herbivore	Benthic Omnivore	Water Column Omnivore	Benthic Carnivore	Water Column Carnivore			
Benthic Invertebrate	0%	0%	0%	0%	0%	0%	0%	0%	0.020	2.55E-04	Assumption.
Water Column Herbivore	0%	100%	0%	0%	0%	0%	0%	0%	0.002	0.025	Assumption.
Benthic Omnivore	0%	0%	100%	0%	0%	0%	0%	0%	0.002	2.50E-01	Assumption.
Water Column Omnivore	0%	0%	0%	100%	0%	0%	0%	0%	0.001	0.25	Assumption.
Benthic Carnivore	0%	0%	50%	0%	50%	0%	0%	0%	0.001	2.0	Assumption.
Water Column Carnivore	0%	0%	0%	0%	0%	100%	0%	0%	0.0002	2.0	Assumption.
Zooplankton	100%	0%	0%	0%	0%	0%	0%	0%	0.0064	5.70E-08	Assumption.

Exhibit A-12. Cadmium Chemical-Specific Parameters for the TRIM.FaTE Screening Scenario

Parameter Name[a]	Units	Value	Reference
CAS number[b]	unitless	7440-43-9	-
Diffusion coefficient in pure air	m^2[air]/day	0.71	USEPA 1999 (Table A-2-35).
Diffusion coefficient in pure water	m^2[water]/day	8.16E-05	USEPA 1999 (Table A-2-35).
Henry's Law constant	Pa-m^3/mol	1.00E-37	USEPA 1999 (Table A-2-35; assumed to be zero).
Melting point	degrees K	594	ATSDR 1999.
Molecular weight	g/mol	112.41	ATSDR 1999.
Octanol-air partition coefficient (K_{oa})	m^3[air]/m^3[octanol]	-	-
Octanol-carbon partition coefficient (K_{oc})		-	-
Octanol-water partition coefficient (K_{ow})	L[water]/kg[octanol]	-	-

[a]All parameters in this table are TRIM.FaTE chemical properties.
[b]This CAS numbers applies to elemental Cd; however, the cations of cadmium are being modeled.

Exhibit A-13. Mercury Chemical-Specific Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)[b]	Hg(2)[b]	MHg[b]	
CAS number	unitless	7439-97-6	14302-87-5	22967-92-6	-
Diffusion coefficient in pure air	m^2[air]/day	0.478	0.478	0.456	USEPA 1997b.
Diffusion coefficient in pure water	m^2[water]/day	5.54E-05	5.54E-05	5.28E-05	USEPA 1997b.
Henry's Law constant	Pa-m^3/mol	719	7.19E-05	0.0477	USEPA 1997b.
Melting point	degrees K	234	5.50E+02	443	CARB 1994.
Molecular weight	g/mol	201	201	216	USEPA 1997b.
Octanol-water partition coefficient (K_{ow})	L[water]/kg[octanol]	4.15	3.33	1.7	Mason et al. 1996.
Vapor washout ratio	m^3[air]/m^3[rain]	1,200	1.6E+06	0	USEPA 1997b, based on Petersen et al. 1995.

[a]All parameters in this table are TRIM.FaTE chemical properties.
[b]On this and all following tables, Hg(0) = elemental mercury, Hg(2) = divalent mercury, and MHg = methyl mercury.

Exhibit A-14. PAH Chemical-Specific Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value							
		2Methyl	712DMB	Acenaphthene	Acenaphthylene	BaA	BaP	BbF	BghiP
CAS number	unitless	91-57-6	57-97-6	83-32-9	208-96-8	56-55-3	50-32-8	205-99-2	191-24-2
Diffusion coefficient in pure air	m^2/day	0.451	0.691	0.009	0.388	0.441	0.372	0.009	0.190
Diffusion coefficient in pure water	m^2/day	6.70E-05	6.91E-05	8.64E-05	6.03E-05	7.78E-05	7.78E-05	8.64E-05	4.54E-05
Henry's Law constant	Pa-m^3/mol	50.56	0.20	18.50	12.70	1.22	0.07	0.05	0.03
Melting point	degrees K	307.75	396.65	366.15	365.65	433	452	441	550.15
Molecular weight	g/mol	142.20	256.35	154.21	152.20	228.29	252.32	252.32	276.34
Octanol-water partition coefficient (K_{ow})	L[water]/L[octanol]	7.24E+03	6.31E+05	8.32E+03	1.00E+04	6.17E+05	9.33E+05	6.03E+05	4.27E+06

Parameter Name	Units	Value					
		BkF	Chr	DahA	Fluoranthene	Fluorene	IcdP
CAS number	unitless	207-08-9	218-01-9	53-70-3	206-44-0	86-73-7	193-39-5
Diffusion coefficient in pure air	m^2/day	0.009	0.009	0.009	0.009	0.009	0.009
Diffusion coefficient in pure water	m^2/day	8.64E-05	8.64E-05	8.64E-05	8.64E-05	8.64E-05	8.64E-05
Henry's Law constant	Pa-m^3/mol	0.04	0.53	0.0076	1.96	9.81	0.03
Melting point	degrees K	490	531	539	383.15	383.15	437
Molecular weight	g/mol	252.32	228.29	278.33	202.26	166.20	276.34
Octanol-water partition coefficient (K_{ow})	L[water]/L[octanol]	8.71E+05	5.37E+05	3.16E+06	1.45E+05	1.51E+04	5.25E+06

Exhibit A-14. PAH Chemical-Specific Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Reference
CAS number	unitless	-
Diffusion coefficient in pure air	m^2/day	USEPA 2005. Exceptions include USEPA 1997a (7,12-Dimethylbenz(a)anthracene), and USEPA 2007 (2-Methylnaphthalene, Acenaphthylene, and Benzo(g,h,i)perylene)
Diffusion coefficient in pure water	m^2/day	USEPA 2005. Exceptions include USEPA 1997a (7,12-Dimethylbenz(a)anthracene), and USEPA 2007 (2-Methylnaphthalene, Acenaphthylene, and Benzo(g,h,i)perylene)
Henry's Law constant	Pa-m^3/mol	USEPA 2005. Exceptions include USEPA 2003 (2-Methylnaphthalene) HSDB 2001a (7,12-Dimethylbenz(a)anthracene), HSDB 2001b (Acenaphthylene), and HSDB 2001c (Benzo(g,h,i)perylene)
Melting point	degrees K	Budavari 1996. Exceptions include USEPA 2003 (2-Methylnaphthalene), HSDB 2001a (7,12-Dimethylbenz(a)anthracene), HSDB 2001b (Acenaphthylene), HSDB 2001c (Benzo(g,h,i)perylene), and USEPA 2005 (Acenaphthene, Fluoranthene, and Fluorene)
Molecular weight	g/mol	Budavari 1996. Exceptions include USEPA 2003 (2-Methylnaphthalene), HSDB 2001a (7,12-Dimethylbenz(a)anthracene), HSDB 2001b (Acenaphthylene), HSDB 2001c (Benzo(g,h,i)perylene), and USEPA 2005 (Acenaphthene, Fluoranthene, and Fluorene)
Octanol-water partition coefficient (K_{ow})	L[water]/L[octanol]	Hansch et al. 1995. Exceptions include Passivirta et al. 1999 (Acenaphthylene, Benzo(k)fluoranthene, and Indeno(1,2,3-cd)pyrene), and Sangster 1993 (Benzo(b)fluoranthene)

Exhibit A-15. Dioxin Chemical-Specific Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value						
		1,2,3,4,6,7,8,9-OCDD	1,2,3,4,6,7,8,9-OCDF	1,2,3,4,6,7,8-HpCDD	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	1,2,3,4,7,8-HxCDD	1,2,3,4,7,8-HxCDF
CAS number	unitless	3268-87-9	39001-02-0	35822-46-9	67562-39-4	55673-89-7	39227-28-6	70648-26-9
Diffusion coefficient in pure air	m^2/day	0.751	0.168	0.782	0.176	0.176	0.816	0.183
Diffusion coefficient in pure water	m^2/day	6.91E-05	6.91E-05	6.91E-05	6.91E-05	6.91E-05	6.91E-05	6.91E-05
Henry's Law constant	Pa-m^3/mol	0.684	0.19	1.22	1.43	1.42	1.08	1.45
Melting point	degrees K	603.0	259.0	538.0	236.5	222.0	546.0	499.0
Molecular weight	g/mol	460	443.76	425.2	409.31	409.31	391	374.87
Octanol-water partition coefficient (K_{ow})	L[water]/L[octanol]	1.58E+08	1.00E+08	1.00E+08	2.51E+07	7.94E+06	6.31E+07	1.00E+07

Parameter Name	Units	Value						
		1,2,3,6,7,8-HxCDD	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDD	1,2,3,7,8,9-HxCDF	1,2,3,7,8-PeCDD	1,2,3,7,8-PeCDF	2,3,4,6,7,8-HxCDF
CAS number	unitless	57653-85-7	57117-44-9	19408-74-3	72918-21-9	40321-76-4	57117-41-6	60851-34-5
Diffusion coefficient in pure air	m^2/day	0.816	0.183	0.816	0.183	0.854	0.192	0.183
Diffusion coefficient in pure water	m^2/day	6.91E-05	6.91E-05	6.91E-05	6.91E-05	6.91E-05	6.91E-05	6.91E-05
Henry's Law constant	Pa-m^3/mol	1.11	0.741	1.11	1.11	0.263	0.507	1.11
Melting point	degrees K	558.0	506.0	517.0	509.0	513.0	499.0	512.5
Molecular weight	g/mol	390.84	374.87	390.84	374.87	356.4	340.42	374.87
Octanol-water partition coefficient (K_{ow})	L[water]/L[octanol]	1.62E+08	8.24E+07	1.62E+08	3.80E+07	1.86E+07	6.17E+06	8.31E+07

Exhibit A-15. Dioxin Chemical-Specific Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		2,3,4,7,8-PeCDF	2,3,7,8-TCDD	2,3,7,8-TCDF	
CAS number	unitless	57117-31-4	1746-01-6	51207-31-9	-
Diffusion coefficient in pure air	m^2/day	0.192	0.899	0.203	US EPA 2005
Diffusion coefficient in pure water	m^2/day	6.91E-05	4.84E-05	5.19E-05	US EPA 2005
Henry's Law constant	Pa-m^3/mol	0.505	3.33	1.46	US EPA 2005
Melting point	degrees K	469.3	578.0	500.0	Mackay et al. 2000. Exceptions include USEPA 2000a (1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDF, and 1,2,3,7,8-PeCDD), ATSDR 1998 (1,2,3,6,7,8-HxCDF, 1,2,3,7,8-PeCDF, and 2,3,4,6,7,8-HxCDF), and NLM 2002 (1,2,3,7,8,9-HxCDD)
Molecular weight	g/mol	340.42	322	306	Mackay et al. 2000. Exceptions include ATSDR 1998 (1,2,3,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 1,2,3,7,8-PeCDD, 1,2,3,7,8-PeCDF, and 2,3,4,6,7,8-HxCDF) and NLM 2002 (1,2,3,6,7,8-HxCDD and 1,2,3,7,8,9-HxCDD)
Octanol-water partition coefficient (K_{ow})	L[water]/L[octanol]	3.16E+06	6.31E+06	1.26E+06	Mackay et al. 1992 as cited in USEPA 2000b. Exceptions include Mackay et al. 2000 (1,2,3,4,7,8,9-HpCDF), USEPA 2000a (1,2,3,6,7,8-HxCDD, 1,2,3,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDD, 1,2,3,7,8,9-HxCDF, and 2,3,4,6,7,8-HxCDF), and Sijm et al. 1989 as cited in USEPA 2000b (1,2,3,7,8-PeCDD)

Exhibit A-16. Cadmium Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Air Compartment Type			
Particle dry deposition velocity	m/day	260	Calculated from Muhlbaier and Tissue 1980.
Washout ratio	m^3[air]/m^3[rain]	200,000	MacKay et al. 1986.
Surface Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, Else = yes	0	Assumption.
Root Zone Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, Else = yes	0	Assumption.
Vadose Zone Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, Else = yes	0	Assumption.
Surface Water Compartment Type			
Ratio of concentration in water to concentration in algae to concentration dissolved in water	L[water]/g[algae wet wt]	1.87	McGeer et al. 2003.

Exhibit A-17. Mercury Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Air Compartment Type					
Particle dry deposition velocity	m/day	500	500	500	CalTOX value cited in McKone et al. 2001.
Demethylation rate	1/day	N/A	N/A	0	Assumption.
Methylation rate	1/day	0	0	0	Assumption.
Oxidation rate	1/day	0.00385	0	0	Low end of half-life range (6 months to 2 years) in USEPA 1997b.
Reduction rate	1/day	0	0	0	Assumption.
Washout ratio	m^3[air]/m^3[rain]	200,000	200,000	200,000	Assumption.
Surface Soil Compartment Type					
Use input characteristic depth (Boolean)	0 = no, Else = yes	0	0	0	Assumption.
Soil-water partition coefficient	L[water]/kg[soil wet wt]	1,000	58,000	7,000	USEPA 1997b.
Vapor dry deposition velocity	m/day	50	2500	0	Hg(0) - from Lindberg et al. 1992; Hg(2) - estimate by USEPA using the Industrial Source Complex (ISC) Model - [See Vol. III, App. A of the Mercury Study Report (USEPA 1997b)].
Demethylation rate	1/day	N/A	N/A	0.06	Range reported in Porvari and Verta 1995 is 3E-2 to 6E-2 /day; value is average maximum potential demethylation rate constant under anaerobic conditions.
Methylation rate	1/day	0	0.001	0	Range reported in Porvari and Verta 1995 is 2E-4 to 1E-3 /day; value is average maximum potential methylation rate constant under anaerobic conditions.
Oxidation rate	1/day	0	0	0	Value assumed in USEPA 1997b.
Reduction rate	1/day	0	1.25E-05	0	Value used for untilled surface soil (2cm), 10% moisture content, in USEPA 1997b; general range is (0.0013/day)*moisture content to (0.0001/day)*moisture content for forested region (Lindberg 1996; Carpi and Lindberg 1997).

Exhibit A-17. Mercury Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Root Zone Soil Compartment Type					
Use input characteristic depth (Boolean)	0 = no, Else = yes	0	0	0	Assumption.
Soil-water partition coefficient	L[water]/kg[soil wet wt]	1,000	58,000	7,000	USEPA 1997b.
Demethylation rate	1/day	N/A	N/A	0.06	Range reported in Porvari and Verta 1995 is 3E-2 to 6E-2 /day; value is average maximum potential demethylation rate constant under anaerobic conditions.
Methylation rate	1/day	0	0.001	0	Range reported in Porvari and Verta 1995 is 2E-4 to 1E-3 /day; value is average maximum potential methylation rate constant under anaerobic conditions.
Oxidation rate	1/day	0	0	0	Value assumed in USEPA 1997b.
Reduction rate	1/day	0	3.25E-06	0	Value used for tilled surface soil (20cm), 10% moisture content, in USEPA 1997b (Lindberg 1996; Carpi and Lindberg 1997).
Vadose Zone Soil Compartment Type					
Use input characteristic depth (Boolean)	0 = no, Else = yes	0	0	0	Assumption.
Soil-water partition coefficient	L[water]/kg[soil wet wt]	1,000	58,000	7,000	USEPA 1997b.
Demethylation rate	1/day	N/A	N/A	0.06	Range reported in Porvari and Verta 1995 is 3E-2 to 6E-2 /day; value is average maximum potential demethylation rate constant under anaerobic conditions.
Methylation rate	1/day	0	0.001	0	Range reported in Porvari and Verta 1995 is 2E-4 to 1E-3 /day; value is average maximum potential methylation rate constant under anaerobic conditions.
Oxidation rate	1/day	0	0	0	Value assumed in USEPA 1997b.
Reduction rate	1/day	0	3.25E-06	0	Value used for tilled surface soil (20cm), 10% moisture content, in USEPA 1997b (Lindberg 1996; Carpi and Lindberg 1997).

Exhibit A-17. Mercury Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Groundwater Compartment Type					
Soil-water partition coefficient	L[water]/kg[soil wet wt]	1,000	58,000	7,000	USEPA 1997b.
Demethylation rate	1/day	N/A	N/A	0.06	Range reported in Porvari and Verta 1995 is 3E-2 to 6E-2 /day; value is average maximum potential demethylation rate constant under anaerobic conditions.
Methylation rate	1/day	0	0.001	0	Range reported in Porvari and Verta 1995 is 2E-4 to 1E-3 /day; value is average maximum potential methylation rate constant under anaerobic conditions.
Oxidation rate	1/day	1.00E-08	0	0	Small default nonzero value (0 assumed in USEPA 1997b).
Reduction rate	1/day	0	3.25E-06	0	Value used for tilled surface soil (20cm), 10% moisture content, in USEPA 1997b (Lindberg 1996; Carpi and Lindberg 1997).
Surface Water Compartment Type					
Algal surface area-specific uptake rate constant	nmol/[µm2-day-nmol]	0	2.04E-10	3.60E-10	Assumes radius = 2.5mm, Mason et al. 1995b, Mason et al. 1996; Hg(0) assumed same as Hg(2).
D_{ow} ("overall K_{ow}")	L[water]/kg[octanol]	0	-a	-b	Mason et al. 1996.
Solids-water partition coefficient	L[water]/kg[solids wet wt]	1,000	100,000	100,000	USEPA 1997b.
Vapor dry deposition velocity	m/day	N/A	2500		USEPA 1997b (Vol. III, App. A).
Demethylation rate	1/day	N/A	N/A	0.013	Average range of 1E-3 to 2.5E-2/day from Gilmour and Henry 1991.
Methylation rate	1/day	0	0.001	0	Value used in EPA 1997; range is 1E-4 to 3E-4/day (Gilmour and Henry 1991).
Oxidation rate	1/day	0	0	0	Assumption.
Reduction rate	1/day	0	0.0075	0	Value used in USEPA 1997b; reported values range from less than 5E-3/day for depths greater than 17m, up to 3.5/day (Xiao et al. 1995; Vandal et al. 1995; Mason et al. 1995a; Amyot et al. 1997).

Exhibit A-17. Mercury Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Sediment Compartment Type					
Solids-water partition coefficient	L[water]/kg[solids wet wt]	3,000	50,000	3,000	USEPA 1997b.
Demethylation rate	1/day	N/A	N/A	0.0501	Average range of 2E-4 to 1E-1/day from Gilmour and Henry 1991.
Methylation rate	1/day	0	1.00E-04	0	Value used in EPA 1997b; range is 1E-5 to 1E-3/day, Gilmour and Henry 1991.
Oxidation rate	1/day	0	0	0	Assumption.
Reduction rate	1/day	0	1.00E-06	0	Inferred value based on presence of Hg(0) in sediment porewater (USEPA 1997b; Vandal et al. 1995).

[a]TRIM.FaTE Formula Property, which varies from 0.025 to 1.625 depending on pH and chloride concentration.
[b]TRIM.FaTE Formula Property, which varies from 0.075 to 1.7 depending on pH and chloride concentration.

Exhibit A-18. PAH Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value								
		2Methyl	712DMB	Acenaph-thene	Acenaph-thylene	BaA	BaP	BbF	BghiP	BkF
Air Compartment Type										
Particle dry deposition velocity	m/day	500	500	500	500	500	500	500	500	500
Half-life	day	0.154	0.092	0.3	0.208	0.125	0.046	0.596	0.215	0.458
Washout ratio		200000	200000	200000	200000	200000	200000	200000	200000	200000
Surface Soil Compartment Type										
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0	0	0	0
Half-life	day	18	24	56	66.5	680	530	610	415	2140
Root Zone Soil Compartment Type										
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0	0	0	0
Half-life	day	18	24	56	66.5	680	530	610	415	2140
Vadose Zone Soil Compartment Type										
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0	0	0	0
Half-life	day	36	48	112	133	1360	1060	1220	830	4280
Groundwater Compartment Type										
Half-life	day	36	48	112	133	1360	1060	1220	830	4280
Surface Water Compartment Type										
Ratio Of Conc In Algae To Conc Dissolved In Water	(g[chem]/kg[algae]) / (g[chem]/L[water])	2.6	333.4	3	3.7	325	510	317	1539	473
Half-life	day	78	216	25	184	0.375	0.138	90	1670	62.4
Sediment Compartment Type										
Half-life	day	2290	2290	2290	2290	2290	2290	2290	2290	2290

Exhibit A-18. PAH Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluor-ene	IcdP	
Air Compartment Type							
Particle dry deposition velocity	m/day	500	500	500	500	500	McKone et al. 2001.
Half-life	day	0.334	0.178	0.46	0.46	0.262	Howard et al. 1991 / upper bound measured or estimated value. Exceptions include ATSDR 2005 (2-Methylnaphthalene), USEPA 1998 (7,12-Dimethylbenz(a)anthracene, Benzo(g,h,i)perylene, and Fluoranthene) / average of range, HSDB 2001d (Acenaphthene), HSDB 2001b (Acenaphthylene), and Spero et al. 2000 (Fluorene).
Washout ratio		200000	200000	200000	200000	200000	Mackay et al. 1986.
Surface Soil Compartment Type							
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	Assumption.
Half-life	day	1000	940	275	33	730	MacKay et al. 2000 / average of range. Exceptions include ATSDR 2005 (2-Methylnaphthalene), USEPA 1998 (7,12-Dimethylbenz(a)anthracene, Benzo(g,h,i)perylene, and Fluoranthene) / average of range, HSDB 2001d (Acenaphthene), HSDB 2001b (Acenaphthylene), and HSDB 2001e (Fluorene).
Root Zone Soil Compartment Type							
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	Assumption.
Half-life	day	1000	940	275	33	730	Howard et al. 1991 / upper bound measured or estimated value. Exceptions include ATSDR 2005 (2-Methylnaphthalene), USEPA 1998 (7,12-Dimethylbenz(a)anthracene, Benzo(g,h,i)perylene, and Fluoranthene) / average of range, HSDB 2001d (Acenaphthene), HSDB 2001b (Acenaphthylene), and HSDB 2001e (Fluorene).
Vadose Zone Soil Compartment Type							
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	Assumption.

Exhibit A-18. PAH Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluora n-thene	Fluor-ene	IcdP	
Vadose Zone Soil Compartment Type, continued							
Half-life	day	2000	1880	550	66	1460	Howard et al. 1991 / upper bound measured or estimated value. Exceptions include ATSDR 2005 (2-Methylnaphthalene), USEPA 1998 (7,12-Dimethylbenz(a)anthracene, Benzo(g,h,i)perylene, and Fluoranthene) / twice average of range, HSDB 2001d (Acenaphthene) / multiplied by 2, HSDB 2001b (Acenaphthylene) / multiplied by 2, and HSDB 2001e (Fluorene) / multiplied by 2.
Groundwater Compartment Type							
Half-life	day	2000	1880	550	66	1460	Howard et al. 1991 / upper bound measured or estimated value. Exceptions include ATSDR 2005 (2-Methylnaphthalene), USEPA 1998 (7,12-Dimethylbenz(a)anthracene, Benzo(g,h,i)perylene, and Fluoranthene) / twice average of range, HSDB 2001d (Acenaphthene) / multiplied by 2, HSDB 2001b (Acenaphthylene) / multiplied by 2, and HSDB 2001e (Fluorene) / multiplied by 2.
Surface Water Compartment Type							
RatioOfConcInAlgaeToConcDissolvedInWater	(g[chem]/kg[algae])/(g[chem]/L[water])	280	1388	67.4	5.8	1653	K_{ow} from Del Vento and Dachs 2002.
Half-life	day	1.626	97.8	160	8.5	750	Howard et al. 1991 / upper bound measured or estimated value. Exceptions include HSDB 2005 (2-Methylnaphthalene), HSDB 2001a (7-12 Dimethylbenz(a)anthracene), HSDB 2001d (Acenaphthene), HSDB 2001b (Acenaphthylene), and HSDB 2001c (Benzo(g,h,i)perylene), Montgomery 2000 (Fluoranthene), and Boyle 1985 (Fluorene).
Sediment Compartment Type							
Half-life	day	2290	2290	2290	2290	2290	Mackay et al. 1992 / PAH values are the mean half-life of the log class that Mackay et al. assigned for sediment, except for BbF and IcdP, which were not in Table 2.3 of Mackay et. al.

Exhibit A-19. Dioxin Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					
		1,2,3,4,6,7,8,9-OCDD	1,2,3,4,6,7,8,9-OCDF	1,2,3,4,6,7,8-HpCDD	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	1,2,3,4,7,8-HxCDD
Air Compartment Type							
Deposition Velocity	m/day	500	500	500	500	500	500
Half-life	day	162	321	64	137	122	42
Washout Ratio	m^3[air]/m^3[rain]	91000	22000	64000	32000	32000	9000
Surface Soil Compartment Type							
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0
Halflife	day	3650	3650	3650	3650	3650	3650
Root Zone Soil Compartment Type							
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth	0 = No, Else = Yes	0	0	0	0	0	0
Half-life	day	3650	3650	3650	3650	3650	3650
Vadose Zone Soil Compartment Type							
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0
Half-life	day	1008	1008	1008	1008	1008	1008
Groundwater Compartment Type							
Half-life	day	1008	1008	1008	1008	1008	1008
Surface Water Compartment Type							
Ratio Of Conc In Algae To Conc Dissolved In Water	(g[chem]/g[algae])/ (g[chem]/L[water])	5.31	4.54	4.54	2.83	1.9	3.88
Half-life	day	0.67	0.58	47	0.58	0.58	6.3
Sediment Compartment Type							
Half-life	day	1095	1095	1095	1095	1095	1095

Exhibit A-19. Dioxin Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					
		1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDD	1,2,3,6,7,8-HxCDF	1,2,3,7,8,9-HxCDD	1,2,3,7,8,9-HxCDF	1,2,3,7,8-PeCDD
Air Compartment Type							
Deposition velocity	m/day	500	500	500	500	500	500
Half-life	day	78	28	55	28	51	18
Washout ratio	m^3[air]/m^3[rain]	10000	9000	10000	9000	10000	18000
Surface Soil Compartment Type							
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0
Half-life	day	3650	3650	3650	3650	3650	3650
Root Zone Soil Compartment Type							
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth	0 = No, Else = Yes	0	0	0	0	0	0
Half-life	day	3650	3650	3650	3650	3650	3650
Vadose Zone Soil Compartment Type							
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	0
Half-life	day	1008	1008	1008	1008	1008	1008
Groundwater Compartment Type							
Half-life	day	1008	1008	1008	1008	1008	1008
Surface Water Compartment Type							
Ratio Of Conc In Algae To Conc Dissolved In Water	(g[chem]/g[algae])/ (g[chem]/L[water])	2.06	5.36	4.25	5.36	3.26	1.55
Half-life	day	0.58	6.3	0.58	6.3	0.58	2.7
Sediment Compartment Type							
Half-life	day	1095	1095	1095	1095	1095	1095

Exhibit A-19. Dioxin Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value				
		1,2,3,7,8-PeCDF	2,3,4,6,7,8-HxCDF	2,3,4,7,8-PeCDF	2,3,7,8-TCDD	2,3,7,8-TCDF
Air Compartment Type						
Deposition velocity	m/day	500	500	500	500	500
Half-life	day	31	59	33	12	19
Washout ratio	m^3[air]/m^3[rain]	13000	10000	14000	18000	19000
Surface Soil Compartment Type						
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0
Half-life	day	3650	3650	3650	3650	3650
Root Zone Soil Compartment Type						
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth	0 = No, Else = Yes	0	0	0	0	0
Half-life	day	3650	3650	3650	3650	3650
Vadose Zone Soil Compartment Type						
Input characteristic depth	m	0.08	0.08	0.08	0.08	0.08
Use input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0
Half-life	day	1008	1008	1008	1008	1008
Groundwater Compartment Type						
Half-life	day	1008	1008	1008	1008	1008
Surface Water Compartment Type						
Ratio Of Conc In Algae To Conc Dissolved In Water	(g[chem]/g[algae])/ (g[chem]/L[water])	1.75	4.26	1.39	1.76	0.71
Half-life	day	0.19	0.58	0.19	2.7	0.18
Sediment Compartment Type						
Half-life	day	1095	1095	1095	1095	1095

Exhibit A-19. Dioxin Chemical-Specific Parameters for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Reference
Air Compartment Type	
Deposition velocity	McKone et al. 2001.
Half-life	Atkinson 1996 as cited in USEPA 2000b; vapor phase reaction with hydroxyl radical.
Washout ratio	Vulykh et al. 2001.
Surface Soil Compartment Type	
Input characteristic depth	Not used (model set to calculate value).
Use input characteristic depth (Boolean)	Assumption.
Half-life	Mackay et al. 2000; the degradation rate was cited by multiple authors, value is for 2,3,7,8-TCDD.
Root Zone Soil Compartment Type	
Input characteristic depth	Not used (model set to calculate value).
Use input characteristic depth	Assumption.
Half-life	Mackay et al. 2000; the degradation rate was cited by multiple authors, value is for 2,3,7,8-TCDD.
Vadose Zone Soil Compartment Type	
Input characteristic depth	Not used (model set to calculate value).
Use input characteristic depth (Boolean)	Assumption.
Half-life	Average value of the range presented in Mackay et al. 2000; based on estimated unacclimated aerobic biodegradation half-life, value is for 2,3,7,8-TCDD.
Groundwater Compartment Type	
Half-life	Average value of the range presented in Mackay et al. 2000; based on estimated unacclimated aerobic biodegradation half-life, value is for 2,3,7,8-TCDD.
Surface Water Compartment Type	
Ratio Of Conc In Algae To Conc Dissolved In Water	Estimated from K_{ow} value using model from DelVento and Dachs 2002
Half-life	Kim and O'Keefe 1998, as cited in USEPA 2000b.
Sediment Compartment Type	
Half-life	Estimation based on Adriaens and Grbic-Galic 1992,1993 and Adriaens et al. 1995 as cited in USEPA 2000b.

Exhibit A-20. Cadmium Chemical-Specific Parameters for Plant Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Leaf Compartment Type			
Transfer factor to leaf particle	1/day	0.002	Assumption.
Particle on Leaf Compartment Type			
Transfer factor to leaf	1/day	0.200	Assumption.
Root Compartment Type - Grasses and Herbs[a]			
Root to Root Soil Partition-Alpha of Steady State	unitless	0.95	Henning et al. 2001.
Root to Root Soil Partition-Partitioning Coefficient	m^3[bulk root soil]/m^3[root]	0.23	Nriagu 1980; based on average value calculated from various agricultural plant species.
Root to Root Soil Partition-Time to Reach Alpha	day	28	Henning et al. 2001.
Stem Compartment Type - Grasses and Herbs[a]			
Transpiration stream concentration factor (TSCF)	m^3[soil pore water]/m^3[xylem fluid]	0.45	Tsiros et al. 1999.

[a]Roots and stems are not modeled for deciduous or coniferous forest in the current version of TRIM.FaTE.

Exhibit A-21. Mercury Chemical-Specific Parameters for Plant Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Leaf Compartment Type					
Transfer factor to leaf particle	1/day	0.002	0.002	0.002	Assumed based on 1% of transfer factor from leaf particle to leaf.
Demethylation rate	1/day	N/A	N/A	0.03	Calculated from Bache et al. 1973.
Methylation rate	1/day	0	0	0	Assumed from Gay 1975, Bache et al. 1973.
Oxidation rate	1/day	1.0E+06	0	0	Assumed to be nearly instantaneous
Reduction rate	1/day	0	0	0	Assumption.
Particle on Leaf Compartment Type					
Transfer factor to leaf	1/day	0.2	0.2	0.2	Assumption.
Demethylation rate	1/day	N/A	N/A	0	Assumption.
Methylation rate	1/day	0	0	0	Assumption.
Oxidation rate	1/day	0	0	0	Assumption.
Reduction rate	1/day	0	0	0	Assumption.
Root Compartment Type - Grasses and Herbs[a]					
Alpha for root-root zone bulk soil	unitless	0.95	0.95	0.95	Selected value.
Root/root-zone-soil-water partition coefficient	m^3[bulk root soil]/ m^3[root]	0	0.18	1.2	Hg^{2-} geometric mean Leonard et al. 1998, John 1972, Hogg et al. 1978; MHg-assumed, based on Hogg et al. 1978.
t-alpha for root-root zone bulk soil	day	21	21	21	Assumption.
Demethylation rate	1/day	N/A	N/A	0	Assumption.
Methylation rate	1/day	0	0	0	Assumption.
Oxidation rate	1/day	0	0	0	Assumption.
Reduction rate	1/day	0	0	0	Assumption.
Stem Compartment Type - Grasses and Herbs[a]					
Transpiration stream concentration factor (TSCF)	m^3[soil pore water]/m^3[xylem fluid]	0	0.5	0.2	Calculation from Norway spruce, Scots pine, Bishop et al. 1998.
Demethylation rate	1/day	N/A	N/A	0.03	Calculated from Bache et al. 1973.
Methylation rate	1/day	0	0	0	Assumption.
Oxidation rate	1/day	0	0	0	Assumption.
Reduction rate	1/day	0	0	0	Assumption.

[a]Roots and stems are not modeled for deciduous or coniferous forest in the current version of TRIM.FaTE.

Exhibit A-22. PAH Chemical-Specific Parameters for Plant Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value								
		2Methyl	712DMB	Acenaph-thene	Acenaph-thylene	BaA	BaP	BbF	BghiP	BkF
Leaf Compartment Type										
Transfer factor to leaf particle	1/day	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Half-life	day	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Particle on Leaf Compartment Type										
Transfer factor to leaf	1/day	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Half-life	day	2.31	2.31	2.31	2.31	1.84	2.31	3.56	2.31	17.80
Root Compartment Type - Grasses and Herbs[a]										
Half-life	day	34.60	34.60	34.60	34.60	34.60	34.60	34.60	34.60	34.60
Root soil-water interaction - alpha	unitless	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Stem Compartment Type - Grasses and Herbs[a]										
Half-life	day	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50

[a]Roots and stems are not modeled for deciduous or coniferous forest in the current version of TRIM.FaTE.

Exhibit A-23. PAH Chemical-Specific Parameters for Plant Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluorene	IcdP	
Leaf Compartment Type							
Transfer factor to leaf particle	1/day	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	Assumption.
Half-life	day	3.50	3.50	3.50	3.50	3.50	Edwards 1988 (calculated from metabolic rate constant).
Particle on Leaf Compartment Type							
Transfer factor to leaf	1/day	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	Assumption.
Half-life	day	4.12	17.80	2.31	2.31	17.80	Calculated as 2 times the measured photolysis half-life from Mackay et al. 1992. Exceptions include values that have been set equal to Benzo(a)pyrene (2-Methylnaphthalene; 7,12-Dimethylbenz(a)anthracene; Acenaphthene; Acenaphthylene; Benzo(ghi)perylene; Fluoranthene; and Fluorene).
Root Compartment Type - Grasses and Herbs[a]							
Half-life	day	34.60	34.60	34.60	34.60	34.60	Edwards 1988 (calculated from metabolic rate constant).
Root soil water interaction - alpha	unitless	0.95	0.95	0.95	0.95	0.95	Assumption.
Stem Compartment Type - Grasses and Herbs[a]							
Half-life	day	3.50	3.50	3.50	3.50	3.50	Edwards 1988 (calculated from metabolic rate constant).

[a]Roots and stems are not modeled for deciduous or coniferous forest in the current version of TRIM.FaTE.

Exhibit A-23. Dioxin Chemical-Specific Parameters for Plant Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
		All Dioxins	
Leaf Compartment Type			
Transfer factor to leaf particle	1/day	0.003	Calculated as 1 percent of transfer factor to leaf; highly uncertain.
Half-life	day	70	Arjmand and Sandermann 1985, as cited in Komoba et al. 1995; soybean root cell culture metabolism test data for DDE.
Particle on Leaf Compartment Type			
Transfer factor to leaf	1/day	0.3	Assumption based on USEPA 2000b (an estimate for mercury) and Trapp 1995; highly uncertain.
Half-life	day	4.4	McCrady and Maggard 1993; photodegradation sorbed to grass foliage in sunlight; assumed 10% sunlight per day.
Root Compartment Type - Grasses and Herbs[a]			
Half-life	day	70	Arjmand and Sandermann 1985, as cited in Komoba et al. 1995; soybean root cell culture metabolism test data for DDE.
Root soil-water interaction - alpha	unitless	0.95	Assumption.
Stem Compartment Type - Grasses and Herbs[a]			
Half-life	day	70	Arjmand and Sandermann 1985, as cited in Komoba et al. 1995; soybean root cell culture metabolism test data for DDE.

[a]Roots and stems are not modeled for deciduous or coniferous forest in the current version of TRIM.FaTE.

Exhibit A-24. Cadmium Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Zooplankton Compartment Type			
Absorption rate constant	L[water]/kg[fish wet wt]-day	1500	Goulet 2007.
Assimilation efficiency from algae	unitless	0.5	Goulet 2007.
Elimination rate constant	1/day	0.03	Goulet 2007.
Benthic Invertebrate Compartment Type			
Sediment partitioning - alpha of equilibrium	unitless	0.95	Assumption.
Sediment partitioning - partition coefficient	kg[bulk sed/kg[invertebrate wet wt]	0.27	Assumption.
Sediment partitioning - time to reach alpha of equilibrium	day	21	Hare et al. 2001.
Benthic Omnivore Compartment Type			
Assimilation efficiency from food	unitless	0.1	Assumption based on Yan and Wang 2002.
Absorption rate constant	unitless	1.23	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.73E-02	Assumption.
Benthic Carnivore Compartment Type			
Assimilation efficiency from food	unitless	0.1	Assumption based on Yan and Wang 2002.
Absorption rate constant	unitless	0.66	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.68E-03	Assumption.
Water-column Herbivore Compartment Type			
Assimilation efficiency from food	unitless	0.1	Assumed value based on Yan and Wang 2002.
Assimilation efficiency from plants	unitless	0.1	Assumed value based on Yan and Wang 2002.
Absorption rate constant	unitless	2.46	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.73E-02	Assumption.

Exhibit A-24. Cadmium Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Water-column Omnivore Compartment Type			
Assimilation efficiency from food	unitless	0.1	Assumption based on Yan and Wang 2002.
Assimilation efficiency from plants	unitless	0.1	Assumption based on Yan and Wang 2002.
Absorption rate constant	unitless	1.23	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.73E-02	Assumption.
Water-column Carnivore Compartment Type			
Assimilation efficiency from food	unitless	0.1	Assumption based on Yan and Wang 2002.
Absorption rate constant	unitless	0.66	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.73E-02	Assumption

Exhibit A-25. Mercury Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Zooplankton Compartment Type					
Assimilation Efficiency From Algae	unitless	0.2	0.015	0.5	Environment Canada 2002.
Half-life	day	1.0E+09	1.0E+09	1.0E+09	Assumption.
How Much Faster Hg Elimination Is Than For MHg	unitless	3	3	1	Assumption.
Methylation rate	1/day	0	0	0	Assumption.
Oxidation rate	1/day	0	1.0E+06	0	Assumption.
Reduction rate	1/day	0	0	0	Assumption.
Benthic Invertebrate Compartment Type					
Alpha of equilibrium for sediment partitioning	unitless	0.95	0.95	0.95	Selected value (i.e., proportion of equilibrium achieved by time “t”).
Benthic invertebrate-bulk sediment partition coefficient	kg[bulk sediment]/kg[invertebrate wet wt]	0.0824	0.0824	5.04	Hg(0) - assumed based on Hg(2) value; Hg(2) and MHg - Saouter et al. 1991.
t-alpha for equilibrium for sediment partitioning	day	14	14	14	Experiment duration from Saouter et al. 1991.
All Fish Compartments Types[a]					
Elimination adjustment factor	unitless	3	3	1	Trudel and Rasmussen 1997.
Assimilation efficiency from food	unitless	0.06	0.06	0.5	Williams et al. 2010.
Demethylation rate	1/day	N/A	N/A	0	Assumption.
Methylation rate	1/day	0	0	0	Assumption.
Oxidation rate	1/day	1.0E+06	0	0	Assumption.
Reduction rate	1/day	0	0	0	Assumption.
Water-column Herbivore Compartment Type					
Assimilation efficiency from plankton	unitless	0.06	0.06	0.5	Williams et al. 2010.

[a]Screening scenario includes: Benthic Omnivore, Benthic Carnivore, Water-column Herbivore, Water-column Omnivore, and Water-column Carnivore.

Exhibit A-26. PAH Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value								
		2Methyl	712DMB	Acenaph-thene	Acenaph-thylene	BaA	BaP	BbF	BghiP	BkF
Zooplankton Compartment Type										
Absorption rate constant	L[water]/kg[fish wet wt]-day	790	42650.94	42231	42302.18	42650.81	42652.78	42650.68	42655.77	42652.5
Assimilation efficiency from algae	unitless	0.5	0.25	0.5	0.5	0.46	0.25	0.25	0.25	0.25
Elimination rate constant	1/day	169.68	2.03	148.07	123.44	2.073	1.3864	2.12	0.33	1.48
Half-life	day	0.007788	17	0.00239	0.00239	1.284	16.5	17	17	17
Benthic Invertebrate Compartment Type										
Clearance constant	unitless	100.6	100.6	100.6	100.6	100.6	100.6	100.6	100.6	100.6
V_d (ratio of concentration in benthic invertebrates to concentration in water)	ml/g	7235	7235	7235	7235	7235	7235	7235	7235	7235
Half-life	day	0.722	17	0.722	0.722	1.284	16.5	17	17	17
All Fish Compartment Types[a]										
Gamma fish	unitless	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Assimilation efficiency from food	unitless	0.5	0.15	0.5	0.32	0.15	0.15	0.15	0.15	0.15
Half-life	day	0.2	2	0.2	0.2	0.408	1.925	2	2	2

[a]Screening scenario includes: Benthic Omnivore, Benthic Carnivore, Water-column Herbivore, Water-column Omnivore, and Water-column Carnivore.

Exhibit A-26. PAH Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluorene	IcdP	
Zooplankton Compartment Type							
Absorption rate constant	L[water]/kg[fish wet wt]-day	42649.95	42655.48	142000	15000	42655.93	K_{ow} from Arnot et al. 2004. Exception is Berrojalbiz et al. 2009 (2-Methylnaphthalene, Fluoranthene, and Fluorene).
Assimilation efficiency from algae	unitless	0.46	0.25	0.49	0.5	0.25	K_{ow} from Arnot et al. 2004. Exception is maximum value from Wang and Wang 2006 (7,12-Dimethylbenz(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Dibenz(a,h)anthracene, and Indeno(1,2,3-cd)pyrene).
Elimination rate constant	1/day	2.3746	0.4331	8.678	81.87	0.269	K_{ow} from Arnot et al. 2004.
Half-life	day	0.495	17	0.00239	0.0002476	17	McElroy 1990. Exceptions include Berrojalbiz et al. 2009 (2-Methylnaphthalene, Fluoranthene, and Fluorene) and Moermond et al. 2007 (Benz(a)anthracene and Benzo(a)pyrene).
Benthic Invertebrate Compartment Type							
Clearance constant	unitless	100.6	100.6	100.6	100.6	100.6	Stehly et al. 1990.
V_d (ratio of concentration in benthic invertebrates to concentration in water)	ml/g	7235	7235	7235	7235	7235	Stehly et al. 1990.
Half-life	day	0.495	17	0.722	0.722	17	Moermond et al. 2007.

Exhibit A-26. PAH Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluorene	IcdP	
All Fish Compartment Types[a]							
Gamma fish	unitless	0.2	0.2	0.2	0.2	0.2	Thomann 1989.
Assimilation efficiency from food	unitless	0.15	0.15	0.14	0.14	0.15	Lemair et al. 1992. Exceptions include Barber 2008 (2-Methylnaphthalene and Acenaphthene) and Niimi and Palazzo 1986 (Acenaphthylene, Fluoranthene, and Fluorene).
Half-life	day	0.533	2	0.165	0.2	2	Moermond et al. 2007.

[a]Screening scenario includes: Benthic Omnivore, Benthic Carnivore, Water-column Herbivore, Water-column Omnivore, and Water-column Carnivore.

Exhibit A-27. Dioxin Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value								
		1,2,3,4,6,7,8,9-OCDD	1,2,3,4,6,7,8,9-OCDF	1,2,3,4,6,7,8-HpCDD	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	1,2,3,4,7,8-HxCDD	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDD	1,2,3,6,7,8-HxCDF
Zooplankton Compartment										
Absorption rate constant	L[water]/kg[fish wet wt]-day	8640	8640	8640	8640	8640	8640	8640	8640	8640
Assimilation efficiency from algae	unitless	0.08	0.05	0.21	0.09	0.2	0.31	0.31	0.31	0.31
Elimination rate constant	1/day	0.0102	0.016	0.016	0.0616	0.1829	0.0252	0.1474	0.0099	0.0194
Half-life	day	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06
Benthic Invertebrate Compartment										
Clearance constant	unitless	0	0	0	0	0	0	0	0	0
Sediment partitioning partition coefficient	kg/kg	0.0013	0.0017	0.0055	0.0012	0.042	0.033	0.0081	0.013	0.02
Sediment partitioning alpha of equilibrium	unitless	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Sediment partitioning time to reach alpha of equilibrium	days	120	42	120	42	42	120	42	120	42
V_d (ratio of concentration in benthic invertebrates to concentration in water)	ml/g	0	0	0	0	0	0	0	0	0
Half-life	day	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2
All Fish Compartments[a]										
Assimilation efficiency from food	unitless	0.08	0.05	0.21[b]	0.09	0.2	0.31[c]	0.31	0.31	0.31
Chemical uptake rate via gill	L[water]/kg[fish wet wt]-day	11	6	56	25	50	102	200	300	200
Half-life	day	70	70	70	70	70	70	70	70	70

Exhibit A-27. Dioxin Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value							
		1,2,3,7,8,9-HxCDD	1,2,3,7,8,9-HxCDF	1,2,3,7,8-PeCDD	1,2,3,7,8-PeCDF	2,3,4,6,7,8-HxCDF	2,3,4,7,8-PeCDF	2,3,7,8-TCDD	2,3,7,8-TCDF
Zooplankton Compartment									
Absorption Rate Constant	L[water]/kg[fish wet wt]-day	8640	8640	8640	8640	8640	8640	8640	8640
Assimilation Efficiency from Algae	unitless	0.31	0.31	0.42	0.42	0.31	0.42	0.41	0.51
Elimination Rate Constant	1/day	0.0099	0.0413	0.0819	0.2316	0.0192	0.4331	0.2268	1.0375
Half-life	day	7E+06	7E+06	7E+06	7E+06	7E+08	7E+08	7E+06	7E+08
Benthic Invertebrate Compartment									
Clearance Constant	unitless	0	0	0	0	0	0	0	0
Sediment Partitioning Partition Coefficient	kg/kg	0.015	0.067	0.098	0.024	0.072	0.17	0.205	0.056
Sediment Partitioning Alpha of Equilibrium	unitless	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Sediment Partitioning Time to Reach Alpha of Equilibrium	days	120	42	120	42	42	42	120	42
V_d (ratio of concentration in benthic invertebrates to concentration in water)	ml/g	0	0	0	0	0	0	0	0
Half-life	day	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2	5776.2
All Fish Compartments[a]									
Assimilation efficiency from food	unitless	0.31	0.31	0.42	0.42	0.31	0.42	0.41	0.51
Chemical uptake rate via gill	L[water]/kg[fish wet wt]-day	300	200	700	300	200	400	600	400
Half-life	day	70	70	70	70	70	70	70	70

Exhibit A-27. Dioxin Chemical-Specific Parameters for Aquatic Species in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Reference
Zooplankton Compartment		
Absorption rate constant	L[water]/kg[fish wet wt]-day	Zhang et al. 2011; used copepod k_u value.
Assimilation efficiency from algae	unitless	Morrison et al. 1999. Exceptions include Niimi and Oliver 1986 (1,2,3,4,6,7,8,9-OCDD, 1,2,3,4,6,7,8,9-OCDF), Berntssen et al. 2007 (1,2,3,4,6,7,8-HpCDD, 1,2,3,4,6,7,8-HpCDF), and 1,2,3,4,7,8,9-HpCDF set conservatively as approximate linear interpolation between values for 1,2,3,4,7,8-HxCDD and 1,2,3,4,6,7,8-HpCDD / 1,2,3,4,6,7,8-HpCDF (i.e., 0.3 to 0.1–0.2).
Elimination rate constant	1/day	Arnot and Gobas 2004; used K_{ow} value.
Half-life	day	Morrison et al. 1999; used metabolic rates for invertebrates.
Benthic Invertebrate Compartment		
Clearance constant	unitless	Assumption.
Sediment partitioning partition coefficient	kg/kg	Rubinstein et al. 1990; used TCDD data for sandworm.
Sediment partitioning alpha of equilibrium	unitless	Rubinstein et al. 1990.
Sediment Partitioning Time to Reach Alpha of Equilibrium	days	Rubinstein et al. 1990.
V_d (ratio of concentration in benthic invertebrates to concentration in water)	ml/g	Assumption.
Half-life	day	Rubinstein et al. 1990; used TCDD data for sandworm.
All Fish Compartmentsa		
Assimilation Efficiency from Food	unitless	Morrison et al. 1999. Exceptions include Niimi and Oliver 1996 (1,2,3,4,6,7,8,9-OCDD, 1,2,3,4,6,7,8,9-OCDF), Van den Berg et al. 1994 (1,2,3,4,6,7,8-HpCDD), Berntssen et al. 2007 (1,2,3,4,6,7,8-HpCDF), and 1,2,3,4,7,8,9-HpCDF set conservatively as approximate linear interpolation between values for 1,2,3,4,7,8-HxCDD and 1,2,3,4,6,7,8-HpCDD / 1,2,3,4,6,7,8-HpCDF (i.e., 0.3 to 0.1–0.2).
Chemical Uptake Rate Via Gill	L[water]/kg[fish wet wt]-day	Muir et al. 1985. Exception is Opperhuizen et al. 1986 (1,2,3,7,8,9-HxCDF, 1,2,3,7,8-PeCDD, 1,2,3,7,8-PeCDF, 2,3,4,7,8-PeCDF, 2,3,7,8-TCDD, 2,3,7,8-TCDF).
Half-life	day	Berntssen et al. 2007.

[a]Screening scenario includes: Benthic Omnivore, Benthic Carnivore, Water-column Herbivore, Water-column Omnivore, and Water-column Carnivore.
[b]0.21 used for benthic omnivore, water column omnivore, and water column herbivore; 0.13 used for benthic carnivore and water column carnivore.
[c]0.31 used for benthic omnivore, water column omnivore, benthic carnivore, and water column carnivore; 0.37 used for water column herbivore.

References

Adriaens, P., Q. Fu, and D. Grbic-Galic. 1995. Bioavailability and transformation of highly chlorinated dibenzo-p-dioxins and dibenzofurans in anaerobic soils and sediments. *Environmental Science and Technology* 29(9): 2252-2260.

Adriaens, P., and D. Grbic-Galic. 1993. Reductive dechlorination of PCDD/F by anaerobic cultures and sediments. *Organohalogen Compounds* 12: 107-110.

Adriaens, P., and D. Grbic-Galic. 1992. Effect of cocontaminants and concentration on the anaerobic biotransformation of PCDD/F in methanogenic river sediments. *Organohalogen Compounds* 8: 209-212.

ATSDR (Agency for Toxic Substances and Disease Registry). 2005. Toxicological profile for naphthalene,1-methylnaphthalene, and 2-methylnaphthalene. Available at: http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=240&tid=43.

ATSDR. 1999. Toxicological profile for cadmium. Available at http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=48&tid=15.

ATSDR. 1998. Toxicological profile for chlorodibenzo-p-dioxins (CDDs). Available at: http://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=938&tid=194.

Ambrose, R.A., Jr., T.A. Wool, and J.L. Martin. 1995. The water quality analysis simulation program, WASP5, Part A: Model documentation. Athens, GA: U.S. EPA National Exposure Research Laboratory, Ecosystems Division.

APHA (American Public Health Association). 1995. Standard methods for the examination of water and waste water. Washington, DC.

Amyot, M., D. Lean, and G. Mierle. 1997. Photochemical formation of volatile mercury in high arctic lakes. *Environmental Toxicology and Chemistry* 16(10):2054-2063.

Arjmand, M., and H. Sandermann. 1985. Metabolism of DDT and related compounds in cell suspension cultures of soybean (*Glycine max* L.) and wheat (*Tritucum aestivum* L.) *Pesticide Biochemistry and Physiology* 23:389.

Arnot, J., and F.A. Gobas. 2004. A food web bioaccumulation model for organic chemicals in aquatic ecosystems. *Environmental Toxicology and Chemistry* 23(10):2343-2355.

Atkinson, R. 1996. Atmospheric chemistry of PCBs, PCDDs and PCDFs. *Issues in Environmental Science and Technology* 6: 53-72.

Bache, C.A., W.J. Gutenmann, L.E. St. John, Jr., R.D. Sweet, H.H. Hatfield, and D.J. Lisk. 1973. Mercury and methylmercury content of agricultural crops grown on soils treated with various mercury compounds. *Journal of Agricultural and Food Chemistry* 21:607-613.

Baes, C.F., III, R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. A review and analysis of parameters for assessing transport of environmentally released radionuclides through agriculture. ORNL-5786. Oak Ridge National Laboratory, Oak Ridge, TN.

Barber, M.C. 2008. Dietary uptake models used for modeling the bioaccumulation of organic contaminants in fish. *Environmental Toxicology and Chemistry* 27(4):755-777.

Berntssen, M.H.G., T.A. Giskegjerde, G. Rosenlund, B.E. Torstensen, and A.K. Lundebye. 2007. Predicting world health organization toxic equivalency factor dioxin and dioxin-like polychlorinated biphenyl levels in farmed Atlantic salmon (*Salmo salar*) based on known levels in feed. *Environmental Toxicology and Chemistry* 26(1):13-23. doi: 10.1897/06-122r.1.

Berrojalbiz, N., S. Lacorte, A. Calbet, E. Saiz, C. Barata, and J. Dachs. 2009. Accumulation and cycling of polycyclic aromatic hydrocarbons in zooplankton. *Environmental Science and Technology* 43(7):2295-2301. doi: 10.1021/es8018226.

Bidleman, T.F. 1988. Atmospheric processes. *Environmental Science and Technology* 22:361-367.

Bishop, K.H.; Lee, Y.H.; Munthe, J.; Dambrine, E. 1998. Xylem sap as a pathway for total mercury and methylmercury transport from soils to tree canopy in the boreal forest. *Biogeochemistry* 40: 101-113.

Boyle, T. 1985. Validation and predictability of laboratory methods for assessing the fate and effects of contaminants in aquatic ecosystems. Baltimore, MD: ASTM International.

Budavari, S. [ed.]. 1996. The Merck Index - An encyclopedia of chemicals, drugs, and biologicals. Whitehouse Station, NJ: Merck and Co., Inc., p. 178.

CARB (California Air Resources Board). 1994. Development of intermedia transfer factors for pollutants, Volume II: Metals and non-volatile organic compounds. PB95-260691. California: Air Resources Board. March.

Cal EPA (California Environmental Protection Agency). 1993. CalTOX, A multimedia total-exposure model for hazardous-waste sites, Part II: The dynamic multimedia transport and transformation. Model Prepared for: The Office of Scientific Affairs. Department of Toxic Substances Control. Sacramento, California. December. Draft Final.

Carpi, A., and S.E. Lindberg. 1997. Sunlight-mediated emission of elemental mercury from soil amended with municipal sewage sludge. *Environmental Science and Technology* 31(7):2085-2091.

Coe, J.M., and S.E. Lindberg. 1987. The morphology and size distribution of atmospheric particles deposited on foliage and inert surfaces. *Journal of the Air Pollution Control Association* 37:237-243.

Crank, J., N.R. McFarlane, J.C. Newby, G.D. Paterson, and J.B. Pedley. 1981. Diffusion processes in environmental systems. In: Paterson et al. 1991. London: Macmillan Press, Ltd.

Del Vento, S., and J. Dachs. 2002. Prediction of uptake dynamics of persistent organic pollutants by bacteria and phytoplankton. *Environmental Toxicology and Chemistry* 21(10):2099-2107.

Edwards, N.T. 1988. Assimilation and metabolism of polycyclic aromatic hydrocarbons by vegetation – an approach to this controversial issue and suggestions for future research. In: (M. Cooke and A.J. Dennis, eds.) *Polynuclear Aromatic Hydrocarbons: A Decade of Progress*. Battelle Press, Columbus, OH; pp. 211-229.

Environment Canada. 2002. Ecosystem Health Science-Based Solutions: Canadian Tissue Residue Guidelines for the protection of Wildlife Consumers of Aquatic Biota: Methylmercury. Report No. 1-4.

Gay, D.D. 1975. Biotransformation and chemical form of mercury in plants. International Conference on Heavy Metals in the Environment, pp. 87-95. Vol. II, Part 1. October.

Gilmour, C.C., and E.A. Henry. 1991. Mercury methylation in aquatic systems affected by acid deposition. *Environmental Pollution* 71:131-169.

Goulet, R.R., S. Krack, P.J. Doyle, L. Hare, B. Vigneault, and J.C. McGeer. 2007. Dynamic multipathway modeling of Cd bioaccumulation in *Daphnia magna* using waterbourne and dietborne exposures. *Aquatic Toxicology.* 81: 117-125.

Hansch, C., A. Leo, and D. Hoekman. 1995. Exploring QSAR - Hydrophobic, electronic, and steric constants. Washington, DC: American Chemical Society 154.

Hare, L; Tessier, A; and Warren, L. 2001. Cadmium accumulation by invertebrates living at the sediment–water interface. *Environmental Toxicology and Chemistry* 20: 880-889.

Harner, T., and Bidleman, T.F. 1998. Octanol-air partition coefficient for describing particle/gas partitioning of aromatic compounds in urban air. *Environmental Science and Technology* 32:1494-1502.

HSDB (Hazardous Substances Data Bank). 2005. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 10/27/2005]. 2-Methylnaphthalene; Hazardous Substances Databank Number: 5274. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+5274.

HSDB. 2001a. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 08/09/2001]. 7,12-Dimethylbenz(a)anthracene; Hazardous Substances Databank Number: 2938. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+2938.

HSDB. 2001b. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 08/09/2001]. Acenaphthylene; Hazardous Substances Databank Number: 2661. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+2661.

HSDB. 2001c. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 08/09/2001]. Benzo(ghi)perylene; Hazardous Substances Databank Number: 6177. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+6177.

HSDB. 2001e. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 08/09/2001]. Fluorene; Hazardous Substances Databank Number: 2165. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+2165.

HSDB. 2001d. Bethesda, MD: National Library of Medicine, U.S. [Last Revision Date 08/09/2001]. Acenaphthene; Hazardous Substances Databank Number: 2659. Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+2659.

Hendriks, AJ; and Heikens, A. 2001. The power of size. 2. Rate constants and equilibrium ratios for accumulation of inorganic substances related to species weight. *Environmental Toxicology and Chemistry* 20: 1421-1437.

Henning, B.J., H.G. Snyman, and T.A.S. Aveling. 2001. Plant-soil interactions of sludge-borne heavy metals and the effect on maize (Zea mays L.) seedling growth. *Water SA* 27(1):71-78.

Hogg, T.J., J.R. Bettany, and J.W.B. Stewart. 1978. The uptake of 203Hg-labeled mercury compounds by bromegrass from irrigated undisturbed soil columns. *Journal of Environmental Quality* 7:445-450.

Holzworth, G.C. 1972. Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States. Prepared for EPA Office of Air Programs. Research Triangle Park, NC.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan, and E.M. Michalenko. 1991. Handbook of environmental degradation rates. Chelsea, Michigan: Lewis Publishers

Hudson, R., S.A. Gherini, C.J. Watras, and D. Porcella. 1994. Modeling the biogeochemical cycle of mercury in lakes: The Mercury Cycling Model (MCM) and its application to the MTL Study Lakes. In: C.J. Watras and J.W. Huckabee, eds. Mercury pollution integration and synthesis. Lewis Publishers. pp. 473-523.

ICF(ICF International). 2005. Memorandum: TRIM.FaTE screening scenario: Aquatic food web analysis; submitted to Deirdre Murphy and Terri Hollingsworth, U.S. EPA, from Margaret McVey and Rebecca Kauffman, ICF Consulting. October 18.

Jackson, R.B., J. Canadell, J.R. Ehleringer, H.A. Mooney, O.E. Sala, and E.D. Schulze. 1996. A global analysis of root distributions for terrestrial biomes. *Oecologia* 108:389-411.

John, M.K. 1972. Mercury uptake from soil by various plant species. *Bulletin of Environmental Contamination and Toxicology* 8:77-80.

Kaushal, S.S., P.M. Groffman, G.E. Likens, K.T. Belt, W.P. Stack, V.R. Kelly, L.E. Band, and G.T. Fisher, 2005. Increased Salinization of Fresh Water in the Northeastern United States. *Proceedings of the National Academy of Sciences* 102:13517-13520.

Kim, M., and P. O'Keefe. 1998. The role of natural organic compounds in photosensitized degradation of polychlorinated dibenzo-p-dioxins and dibenzofurans. *Organohalogen Compounds* 36: 377-380.

Komoba, D., C. Langebartels, and H. Sandermann. 1995. Metabolic processes for organic chemicals in plants. In: Plant contamination modeling and simulation of organic chemical processes. Trapp, S., and Mc Farlane, J.C., eds., CRC Press, Boca Raton, FL. Pages 69-103.

Leith, H. 1975. Primary productivity in the biosphere. In: H. Leith and R.W. Whitaker. Ecological Studies, Volume 14. Springer-Verlag.

Lemair, P., A. Mathieu, S. Carriere, J.F. Narbonne, M. Lafaurie, and J. Giudicelli. 1992. Hepatic biotransformation enzymes in aquaculture European sea bass (*Dicentrarchus labrax*): kinetic parameters and induction with benzo(a)pyrene. *Comparative Biochemistry and Physiology* 103(B): 847-853.

Leonard, T.L., G.E. Taylor, Jr., M.S. Gustin, and G.C.J. Fernandez. 1998. Mercury and plants in contaminated soils: 1. Uptake, partitioning, and emission to the atmosphere. *Environmental Toxicology and Chemistry* 17:2063-2071.

Lindberg, S.E., T.P. Meyers, G.E. Taylor, R.R. Turner, and W.H. Schroeder 1992. Atmosphere-Surface Exchange of Mercury to a Forest: Results of Modelling and Gradient Approaches. *Journal of Geophysical Research* 97(D2):2519-2528.

Lindberg, S.E. 1996. Forests and the global biogeochemical cycle of mercury: The importance of understanding air/vegetation exchange processes. In: W. Baeyans et al., eds. Global and regional mercury cycles: Sources, fluxes, and mass balances. pp. 359-380.

Mackay, D., W.Y. Shiu, and K.C. Ma. 2000. Physical-chemical properties and environmental fate handbook. Boca Raton, FL: CRC Press LLC.

Mackay, D., W.Y. Shiu, and K.C. Ma. 1992. Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals: polynuclear aromatic hydrocarbons, polychlorinated dioxins, and dibenzofurans. Chelsea, MI: Lewis Publishers.

Mackay, D., S. Patterson, and W.H. Schroeder. 1986. Model describing the rates of transfer processes of organic chemicals between atmosphere and water. *Environmental Science and Technology* 20(8): 810-816.

Mason, R.P., J.R. Reinfelder, and F.M.M. Morel. 1996. Uptake, toxicity, and trophic transfer of mercury in a coastal diatom. *Environmental Science and Technology* 30(6):1835-1845.

Mason, R.P., F.M.M. Morel, and H.F. Hemond. 1995a. The role of microorganisms in elemental mercury formation in natural waters. *Water, Air, and Soil Pollution* 80:775-787.

Mason, R.P., J.R. Reinfelder, and F.M.M. Morel. 1995b. Bioaccumulation of mercury and methylmercury. *Water Air and Soil Pollution* 80(1-4):915-921.

McCrady, J.K., and S.P. Maggard. 1993. Update and photodegradation of 2,3,7,8-tetrachloro-p-dioxin sorbed to grass foliage. *Environmental Science and Technology* 27: 343-350.

McElroy, A. E. 1990. Polycyclic aromatic hydrocarbon metabolism in the polychaete *Nereis virens*. *Aquatic Toxicology* 18(1):35-50.

McGeer, J.C., K.V. Brix, J.M. Skeaff, D.K. DeForest, S.I. Brigham, W.J. Adams, and A. Green. 2003. Inverse relationship between bioconcentration factor and exposure concentration for metals: implications for hazard assessment of metals in the aquatic environment. *Environmental Toxicology and Chemistry* (22)5:1017–1037.

McKone, T.E., A. Bodnar, and E. Hertwich. 2001. Development and evaluation of state-specific landscape data sets for multimedia source-to-dose models. University of California at Berkeley. Supported by the U.S. Environmental Protection Agency (Sustainable Technology Division, National Risk Management Research Laboratory) and Environmental Defense Fund. July. LBNL-43722.

Millard, E.S., D.D. Myles, O.E. Johannsson, and K.M. Ralph. 1996. Phytoplankton photosynthesis at two index stations in Lake Ontario 1987-1992: assessment of the long-term response to phosphorus control. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 1092-1111.

Moermond, C. T. A., T.P. Traas, I. Roessink, K. Veltmam, A.J. Hendriks, and A.A. Koelmans. 2007. Modeling decreased food chain accumulation of PAHs due to strong sorption to carbonaceous materials and metabolic transformation. *Environmental Science and Technology* 41(17):6185-6191. doi: 10.1021/es0702364.

Montgomery, J. 2000. Groundwater chemicals desk reference. Boca Raton, FL: CRC Press LLC, p. 1701. Morrison, H.A., D.M. Whittle, C.D. Metcalfe, and A.J. Niimi. 1999. Application of a food web bioaccumulation model for the prediction of polychlorinated biphenyl, dioxin, and furan congener concentrations in Lake Ontario aquatic biota. *Canadian Journal of Fisheries and Aquatic Sciences* 56(8):1389-1400.

Morrison, H., Whittle, D., et al. 1999. Application of a food web bioaccumulation model for the prediction of polychlorinated biphenyl, dioxin, and furan congener concentrations in Lake Ontario aquatic biota. Can. J. Fish. Aquat. Sci. 56: 1389–1400 (1999).

Muhlbaier, J., and G.T. Tissue. 1980. Cadmium ion the southern basin of Lake Michigan. *Water, Air and Soil Pollution* (15):45-49.

Muir, D.C., W.K. Marshall, and G.R. Webster. 1985. Bioconcentration of PCDDs by fish: Effects of molecular structure and water chemistry. *Chemosphere* 14(6/7):829-833.

Muller, H. and Prohl, G. 1993. ECOSYS-87: A dynamic model for assessing radiological consequences of nuclear accidents. Health Physics 64(3):232-252.

NLM (National Library of Medicine). 2002. Hazardous Substance Data Bank (HSDB). Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB.

Niimi, A., and B. Oliver. 1986. Biological half-lives of chlorinated dibenzo-p-dioxins and dibenzofurans in rainbow trout (*Salmo gairdeneri*). *Environmental Toxicology* 5:49-53.

Niimi, A.J,. and V. Palazzo. 1986. Biological half-lives of eight polycyclic aromatic hydrocarbons (PAHs) in rainbow trout (*Salmo gairdneri*). *Water Research* 20(4):503-507.

Nriagu, J.O. 1980. Cadmium in the environment. Part I: Ecological cycling. New York: John Wiley & Sons. Chapter 15: Uptake and effects of cadmium in higher plants. pp. 608-609.

Opperhuizen, A., W.J. Wagenaar, F.W.M. van der Wielen, M. van den Berg, K. Olie, and F.A.P.C. Gobas.1986. Uptake and elimination of PCDD/PCDF congeners by fish after aqueous exposure to a fly-ash extract from a municipal incinerator. *Chemosphere* 15(9–12):2049-2053. doi: 10.1016/0045-6535(86)90511-4.

Passivirta, J., Sinkkonen, S., Mikkelson, P., Rantio, T., Wania, F. (1999) Estimation of vapor pressures, solubilities and Henry's law constants of selected persistent organic pollutants as functions of temperature. Chemosphere 39, 811–832.

Paterson, S., D. Mackay, and A. Gladman. 1991. A fugacity model of chemical uptake by plants from soil and air. *Chemosphere* 23:539-565.

Petersen, G., A. Iverfeldt, and J. Munthe. 1995. Atmospheric mercury species over Central and Northern Europe. Model calculations and comparison with observations from the Nordic Air and Precipitation Network for 1987 and 1988. *Atmospheric Environment* 29:47-68.

Porvari, P., and M. Verta. 1995. Methylmercury production in flooded soils: A laboratory study. *Water, Air, and Soil Pollution* 80:765-773.

Riederer, M. 1995. Partitioning and transport of organic chemicals between the atmospheric environment and leaves. In: Trapp, S. and J. C. McFarlane, eds. Plant contamination: Modeling and simulation of organic chemical processes. Boca Raton, FL: Lewis Publishers. pp. 153-190.

Rubinstein, N.I., R.J. Pruell, B.K. Taplin, J.A. LiVolsi, and C.B. Norwood. 1990. Bioavailability of 2,3,7,8-TCDD, 2,3,7,8-TCDF and PCBs to marine benthos from Passaic river sediments. *Chemosphere* 20:1097-1102.

Sangster, J. (1993) LOGKOW, A Databank of Evaluated Octanol-Water Partition Coefficients. 1st Edition, Montreal, Quebec, Canada.

Saouter, E., F. Ribeyre, A. Boudou, and R. Maurybrachet. 1991. *Hexagenia rigida* (Ephemeroptera) as a biological model in aquatic ecotoxicology - Experimental studies on mercury transfers from sediment. *Environmental Pollution* 69:51-67.

Sijm, D.T.H.M., H. Wever, P.J. de Vries, and A. Opperhuizen. 1989. Octan-1-ol/water partition coefficients of polychlorinated dibenzo-p-dioxins and dibenzofurans: experimental values determined with a stirring method. *Chemosphere* 19(1-6):263-266.

Simonich, S.L., and R.A. Hites. 1994. Importance of vegetation in removing polycyclic aromatic hydrocarbons from the atmosphere. *Nature* 370:49-51.

Spero, J., B. DeVito, and L. Theodore. [eds.]. 2000. Regulatory chemicals handbook. New York, NY: CRC Press, p. 1072.

Stehly, G.R., P.F. Landrum, M.G. Henry, and C. Klemm. 1990. Toxicokinetics of PAHs in *Hexagenia Environmental Toxicology and Chemistry* 9:167-174.

Thibodeaux, L.J. 1996. Environmental chemodynamics: Movement of chemicals in air, water, and soil. New York, NY: John Wiley and Sons, Inc.

Thomann, R.V. 1989. Bioaccumulation model of organic-chemical distribution in aquatic food-chains. *Environmental Science and Technology* 23(6):699-707.

Trapp, S. 1995. Model for uptake of xenobiotics into plants. In: Trapp, S. and J. C. McFarlane, eds. Plant contamination: Modeling and simulation of organic chemical processes. Boca Raton, FL: Lewis Publishers. pp. 107-151.

Trudel, M., and J.B. Rasmussen. 1997. Modeling the elimination of mercury by fish. *Environmental Science and Technology* 31:1716-1722.

Tsiros, I.X.; R.B. Ambrose, and A. Chronopoulou-Sereli. 1999. Air-vegetation partitioning of toxic chemicals in environmental simulation modeling. Global NEST: *The International Journal* 1(3):177-184.

USEPA (U.S. Environmental Protection Agency). 2007. Draft risk assessment for the Siemens Water Technologies Corp. carbon reactivation facility Parker, Arizona. Appendix F. Chemical-physical parameters for compounds not in USEPA's HHRAP. Available at: http://www.epa.gov/region9/waste/siemens/pdf/RiskAssessment/siemens-riskassessAppxF.pdf.

USEPA. 2005. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Companion Database. Available at: http://www3.epa.gov/epawaste/hazard/tsd/td/combust/riskvol.htm#volume2.

USEPA 2003. Toxicological Review of 2-Methylnaphthalene. Available online at: http://cfpub.epa.gov/ncea/iris/iris_documents/documents/toxreviews/1006tr.pdf.

USEPA. 2000a. Estimation Program Interface (EPI) suite. Office of Pollution Prevention and Toxics (OPPT). Available at: http://www2.epa.gov/tsca-screening-tools/epi-suitetm-estimation-program-interface

USEPA. 2000b. Draft exposure and human health reassessment of 2,3,7,8-tetrachlorodibenzo-p-dioxin TCDD) and related compounds, Volume 3: Properties, environmental levels, and background exposures, Chapter 2: Physical and chemical properties and fate and Appendix A. EPA/600/P-00/001Bc. Available at: http://www.epa.gov/ncea/pdfs/dioxin/part1/volume3/chap-2.pdf.

USEPA. 1999. Screening level ecological risk assessment protocol for hazardous waste combustion facilities. Peer Review Draft, November. Available at: http://www3.epa.gov/epawaste/hazard/tsd/td/combust/ecorisk.htm.

USEPA. 1998. Chemical fate half-lives for Toxics Release Inventory (TRI) chemicals. July. SRC TR 98-008.

USEPA. 1997a. Supplemental background document; Nongroundwater pathway risk assessment; Petroleum process waste listing determination. Appendix B. Compound specific input values. Available at: http://www.epa.gov/osw/hazard/wastetypes/wasteid/petroref/appendb.pdf.

USEPA. 1997b. U.S. Environmental Protection Agency. Mercury study report to congress. Volume III: Fate and transport of mercury in the environment. Office of Air Quality Planning and Standards and Office of Research and Development.

Van den Berg, M., J. De Jongh, H. Poiger, and J.R. Olson. 1994. The toxicokinetics and metabolism of polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) and their relevance for toxicity. *CRC Critical Reviews in Toxicology* 24(1):1-74.

Vandal, G.M., W.F. Fitzgerald, K.R. Rolfhus, and C.H.Lamborg. 1995. Modeling the elemental mercury cycle in Pallette Lake, Wisconsin, USA. *Water, Air, and Soil Pollution* 80:789-798.

Vulykh, N., and V. Shatalov. 2001. Investigation of Dioxin/Furan Composition in Emissions and in Environmental Media: Selection of Congeners for Modeling. Technical Note 6/2001. Meteorological Synthesizing Center - East.

Wang, X., and W.X. Wang. 2006. Bioaccumulation and transfer of benzo (a) pyrene in a simplified marine food chain. *Marine Ecology Progress Series* 312:101-111.

Williams, J.J., J. Dutton, C.Y. Chen, and N.S. Fisher. 2010. Metal (As, Cd, Hg, and CH_3Hg) bioaccumulation from water and food by the benthic amphipod *Leptocherius plumulosus*. *Environmental Toxicology and Chemistry* 29(8):1755-1761.

Wilmer, C., and M. Fricker. 1996. Stomata. Second ed. New York, NY: Chapman and Hall. p. 121.

WI DNR (Wisconsin Department of Natural Resources) 2007. A Guide to Understanding the Hydrologic Condition of Wisconsin's Lake Superior Watersheds. Wisconsin Department of Natural Resources (DNR).

Xiao, Z.F., D. Stromberg, and O. Lindqvist. 1995. Influence of humic substances on photolysis of divalent mercury in aqueous solution. *Water, Air, and Soil Pollution* 80:789-798.

Yan, X; and Wang, WX. 2002. Exposure and potential food chain transfer factor of Cd, Se and Zn in marine fish *Lutjanus argentimaculatus*. *Marine Ecology Progress Series* 238: 173-186.

Zhang, Q., L. Yang, and W.X. Wang. 2011. Bioaccumulation and trophic transfer of dioxins in marine copepods and fish. *Environmental Pollution* 159(12):3390-3397.

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Attachment B. Description of Multimedia Ingestion Risk Calculator (MIRC) Used for RTR Exposure and Risk Estimates

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1. Introduction

1.1. Purpose and Overview

This document provides a detailed description of the *Multimedia Ingestion Risk Calculator* (MIRC), a modeling tool and database designed to assist in estimating risks via multiple ingestion pathways, particularly for food products grown or raised at home or on a farm.[27] MIRC was designed to estimate risks to humans from ingestion of produce or animal products, fish, and water in the vicinity of a source of chemical emissions to air. The user can evaluate either generalized (e.g., health protective default) or more site-specific scenarios using the same tool. MIRC includes a database of exposure parameter values, offering the user the option of selecting mean, median, and upper percentile values for many parameters, data permitting. Generally health protective default values were assigned to each parameter in the tool and the default configuration is used for initial risk screening efforts by EPA's Office of Air Quality Planning and Standards' (OAQPS) for Risk and Technology Review (RTR) multimedia risk assessments. MIRC also allows the user to define the farm food chain (FFC) parameter values and receptor characteristics to better represent a site-specific scenario.

With user-input concentrations for one or more chemicals in air and soil and air-to-surface deposition rates, MIRC calculates the chemical's concentrations in home- or farm-grown produce and animal food products using FFC algorithms adapted from EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (hereafter referred to as HHRAP; EPA 2005a). MIRC uses these calculated concentrations, along with user-input chemical concentrations for fish and drinking water, to estimate chemical intake rates, as average daily doses (ADDs), for adults, children, and nursing infants. Users can obtain chemical input concentrations and deposition rates from measurements at an actual site or from a transport and fate model, such as TRIM.FaTE, as is done for RTR risk assessment.

For a specified set of chemical concentrations and MIRC parameter options, MIRC calculates ADDs separately for adults, four age groups of children, and infants to reflect differences in food ingestion rates and diet at different lifestages. MIRC estimates age-specific hazard quotients (HQs) as the ratio of age-specific ADDs to the reference dose (RfD) for a chemical. The most appropriate HQ for a chemical depends on its toxic mode of action and the duration of exposure required to produce an effect. MIRC also estimates average lifetime ADDs and compares those to cancer slope factors (CSFs) to estimate cancer risks. A breast milk ingestion pathway is available to estimate exposure and risks to nursing infants.

MIRC was developed to be a flexible, transparent application. The tool includes chemical transfer and ingestion exposure algorithms and a database of parameter values, many with several options, used by these equations. The MIRC database includes values for the relevant physiochemical properties and toxicity reference values for more than 500 chemicals, including approximately 60 inorganics taken primarily from a database developed for HHRAP (EPA 2005a). Although designed for OAQPS' RTR assessments for sources of hazardous air pollutants (HAPs), the tool is flexible in its design and can be used to assess risks in many other contexts where soil and air concentrations are predicted or measured.

1.2. Scope of MIRC

For persistent and bioaccumulative (PB) chemicals, risks from direct inhalation of the chemical can be much less than risks from ingestion of the chemical in water, fish, and food products

[27] Fully functional versions of MIRC have been developed in both Access™-based and Excel™-based formats; however, MIRC currently is not publicly available.

grown in an area of chemical deposition. Vegetables and fruits in such areas can become contaminated directly by deposition of the airborne chemical to foliage, fruits, and vegetables or indirectly by root uptake of the chemical deposited to soils. Livestock can be exposed to the PB chemicals via ingestion of contaminated forage and incidental ingestion of contaminated soils.

For PB chemicals, evaluation of the inhalation pathway for air pollutants may reveal only a portion of the risk to individuals in such populations. Households that consume high quantities of self-caught fish or locally grown produce and animal products may be particularly susceptible to ingestion of chemicals transferred from air in the vicinity of an air emissions source. For PB chemicals in particular, therefore, EPA developed methods of estimating risk from indirect exposure pathways associated with the deposition of airborne chemicals to gardens and farms, as described in HHRAP (EPA 2005a).

1.3. Use in EPA's Air Toxics Program

For PB-HAPs, indirect exposure pathways, such as ingestion, might contribute more to total risk than the inhalation pathway. EPA therefore developed several computer software tools to assist in evaluating exposure and risk from non-inhalation pathways. EPA developed the Total Risk Integrated Methodology (TRIM) Environmental Fate, Transport, and Ecological Exposure (TRIM.FaTE) computer program to simulate the release, transport, and fate of HAPs from a specific source throughout the area in which local (non-source) chemical deposition is likely to be a concern. TRIM.FaTE models the transport of individual chemicals from the source through air by advection (wind) of particle- and vapor-phase chemical and deposition of the chemical from air to terrestrial and aquatic ecosystems by wet and dry deposition. Movement of the chemical through a watershed via erosion and runoff, uptake by plants, and other abiotic and biotic transfer processes also are simulated. For the chemical that reaches surface waters, TRIM.FaTE models uptake and bioaccumulation to trophic level (TL) 3 and 4 fish (i.e., pan fish and game fish, respectively).

MIRC was developed to process TRIM.FaTE results, in particular, air deposition rates and the concentrations of a chemical, after a specified duration of emissions, in several spatially explicit environmental compartments, including air, surface and root-zone soils, surface and ground waters, and fish. MIRC uses those results to calculate exposure to the chemical through ingestion of locally grown foods, including various types of fruits and vegetables, poultry, swine, and dairy (and beef) cattle. MIRC also calculates the associated risks for individuals who consume those foods. MIRC was designed to use specific TRIM.FaTE results to estimate FFC concentrations, ingestion exposures, and human health risks for OAQPS' RTR assessments. It uses the same approach that OAQPS intends to implement directly in its TRIM system via three modules beyond TRIM.FaTE: TRIM Farm Food Chain, $\text{TRIM.Expo}_{\text{Ingestion}}$, and TRIM.Risk.[28]

1.4. MIRC Highlights

Although designed to assist EPA OAQPS in its RTR assessments, MIRC is a stand-alone software application that can be used in other contexts. A user can supply either measured or estimated chemical concentrations for soil, air, water, and fish, and also can provide air deposition rates likely for the location(s) of interest based on local meteorology. The user can accept the default values for many exposure parameters and screen for small possibilities of risk, or the user can select other options or overwrite parameter values to tailor the estimates to a specific scenario or location.

[28] General information about the TRIM system is available at http://www2.epa.gov/fera/total-risk-integrated-methodology-trim-general.

MIRC complies with EPA's latest guidelines for exposure and risk assessment, including HHRAP; the Agency's 2005 *Guidelines for Carcinogen Risk Assessment* (Cancer Guidelines), *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (Supplemental Guidance), and *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (EPA 2005b,c,d); and its 2008 *Child-Specific Exposure Factors Handbook* (EPA 2008a). In particular, MIRC provides several important capabilities:

- When provided air and soil concentrations, the MIRC software package allows rapid calculation of screening-level exposures and risks associated with household consumption of locally grown/raised foods.
- MIRC can calculate exposures and risks associated with incidental ingestion of surface soils, fish consumption, and drinking water.
- The tool calculates ADDs (i.e., chemical intake rates) for six "built-in" age groups to allow use of age-group-specific body weights, ingestion rates, food preferences, and susceptibility to toxic effects.
- Its database of chemical information covers plant- and animal-specific transfer factors and other inputs that determine concentrations in farm food stuffs.
- Value options for receptor characteristics in the database include the mean and 50th, 90th, 95th, and 99th percentile values where data permit.
- For carcinogens with a mutagenic mode of action, MIRC estimates a lifetime ADD using the three lifestages and potency adjustment factors recommended in EPA's 2005 Cancer Guidelines and Supplemental Guidance.
- The data for exposure parameters in the tool have been updated to include the latest recommended values for children issued September 30, 2008, in the Agency's Child-Specific Exposure Factors Handbook (CSEFH) (EPA 2008a).

1.5. Organization of This Attachment

Sections 2 through 5 of this attachment describe the exposure and risk models implemented in MIRC. Section 2 provides an overview of the FFC exposure scenario and indicates options available to a user to tailor the scenario to specific applications. Section 3 describes the exposure algorithms used in MIRC, including how ADDs are calculated. Section 4 presents the toxicity reference values included in MIRC to calculate risks. Section 5 describes the risk characterization algorithms in MIRC. Section 6 of this document describes data input options for the model. Section 7 describes the default parameterization of MIRC for application to health protective risk screening assessments, and Section 8 provides the references.

Note that the default parameterization described in Section 7 was used to estimate Tier 1 screening threshold emission rates of PB-HAPs from RTR facilities. These emissions levels are assumed to pose negligible risk to subsistence communities in the vicinity of a facility emitting the PB-HAPs to air. Users of MIRC can modify the default values for many of the parameters to better represent a specific exposure scenario.

2. MIRC Overview

The *Multimedia Ingestion Risk Calculator* (MIRC) software package is designed to allow rapid calculation of screening-level exposures and risks associated with subsistence and recreational farmer/fisher populations in the vicinity of a source of chemical emissions to air. The tool allows a user to assess human exposures via ingestion pathways, including drinking water

consumption, incidental soil ingestion, fish ingestion, and ingestion of ten types of farm food chain (FFC) products: exposed fruits, protected fruits, exposed vegetables, protected vegetables, root vegetables, beef, total dairy, pork, poultry, and eggs. The tool also includes a breast milk ingestion and risk module for nursing infants. For fruits and vegetables, the terms "exposed" and "protected" refer to whether the edible portion of the plant is exposed to the atmosphere.

The remainder of this overview consists of three sections. The first (Section 2.1 of this attachment) provides an overview of the MIRC software package. The second and third sections summarize the ingestion exposure pathways included in the tool and the "built-in" receptor age categories, respectively (Sections 2.2 and 2.3 of this attachment).

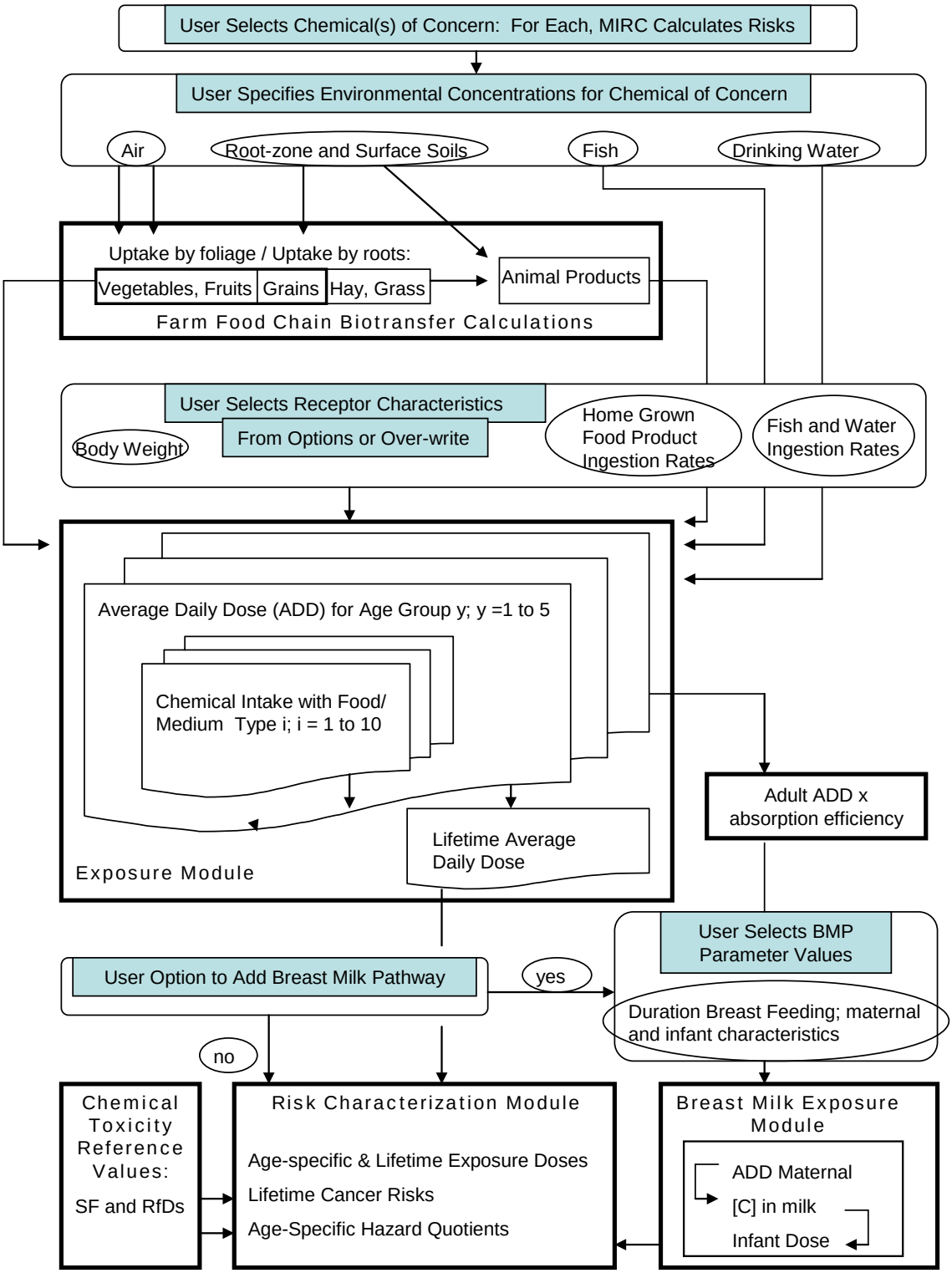
2.1. Software

The MIRC application includes the following components:

- A graphical user interface through which the user locates and accesses various input and output tables.
- Input tables in which the user can enter environmental concentrations of a chemical estimated for air, soil, drinking water, and fish tissue.
- Internal chemical transfer and exposure algorithms and database of options for FFC algorithm parameter value, chemical-specific inputs, and exposure factors.
- Tabulated outputs of calculated chemical concentrations in the various farm food products (e.g., fruits, vegetables, beef, eggs) and ADDs for those foods and for water and fish ingestion for each receptor category.
- Output tables with estimated cancer risks and non-cancer hazard estimates associated with total ingestion exposure to each chemical for each receptor category.

Exhibit B-1 provides a flowchart displaying the types of required and optional inputs and the general flow of calculations carried out by the tool.

Exhibit B-1. Overview of MIRC Software Application for Performing Farm-Food-Chain Ingestion Exposure and Risk Calculations



A form within the graphical user interface enables the user to construct specific scenarios by choosing ingestion sources, receptor ages, and other input choices (e.g., diet composition, body weight percentiles). This feature facilitates the assessment of various exposure scenarios. To begin an assessment, the user must supply values for the following chemical-specific parameters for the scenario being evaluated:

- Air concentration of total chemical,
- Fraction chemical in air in vapor-phase,
- Wet and dry deposition rates for particle-phase chemical,
- Drinking water concentration,
- Chemical concentration in surface soils (two locations; can be tilled and untilled),
- Chemical concentration in root-zone soils (two locations; can be tilled and untilled), and
- Chemical concentrations in upper trophic-level fish.

Users can input measured values or values estimated by TRIM.FaTE or other models for these parameters.

The MIRC application uses the input data and a variety of empirical transfer factor values (included in its database) to estimate chemical concentrations in nine categories of FFC food types (see Section 2.2 of this attachment). The FFC algorithms and transfer factor values included in MIRC are based on those presented in Chapter 5 of EPA's HHRAP (EPA 2005a).

For outputs, MIRC is designed to calculate individual cancer risk and non-cancer hazard quotients for one chemical at a time. It is up to the risk assessor to determine if cancer risks or hazard quotients may be additive across two or more chemicals (i.e., if they cause toxic effects in the same target organ by the same mode of action, such as multiple polycyclic aromatic hydrocarbons (PAHs) that are carcinogenic by a mutagenic mode of action).

The tool assumes that an individual is exposed via all of the pathways specified (e.g., fruits and vegetables, animal products, soil, etc.). The tool therefore is useful in estimating risk to the maximally exposed individuals in a risk assessment. To evaluate other receptor populations, the user must specify the each exposure scenario separately.

2.2. Exposure Pathways

MIRC estimates the concentrations of chemicals in FFC food categories grown in an area of airborne chemical deposition using algorithms and parameter values provided in HHRAP (EPA 2005a). FFC foods are evaluated in ten categories: exposed fruit, protected fruit, exposed vegetables, protected vegetables, root vegetables, beef, total dairy, pork, poultry, and eggs. Exhibit B-2 summarizes the pathways by which chemicals are transferred to these food media. Note that for a general Tier 1 screening-level assessment, all of the pathways can be modeled, as is the case for EPA's *Risk and Technology Review* (RTR) calculation of screening threshold emission rates for persistent and bioaccumulative hazardous air pollutants (PB-HAPs) (EPA 2008b).

Exhibit B-2. Transfer Pathways for Modeled Farm Food Chain (FFC) Media

Farm Food Media	Chemical Transfer Pathways
Exposed fruit and vegetables	• Direct deposition from air of particle-bound chemical • Air-to-plant transfer of vapor phase chemical • Root uptake from soil
Protected fruit and vegetables (including root vegetables)	• Root uptake from soil
Beef and total dairy (including milk)	• Ingestion of forage, silage, and grain[a] • Soil ingestion
Pork	• Ingestion of silage and grain[a] • Soil ingestion
Poultry and eggs	• Ingestion of grain[a] • Soil ingestion

[a]Chemical concentrations in forage, silage, and grain are estimated via intermediate calculations analogous to those used for aboveground produce.

Produce types included in the FFC can accumulate a chemical directly from air and/or soil. For exposed produce, chemical mass is assumed to be transferred to plants from the air in two ways. First, particle-bound chemical can deposit directly on the plant surface. Second, the uptake of vapor-phase chemicals by plants through their foliage can occur. For both exposed and protected produce, the concentration in the plant derived from exposure to the chemical in soil is estimated using an empirical bioconcentration factor (BCF) that relates the concentration in the plant to the concentration present in the soil. For belowground root vegetables, a root concentration factor is applied. The algorithms used to estimate produce concentrations are presented in Section 3.1.1 of this attachment.

Chemical concentrations in animal products are estimated based on the amount of chemical consumed through the diet, including incidental ingestion of soil while grazing. The diet options for farm animals in MIRC include forage (plants grown on-site for animal grazing, such as grass), silage (wet forage grasses, fresh-cut hay, or other fresh plant material that has been stored and fermented), and feed grain products grown on the farm (e.g., corn, soybeans). All three animal feed products are assumed to accumulate chemical via root uptake from the soil. Forage and silage also can accumulate chemical via direct deposition of particle-bound chemical and vapor transfer.

The algorithms in MIRC are based on the assumptions that beef and dairy cattle consume all three feed products, while pigs consume only silage and grain and chickens consume only grain. The incidental ingestion of the chemical in soils during grazing or consumption of foods placed on the ground is estimated using empirical soil ingestion values. For secondary animal products (dairy products and eggs), chemical concentrations are estimated by applying a biotransfer factor to the estimated concentration in the “source” animal (cows and chickens, respectively). The algorithms used to estimate animal product concentrations are described in Section 3.1.2 of this attachment.

2.3. Receptor Groups

As noted in EPA risk assessment guidelines (EPA 2005b,c,d, 2008a), exposures of children are expected to differ from exposures of adults due to differences in body weights, ingestion rates, dietary preferences, and other factors. It is important, therefore, to evaluate the contribution of exposures during childhood to total lifetime risk using appropriate exposure factor values.

EPA's HHRAP (Chapter 4, EPA 2005a) recommends assessing exposures for children and adults separately, but considers all non-infant children in one category. Specifically, HHRAP recommends eight categories of receptor: farmer, child farmer, resident, child resident, fisher, child fisher, acute receptor, and nursing infant. Over time, different EPA programs have used different child age groupings to evaluate body weights, ingestion rates, and other parameter values needed to estimate chemical exposures and risks to children.

To improve the match between age groups used to estimate values across exposure parameters, in 2005, EPA recommended a standard set of child age categories for exposure and risk assessments (EPA 2005b). EPA recommended four age groups for infants: birth to < 1 month; 1 to < 3 months; 3 to < 6 months; and 6 to < 12 months. For young children, EPA recommended an additional four age groups: 1 to < 2 years; 2 to < 3 years; 3 to < 6 years; and 6 to < 11 years. Two age groupings were recommended for teenagers and young adults: 11 to < 16 years; and 16 to < 21 years. These age groupings correspond to different developmental stages and reflect different food ingestion rates per unit body weight, with the highest ingestion rates occurring for the youngest, most rapidly growing, age groups.

For purposes of RTR assessment using MIRC, the selection of age categories is limited by the categories for which most of the FFC food ingestion rates have been calculated. In Chapter 13 of both its *Exposure Factors Handbook* (EFH; EPA 2011a) and its *Child-Specific Exposure Factors Handbook* (CSEFH; EPA 2008a), EPA summarized home-grown/raised food ingestion rates for four children's age groups: 1 to < 3 years; 3 to < 6 years; 6 to < 12 years; and 12 to < 20 years. Intake rates were not calculated for children younger than 1 year because infants are unlikely to consume those foods. They are more likely to be nursing or to be fed formula and other commercial baby-food products.

Although the age groupings used to estimate FFC ingestion rates do not match precisely the groupings that EPA recommended in 2005 for Agency exposure assessments (EPA 2005b), they are the only age-groupings for which such data are available. The U.S. Department of Agriculture's (USDA's) 1987-1988 *Nationwide Food Consumption Survey* (USDA 1992, 1993, 1994a) remains the most recent survey of ingestion rates for home-grown foods, and EPA's analysis of those data, published in its 2011 EFH, remains the most recently published major analysis of those data. Because ingestion of home-grown produce and animal products are the primary exposure pathways for which MIRC was developed, those are the age groupings used for all child parameter values used to estimate exposure and risk in MIRC.

Thus, in MIRC, values for each exposure parameter were estimated for adults (20 to 70 years) and five children's age groups:

- infants under 1 year (i.e., 0 to < 1 year);
- children ages 1 through 2 years (i.e., 1 to < 3 years);
- children ages 3 through 5 years (i.e., 3 to < 6 years);
- children ages 6 through 11 years (i.e., 6 to < 12 years); and
- children ages 12 through 19 years (i.e., 12 to < 20 years).

See Sections 5.1 and 5.2 for descriptions of the risk characterization algorithms used to calculate cancer and non-cancer effects, respectively, for the above age groupings. Exposure and risks to infants under 1 year of age are estimated only for the breast-milk-ingestion pathway.

For assessment of cancer risks from early-life exposure, EPA recognizes that infants and children may be more sensitive to a carcinogenic chemical than adults, with cancers appearing earlier in life or with lower doses experienced during childhood (EPA 2005c, d). Thus, the "potency" of a carcinogen might be higher for infants and children than for adults. To date, however, data by which to evaluate the relative sensitivity of children and adults to the same daily dose of a carcinogen remain limited. Based on analyses of radioactive and other carcinogenic chemicals, EPA recommends evaluating two lifestages for children separately from adults for chemicals that cause cancer by a mutagenic mode of action (MOA): from birth to < 2 years and from 2 to < 16 years (EPA 2005c,d). EPA also suggests that, as data become available regarding carcinogens with a mutagenic MOA, further refinements of these age groupings may be considered.

For assessing risks from exposures to carcinogenic chemicals that act via a mutagenic MOA, the two early lifestages recommended by EPA (EPA 2005c,d) also are included in MIRC:

- children under the age of 2 years (i.e., 0 to < 2 years); and
- children from 2 through 15 years (i.e., 2 to < 16 years).

Different age groupings are needed for the assessment of risks from carcinogenic chemicals with a mutagenic MOA and other carcinogens with other or unknown MOAs. Currently in MIRC, the only PB-HAPs with a mutagenic mode of carcinogenesis are the carcinogenic PAHs. See Section 5.1 for a description of the age-dependent adjustment factors (ADAFs) that are used to calculate cancer risks for chemicals with a mutagenic MOA.

3. Exposure Algorithms

The exposure algorithms in MIRC are described below in four sections. Section 3.1 of this attachment presents the algorithms used to estimate chemical concentrations in FFC foods from chemical concentrations in soil and air. Pathway-specific algorithms used to estimate chemical intakes by adults and non-infant children are described in Section 3.2, and total chemical intake calculations are described in Section 3.3. Finally, the sets of algorithms used to estimate chemical intake via consumption of breast milk by nursing infants are described in Section 3.4. As noted previously, the exposure algorithms used in MIRC are based on those presented in HHRAP (EPA 2005b). Any differences between MIRC and HHRAP are explained in this section.

3.1. Farm Food Chain Algorithms

The algorithms and parameters used to estimate chemical concentrations in produce and animal products are described in Sections 3.1.1 and 3.1.2 of this attachment, respectively. Discussions of the parameter value options and the values selected as defaults in MIRC for RTR risk assessment are provided in Section 6.2. The use of TRIM.FaTE to model chemical fate and transport in the environment prior to FFC calculations drives the most significant difference between the FFC algorithms included in HHRAP and the equations used for RTR. The approach in HHRAP uses estimated ambient air concentrations and deposition rates from dispersion model simulations that use unit emission rates. Chemical-specific emission rates (adjusted for vapor and particle-bound fractions) are then incorporated into some of the HHRAP FFC algorithms to calculate concentrations in FFC media. Soil concentrations are calculated using a similar approach in HHRAP. For assessment of multipathway exposures for RTR, TRIM.FaTE is used to estimate air concentrations, air-to-surface deposition rates, and soil concentrations, and these outputs are used in the FFC algorithms.

3.1.1. Estimating Chemical Concentrations in Produce

Produce (vegetables and fruits) can become contaminated directly by deposition of airborne chemicals to foliage and fruits or indirectly by uptake of chemicals deposited to the soil. Given these two contamination processes, produce is divided into two main groups: aboveground and belowground produce. Aboveground produce is divided into fruits and vegetables. These groups are further subdivided into "exposed" and "protected" depending on whether the edible portion of the plant is exposed to the atmosphere or is protected by a husk, hull, or other outer covering.

Exhibit B-3 lists the pathways by which chemicals are transferred to the FFC produce categories. Note that for a general screening-level assessment, all of the pathways can be modeled, as was done for EPA's calculation of Tier 1 screening threshold emission rates for PB-HAPs in its RTR assessments (EPA 2008b), and as described in the Technical Support Document. Sections 3.1.1.1 and 3.1.1.2 below describe the transfer pathways and algorithms for aboveground and belowground produce, respectively.

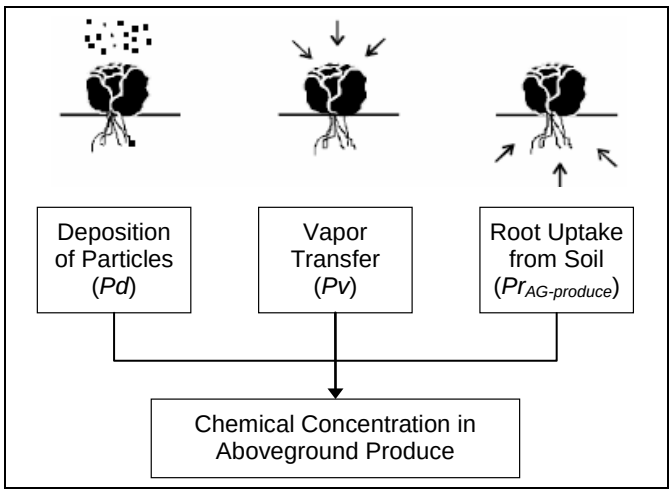
Exhibit B-3. Chemical Transfer Pathways for Produce

Farm Food Media		Chemical Transfer Pathways
Aboveground Produce	Exposed fruits and vegetables	Direct deposition from air of particle-bound chemical Air-to-plant transfer of vapor phase chemical Root uptake from soil
	Protected fruits and vegetables	Root uptake from soil
Belowground Produce	Root vegetables	Root uptake from soil

3.1.1.1. Aboveground Produce

For aboveground *exposed* produce, chemical mass is assumed to be transferred to plants from the air in three ways, as illustrated in Exhibit B-4. First, particle-bound chemical can deposit directly on the plant surface via deposition (*Pd*). The amount of chemical accumulated is estimated based on the areal fraction of chemical deposition intercepted by the plant surface, minus a loss factor that is intended to account for removal of deposited chemical by wind and rain and changes in concentration due to growth dilution. Second, for chemical present in air in the vapor phase, the concentration of chemical accumulated by the plant's foliage is estimated using an empirical air-to-plant biotransfer factor (*Pv*). Third, the chemical concentration in the plant due to root uptake from the soil ($Pr_{AG\text{-}produce}$) is estimated using an empirical bioconcentration factor ($Br_{AG\text{-}produce}$) that relates the chemical

Exhibit B-4. Estimating Chemical Concentration in Aboveground Produce



concentration in the plant to the average chemical concentration in the soil at the root-zone depth in the produce-growing area ($Cs_{root\text{-}zone_produce}$).

The edible portions of aboveground *protected* produce are not subject to contamination via particle deposition (*Pd*) or vapor transfer *(Pv*). Therefore, root uptake of chemicals is the primary mechanism through which aboveground protected produce becomes contaminated. As shown below, the chemical concentration in the aboveground plant due to root uptake from soil ($Pr_{AG\text{-}produce\text{-}DW}$) is estimated using an empirical bioconcentration factor ($Br_{AG\text{-}produce\text{-}DW}$) that relates the chemical concentration in the plant to the average chemical concentration in the soil at the root-zone depth in the produce-growing area ($Cs_{root\text{-}zone_produce}$). These equations all assume measurements on a dry-weight (DW) basis.

Equation B-1. Chemical Concentration in Aboveground Produce

$$C_{AG-produce-DW(i)} = Pr_{AG-produce-DW(i)} + Pd_{(i)} + Pv_{(i)}$$

where:

$C_{AG\text{-}produce\text{-}DW(i)}$	=	Concentration of chemical in edible portion of aboveground produce type i, exposed or protected, on a dry-weight (DW) basis (mg/kg produce DW)
$Pd_{(i)}$	=	Chemical concentration in edible portion of aboveground produce type i due to deposition of particles (mg/kg produce DW); for protected aboveground produce, Pd equals zero
$Pr_{AG\text{-}produce\text{-}DW(i)}$	=	Chemical concentration in edible portion of aboveground produce type i, exposed or protected, due to root uptake from soil at the root-zone depth of the produce growing area (mg/kg produce DW)
$Pv_{(i)}$	=	Chemical concentration in edible portion of aboveground produce type i due to air-to-plant transfer (µg/g [or mg/kg] produce DW); for protected aboveground produce, Pv equals zero

Equation B-2. Chemical Concentration in Aboveground Produce Due to Root Uptake

$$Pr_{AG-produce-DW(i)} = Cs_{\text{root-zone_produce}} \times Br_{AG-produce-DW(i)}$$

where:

$Pr_{AG\text{-}produce\text{-}DW(i)}$	=	Concentration of chemical in edible portion of aboveground produce type *i*, *exposed* or *protected*, due to root uptake from soil at root-zone depth in the produce-growing area, on a dry-weight (DW) basis (mg/kg produce DW)
$Cs_{root\text{-}zone_produce}$	=	Average chemical concentration in soil at root-zone depth in produce-growing area (mg/kg soil DW)
$Br_{AG\text{-}produce\text{-}DW(i)}$	=	Chemical-specific plant/soil chemical bioconcentration factor for edible portion of aboveground produce type *i*, *exposed* or *protected* (g soil DW / g produce DW)

Equation B-3. Chemical Concentration in Aboveground Produce Due to Deposition of Particle-phase Chemical

$$Pd_{(i)} = \frac{1{,}000 \times (Drdp + (Fw \times Drwp)) \times Rp_{(i)} \times (1 - e^{(-kp(i)*Tp(i))})}{Yp_{(i)} \times kp_{(i)}}$$

where:

$Pd_{(i)}$	=	Chemical concentration in aboveground produce type *i* on a dry-weight (DW) basis due to particle deposition (mg/kg produce DW); set equal to zero for *protected* aboveground produce
Drdp	=	Average annual dry deposition of particle-phase chemical (g/m^2-yr)
Fw	=	Fraction of wet deposition that adheres to plant surfaces; 0.2 for anions, 0.6 for cations and most organics (unitless)
Drwp	=	Average annual wet deposition of particle-phase chemical (g/m^2-yr)
$Rp_{(i)}$	=	Interception fraction of the edible portion of plant type *i* (unitless)
$kp_{(i)}$	=	Plant surface loss coefficient for plant type *i* (yr^{-1})
$Tp_{(i)}$	=	Length of exposure to deposition in the field per harvest of the edible portion of plant type *i* (yr)
$Yp_{(i)}$	=	Yield or standing crop biomass of the edible portion of plant type i (kg produce DW/m^2)

Note that Equation B-3 differs from Equation 5-14 in HHRAP, from which it is derived. In HHRAP, Equation 5-14 includes the term *Q* x (*1 – Fv*) to indicate the emissions rate, in g/sec, of chemical from the source and the proportion of the chemical that remains in, or partitions to, the particle-phase in the air. Also in HHRAP, the dry and wet particle phase deposition rates, *Dydp* and *Dywp,* respectively, are normalized to the emission rate and are expressed in units of sec/m^2-yr.

With MIRC, the user inputs both the dry and wet particle-phase deposition rates, *Drdp* and *Drwp*, respectively, in units of g/m^2-yr for a specific location relative to an emissions source. Those deposition rates might be values measured near that location or estimated using a fate and transport model, such as TRIM.FaTE, in conjunction with local meteorological information and emissions rate data. The chemical emissions term used in HHRAP, *Q*, therefore, is not used in MIRC's Equation B-3. In addition, in MIRC, *Drdp* and *Drwp*, the average annual dry- and wet-particle-phase deposition rates, respectively, are in units of g/m^2-yr. Users of TRIM.FaTE should note that the dry- and wet-particle-deposition rates output from TRIM.FaTE are in units of g/m^2-day; therefore, users must adjust the TRIM.FaTE output values to units of g/m^2-yr (i.e., multiply by 365 days/yr) before inputting values for *Drdp* and *Drwp* into MIRC.

Equation B-4. Chemical Concentration in Aboveground Produce Due to Air-to-Plant Transfer of Vapor-phase Chemical

$$Pv_{(i)} = \frac{Ca \times Fv \times Bv_{AG(i)} \times VG_{AG(i)}}{\rho_a}$$

where:

$Pv_{(i)}$	=	Concentration of chemical in edible portion of aboveground produce type *i* from air-to-plant transfer of vapor-phase chemical on a dry-weight (DW) basis (µg/g produce DW); set equal to zero for *protected* aboveground produce
Ca	=	Average annual *total* chemical concentration in air (g/m^3)
Fv	=	Fraction of airborne chemical in vapor phase (unitless)
$Bv_{AG(i)}$	=	Air-to-plant biotransfer factor for aboveground produce type *i* for vapor-phase chemical in air ([mg/g produce DW] / [mg/g air], i.e., g air/ g produce DW)
$VG_{AG(i)}$	=	Empirical correction factor for aboveground *exposed* produce type *i* to address possible overestimate of the diffusive transfer of chemical from the outside to the inside of bulky produce, such as fruit (unitless)
ρ_a	=	Density of air (g/m^3)

Note that Equation B-4 differs from Equation 5-18 in HHRAP, from which it is derived. In HHRAP, Equation 5-18 includes the term *Q* x *Fv* to indicate the emissions rate, in g/sec, of chemical from the source and the fraction of the chemical in vapor phase in the air. HHRAP also includes the parameter *Cyv*, or the unitized yearly average air concentration of vapor-phase chemical in units of µg-sec/g-m^3. For MIRC, the user inputs the average annual total air concentration of the chemical, *Ca*, for a specific location relative to the source in units of g/m^3; MIRC includes a chemical-specific default value for *Fv* for chemicals included in its database. The air concentration might be a value measured near that location or a value estimated by a fate and transport model such as TRIM.FaTE. Users of TRIM.FaTE should note that the average annual concentration of the total chemical in air (i.e., total of both vapor and particulate phases), *Ca*, output from TRIM.FaTE is in units µg/m^3; therefore, the user must adjust the value to units of g/m^3 (i.e., divide by 1,000 µg/g) before entering it in MIRC.

The calculations of chemical concentration in aboveground produce, ($C_{AG\text{-}produce\text{-}DW}$), shown above, are on a dry-weight (DW) basis. The family FFC food ingestion rates, on the other hand, are on a fresh- or wet-weight (WW) basis. MIRC therefore calculates the concentration in aboveground produce on a wet-weight basis, $C_{AG\text{-}produce\text{-}WW}$, using Equation B-5 and the moisture content (*MAF*) of the FFC food category.

Equation B-5. Conversion of Aboveground Produce Chemical Concentration from Dry- to Wet-Weight Basis

$$C_{AG-produce-WW(i)} = C_{AG-produce-DW(i)} \times \left(\frac{(100 - MAF_{(i)})}{100} \right)$$

where:

$C_{AG\text{-}produce\text{-}WW(i)}$	=	Chemical concentration in edible portion of aboveground produce type i on a wet-weight (WW) basis (mg/kg produce WW)
$C_{AG\text{-}produce\text{-}DW(i)}$	=	Chemical concentration in edible portion of aboveground produce type i on a dry-weight (DW) basis (mg/kg produce DW)
$MAF_{(i)}$	=	Moisture adjustment factor for aboveground produce type i to convert the chemical concentration estimated for dry-weight produce to the corresponding chemical concentration for full-weight fresh produce (percent water)

3.1.1.2. Belowground Produce

The equations by which chemical concentrations are estimated in belowground produce are different for nonionic organic chemicals than for inorganic chemicals and ionic organic chemicals.

3.1.1.2.1. Nonionic Organic Chemicals

For belowground produce, the nonionic organic chemical concentration in the tuber or root vegetable is derived from exposure to the chemical in soil and is estimated using an empirical root concentration factor (*RCF*) and the average chemical concentration in the soil at the root-zone depth in the produce-growing area ($Cs_{root\text{-}zone_produce}$), as shown in Equation B-6. The RCF relates the chemical concentration in the plant on a wet-weight basis to the average chemical concentration in the root-zone soil ($Cs_{root\text{-}zone_produce}$) on a dry-weight basis. Belowground produce (i.e., tubers or root vegetables) are protected from the deposition and vapor transfer by being covered by soil. Therefore, root uptake of chemicals is the primary mechanism through which belowground produce becomes contaminated.

Equation B-6. Chemical Concentration in Belowground Produce: Nonionic Organic Chemicals

$$C_{\text{BG-produce-WW}} = \frac{Cs_{root-zone_produce} \times RCF \times VG_{rootveg}}{Kds \times UCF}$$

where:

$C_{BG\text{-}produce\text{-}WW}$	=	Concentration of chemical in belowground (BG) produce (i.e., tuber or root vegetable) on a wet-weight (WW) basis (mg chemical/kg produce WW)*
$Cs_{root\text{-}zone_produce}$	=	Average chemical concentration in soil at root-zone depth in produce-growing area, on a dry-weight (DW) basis (mg chemical/kg soil DW)
RCF	=	Chemical-specific root concentration factor for tubers and root produce (L soil pore water/kg root WW)*
$VG_{rootveg}$	=	Empirical correction factor for belowground produce (i.e., tuber or root vegetable) to account for possible overestimate of the diffusive transfer of chemicals from the outside to the inside of bulky tubers or roots (based on carrots and potatoes) (unitless) *
Kds	=	Chemical-specific soil/water partition coefficient (L soil pore water/kg soil DW)
UCF	=	Units conversion factor of 1 kg/L

*Note that there is only one type of BG produce; hence there are no plant-type-specific subscripts.

The RCF, as developed by Briggs *et al*. (1982), is the ratio of the chemical concentration in the edible root on a wet-weight basis to its concentration in the soil pore water. RCFs are based on experiments with growth solutions (hydroponic) instead of soils; therefore, it is necessary to divide the soil concentration by the chemical-specific soil/water partition coefficient (*Kds*). There is no conversion of chemical concentrations in belowground produce from DW to WW because the values are already on a WW basis.

For nonionic organic chemicals, it is possible to predict RCF values and Kds values (for a specified soil organic carbon content) from an estimate of the chemical's K_{ow} from empirically

derived regression models. Those models are shown in HHRAP Appendix A-2, Equations A-2-14 and A-2-15 (RCF) and in Equations A-29 and A-2-10 (Kds). The RCF and Kds values so calculated for many of the chemicals in HHRAP are included in the MIRC database (including the values for PAHs and dioxins).

3.1.1.2.2. Inorganic and Ionic Organic Chemicals

For inorganic chemicals and ionized organic chemicals, it is not possible to predict RCF or Kds values from K_{ow} . For inorganic chemicals, chemical specific empirical values for the root/soil bioconcentration factor must be used. The root/soil bioconcentration factor, now specified as $Br_{BG\text{-}produce\text{-}DW}$, must be obtained from the literature for each inorganic chemical on a DW basis. For inorganic chemicals, therefore, Equation B-7 is used instead of Equation B-6.

Equation B-7. Chemical Concentration in Belowground Produce: Inorganic Chemicals

$$C_{BG\text{-}produce\text{-}DW} = \frac{Cs_{root-zone_produce} \times Br_{BG-produce-DW} \times VG_{rootveg}}{1}$$

where:

$C_{BG\text{-}produce\text{-}DW}$	=	Concentration of chemical in edible portion of aboveground produce, due to root uptake from soil at root-zone depth in the produce-growing area, on a dry-weight (DW) basis (mg/kg produce DW)
$Cs_{root\text{-}zone_produce}$	=	Average chemical concentration in soil at root-zone depth in produce-growing area (mg/kg soil DW)
$Br_{BG\text{-}produce\text{-}DW}$	=	Chemical-specific root/soil chemical bioconcentration factor for edible portion of belowground produce (g soil DW / g produce DW)
$VG_{rootveg}$	=	Empirical correction factor for belowground produce (as in Equation B-6) (unitless)

As for the aboveground produce, the DW estimate of concentration of chemical in the root vegetables must be transformed to a WW estimate, as shown in Equation B-8.

Equation B-8. Conversion of Belowground Produce Chemical Concentration from Dry- to Wet-Weight Basis

$$C_{BG-produce-WW} = C_{BG-produce-DW} \times \left(\frac{(100 - MAF_{BG})}{100} \right)$$

where:

$C_{BG\text{-}produce\text{-}WW}$	=	Chemical concentration in edible portion of belowground produce on a weight-weight (WW) basis (mg/kg produce WW)
$C_{BG\text{-}produce\text{-}DW}$	=	Concentration of chemical in edible portion of aboveground produce, due to root uptake from soil at root-zone depth in the produce-growing area, on a dry-weight (DW) basis (mg/kg produce DW)
$MAF_{(BG)}$	=	Moisture adjustment factor (as in Equation B-5, but single value for below ground produce) (percent water)

3.1.2. Estimating Chemical Concentrations in Animal Products

Chemical concentrations in animal products are estimated based on the amount of chemical consumed by each animal group *m* through each plant feed type *i* ($Plant_{Ch\text{-}Intake(i,m)}$) and incidental ingestion of soil for ground-foraging animals ($Soil_{Ch\text{-}Intake(m)}$). Exhibit B-5 summarizes the pathways by which chemicals are transferred to these home- or farm-raised animal food products. Note that for a general screening-level assessment, all of the pathways can be modeled, as is done for EPA's RTR calculation of screening threshold emission rates for PB-HAPs (EPA 2008b).

The feed options for farm animals in MIRC include forage (plants grown on-site for animal grazing, such as grass), silage (wet forage grasses, fresh-cut hay, or other fresh plant material that has been stored and fermented), and grain products grown on the farm. As seen in Exhibit B-5, the algorithms in MIRC for chemical intake with plant feeds ($Plant_{Ch\text{-}Intake(i,m)}$) are based on the assumptions that beef and dairy cattle consume all three plant feed products, while pigs consume only silage and grain, and chickens consume only grain.

Exhibit B-5. Chemical Transfer Pathways for Animal Products

Farm Food Media		Chemical Transfer Pathways
Animal Products	Beef and total dairy (including milk)	• Ingestion of forage, silage, and grain[a] • Incidental soil ingestion
	Pork	• Ingestion of silage and grain[a] • Incidental soil ingestion
	Poultry and eggs	• Ingestion of grain[a] • Incidental soil ingestion

[a]Chemical concentrations in plant feed (i.e., forage, silage, and grain) are estimated via intermediate calculations (see Equation B-13, Equation B-14, Equation B-3, and Equation B-4).

Forage and silage are exposed to the air and can accumulate chemicals via direct deposition of particle-bound chemical and transfer of vapor-phase chemical, while all animal feed grains are assumed to be protected from the air by a husk or pod (e.g., corn, soybeans). All three animal feed products are assumed to accumulate chemical via root uptake.

Chemical concentrations are estimated for animal feeds using algorithms analogous to those for aboveground farm produce described above. MIRC uses Equation B-9 to calculate the concentration of chemical in beef, pork, or total dairy and Equation B-10 to calculate the concentration of chemical in poultry or eggs. The chemical concentration in mammalian farm animals (i.e., beef and pigs) is adjusted using a metabolism factor (*MF*) that accounts for endogenous degradation of the chemical (see Equation B-9). *MF* is set to 1.0 for chemicals that are not metabolized and for chemicals for which the metabolic degradation rate is unknown. Although other vertebrates, including birds, are likely to have similar metabolic pathways for most chemicals, the health protective assumption is that birds do not metabolize any chemicals; therefore, the *MF* is omitted from Equation B-10 for poultry and eggs.

Equation B-9. Chemical Concentration in Beef, Pork, or Total Dairy

$$C_{mammal(m)} = Ba_{(m)} \times MF \times \left(Soil_{Ch-Intake(m)} + \sum_{i=1}^{n} Plant_{Ch-Intake(i,m)} \right)$$

where:

$C_{mammal(m)}$	=	Concentration of chemical in mammalian animal product *m*, where *m* = beef, pork, or total dairy (mg chemical/kg animal product WW)
$Ba_{(m)}$	=	Chemical-specific biotransfer factor for chemical in diet to chemical in animal food product *m*, where *m* = beef, pork, or total dairy ([mg chemical/kg animal product WW] / [mg chemical intake/day] or day/kg WW)
MF	=	Chemical-specific mammalian metabolism factor that accounts for endogenous degradation of the chemical (unitless)
$Soil_{Ch\text{-}Intake(m)}$	=	Incidental ingestion of chemical in surface soils by livestock type *m* during grazing or consumption of foods placed on the ground (mg/day); see Equation B-11 below
$Plant_{Ch\text{-}Intake(i,m)}$	=	For livestock (animal product) type *m*, ingestion of chemical from plant feed type *i* (mg chemical/kg livestock WW); see Equation B-12 below (If *m* =beef or total dairy, then *n* = 3 and *i* = forage, silage, and grain; *m* = pork, then *n* = 2 and *i* = silage and grain; *m* = poultry, then *n* = 1 and *I* = grain.)

Equation B-10. Chemical Concentration in Poultry or Eggs

$$C_{poultry(m)} = Ba_{(m)} \times \left(Soil_{Ch-Intake(m)} + Plant_{Ch-Intake(i,m)}\right)$$

where:

$C_{poultry(m)}$	=	Concentration of chemical in food product *m*, where *m* = poultry or eggs (mg chemical/kg animal product WW)
$Ba_{(m)}$	=	Chemical-specific biotransfer factor for food product *m*, where *m* = poultry or eggs (day/kg animal product WW)
$Soil_{Ch\text{-}Intake(m)}$	=	Incidental ingestion of chemical in surface soils by consumption of food on the ground (mg chemical/day) where *m* = poultry; see Equation B-11
$Plant_{Ch\text{-}Intake(i,m)}$	=	For poultry (and eggs), animal *m*, ingestion of the chemical in plant feed type *i* (mg chemical/day), which for poultry is limited to grain; see Equation B-12

In MIRC, the incidental ingestion of the chemical in soils by livestock during grazing or consumption of feed placed on the ground ($Soil_{Ch\text{-}Intake(m)}$) is estimated using empirical soil ingestion rates (*Qs*) and a soil bioavailability factor for livestock (*Bs*), as shown in Equation B-11. At this time, the default value for *Bs* in MIRC for all chemicals is 1.0 (i.e., the chemical in soil is assumed to be 100 percent bioavailable to the animal). This assumption may be reasonably accurate for the soil surface to which airborne chemical is deposited. MIRC allows the user to enter a surface soil concentration for areas where livestock forage, $Cs_{S\text{-}livestock}$, that is distinct from the surface soil concentration input for areas where produce may be grown and where humans might incidentally ingest soils (see Section 6.1 of this attachment).

Equation B-11. Incidental Ingestion of Chemical in Soil by Livestock

$$Soil_{Ch-Intake(m)} = Qs \times Cs_{s-livestock} \times Bs$$

where:

$Soil_{Ch\text{-}Intake(m)}$	=	Incidental ingestion of the chemical in surface soils by livestock type *m* during grazing or consumption of foods placed on the ground (mg chemical/day)
$Qs_{(m)}$	=	Quantity of soil eaten by animal type *m* each day (kg soil DW/day)
$Cs_{s\text{-}livestock}$	=	Chemical concentration in surface soil in contaminated area where livestock feed (mg chemical/kg soil DW)
Bs	=	Soil bioavailability factor for livestock (unitless) (assumed to be the same for birds and mammals)

Animal ingestion of the chemical in feed is calculated for each type of livestock based on their assumed diets. For *m* = beef and dairy cattle, chemical intake is estimated for all three feed types: *i* = forage, silage, and grain. For pork, chemical intake is estimated only for silage and grain. The chemical intake for poultry is based on grain consumption only. The intake of chemical with each feed type, *i*, $Plant_{Ch\text{-}Intake(i,m)}$, is calculated separately according to Equation B-12. Note that the animal feed ingestion rates are on a dry-weight (DW) basis; hence, no DW to wet weight (WW) conversion is needed.

Equation B-12. Ingestion of Chemical in Feed by Livestock

$$Plant_{Ch-Intake(i,m)} = F_{(i,m)} \times Qp_{(i,m)} \times C_{feed(i)}$$

where:

$Plant_{Ch\text{-}Intake(i,m)}$	=	Ingestion of chemical in plant feed type *i* (mg chemical/day), where *i* = forage, silage, or grain, for livestock type *m*
$F_{(i,m)}$	=	Fraction of plant feed type *i* obtained from contaminated area used to grow animal feed, where *I* = forage, silage, or grain (unitless) for livestock type *m*
$Qp_{(i,m)}$	=	Quantity of plant feed type *i* consumed per animal per day (kg plant feed DW/day), where *i* = forage, silage, or grain, for livestock type *m*
$C_{feed(i)}$	=	Concentration of chemical in ingested plant feed type *i* (mg chemical/kg plant feed DW), where *i* = forage, silage, or grain

The concentrations of chemical in the three different types of plant feeds for livestock are calculated according to Equation B-13. The equation is the same as that for aboveground produce in Equation B-1, with the exception that the concentrations are for plants used as animal feeds (not produce consumed by humans) and all types of plant feed (i.e., forage, silage, and grain) are aboveground.

Equation B-13. Chemical Concentration in Livestock Feed (All Aboveground)

$$C_{feed(i)} = Pr_{feed(i)} + Pd_{(i)} + Pv_{(i)}$$

where:

$C_{feed(i)}$	=	Concentration of chemical in plant feed type *i* on a dry-weight (DW) basis (mg chemical/kg plant feed DW), where *i* = forage, silage, or grain

$Pr_{feed(i)}$ = Concentration of chemical in plant feed type *i* due to root uptake from soil (mg/kg DW), where *i* = forage, silage, or grain; see Equation B-14 below

$Pd_{(i)}$ = Concentration of chemical in plant feed type *i* due to wet and dry deposition of particle-phase chemical (mg/kg DW), where *i* = forage, silage, or grain; when *i* = grain, the *Pd* term equals zero

$Pv_{(i)}$ = Concentration of chemical in plant feed type *i* due to air-to-plant transfer of vapor-phase chemical (µg/g [or mg/kg] DW) where *i* = forage, silage, or grain; when *i* = grain, the *Pd* term equals zero

MIRC calculates the chemical concentration in animal feed due to root uptake from the soil using Equation B-14. The equation is the same as Equation B-2, except that a *Br* value appropriate to grasses is used and MIRC allows for different soil concentrations in the area used to grow animal feed than in the area used to grow produce for human consumption (see Section 6.1 of this attachment, user inputs). Note that for feed type *i* = grains, the *Pd* and *Pv* terms do not apply (are set to zero), because the feed products (i.e., corn kernels, soy beans) are protected from the air (i.e., by husks, pods).

Equation B-14. Chemical Concentration in Livestock Feed Due to Root Uptake

$$Pr_{feed(i)} = Cs_{root-zone_feed(i)} \times Br_{feed(i)}$$

where:

$Pr_{feed(i)}$ = Concentration of chemical in plant feed type *i* due to root uptake from soil on a dry-weight (DW) basis (mg chemical/kg plant feed DW), where *i* = forage, silage, or grain

$Cs_{root\text{-}zone_feed(i)}$ = Average chemical concentration in soil at root-zone depth in area used to grow plant feed type *i* (mg chemical/kg soil DW), where *i* = forage, silage, or grain

$Br_{feed(i)}$ = Chemical-specific plant-soil bioconcentration factor for plant feed type *i* (kg soil DW/kg plant feed DW), where *i* = forage, silage, or grain

The algorithms used to calculate $Pd_{(i)}$ and $Pv_{(i)}$ when plant feed type *i* = forage and silage are identical to those used to calculate $Pd_{(i)}$ and $Pv_{(i)}$ for aboveground exposed produce (i.e., Equation B-3 and Equation B-4, respectively).

There are no conversions of DW feed to WW feed, because all feed ingestion rates for livestock are based on DW feed.

3.2. Chemical Intake Calculations for Adults and Non-Infant Children

MIRC calculates human chemical intake rates from the ingestion of home-grown foods as average daily doses (ADDs) normalized to body weight for each age group, chemical, and food type separately. ADDs, calculated using Equation B-15, are expressed in milligrams of chemical per kilogram of receptor body weight per day (mg/kg-day).

Equation B-15. Average Daily Dose for Specified Age Group and Food Type

$$ADD_{(y,i)} = \left(\frac{C_{(i)} \times IR_{(y,i)} \times FC_{(i)} \times ED_{(y)}}{BW_{(y)} \times AT_{(y)}} \right) \left(\frac{EF_{(y)}}{365 \text{ days}} \right)$$

where:

$ADD_{(y,i)}$ = Average daily dose for age group *y* from food type or ingestion medium *i* (mg chemical/kg body weight-day)

$C_{(i)}$ = Concentration of chemical in food type *i* harvested from the contaminated area (mg chemical/kg food or mg food/L water)

$IR_{(y,i)}$ = Ingestion rate for age group *y* of food type *i* (kg/day or L/day)

$FC_{(i)}$ = Fraction of food type *i* that was harvested from contaminated area (unitless)

$ED_{(y)}$ = Exposure duration for age group *y* (years)

$BW_{(y)}$ = Body weight for age group *y* (kg)

$AT_{(y)}$ = Averaging time for calculation of daily dose (years) for age group *y*, set equal to ED in MIRC

$EF_{(y)}$ = Annual exposure frequency for age group *y* (days)

Equation B-15 takes into account the chemical concentration in each food type *i* (or in water), the quantity of food brought into the home for consumption, the loss of some of the mass of the foods due to preparation and cooking, how much of the food is consumed per year, the amount of the food obtained from contaminated areas, and the consumer's body weight (EPA 2011a, 2003a). In MIRC, ADDs are calculated separately for each chemical, home-grown food type, and consumer age group.

ADD values, expressed as intakes, not absorbed doses, are appropriate for comparison with RfDs and for use with cancer slope factors (CSFs) to estimate risk, as discussed in Section 5 of this attachment. An exception is for the breast-milk exposure pathway, where calculating the dose available to and absorbed by the nursing infant is related to the dose absorbed by the mother as discussed in Section 3.4 of this attachment.

MIRC evaluates only one exposure scenario at a time. For screening-level assessments, all components of this equation are assumed to remain constant for consumers in a given age group over time (e.g., seasonal and annual variations in diet are not explicitly taken into account). To calculate an $ADD_{(y,i)}$ from the contaminated area for food group *i* over an entire lifetime of exposure, age-group-specific ingestion rates and body weights are used for the age groups described in Section 2.3 of this attachment. In MIRC, the averaging time used to calculate the daily dose for an age group (AT_y) is equal to the exposure duration for that group (ED_y); therefore these variables drop out of Equation B-15.

For each chemical included in a screening scenario, total average daily exposure for age group *y* ($ADD_{(y)}$) is estimated as the sum of chemical intake from all ingestion pathways combined: Note that the last exposure pathway is limited to infants.

- Incidental soil ingestion;
- Ingestion of fish;
- Ingestion of homegrown fruits (exposed and protected);
- Ingestion of homegrown vegetables (exposed, protected, and root);
- Ingestion of animal products from home-raised animals:
  - Milk and other dairy products from cows,

  - Beef products,
  - Pork products, and
  - Poultry and eggs;
- Ingestion of drinking water from specified source; and
- Ingestion of breast milk by infants.

The algorithms for the first six exposure pathways listed above are described in Sections 3.2.1 through 3.2.6 of this attachment. The algorithms for the breast-milk ingestion pathway are described in Section 3.4.

3.2.1. Chemical Intake from Soil Ingestion

Equation B-16 shows the equation used to estimate chemical intake through incidental ingestion of soil.

Equation B-16. Chemical Intake from Soil Ingestion

$$ADD_{Soil(y)} = \left(\frac{C_{Soil} \times IR_{Soil(y)} \times FC_{Soil} \times 0.001 \ \frac{mg}{\mu g}}{BW_{(y)}} \right) \left(\frac{EF}{365 \text{ days}} \right)$$

where:

$ADD_{Soil(y)}$	=	Average daily chemical intake from incidental ingestion of soil or ingestion by child in age group *y* (mg chemical/kg body weight-day)
C_{Soil}	=	Concentration of chemical in soil from contaminated area on a dry-weight (DW) basis (µg/g soil DW)
$IR_{Soil(y)}$	=	Soil ingestion rate for age group *y* (g DW/day)
FC_{Soil}	=	Fraction of soil ingested that is from contaminated area (unitless)
$BW_{(y)}$	=	Body weight for age group *y* (kg)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤ 365 days)

Note: MIRC saves soil ingestion rates in units of mg/day (not g/day); therefore, there is an additional 0.001 g/mg conversion unit in the actual MIRC algorithm than shown here.

3.2.2. Chemical Intake from Fish Ingestion

Ingestion of locally caught fish is included as a possible exposure pathway in MIRC (Equation B-17). Two types of fish are included in the exposure algorithm: trophic level 3.5 (abbreviated as TL3) fish, equivalent to benthic carnivores such as catfish and trophic level 4 (TL4) fish in the water column, equivalent to game fish such as lake trout and walleye. The chemical concentration in fish in Equation B-17 is estimated as the consumption-weighted chemical concentration using Equation B-18.

Equation B-17. Chemical Intake from Fish Ingestion

$$ADD_{Fish(y)} = (1 - L1_{Fish}) \times (1 - L2_{Fish}) \times \frac{\left(C_{Fish} \times IR_{Fish(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{Fish}\right)}{BW_{(y)}} \times \left(\frac{EF}{365 \text{ days}}\right)$$

Equation B-18. Consumption-weighted Chemical Concentration in Fish

$$\mathrm{C_{Fish}} = (\mathrm{C_{FishTL3}} \times \mathrm{F_{TL3}}) + (\mathrm{C_{FishTL4}} \times \mathrm{F_{TL4}})$$

where:

$ADD_{Fish(y)}$	=	Average daily chemical intake from ingestion of local fish for age group *y* (mg/kg-day)
$L1_{Fish}$*	=	Weight of fish brought into home that is discarded during preparation (e.g., head, bones, liver, other viscera, belly fat, skin with fat) (unitless)
$L2_{Fish}$*	=	Loss of weight during cooking, such as evaporation and loss of fluids into pan (unitless)
$C_{FishTL3}$	=	Chemical concentration in whole fish for trophic level 3.5 (TL3) fish on a wet-weight (WW) basis (mg/kg WW)
$C_{FishTL4}$	=	Chemical concentration in whole fish for trophic level 4 (TL4) fish on a wet-weight (WW) basis (mg/kg WW)
F_{TL3}	=	Fraction of fish intake that is from TL3 (unitless)
F_{TL4}	=	Fraction of fish intake that is from TL4 (unitless)
C_{Fish}	=	Consumption-weighted mean chemical concentration in total fish (i.e., as specified by Equation B-18) (mg/kg WW)
FC_{Fish}	=	Fraction of local fish consumed derived from contaminated area (unitless)
$BW_{(y)}$	=	Body weight for age *y* (kg)
$IR_{Fish(y)}$*	=	Local fish ingestion rate for age *y* (g WW/day)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤ 365 days)

*Parameter values must be internally consistent. In contrast to the tables included in MIRC for ingestion rate options for homegrown food products, which are based on the products as brought into the home from the field (see Section 6.3.3 of this attachment), the tables of fish ingestion rate options included in MIRC are on an "as consumed" basis (i.e., after preparation and cooking losses), and L1 and L2 therefore are set equal to zero. If the user wishes to enter local fish ingestion rates on an "as harvested" basis, the user also should enter L1 and L2 values as specified in Section 6.4.3 of this attachment.

When whole fish are prepared for cooking, it is usual for the viscera, head, and fins to be removed, particularly for larger fish. Many persons also remove (or do not eat) the skin, bones, and belly fat. EPA has, therefore, estimated the proportion of the weight of whole fish that tends to be lost during preparation and cooking across a variety of fish species (EFH; EPA 2011a) and included those losses in its HHRAP algorithms for chemical intake from fish ($L1_{Fish}$ and $L2_{Fish}$ in Equation B-17).

3.2.3. Chemical Intake from Fruit Ingestion

Average daily doses of a chemical from homegrown exposed fruits are calculated separately for exposed and protected fruits (Equation B-19 and Equation B-20, respectively).

Equation B-19. Chemical Intake from Consumption of Exposed Fruits

$$ADD_{ExpFruit(y)} = \left(1 - L1_{ExpFruit}\right) \times \left(1 - L2_{ExpFruit}\right) \times \left(C_{ExpFruit} \times IR_{ExpFruit(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{ExpFruit}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

Equation B-20. Chemical Intake from Consumption of Protected Fruits

$$ADD_{ProFruit(y)} = \left(1 - L1_{ProFruit}\right) \times \left(C_{ProFruit} \times IR_{ProFruit(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{ProFruit}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

where:

$ADD_{ExpFruit(y)}$ $ADD_{ProFruit(y)}$	=	Average daily chemical intake from ingestion of exposed fruit or protected fruit (depending on subscript) (mg chemical/kg body weight-day)
$L1_{ExpFruit}$	=	Mean reduction in fruit weight resulting from removal of skin or peel, core or pit, stems or caps, seeds and defects, and from draining liquids from canned or frozen forms (unitless)
$L1_{ProFruit}$	=	Mean reduction in fruit weight that results from paring or other preparation techniques for protected fruits (unitless)
$L2_{ExpFruit}$	=	Mean reduction in fruit weight that results from draining liquids from cooked forms of the fruit (unitless)
$C_{ExpFruit}$ $C_{ProFruit}$	=	Chemical concentration in whole exposed fruits or whole protected fruits (depending on subscript) on a wet-weight (WW) basis (mg chemical/kg exposed fruit WW)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤ 365 days)
$FC_{ExpFruit}$ $FC_{ProFruit}$	=	Fraction of exposed fruits or protected fruits (depending on subscript) obtained from contaminated area (unitless)
$IR_{ExpFruit(y)}$ $IR_{ProFruit(y)}$	=	Ingestion rate of home-grown exposed fruits or protected fruits (depending on subscript) for age *y* (g WW/kg body weight-day)

Fruit ingestion rates in the survey were based on weights of unprepared fruits (e.g., one apple; one pear) or the weight of a can of fruit (e.g., 8 oz. can). The weight of the fruit ingested is less than the initial weight owing to common preparation actions ($L1_{ExpFruit}$ and $L1_{ProFruit}$; e.g., coring apples and pears; peeling apples; pitting cherries). Cooking of exposed fruit (e.g., berries, apples, peaches) often results in further weight loss that results from liquids lost during cooking and drained from the cooking vessel ($L2_{ExpFruit}$). EPA has assumed that cooking of protected fruit results in no loss of weight for the fruit.

3.2.4. Chemical Intake from Vegetable Ingestion

MIRC includes three separate algorithms for homegrown vegetables adapted from EPA's HHRAP Modeling System (EPA 2005a): one for exposed vegetables such as asparagus, broccoli, lettuce, and tomatoes (although they are actually a fruit); one for protected vegetables

such as corn, cabbage, soybeans, and peas; and one for root vegetables such as carrots, beets, and potatoes (see Equation B-21, Equation B-22, and Equation B-23, respectively).

Equation B-21. Chemical Intake from Exposed Vegetables

$$ADD_{ExpVeg(y)} = \left(1 - L1_{ExpVeg}\right) \times \left(C_{ExpVeg} \times IR_{ExpVeg(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{ExpVeg}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

Equation B-22. Chemical Intake from Protected Vegetables

$$ADD_{ProVeg(y)} = \left(1 - L1_{ProVeg}\right) \times \left(C_{ProVeg} \times IR_{ProVeg(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{ProVeg}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

Equation B-23. Chemical Intake from Root Vegetables

$$ADD_{RootVeg(y)} = \left(1 - L1_{RootVeg}\right) \times \left(1 - L2_{RootVeg}\right) \times \left(C_{RootVeg} \times IR_{RootVeg(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{RootVeg}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

where:

$ADD_{ExpVeg(y)}$ $ADD_{ProVeg(y)}$ $ADD_{RootVeg(y)}$	=	Average chemical intake from ingestion of exposed vegetables, protected vegetables, or root vegetables (depending on subscript) for age group *y* (mg chemical/kg body weight-day)
$L1_{ExpVeg}$	=	Mean net preparation and cooking weight loss for exposed vegetables (unitless); includes removing stalks, paring skins, discarding damaged leaves
$L1_{ProVeg}$	=	Mean net cooking weight loss for protected vegetables (unitless); includes removing husks, discarding pods of beans and peas, removal of outer leaves
$L1_{RootVeg}$	=	Mean net cooking weight loss for root vegetables (unitless); includes losses from removal of tops and paring skins
$L2_{RootVeg}$	=	Mean net post cooking weight loss for root vegetables from draining cooking liquids and removal of skin after cooking (unitless)
C_{ExpVeg} C_{ProVeg} $C_{RootVeg}$	=	Chemical concentration in exposed vegetables, protected vegetables, or root vegetables (depending on subscript) on a wet-weight (WW) basis (mg chemical/kg vegetable WW)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤365 days)
FC_{ExpVeg} FC_{ProVeg} $FC_{RootVeg}$	=	Fraction of exposed vegetables, protected vegetables, or root vegetables (depending on subscript) obtained from contaminated area (unitless)
$IR_{ExpVeg(y)}$ $IR_{ProVeg(y)}$ $IR_{RootVeg(y)}$	=	Ingestion rate of exposed vegetables, protected vegetables, or root vegetables (depending on subscript) for age group *y* (g vegetable WW/kg body weight-day)

3.2.5. Chemical Intake from Animal Product Ingestion

Calculations of chemical intake from the consumption of farm animals and related food products are provided below in Equation B-24 through Equation 2-28 for homegrown beef, dairy (milk), pork, poultry, and eggs, respectively.

Equation B-24. Chemical Intake from Ingestion of Beef

$$ADD_{Beef(y)} = (1 - L1_{Beef}) \times (1 - L2_{Beef}) \times \left(C_{Beef} \times IR_{Beef(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Beef} \right) \times \left(\frac{EF}{365 \text{ days}} \right)$$

where:

$ADD_{Beef(y)}$ = Average daily chemical intake from ingestion of beef for age group y (mg/kg-day)

$L1_{Beef}$ = Mean net cooking loss for beef (unitless)

$L2_{Beef}$ = Mean net post cooking loss for beef (unitless)

C_{Beef} = Concentration of contaminant in beef (mg/kg WW))

EF = Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤ 365 days)

$IR_{Beef(y)}$ = Ingestion rate of contaminated beef for age group y (g WW/kg-day)

$FCBeef$ = Fraction of beef consumed raised on contaminated area or fed contaminated silage and grains (unitless)

Equation B-25. Chemical Intake from Dairy Ingestion

$$ADD_{Dairy(y)} = \left(C_{Dairy} \times IR_{Dairy(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Dairy} \right) \times \left(\frac{EF}{365 \text{ days}} \right)$$

where:

$ADD_{Dairy(y)}$ = Average daily chemical intake from ingestion of total dairy for age group *y* (mg/kg-day)

C_{Dairy} = Average concentration of contaminant in total dairy (mg/kg WW)

EF = Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤ 365 days)

$IR_{Dairy(y)}$ = Ingestion rate of contaminated total dairy for age group *y* (g WW/kg-day)

FC_{Dairy} = Fraction of total dairy products from contaminated area (unitless)

Equation B-26. Chemical Intake from Pork Ingestion

$$ADD_{Pork(y)} = (1 - L1_{Pork}) \times (1 - L2_{Pork}) \times \left(C_{Pork} \times IR_{Pork(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Pork} \right) \times \left(\frac{EF}{365 \text{ days}} \right)$$

where:

$ADD_{Pork(y)}$	=	Average daily chemical intake from ingestion of pork for age group *y* (mg/kg-day)
$L1_{Pork}$	=	Mean net cooking loss for pork (unitless); includes dripping and volatile losses during cooking; averaged over various cuts and preparation methods
$L2_{Pork}$	=	Mean net post cooking loss for pork (unitless); includes losses from cutting, shrinkage, excess fat, bones, scraps, and juices; averaged over various cuts and preparation methods
C_{Pork}	=	Concentration of contaminant in pork (mg/kg WW)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤365 days)
$IR_{Pork(y)}$	=	Ingestion rate of contaminated pork for age *y* (g WW/kg-day)
FC_{Pork}	=	Fraction of pork obtained from contaminated area (unitless)

Equation B-27. Chemical Intake from Poultry Ingestion

$$ADD_{Poultry(y)} = \left(1 - L1_{Poultry}\right) \times \left(1 - L2_{Poultry}\right) \times \left(C_{Poultry} \times IR_{Poultry(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{Poultry}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

where:

ADDPoultry(y)	=	Average daily dose (chemical intake) from ingestion of poultry (mg/kg-day)
L1Poultry	=	Mean net cooking loss for poultry (unitless)
L2Poultry	=	Mean net post cooking loss for poultry (unitless)
CPoultry	=	Concentration of chemical in poultry (mg/kg WW)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤365 days)
IRPoultry(y)	=	Ingestion rate of poultry for age group *y* (g WW/kg-day)
$FC_{Poultry}$	=	Fraction of poultry from contaminated area or fed contaminated grains (unitless)

The reduction in the weight of beef, pork, and poultry during and after cooking may correlate with an increase or decrease in the concentration of the chemical in the food as consumed depending on the chemical and depending on the cooking method.

Equation B-28. Chemical Intake from Egg Ingestion

$$ADD_{Egg(y)} = \left(C_{Egg} \times IR_{Egg(y)} \times 0.001\frac{\text{kg}}{\text{g}} \times FC_{Egg}\right) \times \left(\frac{EF}{365\text{ days}}\right)$$

where:

$ADD_{Egg(y)}$	=	Average daily chemical intake from ingestion of eggs for age group *y* (mg/kg-day)

C_{Egg}	=	Concentration of contaminant in eggs (mg/kg WW)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤ 365 days)
$IR_{Egg(y)}$	=	Ingestion rate of contaminated eggs for age group *y* (g WW/kg-day)
FC_{Egg}	=	Fraction of eggs obtained from contaminated area (unitless)

3.2.6. Chemical Intake from Drinking Water Ingestion

If the user chooses to evaluate chemical ingestion via drinking water, the user specifies a chemical concentration in g/L (equivalent to mg/mL) based on their particular scenario. The chemical concentration could represent water from groundwater wells, community water, nearby surface waters, or other source. For this exposure pathway, ingestion rates are in units of milliliters of water per day (mL/day) (see Equation B-29).

Equation B-29. Chemical Intake from Drinking Water Ingestion

$$ADD_{DW(y)} = \left(\frac{C_{DW} \times IR_{DW(y)} \times FC_{DW}}{BW_{(y)}} \right) \times \left(\frac{EF}{365 \text{ days}} \right)$$

where:

$ADD_{DW(y)}$	=	Average daily chemical intake from ingestion of drinking water from local residential water source for age group *y* (mg/kg-day)
C_{DW}	=	Concentration of contaminant in drinking water (g/L)
$IR_{DW(y)}$	=	Drinking water ingestion rate for age group *y* (mL/day)
FC_{DW}	=	Fraction of drinking water obtained from contaminated area (unitless)
$BW_{(y)}$	=	Body weight of age group *y* (kg)
EF	=	Exposure frequency; number of days per year of exposure for family(ies) as specified for scenario (≤365 days)

3.3. Total Chemical Intake

To estimate the total ADD, or intake of a chemical from all of the exposure media that a single individual in each age group is expected to contact (e.g., soil, local fish, five types of home-grown produce, and five types of home-raised animals or animal products), the media-specific chemical intakes are summed for each age group. Total average daily exposure for a particular age group *y* ($ADD_{(y)}$) is estimated as the sum of chemical intake from all ingestion pathways combined, as illustrated in Equation B-30 through Equation B-35 below.

Equations B-30 to B-35. Total Average Daily Dose of a Chemical for Different Age Groups

Equation B-30. $ADD_{(<1)} = ADD_{breastmilk}$

Equation B-31. $ADD_{(1-2)} = \sum_{i=1}^{n} ADD_{(1-2,i)}$

Equation B-32. $ADD_{(3-5)} = \sum_{i=1}^{n} ADD_{(3-5,i)}$

Equation B-33. $ADD_{(6-11)} = \sum_{i=1}^{n} ADD_{(6-11,i)}$

Equation B-34. $ADD_{(12-19)} = \sum_{i=1}^{n} ADD_{(12-19,i)}$

Equation B-35. $ADD_{(adult)} = \sum_{i=1}^{n} ADD_{(adult,i)}$

where *i* represents the ith food type or ingestion medium and *n* equals the total number of food types or ingestion media, and *ADD* parameters are defined below:

$ADD_{(<1)}$	=	Total average daily dose of chemical for infants less than one year from ingestion of breast milk (mg/kg-day)
$ADD_{(1-2)}$	=	Total average daily dose of chemical from all ingestion sources for children ages 1 through 2 years (mg/kg-day)
$ADD_{(3-5)}$	=	Total average daily dose for children ages 3 through 5 years (mg/kg-day)
$ADD_{(6-11)}$	=	Total average daily dose for children ages 6 through 11 years (mg/kg-day)
$ADD_{(12-19)}$	=	Total average daily dose for children ages 12 through 19 years (mg/kg-day)
$ADD_{(adult)}$	=	Total average daily dose for adult age 20 up to 70 years (mg/kg-day)

The lifetime average daily dose (*LADD*) is calculated as the time-weight average of the *ADD* values for each age group (Equation B-36).

Equation B-36. Lifetime Average Daily Dose (LADD)

$$LADD = ADD_{(<1)}\left(\frac{1}{70}\right) + ADD_{(1\text{-}2)}\left(\frac{2}{70}\right) + ADD_{(3\text{-}5)}\left(\frac{3}{70}\right) + ADD_{(6\text{-}11)}\left(\frac{6}{70}\right) + ADD_{(12\text{-}19)}\left(\frac{8}{70}\right) + ADD_{(adult)}\left(\frac{50}{70}\right)$$

The time-weighting factors simply equal the duration of exposure for the specified age category in years divided by the total lifespan, assumed to be 70 years.

3.4. Chemical Intake Calculations for Nursing Infants

The scientific literature indicates that infants can be exposed to some chemicals via their mothers' breast milk. The magnitude of the exposure can be estimated from information on the mother's exposure, data on the partitioning of the chemical into various compartments of the mother's body and into breast milk, and information on the infant's consumption of milk and absorption of the chemical. To add this exposure pathway to the MIRC application, we adapted exposure algorithms and default assumptions from EPA's *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (EPA 1998), hereafter referred to as MPE, as explained below.

Note that this pathway generally is of most concern for *lipophilic* bioaccumulative chemicals (e.g., dioxins) that can cause developmental effects. The period of concern for the more *hydrophilic* chemicals that cause developmental effects generally is earlier, that is, from conception to birth. Hydrophilic chemicals generally exchange well between the maternal and fetal blood supplies at the placenta.

3.4.1. Infant Average Daily Absorbed Dose

The average daily dose of chemical *absorbed* by the infant (DAI_{inf}) is estimated in MIRC with Equation B-37. This basic exposure equation relies on the concentration of the chemical in the breast milk, the infant's breast-milk ingestion rate (IR_{milk}), the absorption efficiency of the chemical by the oral route of exposure (AE_{inf}), the bodyweight of the infant (BW_{inf}), and the duration of breast feeding (ED). Equation B-37 is EPA's (EPA 1998) modification of an average daily dose for the infant model first published by Smith (1987) and includes variables for both the concentration of the chemical in the breast milk fat ($C_{milkfat}$) and the concentration of the chemical in the aqueous phase of breast milk ($C_{aqueous}$). The remainder of the DAI_{inf}-associated equations assume that most chemicals of concern will partition *either* to the lipid phase *or* to the aqueous phase of breast milk, although some chemicals may partition significantly to both phases of milk. Thus, the remaining equations in MIRC assume that either $C_{milkfat}$ or $C_{aqueous}$ is equal to zero and hence drops out of the equation.

For the parameters in Equation B-37 (and the equations that follow) that are not calculated from another equation, an EPA default value and options for other values available in MIRC for the infant breast-milk-exposure pathway are described in Section 6.4 of this attachment. The user also can overwrite those parameter values with a different value from the literature as appropriate.

Equation B-37. Average Daily Dose of Chemical to the Nursing Infant

$$DAI_{inf} = \frac{\left[\left(C_{milkfat} \times f_{mbm}\right) + \left(C_{aqueous} \times \left(1 - f_{mbm}\right)\right)\right] \times IR_{milk} \times AE_{inf} \times ED}{BW_{inf} \times AT}$$

where:

DAI_{inf}	=	Average daily dose of chemical absorbed by infant (mg chemical/kg body weight-day)
$C_{milkfat}$	=	Concentration of chemical in lipid phase of maternal milk (mg chemical/kg milk lipid; calculated using Equation B-38)
f_{mbm}	=	Fraction of fat in breast milk (unitless)
$C_{aqueous}$	=	Concentration of chemical in aqueous phase of maternal milk (mg chemical/kg aqueous phase milk; calculated using Equation B-42)
IR_{milk}	=	Infant milk ingestion rate over the duration of nursing (kg milk/day)
AE_{inf}	=	Absorption efficiency of the chemical by the oral route of exposure (i.e., chemical-specific fraction of ingested chemical that is absorbed by the infant) (unitless)
ED	=	Exposure duration, i.e., duration of breast feeding (days)
BW_{inf}	=	Body weight of infant averaged over the duration of nursing (kg)
AT	=	Averaging time associated with exposure of interest; equal to ED (days)

As mentioned above, Equation B-37 includes terms for the chemical in both the lipid- and non-lipid phases of milk. The remaining equations, however, assume that a chemical of concern will partition to the lipid or aqueous phase of breast milk, but not to both. Different models are used to estimate $C_{milkfat}$ (described in Section 3.4.2 of this attachment) and $C_{aqueous}$ (described in Section 3.4.3 of this attachment).

3.4.2. Chemical Concentration in Breast Milk Fat

When developing the Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions (MPE) (EPA 1998), EPA reviewed three first-order kinetics models for estimating chemical concentration in breast milk fat. The model selected for use in MIRC is the model selected in MPE. The other two models were not considered in MPE because one used a biotransfer factor (BTF) approach considered more of a screening model than a predictive tool (Travis *et al.* 1988) and the other assumed that the contaminant concentration in the maternal fat compartment is at steady state and that the concentration in breast milk fat is the same as in maternal body fat (Smith 1987). The model in MIRC is a changing-concentration model that EPA adapted from a model by Sullivan *et al*. (1991). The model, shown in Equation B-38, estimates the average chemical concentration in the breast milk over the entire period of breast feeding by reference to a maximum theoretical steady-state concentration. Studies of lipophilic chemicals such as dioxins suggest that concentrations in the maternal milk are highest during the first few weeks of breast feeding and then decrease over time (ATSDR 1998). Equation B-38 accounts for the changing concentration in breast milk fat, but estimates one average value to represent the concentration over the entire duration of breast feeding. The model is dependent on the maternal body burden of the chemical and assumes that the chemical concentration in breast milk fat is the same as the concentration in general maternal body fat. According to reviewers of the model, this assumption warrants further investigation because milk fat appears to be synthesized in the mammary glands and may have lower chemical concentrations than general body fat stores (EPA 2001a).

Equation B-38. Chemical Concentration in Breast Milk Fat

$$C_{milkfat} = \frac{DAI_{mat} \times f_f}{k_{elim} \times f_{fm}} \times \left[\frac{k_{elim}}{k_{fat_elac}} + \frac{1}{k_{fat_elac} \times t_{bf}} \left(1 - e^{-k_{elim} t_{pn}} - \frac{k_{elim}}{k_{fat_elac}} \right) \left(1 - e^{-k_{fat_elac} t_{bf}} \right) \right]$$

where:

$C_{milkfat}$ = Concentration of chemical in lipid phase of maternal milk (mg chemical/kg lipid)

DAI_{mat} = Daily absorbed maternal chemical dose (mg chemical/kg maternal body weight-day; calculated using Equation B-39)

f_f = Fraction of total maternal body burden of chemical that is stored in maternal fat (mg chemical in body fat / mg total chemical in whole body; value from literature or EPA default - see Section 6.5 of this attachment)

k_{elim} = Chemical-specific total elimination rate constant for elimination of the chemical by non-lactating women (per day; e.g., via urine, bile to feces, exhalation; value from literature or calculated using Equation B-40)

f_{fm} = Fraction of maternal body weight that is fat stores (unitless)

k_{fat_elac} = Chemical-specific rate constant for total elimination of chemical in the lipid phase of milk during nursing (per day; value from literature or calculated using Equation B-41)

t_{bf} = Duration of breast feeding (days)

t_{pn} = Duration of mother's exposure prior to parturition and initiation of breast feeding (days)

Equation B-38 relies on the daily maternal absorbed intake (DAI_{mat}) to determine the concentration of the chemical in the breast milk fat. DAI_{mat} is multiplied by the fraction of the chemical that is stored in maternal fat (f_f) to determine the amount (i.e., mass) of chemical in the fat. This product, divided by the chemical-specific elimination rate constant (k_{elim}) for non-lactating adult women and the fraction of the mother's weight that is fat (f_{fm}), represents the maximum theoretical steady-state concentration of the chemical in an adult woman. If used alone to estimate the chemical concentration in breast milk fat, the equation as explained thus far is likely to overestimate the chemical concentration in milk fat because it does not account for losses due to breast feeding. Alone, this term ($DAI_{mat}\, f_f \,/\, k_{elim}\, f_{fm}$) also assumes that the biological half-life of the chemical in the mother's breast milk fat is small relative to the duration of the mother's exposure. However, for chemicals with half-lives that are longer than the exposure duration, which are the chemicals of concern in the applications of MIRC to date, an additional term is needed to determine the average concentration in the milk fat over the duration of her exposure.

To account for breast feeding losses and longer chemical half-lives in the mother than the exposure duration, an additional term is included in Equation B-38. This term includes a fraction dependent on two rate constants, k_{elim} and the elimination constant for a lipophilic chemical in lactating women via the lipid phase of breast milk (k_{fat_elac}), the duration of the mother's chemical exposure prior to nursing (t_{pn}), and the duration of breast feeding (t_{bf}). The whole body concentration ($DAI_{mat}\, f_f \,/\, k_{elim}\, f_{fm}$), the maximum theoretical steady-state concentration, is multiplied by the rate of elimination averaged over the duration of the mother's exposure, including her exposure prior to and during lactation. To review the derivation of Equation B-38, see Appendix B of MPE (EPA 1998).

To estimate an average daily dose *absorbed* by an infant's mother, or DAI_{mat}, the average daily dose (*ADD*) (in mg/kg-day) for the chemical from all sources that MIRC calculates for adults ($ADD_{(adult)}$, described in Section 3.3 of this attachment, Equation B-35), is multiplied by an absorption efficiency (AE_{mat}) or fraction of the chemical absorbed by the oral route of exposure, as shown in Equation B-39. The value for AE_{mat} can be estimated from absorption efficiencies for adults in general. Available data for some chemicals, in particular some inorganic compounds, indicate AE values for ingestion exposures of substantially less than 100 percent. For a few of these chemicals, data also indicate lower AEs for the chemical when ingested in food or in soil than when ingested in water (e.g., cadmium). For a screening level assessment, however, it is reasonable to either assume 100 percent for the AE_{mat} or to use the higher AE_{mat} of the food and water AE_{mat} values if available; hence, a single AE_{mat} parameter is included in Equation B-39.

Equation B-39. Daily Maternal Absorbed Intake

$$DAI_{mat} = ADD_{(adult)} \times AE_{mat}$$

where:

DAI_{mat} = Daily maternal dose of chemical absorbed from medium *i* (mg/kg-day)

$ADD_{(adult)}$ = Average daily dose to the mother (mg/kg-day) (calculated by MIRC – see Section 3.3 of this attachment, Equation B-35)

AE_{mat} = Absorption efficiency of the chemical by the oral exposure route (i.e., chemical-specific fraction of ingested chemical that is absorbed) by the mother (unitless) (value from literature or EPA default – see Section 6.4 of this attachment)

Equation B-35, used to calculate $ADD_{(adult)}$, is based on many medium-specific ingestion rates that are normalized to body weight. The adult body weights to which the homegrown food ingestion rates are normalized are the body weights of the consumers in the original USDA survey (see Section 6.3.3 of this attachment), which included both males and females. An assumption in the breast-milk exposure pathway is that those ingestion rates also are applicable to nursing mothers. The original data for ingestion rates for soil, drinking water, and fish are on a per person basis for males and females combined. MIRC divides those chemical intakes by an adult body weight for males and females combined as specified by the user (e.g., 71.4 kg mean value) to estimate the ADD normalized to body weight from those sources. If the user finds that those exposure media contribute the majority of the chemical intake for the risk scenario under consideration, the user may use alternative ingestion rates for those media and alternative body weights for nursing women, as described in Section 6.5 of this attachment.

Elimination rates for chemicals often are reported as the half-life of the chemical in the body following a known dose of chemical. Many chemicals exhibit a two-phase elimination process, the first being more rapid than the second. For screening risks for persistent and bioaccumulative chemicals, the half-life of the slower phase of elimination, presumably from non-blood compartments of the body, is the more important of the two. Assuming first-order kinetics, Equation B-40 is used to convert a measured half-life for elimination of a chemical for adults or non-lactating women to an elimination rate constant (EPA 1998). The equation can be used to estimate any kind of chemical loss rate constant from a measured chemical half-life.

Equation B-40. Biological Elimination Rate Constant for Chemicals for Non-lactating Women

$$k_{elim} = \frac{\ln 2}{h}$$

where:

k_{elim} = Chemical-specific elimination rate constant for elimination of the chemical for non-lactating women (per day; e.g., via urine, bile to feces, exhalation)

$ln2$ = Natural log of 2 (unitless constant)

h = Chemical-specific biological half-life of chemical for non-lactating women (days)

For chemicals transferred from the body of lactating women to breast milk, the rate of chemical elimination is augmented by the rate of chemical loss via the milk through breast feeding. The total elimination rate for lactating women sometimes is measured directly and reported in the literature. Where direct measurements are not available, and for chemicals that partition predominantly to the lipid-phase of milk, EPA has used Equation B-41 to estimate the total chemical elimination rate for lactating women, k_{fat_elac} (EPA 1998).

Equation B-41. Biological Elimination Constant for Lipophilic Chemicals for Lactating Women

$$k_{fat_elac} = k_{elim} + \frac{IR_{milk} \times f_f \times f_{mbm}}{f_{fm} \times BW_{mat}}$$

where:

k_{fat_elac} = Rate constant for total elimination of chemical during nursing (per day); accounts for both elimination by adults in general and the additional chemical elimination via the lipid phase of milk in nursing women

k_{elim} = Elimination rate constant for chemical from adults, including non-lactating women (per day; e.g., via urine, bile to feces, exhalation; chemical-specific; value from literature or calculated from half-life using Equation B-40)

IR_{milk} = Infant milk ingestion rate over the duration of nursing (kg/d)

f_f = Fraction of total maternal body burden of chemical that is stored in maternal fat (mg chemical in body fat / mg chemical total in body; value from literature or EPA default)

f_{mbm} = Fraction of fat in breast milk (unitless)

f_{fm} = Fraction of maternal body weight that is fat stores (unitless)

BW_{mat} = Maternal body weight over the entire duration of the mother's exposure to the chemical including during pregnancy and lactation (kg)

Equation B-41 is based on a model from Smith (1987) and accounts for the additional elimination pathway for lipophilic chemicals via the breast milk fat. The term K_{fat_elac} is estimated by adding an estimate of the first-order elimination constant for breast feeding losses to k_{elim}, which is the chemical-specific total elimination rate constant for non-lactating women. The breast feeding losses are estimated from the infant's intake rate of breast milk (IR_{milk}), the fraction of the total maternal body burden of the chemical that is stored in maternal body fat (f_f), the fraction of the mother's breast milk that consists of fat (lipids) (f_{mbm}), the mother's body weight (BW_{mat}), and the fraction of the mother's weight that is body fat (f_{fm}). In Equation B-41, the value for the mother's body weight should be specific to women of child-bearing age, as opposed to a body weight value for both males and females that is used to estimate an adult average daily dose and the mother's absorbed daily intake in Equation B-39. Body weight values for the mother are described in Section 6.5 of this attachment. Smith's (1987) model assumes that the chemical partitions to the lipid-phase of breast milk to the same degree that it partitions into the mother's body fat. For highly lipophilic compounds, losses from breast feeding can be larger than losses by all other pathways (EPA 1998).

3.4.3. Chemical Concentration in Aqueous Phase of Breast Milk

When developing MPE (EPA 1998), EPA also considered models to estimate chemical concentrations in the aqueous phase of breast milk ($C_{aqueous}$). EPA adapted Smith's (1987) steady state concentration model for estimating $C_{milkfat}$ and developed the $C_{aqueous}$ model shown in Equation B-42 (EPA 1998). Chemicals that would partition to the aqueous phase of human milk include water-soluble chemicals, such as salts of metals, and other hydrophilic chemicals that may be in equilibrium with bound forms of the chemical in different tissues. The $C_{aqueous}$ equation assumes that the chemical concentration in the aqueous phase of milk is directly proportional to the chemical concentration in the mother's blood plasma. The portion of chemical sequestered in red blood cells (e.g., bound to RBC proteins) is assumed to be unavailable for direct transfer to breast milk.

Equation B-42. Chemical Concentration in Aqueous Phase of Breast Milk

$$C_{aqueous} = \frac{DAI_{mat} \times f_{pl} \times Pc_{bm}}{k_{aq_elac} \times f_{pm}}$$

where:

$C_{aqueous}$ = Concentration of chemical in aqueous phase of maternal milk (mg/kg)

DAI_{mat} = Daily absorbed maternal chemical dose (mg/kg-day; calculated by Equation B-39)

f_{pl} = Fraction of chemical in the body (based on absorbed intake) that is in the blood plasma compartment (unitless; value from literature or calculated by Equation B-43)

Pc_{bm} = Partition coefficient for chemical between the plasma and breast milk in the aqueous phase (unitless); assumed to equal 1.0

k_{aq_elac} = Chemical-specific rate constant for total elimination of chemical in the aqueous phase of milk during nursing (per day; value from literature or calculated in Equation B-44)

f_{pm} = Fraction of maternal weight that is blood plasma (unitless)

Equation B-42 is a steady-state concentration model that, like the Equation B-38 for $C_{milkfat}$, is dependent on the maternal absorbed daily intake (DAI_{mat}). In Equation B-42, DAI_{mat} is multiplied by the fraction of the absorbed chemical that is circulating in the blood plasma compartment (f_{pl}) and a partitioning coefficient for the chemical between plasma and the aqueous phase of breast milk (Pc_{bm}). For highly water-soluble chemicals that are not transported via special carrier molecules, the chemical is assumed to diffuse passively from the mother's blood serum to the aqueous phase of her milk, in which case Pc_{bm} would equal 1.0. The denominator includes the biological elimination constant for the chemical in the aqueous phase of breast milk in lactating women (k_{aq_elac}) and the fraction of the mother's weight that is plasma (f_{pl}). Because the model assumes steady-state, it does not account for chemical species with long half-lives in the body or for body burden losses due to lactation. These factors are important for highly lipophilic chemicals and for non-lipophilic chemicals such as methyl mercury, lead, and cadmium that partition into body compartments such as red blood cells and bone. While these latter chemicals or forms of these chemicals are water-soluble when free, they have relatively long half-lives because they are in equilibrium with the chemical bound to macromolecules in some tissue compartments. Lead is of particular concern because it can be released from the bone into the blood during lactation, and thus into the breast milk (EPA 2001a). Due to this limitation, the model may over- or underestimate exposure to the infant.

Because Equation B-42 is based on the relationship between the chemical concentrations in the aqueous phase of breast milk and the blood plasma, a value for the fraction of the chemical in the mother's blood plasma (f_{pl}) is required. Ideally, an empirical value for f_{pl} should be used. If empirical values are not available, f_{pl} can be estimated from Equation B-43, provided that an empirical value can be found for the fraction of the chemical in the body that is in the mother's whole blood compartment (f_{bl}; EPA 1998).

Equation B-43. Fraction of Total Chemical in Body in the Blood Plasma Compartment

$$f_{pl} = \frac{f_{bl} \times f_{bp}}{f_{bp} + Pc_{RBC}\left(1 - f_{bp}\right)}$$

where:

f_{pl} = Fraction of chemical in body (based on absorbed intake) that is in the blood plasma compartment (unitless); chemical-specific

f_{bl} = Fraction of chemical in body (based on absorbed intake) in the whole blood compartment (unitless); chemical-specific

f_{bp} = Fraction of whole blood that is plasma (unitless)

$PcRBC$ = Partition coefficient for chemical between red blood cells and plasma (unitless); chemical-specific

If the fraction of the total chemical in the body that is in the whole blood compartment (f_{bl}) is known for a given chemical, then the fraction of that chemical that is in blood plasma depends only on the partition coefficient for the chemical between the red blood cells and the plasma (Pc_{RBC}) and the fraction of whole blood that is plasma (f_{bp}).

Another parameter for which a value is needed to solve Equation B-42 is the total chemical elimination rate for lactating women for hydrophilic chemicals, k_{aq_elac}. As for k_{fat_elac} for lipophilic chemicals, k_{aq_elac} for hydrophilic chemicals would be equal to k_{elim} plus the loss rate for the chemical in the aqueous phase of breast-milk during lactation. In the case of hydrophilic chemicals, EPA has yet to propose a term for the additional elimination of a chemical in the aqueous phase of milk from breast feeding. Given basic physiological mechanisms, we assume that chemical loss rates via urine are likely to be significantly higher than loss rates from nursing, however. This is because the counter-current anatomy of kidney tubules allows substantial concentration of chemicals in the tubules for elimination in urine compared with the concentration in circulating blood and because of active secretion of some chemicals into urine. Therefore, the best estimation of elimination of hydrophilic chemicals by lactating women is simply k_{elim}, the elimination of the chemical from a non-lactating woman, as shown in Equation B-40. The extent to which k_{elim} is an underestimate of k_{aq_elac} for a given chemical will determine the extent of health protective bias in k_{aq_elac}.

Equation B-44. Biological Elimination Rate Constant for Hydrophilic Chemicals

$$k_{aq_elac} = k_{elim}$$

where:

k_{aq_elac} = Chemical-specific rate constant for total elimination of chemical by lactating women for hydrophilic chemicals (per day)

k_{elim} = Chemical-specific rate constant for total elimination of chemical by non-lactating women (per day; e.g., via urine, bile to feces, exhalation; value from literature or calculated from half-life using Equation B-40)

3.4.4. Alternative Model for Infant Intake of Methyl Mercury

In this version of MIRC, we were unable to fully parameterize the aqueous model for mercury. In particular, no empirical value could be found for the steady-state fraction of total hydrophilic chemical body burden in the mother that is in the blood plasma (f_{pl}, see Exhibit B-29). This parameter could be estimated using Equation B-43 if a suitable chemical-specific fraction of chemical in the body that is in the whole blood (f_{bl}) could be found. However, the value found for f_{bl} is based on a single-dose study and is not considered reliable for use in chronic exposure calculations.

We therefore conducted a literature search to identify existing physiologically based toxicokinetic (PBTK) models of lactational transfer of methylmercury (MeHg) in humans. Most PBTK models that we identified focused on gestational transfer of mercury between mother and

fetus, including a PBTK dynamic compartmental model for gestational transfer of MeHg in humans developed by Gearhart *et al*. (1995, 1996), and reparameterized by Clewell *et al*. (1999).

We did find, however, that Byczkowski and Lipscomb (2001) had added a lactational transfer module to the Clewell *et al*. (1999) model. Byczkowski and Lipscomb compared their model's predictions to epidemiological data from mother-nursing-infant pairs obtained following an accidental high-dose poisoning in Iraq (Amin-Zaki *et al*. 1976) and from 34 mother-nursing-infant pairs examined in a low-dose, chronic exposure environment (Fujita and Takabatake 1977). Using data from the Iraq incident, Byczkowski and Lipscomb (2001) found good agreement between their model's predictions and the clinical data relating MeHg concentrations in breast milk to MeHg concentrations in infant's blood with time following the poisoning. To compare their model's predictions to data from chronic exposure to low doses of MeHg, Byczkowski and Lipscomb (2001) simulated MeHg intake for 500 days prior to conception, continued through gestation, and 6.5 months (200 days) of lactation. Their model's predictions were consistent with Fujita and Takabatake's (1977) study, although use of hair/blood partition coefficients based on the results of the 1977 study precluded use of this comparison as model validation. Both the model predictions and the mean values from the 1977 data indicated that the concentration of MeHg in the blood of nursing infants was close to the MeHg concentration in their mothers' blood (approximately 0.025 to 0.027 mg/L, Figure 4 of report). At those blood concentrations, the PBTK model estimated the average maternal intake of MeHg to be 0.68 ± 0.33 (SD) µg/kg-day and the average infant intake of MeHg to be 0.80 ± 0.38 µg/kg-day. Therefore, for purposes of MIRC, the DAI_{inf} of MeHg is estimated to be the same as the maternal intake per unit body weight (Equation B-42).

Equation B-45. Calculation of Infant Average Daily Absorbed Dose of Methyl Mercury

$$DAI_{inf_MeHg} = DAI_{mat_MeHg}$$

where:

DAI_{inf_MeHg} = Average daily dose of MeHg absorbed by infant from breast milk (mg/kg-day)

DAI_{mat_MeHg} = Average daily dose of methyl mercury absorbed by the mother, predominantly from fish (mg/kg-day)

4. Dose-Response Values Used for Assessment

Chemical dose-response values included in MIRC include carcinogenic potency slope factors for ingestion and non-cancer oral reference doses (RfDs) for chronic exposures. The dose-response values currently used in MIRC for RTR assessments are shown in Exhibit B-6 For some chemicals, OAQPS has identified dose-response values for use in RTR (EPA 2007a), and these dose-response values are used in MIRC for RTR assessments. In general, OAQPS chose these values based on the following hierarchy of sources: EPA's Integrated Risk Information System (IRIS); the Centers for Disease Control's Agency for Toxic Substances and Disease Registry (ATSDR); and the California Environmental Protection Agency's (CalEPA's) Office of Environmental Health Hazard Assessment (OEHHA) Toxicity Criteria Database. For PB-HAP chemicals that are currently evaluated in MIRC but do not currently have dose-response values identified by OAQPS for RTR, alternative methods for deriving values were used (see Sections 4.2 and 4.4 of this attachment).

Exhibit B-6. Oral Dose-response Values Used to Calculate RTR Screening Threshold Emission Rates for PB-HAP Chemicals[a]

Chemical	CAS No.	Cancer Slope Factor		Reference Dose	
		Value $(mg/kg\text{-}day)^{-1}$	Source	Value (mg/kg-day)	Source
Inorganics					
Cadmium compounds in food[b]	7440439	not available		1.0E-03	IRIS
Mercury (elemental)	7439976	not available		not available	
Mercuric chloride	7487947	not available		3.0E-04	IRIS
Methyl mercury (MeHg)	22967926	not available		1.0E-04	IRIS
Dioxins					
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	35822469	1.50E+03	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562394	1.50E+03	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673897	1.50E+03	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	39227286	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,4,7,8-Hexachlorodibenzofuran	70648269	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653857	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,6,7,8-Hexachlorodibenzofuran	57117449	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408743	6.20E+03	IRIS	not available	
1,2,3,7,8,9-Hexachlorodibenzofuran	72918219	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	
2,3,4,6,7,8-Hexachlorodibenzofuran	60851345	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	3268879	4.50E+01	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	39001020	4.50E+01	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321764	1.50E+05	Derived from WHO 2005 TEFs[c]	not available	
1,2,3,7,8-Pentachlorodibenzofuran	57117416	4.50E+03	Derived from WHO 2005 TEFs[c]	not available	
2,3,4,7,8-Pentachlorodibenzofuran	57117314	4.50E+04	Derived from WHO 2005 TEFs[c]	not available	
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746016	1.50E+05	EPA ORD	7E-10	IRIS
2,3,7,8-Tetrachlorodibenzofuran	51207319	1.50E+04	Derived from WHO 2005 TEFs[c]	not available	

Exhibit B-6. Oral Dose-response Values Used to Calculate RTR Screening Threshold Emission Rates for PB-HAP Chemicals[a]

Chemical	CAS No.	Cancer Slope Factor		Reference Dose	
		Value $(mg/kg\text{-}day)^{-1}$	Source	Value (mg/kg-day)	Source
Polycyclic Organic Matter					
1-Methylnaphthalene	90120	5.0E-01	EPA 1999, POM Group 72002[d]	7.0E-02	ATSDR
2-Acetylaminofluorene	53963	1.0E+01	EPA 1999, POM Group 75002[d]	not available	
2-Chloronaphthalene	91587	5.0E-01	EPA 1999, POM Group 72002[d]	8.0E-02	IRIS
2-Methylnaphthalene	91576	5.0E-01	EPA 1999, POM Group 72002[d]	5.0E-02	ATSDR
3-Methylcholanthrene	56495	2.2E+1	CalEPA	not available	
7,12-Dimethylbenz(a)anthracene	57976	2.5E+02	CalEPA	not available	
Acenaphthene	83329	5.0E-01	EPA 1999, POM Group 72002[d]	6.0E-02	IRIS
Acenaphthylene	208968	5.0E-01	EPA 1999, POM Group 72002[d]	not available	
Anthracene	120127	0[e]	IRIS	3.0E-01	IRIS
Benz(a)anthracene	56553	1.2E+00	CalEPA	not available	
Benzo(a)pyrene	50328	7.3E+00	IRIS	not available	
Benzo(b)fluoranthene	205992	1.2E+00	CalEPA	not available	
Benzo(e)pyrene	192972	5.0E-01	EPA 1999, POM Group 72002[d]	not available	
Benzo(g,h,i)perylene	191242	5.0E-01	EPA 1999, POM Group 72002[d]	not available	
Benzo(k)fluoranthene	207089	1.2E+00	CalEPA	not available	
Carbazole	86748	2.0E-02	HEAST	not available	
Chrysene	218019	1.2E-01	CalEPA	not available	
Dibenzo(a,h)anthracene	53703	4.1E+00	CalEPA	not available	
Dibenzo(a,i)pyrene	189559	1.2E+02	CalEPA	not available	
Dibenzo(a,j)acridine	224420	1.2E+00	CalEPA	not available	
Fluoranthene	206440	5.0E-01	EPA 1999, POM Group 72002[d]	4.0E-02	IRIS
Fluorene	86737	5.0E-01	EPA 1999, POM Group 72002[d]	4.0E-02	IRIS
Indeno(1,2,3-c,d)pyrene	193395	1.2E+00	CalEPA	not available	
PAH, total	234	5.0E-01	EPA 1999, POM Group 71002[d]	not available	
Perylene	198550	5.0E-01	EPA 1999, POM Group 72002[d]	not available	
Phenanthrene	85018	0[e]	IRIS	not available	
Polycyclic Organic Matter	246	5.0E-01	EPA 1999, POM Group 71002[d]	not available	

Exhibit B-6. Oral Dose-response Values Used to Calculate RTR Screening Threshold Emission Rates for PB-HAP Chemicals[a]

Chemical	CAS No.	Cancer Slope Factor		Reference Dose	
		Value $(mg/kg\text{-}day)^{-1}$	Source	Value (mg/kg-day)	Source
Pyrene	129000	0[e]	IRIS	3.0E-02	IRIS
Retene	483658	5.0E-01	EPA 1999, POM Group 72002[d]	not available	

ATSDR = Agency for Toxic Substances and Disease Registry, IRIS = Integrated Risk Information System, EPA OAQPS = EPA's Office of Air Quality Planning and Standards, CalEPA = California EPA, EPA ORD = EPA's Office of Research and Development, HEAST = EPA Health Effects Assessment Tables, TEF = toxic equivalency factor

[a]Values as of June 2012; these values may be updated as newer ones become available.

[b]There are RfDs for both water ingestion and food ingestion for cadmium – the RfD for food is used.

[c]Dose-response values for these dioxin congeners are not available from EPA sources. CSFs for these congeners were derived as discussed in Section 4.2 of this attachment.

[d]The method to assign oral cancer slope factors to polycyclic organic matter (POM) without CSFs available from other EPA sources is the same as that used in the 1999 National Air Toxics Assessment (EPA 1999). A complete description of the methodology is available at: http://archive.epa.gov/nata2002/web/pdf/pom_approach.pdff and is summarized in Section 4.4 of this attachment.

[e]Weight of evidence evaluations indicated that the available data were adequate to determine that this chemical was not carcinogenic (EPA 2010a),

4.1. Cadmium

EPA has developed two chronic RfDs for cadmium (Cd), one for food and one for water, based on data in IRIS indicating a lower absorption efficiency of cadmium from food than from water. The default RfD set in MIRC is the higher RfD for Cd compounds in food (as described in Section A.2.3, the drinking water exposure pathway is not modeled in the screening scenario because the likelihood that humans would use a lake as a drinking water source is assumed to be low). Users of MIRC who assess exposures via drinking water would need to use the RfD for Cd compounds in water (i.e., 5.0E-04 mg/kg-day).

4.2. Dioxins (2,3,7,8-TCDD)

For chemicals for which the critical health effect is developmental, either *in utero* and/or during the first months or years of life, the exposure duration and timing of exposure for comparison with the RfD (or comparable values) require special consideration. The most sensitive health endpoints for both mercury and 2,3,7,8-TCDD are neurological effects during development that have long-lasting effects on learning and social behaviors. To ensure a protective risk characterization for these chemicals, it is important to use the shortest exposure duration appropriate, at the appropriate life stage, for comparison with the toxicity reference values. This approach avoids "dilution" of an estimated average ADD that would result from averaging the lower daily chemical intake rates normalized to body weight for older children and adults with the potentially higher daily intake rates of infants over a longer exposure averaging period.

The convention for assessing risk from mixtures of dioxins is by application of toxic equivalency factors (TEFs) to dioxin concentrations, which are then expressed as toxic equivalents (TEQs). Of the dioxin congeners, 2,3,7,8-TCDD is the most widely studied and considered to be one of the most toxic congeners. It is therefore assigned a TEF of 1, with the other dioxin congener TEQ concentrations scaled relative to 2,3,7,8-TCDD concentrations on the basis of toxicity. For risk assessment of dioxins for RTR (with one exception), the World Health Organization (WHO) 2005 TEFs presented in Exhibit B-7 were used to derive the CSFs (shown in Exhibit B-6) for dioxin congeners without available EPA dose response values. The one exception is 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin, whose TEF was based on data from IRIS.

Exhibit B-7. WHO 2005 Toxic Equivalency Factors (TEFs) for Dioxin Congeners

Dioxin Congener	CAS No.	WHO 2005 Toxic Equivalency Factor[a]
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	35822469	0.01
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562394	0.01
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673897	0.01
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	39227286	0.1
1,2,3,4,7,8-Hexachlorodibenzofuran	70648269	0.1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653857	0.1
1,2,3,6,7,8-Hexachlorodibenzofuran	57117449	0.1
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin[b]	19408743	0.04
1,2,3,7,8,9-Hexachlorodibenzofuran	72918219	0.1
2,3,4,6,7,8-Hexachlorodibenzofuran	60851345	0.1
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	3268879	3E-04
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	39001020	3E-04
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321764	1
1,2,3,7,8-Pentachlorodibenzofuran	57117416	0.03
2,3,4,7,8-Pentachlorodibenzofuran	57117314	0.3
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746016	1
2,3,7,8-Tetrachlorodibenzofuran	51207319	0.1

[a]Source: van den Berg et al. 2006, with the one exception in the next footnote.
[b]For 1,2,3,7,8,9-HexCDD, OAQPS identified an oral cancer slope factor from IRIS. For the purposes of these multipathway assessments, EPA uses the TEF derived from this IRIS oral CSF (6200 1/mg/kg/d, equaling a TEF of 0.041) rather than the WHO 2005 TEF of 0.1.

4.3. Mercury

The RfD applies to the pregnant mother as well as young children. EPA has not specified the minimum exposure duration at the RfD level of exposure that is appropriate to use in characterizing risk; we assume 10 years for women of childbearing age and 1 year for infants. We note that human exposures to MeHg are primarily through the consumption of fish and shellfish (EPA 2001b). EPA found that, on average, approximately 76 percent of the exposure to MeHg for women of childbearing age could be attributed to ingestion of mercury in freshwater and estuarine fish and shellfish, with the remaining 24 percent derived from marine fish and shellfish. Other sources accounted for less than 0.06 percent of total exposures (EPA 2001b).

4.4. Polycyclic Organic Matter

Dose-response values for some of the POM species that are included in the screening assessment were not identified by OAQPS; for these POM species, an alternative methodology for identifying CSFs was needed. Previously, for risk assessment of inhalation exposures to polycyclic organic matter (POM) for EPA's National-Scale Air Toxics Assessments (NATA) and for RTR, OAQPS developed an approach for characterizing risks associated with the individual POM species and POM groups reported in the National Emissions Inventory (NEI). Individual POMs were assigned to one of eight POM groups according to cancer potencies derived by EPA for IRIS and by CalEPA, and based on assumptions regarding relative carcinogenicity. OAQPS then estimated an inhalation CSF for each POM group. The same approach was used to derive oral CSFs for POMs without available CSFs. Each POM group (with all its member

POM species reported in NEI, not just the species currently evaluated in this assessment) and the corresponding CSFs using this methodology are presented in Exhibit B-8. These group CSFs are used only when OAQPS has not, for the purposes of RTR, identified a CSF specific to the individual chemical.

Exhibit B-8. Oral Dose-response Values for Polycyclic Organic Matter (POM) Groups[a]

Individual POM or POM Group	CAS No.	Cancer Slope Factor[b] $(mg/kg\text{-}day)^{-1}$
POM Group 71002		
Benz(a)anthracene/chrysene (7-PAH)	103	0.5
Total PAH	234	
Polycyclic organic matter	246	
16-PAH	40	
16-PAH–7-PAH	75040	
POM Group 72002		
Anthracene	120127	0.5
Pyrene	129000	
Benzo(g,h,i) perylene	191242	
Benzo(e)pyrene	192972	
Benzo(c)phenanthrene	195197	
Perylene	198550	
Benzo(g,h,i)fluoranthene	203123	
Benzo(a)fluoranthene	203338	
Fluoranthene	206440	
Acenaphthylene	208968	
1-Methylpyrene	2381217	
12-Methylbenz(a)anthracene	2422794	
Methylbenzopyrenes	247	
Methylchrysene	248	
Methylanthracene	26914181	
Benzofluoranthenes	56832736	
9-Methylbenz(a)anthracene	779022	
1-Methylphenanthrene	832699	
Acenaphthene	83329	
Phenanthrene	85018	
Fluorene	86737	
2-Methylnaphthalene	91576	
2-Chloronaphthalene	91587	
POM Group 73002		
7,12-Dimethylbenz(a)anthracene	57976	1000
POM Group 74002		
Dibenzo(a,i)pyrene	189559	100
Dibenzo(a,h)pyrene	189640	

Exhibit B-8. Oral Dose-response Values for Polycyclic Organic Matter (POM) Groups[a]

Individual POM or POM Group	CAS No.	Cancer Slope Factor[b] $(mg/kg\text{-}day)^{-1}$
POM Group 75002		
3-Methylcholanthrene	56495	10
Dibenzo(a,e)pyrene	192654	
5-Methylchrysene	3697243	
Benzo(a)pyrene	**50328**	
Dibenzo(a,h)anthracene	53703	
POM Group 76002		
Benzo(b+k)fluoranthene	102	1
Indeno(1,2,3-c,d)pyrene	193395	
Benzo(j)fluoranthene	205823	
Benzo(b)fluoranthene	205992	
Benzo(k)fluoranthene	207089	
Dibenzo(a,j)acridine	224420	
Benz(a)anthracene	56553	
POM Group 77002		
Chrysene	218019	0.1
POM Group 78002		
7-PAH	75	0.5

[a]These group CSFs are used only when OAQPS has not, for the purposes of RTR, identified a CSF specific to the individual chemical.
[b]The method to assign oral cancer slope factors to POM groups was the same as that used in the 1999 National Air Toxics Assessment (EPA 1999). A complete description of the methodology is available at: http://archive.epa.gov/nata2002/web/pdf/pom_approach.pdf.

5. Risk Estimation

For persistent and bioaccumulative hazardous air pollutants (PB-HAPs), risks from inhalation of a chemical directly from air generally will be negligible compared with risks from ingestion of the chemical from foodstuffs grown in an area subject to air deposition of the chemical. Risk characterization for carcinogens with a linear mode of action at low doses is described in Section 5.1 of this attachment. Risk characterization for chemicals likely to exhibit a threshold for response (e.g., non-cancer hazards) is described in Section 5.2.

5.1. Cancer Risks

The estimated risk of developing cancer from exposure to a chemical from a specified source is characterized as the excess lifetime cancer risk (ELCR). The ELCR represents the incremental probability of an individual developing cancer over a lifetime as a result of lifetime exposure to the chemical. For a known or suspected carcinogen with a low-dose linear mode of action, the estimated ELCR is calculated as the product of the lifetime average daily dose (LADD) and the cancer slope factor (CSF):

Equation B-46. Calculation of Excess Lifetime Cancer Risk

$$ELCR = LADD \times CSF$$

where:

ELCR	=	Estimated excess lifetime cancer risk from a chemical summed across all exposure pathways and media (unitless)
LADD	=	Lifetime average total daily dose from all exposure pathways and media (mg/kg-day)
CSF	=	Oral carcinogenic potency slope factor for chemical (per mg/kg-day)

As described in Section 3.3 of this attachment, the *LADD* (in mg/kg-day) for a chemical is calculated to reflect age-related differences in exposure rates that are experienced by a hypothetical individual throughout his or her lifetime of exposure. The total chemical intake is normalized to a lifetime, which for the purposes of this assessment is assumed to be 70 years.

EPA considers the possibility that children might be more sensitive than adults to toxic chemicals, including chemical carcinogens (EPA 2005b,c). Where data allow, EPA recommends development of lifestage-specific cancer potency CSFs. To date, EPA has developed a separate slope factor for early lifestage exposure for only one chemical (i.e., 1,1,1-trichloroethane; EPA 2007b), and current data availability for most chemicals preclude this approach. EPA has, therefore, examined options for default adjustments of the CSF to protect children. To date, the only mode of action (MOA) for carcinogenesis for which EPA has adequate data to develop a reasonable quantitative default approach is mutagenesis (EPA 2005b,c). For carcinogens with a mutagenic MOA for cancer, EPA concluded that the carcinogenic potency of a chemical may be approximately tenfold greater for the first 2 years of life (i.e., birth up to second birthday) and threefold greater for the next 14 years of life (i.e., ages 2 through 15) than for adults (EPA 2005c). These conclusions are represented by age-dependent adjustment factors (ADAFs) of 10, 3, and 1 for the first two lifestages and for adults, respectively.

These three lifestages do not match the age categories for the home-grown food ingestion rates, the age categories in MIRC. As a consequence, ADAFs for the age groups in MIRC are adapted as time-weighted average values as follows:

$$ADAF_{(<1)} = 10 \qquad ADAF_{(6\text{-}11)} = 3$$

$$ADAF_{(1\text{-}2)} = \frac{(10 \times 1\,\text{yr}) + (3 \times 1\,\text{yr})}{2} = 6.5 \qquad ADAF_{(12\text{-}19)} = \frac{(3 \times 4\ \text{yrs}) + (1 \times 4\ \text{yrs})}{8} = 2$$

$$ADAF_{(3\text{-}5)} = 3 \qquad ADAF_{(adult)} = 1$$

To estimate total lifetime risk from a lifetime of exposure to such a chemical, EPA recommends estimating the cancer risk for each of the three lifestages separately and then adding the risks for i = 1 to 6 age groups.

Equations B-47 to B-53. Lifetime Cancer Risk: Chemicals with a Mutagenic MOA for Cancer

Equation B-47. $Risk_{(<1)} = ADD_{(0–<1)} \times 10 \times CSF \times (1\ yr/70\ yr)$

Equation B-48. $Risk_{(1–2)} = ADD_{(1–2)} \times 6.5 \times CSF \times (2\ yr/70\ yr)$

Equation B-49. $Risk_{(3–5)} = ADD_{(3–5)} \times 3 \times CSF \times (3\ yr/70\ yr)$

Equation B-50. $Risk_{(6–11)} = ADD_{(6–11)} \times 3 \times CSF \times (6\ yr/70\ yr)$

Equation B-51. $Risk_{(12–19)} = ADD_{(12–19)} \times 2 \times CSF \times (8\ yr/70\ yr)$

Equation B-52. $Risk_{(adult)} = ADD_{(adult)} \times 1 \times CSF \times (50\ yr/70\ yr)$

Equation B-53. $\boldsymbol{ELCR} = \sum_{i=1}^{n} Risk_{(i)}$

In other words, Equation B-53 indicates that the total excess lifetime cancer risk (ELCR) equals the sum of the age-group-specific risks estimated by Equation B-47 through Equation B-52, where:

$Risk_{(<1)}$ = Risk from chemical ingestion in first year of life

$Risk_{(1-2)}$ = Risk from chemical ingestion from first birthday through age 2 years

$Risk_{(3-5)}$ = Risk from chemical ingestion from age 3 through 5 years of age

$Risk_{(6-11)}$ = Risk from chemical ingestion from age 6 through 11 years of age

$Risk_{(12-19)}$ = Risk from chemical ingestion from age 12 through 19 years of age

$Risk_{(adult)}$ = Risk from chemical ingestion from age 20 to 70 years age

$ADD_{(<1)}$ = Average daily dose for infants under one year of age (mg/kg-day)

$ADD_{(1-2)}$ = Average daily dose from first birthday through age 2 years of age (mg/kg-day)

$ADD_{(3-5)}$ = Average daily dose from age 3 through 5 years of age (mg/kg-day)

$ADD_{(6-11)}$ = Average daily dose from age 6 through 11 years of age (mg/kg-day)

$ADD_{(12-19)}$ = Average daily dose from age 12 through 19 years of age (mg/kg-day)

$ADD_{(adult)}$ = Average daily dose for adults age 20 to 70 years of age (mg/kg-day)

CSF = Oral carcinogenic potency slope factor for chemical (per mg/kg-day)

$Risk_{(i)}$ = Risk from chemical ingestion for the ith age group

$ELCR$ = Total extra lifetime cancer risk (incremental or extra risk)

n = Number of age groups (i.e., 6)

5.2. Non-cancer Hazard Quotients

Non-cancer risks are presented as hazard quotients (HQs), that is, the ratio of the estimated daily intake (i.e., ADD) to the reference dose (e.g., chronic RfD). If the HQ for a chemical is equal to or less than 1, EPA believes that there is no appreciable risk that non-cancer health effects will occur. If the HQ is greater than 1 then there is at least some possibility for an adverse health effect. The larger the HQ value, the more likely it is that an adverse health effect may occur.

5.2.1. Hazard Quotients for Chemicals with a Chronic RfD

For chemicals with a chronic RfD, MIRC calculates an HQ for each age group separately using Equation B-54 to indicate the potential for adverse health effects associated with chronic exposure via ingestion pathways. The HQ is the ratio of a long-term, daily average exposure normalized to the receptor's body weight (i.e., ADD) to the RfD for that chemical. HQs are threshold effects and are not additive across age groups.

Equation B-54. Hazard Quotient for Chemicals with a Chronic RfD

$$HQ = \frac{ADD}{RfD}$$

where:

HQ	=	Hazard quotient for chemical (unitless)
ADD	=	Average daily ingested dose of chemical (mg/kg-day) from all food types and ingested media for the age group
RfD	=	Chronic oral reference dose for chemical (mg/kg-day)

5.2.2. Hazard Quotients for Chemicals with RfD Based on Developmental Effects

For chemicals for which the toxicity reference value is an RfD based on developmental effects, a shorter exposure duration (ED) and averaging time (AT) may be required. For this type of chemical (e.g., methylmercury, 2,3,7,8-TCDD), the appropriate ED/AT and sensitive lifestage for exposure may need to be estimated from the information provided in the critical developmental study(ies) from which the RfD was derived (e.g., in consultation with the RfD documentation in EPA's IRIS or in a toxicological profile developed for the chemical). For screening-level risk assessments, however, a health protective approach is to compare the highest ADD from among the child age categories provided in MIRC to the RfD, as is done for all PB-HAPs. This approach ensures that the highest exposure from among the various age groups evaluated is taken into consideration, regardless of which age group might be most relevant to the health effect of interest (i.e., the age group on which the RfD is based).

5.2.3. Hazard Index for Chemicals with RfDs

When conducting screening-level assessments for multiple chemicals, it can be informative to calculate a hazard index (HI) for toxicologically similar chemicals (EPA 2000). The HI is the sum of HQs across chemicals (not age groups) as shown in Equation B-55. As with the HQ, if the HI value is less than 1, adverse health effects are not expected for that suite of chemicals. If the screening level HI exceeds 1, however, the risk assessor may in some instances, evaluate the assumptions of the screening-level assessment to determine if more realistic local values are available for parameters that drive risk. In addition, the risk assessor may need to examine the mode of action (MOA) and target organ(s) for the chemicals with the highest HQs to develop an appropriate approach to assessing their potential joint action.

Equation B-55. Hazard Index Calculation

$$HI = HQ_1 + HQ_2 \ldots HQ_n$$

where:

HI = Hazard index (unitless)

HQ_1 = Hazard Quotient for chemical 1 (unitless)

HQ_2 = Hazard Quotient for chemical 2 (unitless)

HQ_n = Hazard Quotient for chemical *n* (unitless)

The HI approach can be appropriate for chemicals with the same MOA and same target organ; however, MOA often is difficult to determine. An HI usually is "developed for each exposure route of interest, and for a single toxic effect or for toxicity to a single target organ" (EPA 2000; p 79). If a receptor is exposed to multiple chemicals that affect different target organs or that operate by different MOAs, and if more than one HQ is close to 1, the risk assessor in some circumstances, may consider whether chemical interactions play a role in chemical toxicity (EPA 2000). Exposures to more than one chemical can result in a greater or lesser toxic response than might be predicted on the basis of one or the other chemical acting alone (toxicologically independent) or acting in concert (toxicologically similar chemicals). Users are referred to EPA's *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures* for approaches to assessing the potential for adverse health effects from exposure to multiple chemicals (EPA 2000).

Note that users of MIRC are responsible for determining how to interpret HQs for multiple chemicals.

6. Model Input Options

This section describes the input options currently included in MIRC. Required user inputs for environmental media concentrations and air deposition rates, such as those predicted by (output of) TRIM.FaTE, are described in Section 6.1 of this attachment. Values for farm-food-chain (FFC) parameters for specific types of produce and animal products are discussed in Section 6.2. Options for parameterizing receptor characteristics are described in Section 6.3, including age-group-specific values for body weight, water ingestion, and food ingestion by food type. Options for other exposure parameter values in MIRC, such as exposure frequency and loss of chemical during food preparation and cooking, are provided in Section 6.4.

Where values for chemical-specific parameters are presented, values are presented only for PB-HAP chemicals currently evaluated using the TRIM-based RTR screening scenario. The database included with MIRC contains chemical-specific parameter values for a large number of chemicals (more than 500), because all of the chemical-specific input data compiled by EPA for use in HHRAP were uploaded into MIRC. However, only chemicals that are PB-HAPs evaluated for RTR are discussed in this document (see Sections 1.1.1 and 2.2.2), and the HHRAP inputs provided for other chemicals have not been reviewed or verified. The data presented in this chapter were reviewed and used to develop the set of modeling defaults used to calculate screening threshold emission rates for RTR. Note that the default values used to estimate RTR screening thresholds, and the justification for selecting a specific value from the data sets described in this chapter, are discussed in Chapter 7.

6.1. Environmental Concentrations

As noted in Section 2 of this attachment, MIRC is intended to estimate exposures and risks to self-sufficient farming and fishing families from ingestion of FFC media in an area of airborne chemical deposition. The tool analyzes one exposure scenario at a time (e.g., adult farmer exposed to dioxin from ingestion of beef); therefore, it is best used to evaluate a maximally exposed individual (MEI) or family when MIRC is used to screen for possible risks.

The following values specific to the air pollutant of concern are required inputs to MIRC:

- a single air concentration (in g/m^3);
- the fraction of chemical in the air that is in the vapor phase;
- air-to-surface deposition rates for both vapor- and particle-phase chemical in the air (in g/m^2-yr);
- two fish tissue concentrations, one each for forage and game fish (i.e., fish in TL 3 and TL 4) (in mg/kg wet weight);
- concentrations in drinking water (in g/L); and
- four chemical concentrations in soil (in µg/g dry weight), one each for:
  - surface soil in produce growing area,
  - surface soil where livestock feed,
  - root-zone soil in produce growing area, and
  - root-zone soil in livestock feed growing area.

The MIRC software is configured to estimate ingestion exposures via drinking water for a specified chemical concentration in the drinking water source (e.g., groundwater well). However, no exposure via drinking water is assumed to occur when calculating the Tier 1 screening thresholds. As discussed in Section 2.2.3, the drinking water exposure pathway is not modeled for the scenario developed for the Tier 1 assessment because the likelihood that humans would use a lake as a drinking water source is assumed to be low.

The user must provide the inputs listed above; no default values are included for these parameters in MIRC. Media concentrations output by TRIM.FaTE can be entered into the tool manually from model output files or can be imported directly from the TRIM.FaTE output files. For RTR evaluations, a tool to facilitate this process was developed using a Microsoft® Excel™ routine written in Visual Basic.

6.2. Farm-Food-Chain Parameter Values

Using the chemical information specified in Section 6.1 above as inputs, MIRC calculates chemical concentrations in foods that are commonly grown or raised on family farms: exposed and protected fruits; exposed and protected vegetables; root vegetables; beef; total dairy products; pork; and poultry and eggs.

6.2.1. List of Farm-Food-Chain (FFC) Parameters

MIRC estimates chemical concentrations in the produce identified above using algorithms from HHRAP (EPA 2005a) as described in Section 3.2 of this attachment. Parameter values required for these HHRAP algorithms, including chemical-specific media transfer factors (e.g.,

soil-to-plant transfer coefficients) and plant- and animal-specific properties (e.g., plant interception fraction, quantity of forage consumed by cattle), are included in tables in MIRC. As described in Section 7 of this attachment, the HHRAP-recommended parameter values are the default values in MIRC; however, these and other inputs in MIRC can be revised as needed. Exhibit B-9 describes the parameters that are included in the algorithms used to estimate chemical concentrations in the farm food categories. The parameter names and symbols are referenced in this section for plants/produce and animal products.

Exhibit B-9. MIRC Parameters Used to Estimate Chemical Concentrations in Farm Foods

Parameter	Description	Units
Plants/Produce		
$Br_{AG\text{-}produce\text{-}DW(i)}$	Chemical-specific plant/soil chemical bioconcentration factor for edible portion of aboveground produce type i, exposed or protected	Unitless (g soil DW / g produce DW)
$Bv_{AG(i)}$	Chemical-specific air-to-plant biotransfer factor for aboveground produce type i for vapor-phase chemical in air	Unitless ([mg chemical / g DW plant] / [mg chemical / g air])
Fw	Fraction of wet deposition that adheres to plant surfaces; 0.2 for anions, 0.6 for cations and most organics	Unitless
Kds	Chemical-specific soil/water partition coefficient	L soil pore water / kg soil DW
$kp_{(i)}$	Plant-specific surface loss coefficient for aboveground exposed produce and animal forage and silage	yr^{-1}
$MAF_{(i)}$	Moisture adjustment factor for aboveground produce type *i* to convert the chemical concentration estimated for dry-weight produce to the corresponding chemical concentration for full-weight fresh produce	Percent water
RCF	Chemical-specific root concentration factor for tubers and root produce on a wet-weight (WW) basis	L soil pore water/ kg root WW
$Rp_{(i)}$	Plant-specific interception fraction for the edible portion of aboveground exposed produce or animal forage and silage	Unitless
$Tp_{(i)}$	Length of plant exposure to deposition per harvest of the edible portion of aboveground exposed produce or animal forage and silage	Year
$VG_{AG(i)}$	Empirical correction factor for aboveground exposed produce type i to address possible overestimate of the diffusive transfer of chemical from the outside to the inside of bulky produce, such as fruit	Unitless
$VG_{rootveg}$	Empirical correction factor for belowground produce (i.e., tuber or root vegetable) to account for possible overestimate of the diffusive transfer of chemicals from the outside to the inside of bulky tubers or roots (based on carrots and potatoes)	Unitless
$Yp_{(i)}$	Plant-specific yield or standing crop biomass of the edible portion of produce or animal feed	kg produce DW/m^2
Animal Products		
Bs	Soil bioavailability factor for livestock	Unitless
MF	Chemical-specific mammalian metabolism factor that accounts for endogenous degradation of the chemical	Unitless

Exhibit B-9. MIRC Parameters Used to Estimate Chemical Concentrations in Farm Foods

Parameter	Description	Units
$Ba_{(beef)}$	Chemical-specific biotransfer factor for chemical in diet of cow to chemical in beef on a fresh-wet (FW; equivalent to WW) basis	mg chemical/kg FW tissue/mg chemical/day or day/kg FW tissue
$Ba_{(dairy)}$	Biotransfer factor in dairy	day/kg FW tissue
$Ba_{(pork)}$	Biotransfer factor in pork	day/kg FW tissue
$Ba_{(poultry)}$	Biotransfer factor in poultry	day/kg FW tissue
$Ba_{(eggs)}$	Biotransfer factor in eggs	day/kg FW tissue
$Qs_{(m)}$	Quantity of soil eaten by animal type m each day	kg/day
$Qp_{(i,m)}$	Quantity of plant feed type i consumed per animal type m each day	kg/day

Source: EPA Source: EPA 2005a
DW = dry weight; FW = fresh weight; WW = wet weight

6.2.2. Produce Parameter Values

Exhibit B-10 and Exhibit B-11 provide the chemical-specific input values that are the current defaults for produce FFC food types in MIRC. Exhibit B-12 presents additional non-chemical-specific input values for parameters used in the algorithms that calculate chemical concentrations in produce. Unless otherwise noted, the default parameter values were obtained from HHRAP. Options for other parameter values are not included in MIRC at this time; however, the user can overwrite values if appropriate. Refer to HHRAP (EPA 2005a, Chapter 5 and associated appendices) for detailed descriptions of these parameters and documentation of input values.

Exhibit B-10. Chemical-Specific Inputs for Produce Parameters for Chemicals Included in MIRC

Chemical	Fraction of Wet Deposition (*Fw*) (unitless)[a]	Root Concentration Factor (*RCF*) (belowground) (L/kg)[b]	Soil-Water Partition Coefficient (*Kds*) (L/kg)[c]	Chemical Air-to-Plant Biotransfer Factor ($Bv_{AG(i)}$) (unitless)[d]
Inorganics				
Cadmium compounds	0.6	NA	7.5E+01	NA[e]
Mercury (elemental)	0.6	NA	1.0E+03	0[f]
Mercuric chloride	0.6	NA	5.8E+04	1.8E+03
Methyl mercury	0.6	NA	7.0E+03	0[f]
PAHs				
2-Methylnaphthalene	0.6	2.2E+02	5.0E+01	1.4E+00
7,12-Dimethylbenz(a)anthracene	0.6	6.8E+03	4.0E+03	4.2E+04
Acenaphthene	0.6	2.4E+02	3.9E+01	4.6E+00
Acenaphthylene	0.6	2.8E+02	6.8E+01	8.1E+00
Benz(a)anthracene	0.6	6.7E+03	2.9E+03	6.8E+03
Benzo(a)pyrene	0.6	9.2E+03	7.8E+03	1.7E+05

Exhibit B-10. Chemical-Specific Inputs for Produce Parameters for Chemicals Included in MIRC

Chemical	Fraction of Wet Deposition (*Fw*) (unitless)[a]	Root Concentration Factor (*RCF*) (belowground) (L/kg)[b]	Soil-Water Partition Coefficient (*Kds*) (L/kg)[c]	Chemical Air-to-Plant Biotransfer Factor ($Bv_{AG(i)}$) (unitless)[d]
Benzo(b)fluoranthene	0.6	6.6E+03	3.8E+03	1.7E+05
Benzo(g,h,i)perylene	0.6	3.0E+04	2.6E+04	2.3E+06
Benzo(k)fluoranthene	0.6	8.7E+03	5.5E+03	2.8E+05
Chrysene	0.6	6.0E+03	3.4E+03	1.4E+04
Dibenz(a,h)anthracene	0.6	2.3E+04	1.4E+04	6.2E+06
Fluoranthene	0.6	2.2E+03	3.9E+02	9.0E+02
Fluorene	0.6	3.8E+02	6.2E+01	1.6E+01
Indeno(1,2,3-cd)pyrene	0.6	3.5E+04	3.2E+04	2.8E+06
Dioxins				
OctaCDD, 1,2,3,4,6,7,8,9-	0.6	4.8E+05	7.8E+05	2.4E+06
OctaCDF, 1,2,3,4,6,7,8,9-	0.6	3.4E+05	4.9E+05	2.3E+06
HeptaCDD, 1,2,3,4,6,7,8-	0.6	3.4E+05	4.9E+05	9.1E+05
HeptaCDF, 1,2,3,4,6,7,8-	0.6	1.2E+05	1.2E+05	8.3E+05
HeptaCDF, 1,2,3,4,7,8,9-	0.6	4.8E+04	3.9E+04	8.3E+05
HexaCDD, 1,2,3,4,7,8-	0.6	2.4E+05	3.1E+05	5.2E+05
HexaCDF, 1,2,3,4,7,8-	0.6	5.7E+04	4.9E+04	1.6E+05
HexaCDD, 1,2,3,6,7,8-	0.6	4.9E+05	8.0E+05	5.2E+05
HexaCDF, 1,2,3,6,7,8-	0.6	2.9E+05	4.1E+05	1.6E+05
HexaCDD, 1,2,3,7,8,9 -	0.6	4.9E+05	8.0E+05	5.2E+05
HexaCDF, 1,2,3,7,8,9-	0.6	1.6E+05	1.9E+05	1.6E+05
HexaCDF, 2,3,4,6,7,8-	0.6	2.9E+05	4.1E+05	1.6E+05
PentaCDD, 1,2,3,7,8-	0.6	9.2E+04	9.2E+04	2.4E+05
PentaCDF, 1,2,3,7,8-	0.6	3.9E+04	3.0E+04	9.8E+04
PentaCDF, 2,3,4,7,8-	0.6	2.3E+04	1.6E+04	9.8E+04

Exhibit B-10. Chemical-Specific Inputs for Produce Parameters for Chemicals Included in MIRC

Chemical	Fraction of Wet Deposition (*Fw*) (unitless)[a]	Root Concentration Factor (*RCF*) (belowground) (L/kg)[b]	Soil-Water Partition Coefficient (*Kds*) (L/kg)[c]	Chemical Air-to-Plant Biotransfer Factor ($Bv_{AG(i)}$) (unitless)[d]
TetraCDD, 2,3,7,8-	0.6	4.0E+04	3.1E+04	6.6E+04
TetraCDF, 2,3,7,8-	0.6	1.2E+04	6.2E+03	4.6E+04

Source: EPA 2005a. NA = not applicable.

[a]6E-01 is the value for cations and most organic chemicals. As described in HHRAP (EPA 2005a), Appendix B (available at http://www3.epa.gov/epawaste/hazard/tsd/td/combust/risk.htm), EPA estimated this value (EPA 1994a, 1995a) from a study by Hoffman et al. (1992) in which soluble gamma-emitting radionuclides and insoluble particles tagged with gamma-emitting radionuclides were deposited onto pasture grass via simulated rain. Note that the values developed experimentally for pasture grass may not accurately represent all aboveground produce-specific values. Also note that values based on the behavior of insoluble particles tagged with radionuclides may not accurately represent the behavior of organic compounds under site-specific conditions.

[b]For nonionic organic chemicals, as described in HHRAP (EPA 2005a), Appendix A (available at http://www3.epa.gov/epawaste/hazard/tsd/td/combust/risk.htm), RCF is used to calculate the below-ground transfer of contaminants from soil to a root vegetable on a wet-weight basis as shown in Equation B-6. EPA estimated chemical-specific values for RCF from empirical regression equations developed by Briggs et al. (1982) based on their experiments measuring uptake of compounds into barley roots from growth solution. Briggs' regression equations allow calculation of RCF values from log Kow. For metals and mercuric compounds, empirical values for soil to root vegetable transfer on a dry-weight basis are available in the literature, thus the RCF was not needed.

[c]As discussed in HHRAP (EPA 2005a), Appendix A, Kds describes the partitioning of a compound between soil pore-water and soil particles and strongly influences the release and movement of a compound into the subsurface soils and underlying aquifer. Kds values for mercuric compounds were obtained from EPA (1997b). Kds for cadmium compounds were obtained from EPA 1996. For all PAHs and dioxins, Kds was calculated by multiplying Koc times the screening scenario's fraction organic carbon content (0.008). Empirical information for Koc was available for acenaphthene, benz(a)anthracene, benzo(a)pyrene, dibenz(a,h)anthracene, fluoranthene, and fluorene in USEAP 1996. For all other organic compounds, the Koc was calculated using the correlation equations presented in USEAP 2005a.

[d]As discussed in HHRAP (EPA 2005a), Appendix A, the value for mercuric chloride was obtained from EPA 1997b. BvAG(i) values for PAHs were calculated using the correlation equation derived for azalea leaves as cited in Bacci et al. (1992), then reducing this value by a factor of 100, as suggested by Lorber (1995), who concluded that the Bacci factor reduced by a factor of 100 was similar to his own observations in various studies. The values for dioxins were obtained from Lorber and Pinsky (2000).

[e]It is assumed that metals, with the exception of vapor-phase elemental mercury, do not transfer significantly from air into leaves.

[f]Speciation and fate and transport of mercury from emissions suggest that BvAG(i) values for elemental and methyl mercury are likely to be zero (EPA 2005a).

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
Inorganics				
Cadmium compounds	Exp. Fruit	1.3E-01	-	1.0E+00
	Exp. Veg.	1.3E-01	-	1.0E+00
	Forage	3.6E-01	-	1.0E+00
	Grain	6.2E-02	-	-
	Prot. Fruit	1.3E-01	-	-
	Prot. Veg.	1.3E-01	-	-
	Root	6.4E-02	1.0E+00	-
	Silage	3.6E-01	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
Mercury (elemental)	Exp. Fruit	-	-	1.0E+00
	Exp. Veg.	-	-	1.0E+00
	Forage	-	-	1.0E+00
	Grain	-	-	-
	Prot. Fruit	-	-	-
	Prot. Veg.	-	-	-
	Root	-	1.0E+00	-
	Silage	-	-	5.0E-01
Mercuric chloride	Exp. Fruit	1.5E-02	-	1.0E+00
	Exp. Veg.	1.5E-02	-	1.0E+00
	Forage	0.0E+00	-	1.0E+00
	Grain	9.3E-03	-	-
	Prot. Fruit	1.5E-02	-	-
	Prot. Veg.	1.5E-02	-	-
	Root	3.6E-02	1.0E+00	-
	Silage	0.0E+00	-	5.0E-01
Methyl mercury	Exp. Fruit	2.9E-02	-	1.0E-02
	Exp. Veg.	2.9E-02	-	1.0E-02
	Forage	0.0E+00	-	1.0E+00
	Grain	1.9E-02	-	-
	Prot. Fruit	2.9E-02	-	-
	Prot. Veg.	2.9E-02	-	-
	Root	9.9E-02	1.0E-02	-
	Silage	0.0E+00	-	5.0E-01
PAHs				
2-Methylnaphthalene	Exp. Fruit	2.3E-01	-	1.0E+00
	Exp. Veg.	2.3E-01	-	1.0E+00
	Forage	2.3E-01	-	1.0E+00
	Grain	2.3E-01	-	-
	Prot. Fruit	2.3E-01	-	-
	Prot. Veg.	2.3E-01	-	-
	Root	4.4E+00	1.0E+00	-
	Silage	2.3E-01	-	5.0E-01
7,12-Dimethylbenz(a)anthracene	Exp. Fruit	1.7E-02	-	1.0E-02
	Exp. Veg.	1.7E-02	-	1.0E-02
	Forage	1.7E-02	-	1.0E+00
	Grain	1.7E-02	-	-
	Prot. Fruit	1.7E-02	-	-
	Prot. Veg.	1.7E-02	-	-
	Root	1.7E+00	1.0E-02	-
	Silage	1.7E-02	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
Acenaphthene	Exp. Fruit	2.1E-01	-	1.0E+00
	Exp. Veg.	2.1E-01	-	1.0E+00
	Forage	2.1E-01	-	1.0E+00
	Grain	2.1E-01	-	-
	Prot. Fruit	2.1E-01	-	-
	Prot. Veg.	2.1E-01	-	-
	Root	6.2E+00	1.0E+00	-
	Silage	2.1E-01	-	5.0E-01
Acenaphthylene	Exp. Fruit	1.9E-01	-	1.0E-02
	Exp. Veg.	1.9E-01	-	1.0E-02
	Forage	1.9E-01	-	1.0E+00
	Grain	1.9E-01	-	-
	Prot. Fruit	1.9E-01	-	-
	Prot. Veg.	1.9E-01	-	-
	Root	4.1E+00	1.0E-02	-
	Silage	1.9E-01	-	5.0E-01
Benz(a)anthracene	Exp. Fruit	1.7E-02	-	1.0E-02
	Exp. Veg.	1.7E-02	-	1.0E-02
	Forage	1.7E-02	-	1.0E+00
	Grain	1.7E-02	-	-
	Prot. Fruit	1.7E-02	-	-
	Prot. Veg.	1.7E-02	-	-
	Root	2.3E+00	1.0E-02	-
	Silage	1.7E-02	-	5.0E-01
Benzo(a)pyrene	Exp. Fruit	1.4E-02	-	1.0E-02
	Exp. Veg.	1.4E-02	-	1.0E-02
	Forage	1.4E-02	-	1.0E+00
	Grain	1.4E-02	-	-
	Prot. Fruit	1.4E-02	-	-
	Prot. Veg.	1.4E-02	-	-
	Root	1.2E+00	1.0E-02	-
	Silage	1.4E-02	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
Benzo(b)fluoranthene	Exp. Fruit	1.8E-02	-	1.0E-02
	Exp. Veg.	1.8E-02	-	1.0E-02
	Forage	1.8E-02	-	1.0E+00
	Grain	1.8E-02	-	-
	Prot. Fruit	1.8E-02	-	-
	Prot. Veg.	1.8E-02	-	-
	Root	1.7E+00	1.0E-02	-
	Silage	1.8E-02	-	5.0E-01
Benzo(g,h,i)perylene	Exp. Fruit	5.7E-03	-	1.0E-02
	Exp. Veg.	5.7E-03	-	1.0E-02
	Forage	5.7E-03	-	1.0E+00
	Grain	5.7E-03	-	-
	Prot. Fruit	5.7E-03	-	-
	Prot. Veg.	5.7E-03	-	-
	Root	1.1E+00	1.0E-02	-
	Silage	5.7E-03	-	5.0E-01
Benzo(k)fluoranthene	Exp. Fruit	1.4E-02	-	1.0E-02
	Exp. Veg.	1.4E-02	-	1.0E-02
	Forage	1.4E-02	-	1.0E+00
	Grain	1.4E-02	-	-
	Prot. Fruit	1.4E-02	-	-
	Prot. Veg.	1.4E-02	-	-
	Root	1.6E+00	1.0E-02	-
	Silage	1.4E-02	-	5.0E-01
Chrysene	Exp. Fruit	1.9E-02	-	1.0E-02
	Exp. Veg.	1.9E-02	-	1.0E-02
	Forage	1.9E-02	-	1.0E+00
	Grain	1.9E-02	-	-
	Prot. Fruit	1.9E-02	-	-
	Prot. Veg.	1.9E-02	-	-
	Root	1.7E+00	1.0E-02	-
	Silage	1.9E-02	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
Dibenz(a,h)anthracene	Exp. Fruit	6.8E-03	-	1.0E-02
	Exp. Veg.	6.8E-03	-	1.0E-02
	Forage	6.8E-03	-	1.0E+00
	Grain	6.8E-03	-	-
	Prot. Fruit	6.8E-03	-	-
	Prot. Veg.	6.8E-03	-	-
	Root	1.6E+00	1.0E-02	-
	Silage	6.8E-03	-	5.0E-01
Fluoranthene	Exp. Fruit	4.0E-02	-	1.0E-02
	Exp. Veg.	4.0E-02	-	1.0E-02
	Forage	4.0E-02	-	1.0E+00
	Grain	4.0E-02	-	-
	Prot. Fruit	4.0E-02	-	-
	Prot. Veg.	4.0E-02	-	-
	Root	5.6E+00	1.0E-02	-
	Silage	4.0E-02	-	5.0E-01
Fluorene	Exp. Fruit	1.5E-01	-	1.0E-02
	Exp. Veg.	1.5E-01	-	1.0E-02
	Forage	1.5E-01	-	1.0E+00
	Grain	1.5E-01	-	-
	Prot. Fruit	1.5E-01	-	-
	Prot. Veg.	1.5E-01	-	-
	Root	6.2E+00	1.0E-02	-
	Silage	1.5E-01	-	5.0E-01
Indeno(1,2,3-cd)pyrene	Exp. Fruit	5.1E-03	-	1.0E-02
	Exp. Veg.	5.1E-03	-	1.0E-02
	Forage	5.1E-03	-	1.0E+00
	Grain	5.1E-03	-	-
	Prot. Fruit	5.1E-03	-	-
	Prot. Veg.	5.1E-03	-	-
	Root	1.1E+00	1.0E-02	-
	Silage	5.1E-03	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
Dioxins				
OctaCDD, 1,2,3,4,6,7,8,9-	Exp. Fruit	7.1E-04	-	1.0E-02
	Exp. Veg.	7.1E-04	-	1.0E-02
	Forage	7.1E-04	-	1.0E+00
	Grain	7.1E-04	-	-
	Prot. Fruit	7.1E-04	-	-
	Prot. Veg.	7.1E-04	-	-
	Root	6.1E-01	1.0E-02	-
	Silage	7.1E-04	-	5.0E-01
OctaCDF, 1,2,3,4,6,7,8,9-	Exp. Fruit	9.2E-04	-	1.0E-02
	Exp. Veg.	9.2E-04	-	1.0E-02
	Forage	9.2E-04	-	1.0E+00
	Grain	9.2E-04	-	-
	Prot. Fruit	9.2E-04	-	-
	Prot. Veg.	9.2E-04	-	-
	Root	6.8E-01	1.0E-02	-
	Silage	9.2E-04	-	5.0E-01
HeptaCDD, 1,2,3,4,6,7,8-	Exp. Fruit	9.2E-04	-	1.0E-02
	Exp. Veg.	9.2E-04	-	1.0E-02
	Forage	9.2E-04	-	1.0E+00
	Grain	9.2E-04	-	-
	Prot. Fruit	9.2E-04	-	-
	Prot. Veg.	9.2E-04	-	-
	Root	6.8E-01	1.0E-02	-
	Silage	9.2E-04	-	5.0E-01
HeptaCDF, 1,2,3,4,6,7,8-	Exp. Fruit	2.0E-03	-	1.0E-02
	Exp. Veg.	2.0E-03	-	1.0E-02
	Forage	2.0E-03	-	1.0E+00
	Grain	2.0E-03	-	-
	Prot. Fruit	2.0E-03	-	-
	Prot. Veg.	2.0E-03	-	-
	Root	9.4E-01	1.0E-02	-
	Silage	2.0E-03	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
HeptaCDF, 1,2,3,4,7,8,9-	Exp. Fruit	4.0E-03	-	1.0E-02
	Exp. Veg.	4.0E-03	-	1.0E-02
	Forage	4.0E-03	-	1.0E+00
	Grain	4.0E-03	-	-
	Prot. Fruit	4.0E-03	-	-
	Prot. Veg.	4.0E-03	-	-
	Root	1.2E+00	1.0E-02	-
	Silage	4.0E-03	-	5.0E-01
HexaCDD, 1,2,3,4,7,8-	Exp. Fruit	1.2E-03	-	1.0E-02
	Exp. Veg.	1.2E-03	-	1.0E-02
	Forage	1.2E-03	-	1.0E+00
	Grain	1.2E-03	-	-
	Prot. Fruit	1.2E-03	-	-
	Prot. Veg.	1.2E-03	-	-
	Root	7.6E-01	1.0E-02	-
	Silage	1.2E-03	-	5.0E-01
HexaCDF, 1,2,3,4,7,8-	Exp. Fruit	3.5E-03	-	1.0E-02
	Exp. Veg.	3.5E-03	-	1.0E-02
	Forage	3.5E-03	-	1.0E+00
	Grain	3.5E-03	-	-
	Prot. Fruit	3.5E-03	-	-
	Prot. Veg.	3.5E-03	-	-
	Root	1.2E+00	1.0E-02	-
	Silage	3.5E-03	-	5.0E-01
HexaCDD, 1,2,3,6,7,8-	Exp. Fruit	7.0E-04	-	1.0E-02
	Exp. Veg.	7.0E-04	-	1.0E-02
	Forage	7.0E-04	-	1.0E+00
	Grain	7.0E-04	-	-
	Prot. Fruit	7.0E-04	-	-
	Prot. Veg.	7.0E-04	-	-
	Root	6.1E-01	1.0E-02	-
	Silage	7.0E-04	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
HexaCDF, 1,2,3,6,7,8-	Exp. Fruit	1.0E-03	-	1.0E-02
	Exp. Veg.	1.0E-03	-	1.0E-02
	Forage	1.0E-03	-	1.0E+00
	Grain	1.0E-03	-	-
	Prot. Fruit	1.0E-03	-	-
	Prot. Veg.	1.0E-03	-	-
	Root	7.1E-01	1.0E-02	-
	Silage	1.0E-03	-	5.0E-01
HexaCDD, 1,2,3,7,8,9-	Exp. Fruit	7.0E-04	-	1.0E-02
	Exp. Veg.	7.0E-04	-	1.0E-02
	Forage	7.0E-04	-	1.0E+00
	Grain	7.0E-04	-	-
	Prot. Fruit	7.0E-04	-	-
	Prot. Veg.	7.0E-04	-	-
	Root	6.1E-01	1.0E-02	-
	Silage	7.0E-04	-	5.0E-01
HexaCDF, 1,2,3,7,8,9-	Exp. Fruit	1.6E-03	-	1.0E-02
	Exp. Veg.	1.6E-03	-	1.0E-02
	Forage	1.6E-03	-	1.0E+00
	Grain	1.6E-03	-	-
	Prot. Fruit	1.6E-03	-	-
	Prot. Veg.	1.6E-03	-	-
	Root	8.5E-01	1.0E-02	-
	Silage	1.6E-03	-	5.0E-01
HexaCDF, 2,3,4,6,7,8-	Exp. Fruit	1.0E-03	-	1.0E-02
	Exp. Veg.	1.0E-03	-	1.0E-02
	Forage	1.0E-03	-	1.0E+00
	Grain	1.0E-03	-	-
	Prot. Fruit	1.0E-03	-	-
	Prot. Veg.	1.0E-03	-	-
	Root	7.1E-01	1.0E-02	-
	Silage	1.0E-03	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
PentaCDD, 1,2,3,7,8-	Exp. Fruit	2.4E-03	-	1.0E-02
	Exp. Veg.	2.4E-03	-	1.0E-02
	Forage	2.4E-03	-	1.0E+00
	Grain	2.4E-03	-	-
	Prot. Fruit	2.4E-03	-	-
	Prot. Veg.	2.4E-03	-	-
	Root	1.0E+00	1.0E-02	-
	Silage	2.4E-03	-	5.0E-01
PentaCDF, 1,2,3,7,8-	Exp. Fruit	4.6E-03	-	1.0E-02
	Exp. Veg.	4.6E-03	-	1.0E-02
	Forage	4.6E-03	-	1.0E+00
	Grain	4.6E-03	-	-
	Prot. Fruit	4.6E-03	-	-
	Prot. Veg.	4.6E-03	-	-
	Root	1.3E+00	1.0E-02	-
	Silage	4.6E-03	-	5.0E-01
PentaCDF, 2,3,4,7,8-	Exp. Fruit	6.8E-03	-	1.0E-02
	Exp. Veg.	6.8E-03	-	1.0E-02
	Forage	6.8E-03	-	1.0E+00
	Grain	6.8E-03	-	-
	Prot. Fruit	6.8E-03	-	-
	Prot. Veg.	6.8E-03	-	-
	Root	1.5E+00	1.0E-02	-
	Silage	6.8E-03	-	5.0E-01
TetraCDD, 2,3,7,8-	Exp. Fruit	4.5E-03	-	1.0E-02
	Exp. Veg.	4.5E-03	-	1.0E-02
	Forage	4.5E-03	-	1.0E+00
	Grain	4.5E-03	-	-
	Prot. Fruit	4.5E-03	-	-
	Prot. Veg.	4.5E-03	-	-
	Root	1.3E+00	1.0E-02	-
	Silage	4.5E-03	-	5.0E-01

Exhibit B-11. Chemical-Specific Inputs by Plant Type for Chemicals in MIRC

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)[a]	Empirical Correction Factor- Belowground Produce ($VG_{rootveg}$) (unitless)[b]	Empirical Correction Factor- Aboveground Produce ($VG_{AG(i)}$) (unitless)[c]
TetraCDF, 2,3,7,8-	Exp. Fruit	1.2E-02	-	1.0E-02
	Exp. Veg.	1.2E-02	-	1.0E-02
	Forage	1.2E-02	-	1.0E+00
	Grain	1.2E-02	-	-
	Prot. Fruit	1.2E-02	-	-
	Prot. Veg.	1.2E-02	-	-
	Root	1.9E+00	1.0E-02	-
	Silage	1.2E-02	-	5.0E-01

[a]As discussed in HHRAP (EPA 2005a), the $Br_{AG\text{-}produce\text{-}DW(i)}$ for aboveground produce and forage accounts for the uptake from soil and the subsequent transport of contaminants through the roots to the aboveground plant parts. For organics, correlation equations to calculate values for *Br* on a dry weight basis were obtained from Travis and Arms (1988). For cadmium, *Br* values were derived from uptake slope factors provided in EPA 1992. Uptake slope is the ratio of contaminant concentration in dry weight plant tissue to the mass of contaminant applied per hectare soil. *Br* aboveground values for mercuric chloride and methyl mercury were calculated using methodology and data from Baes, et al. (1984). *Br* forage values for mercuric chloride and methyl mercury (on a dry weight basis) were obtained from EPA 1997b. The HHRAP methodology assumes that elemental mercury doesn't deposit onto soils. Therefore, it's assumed that there is no plant uptake through the soil.

[b]As discussed in HHRAP (EPA 2005a), Appendix B, $VG_{rootveg}$ represents an empirical correction factor that reduces produce concentration. Because of the protective outer skin, size, and shape of bulky produce, transfer of lipophilic chemicals (i.e., log K_{ow} greater than 4) to the center of the produce is not likely. In addition, typical preparation techniques, such as washing, peeling, and cooking, further reduce the concentration of the chemical in the vegetable as consumed by removing the high concentration of chemical on and in the outer skin, leaving the flesh with a lower concentration than would be the case if the entire vegetable were pureed without washing. For belowground produce, HHRAP (EPA 2005a) recommends using a $VG_{rootveg}$ value of 0.01 for PB-HAP with a log K_{ow} greater than 4 and a value of 1.0 for PB-HAP with a log K_{ow} less than 4 based on information provided in EPA 1994b. In developing these values, EPA (1994b) assumed that the density of the skin and the whole vegetable are equal (potentially overestimating the concentration of PB-HAP in belowground produce due to root uptake).

[c]As discussed in HHRAP (EPA 2005a), Appendix B, VG_{ag} represents an empirical correction factor that reduces aboveground produce concentration and was developed to estimate the transfer of PB-HAP into leafy vegetation versus bulkier aboveground produce (e.g., apples). Because of the protective outer skin, size, and shape of bulky produce, transfer of lipophilic PB-HAP (log K_{ow} greater than 4) to the center of the produce is not likely. In addition, typical preparation techniques, such as washing, peeling, and cooking, further reduce residues. For aboveground produce, HHRAP (EPA 2005a) recommends using a VG_{ag} value of 0.01 for PB-HAP with a log K_{ow} greater than 4 and a value of 1.0 for PB-HAP with a log K_{ow} less than 4 based on information provided in EPA 1994b. In developing these values, EPA (1994b) assumed the following: (1) translocation of compounds deposited on the surface of aboveground vegetation to inner parts of aboveground produce would be insignificant (potentially underestimating the concentration of PB-HAP in aboveground produce due to air-to-plant transfer); (2) the density of the skin and the whole vegetable are equal (potentially overestimating the concentration of PB-HAP in aboveground produce due to air-to-plant transfer); and (3) the thickness of vegetable skin and broadleaf tree skin are equal (effects on the concentration of PB-HAP in aboveground produce due to air-to-plant transfer unknown).

For forage, HHRAP recommends a VG_{ag} value of 1.0, also based on information provided in EPA 1994b.

A VG_{ag} value for silage is not provided in EPA 1994b; the VGag value for silage of 0.5 was obtained from NC DEHNR (1997); however, NC DEHNR does not present a specific rationale for this recommendation. Depending on the composition of the site-specific silage, this value may under- or overestimate the actual value.

Exhibit B-12. Non-Chemical-Specific Produce Inputs

Plant Part	Interception Fraction ($Rp_{(i)}$) (unitless)[a]	Plant Surface Loss Coefficient ($kp_{(i)}$) (1/year)[b]	Length of Plant Exposure to Deposition ($Tp_{(i)}$) (year)[c]	Yield or Standing Crop Biomass ($Yp_{(i)}$) (kg/m^2)[d]	Plant Tissue-Specific Moisture Adjustment Factor ($MAF_{(i)}$) (percent)[e]
Exposed Vegetable	0.982	18	0.16	5.66	92
Protected Fruit	NA	NA	NA	NA	90
Protected Vegetable	NA	NA	NA	NA	80
Forage (animal feed)	0.5	18	0.12	0.24	92
Exposed Fruit	0.053	18	0.16	0.25	85
Root Vegetables	NA	NA	NA	NA	87
Silage (animal feed)	0.46	18	0.16	0.8	92
Grain (animal feed)	NA	NA	NA	NA	90

Source: EPA 2005a. NA = not applicable.

[a]Baes *et al*. (1984) used an empirical relationship developed by Chamberlain (1970) to identify a correlation between initial Rp values and pasture grass productivity (standing crop biomass [*Yp*]) to calculate *Rp* values for exposed vegetables, exposed fruits, forage, and silage. Two key uncertainties are associated with using these values for *Rp*: (1) Chamberlain's (1970) empirical relationship developed for pasture grass may not accurately represent aboveground produce. (2) The empirical constants developed by Baes *et al*. (1984) for use in the empirical relationship developed by Chamberlain (1970) may not accurately represent the site-specific mixes of aboveground produce consumed by humans or the site-specific mixes of forage or silage consumed by livestock.

[b]The term *kp* is a measure of the amount of chemical that is lost to natural physical processes (e.g., wind, water) over time. The HHRAP-recommended value of 18 yr^{-1} (also recommended by EPA 1994a and 1998) represents the midpoint of a range of values reported by Miller and Hoffman (1983). There are two key uncertainties associated with using these values for *kp*: (1) The recommended equation for calculating *kp* includes a health protective bias in that it does not consider chemical degradation processes. (2) Given the reported range of *kp* values from 7.44 to 90.36 yr^{-1}, plant concentrations could range from about 1.8 times higher to about 5 times lower than the plant concentrations estimated in FFC media using the midpoint *kp* value of 18.

[c]HHRAP (EPA 2005a) recommends using a *Tp* value of 0.16 years for aboveground produce and cattle silage. This is consistent with earlier reports by EPA (1994a, 1998) and NC DEHNR (1997), which recommended treating *Tp* as a constant based on the average period between successive hay harvests. Belcher and Travis (1989) estimated this period at 60 days. *Tp* is calculated as 60 days ÷ 365 days/year = 0.16 years. For forage, the average of the average period between successive hay harvests (60 days) and the average period between successive grazing (30 days) is used (that is, 45 days), and *Tp* is calculated as (60 days + 30 days)/ 2 ÷ 365 days/yr = 0.12 yr. Two key uncertainties are associated with use of these values for *Tp*: (1) The average period between successive hay harvests (60 days) may not reflect the length of the growing season or the length between successive harvests for site-specific aboveground produce crops. The concentration of chemical in aboveground produce due to direct (wet and dry) deposition (*Pd*) will be underestimated if the site-specific value of *Tp* is less than 60 days, or overestimated if the site-specific value of *Tp* is more than 60 days.

[d]*Yp* values for aboveground produce and forage were calculated using an equation presented in Baes *et al*. (1984) and Shor *et al*. (1982): $Yp = Y_{hi} / A_{hi}$, where Y_{hi} = Harvest yield of ith crop (kg DW) and A_{hi} = Area planted to i^{th} crop (m2), and using values for Y_h and A_h from USDA (1994b and 1994c). A production-weighted U.S. average *Yp* of 0.8 kg DW/m2 for silage was obtained from Shor *et al*. 1982.

[e]*MAF* represents the plant tissue-specific moisture adjustment factor to convert dry-weight concentrations into wet-weight concentrations (which are lower owing to the dilution by water compared with dry-weight concentrations). Values obtained from Chapter 10 of EPA's 2003 SAB Review materials for 3MRA Modeling System, Volume II, "Farm Food Chain and Terrestrial Food Web Data" (EPA 2003a), which references EPA 1997c. Note that the value for grain used as animal feed is based on corn and soybeans, not seed grains such as barley, oats, or wheat.

6.2.3. Animal Product Parameter Values

MIRC also requires chemical-specific inputs for many of the animal product algorithms. The relevant values are shown in Exhibit B-13 for the chemicals included in MIRC to date. The HHRAP algorithms require additional inputs for the animal products calculations that are not specific to PB-HAPs, but are specific to the animal and animal product type. The soil and plant ingestion rates recommended in HHRAP for beef cattle, dairy cattle, swine, and chicken are provided in Exhibit B-14.

Exhibit B-13. Animal Product Chemical-specific Inputs for Chemicals Included in MIRC

Compound Name	Soil Bio-Availability Factor (*Bs*) (unitless)	Biotransfer Factors (Ba_m) (day/kg FW tissue)[a] and Metabolism Factors (MF) (unitless)[b]						
		Mammal				Non-mammal		
		Beef (Ba_{beef})	Dairy (Ba_{dairy})	Pork (Ba_{pork})	*MF*	Eggs (Ba_{eggs})	Poultry ($Ba_{poultry}$)	*MF*
Inorganics								
Cadmium compounds	1	1.2E-04	6.5E-06	1.9E-04	1	2.5E-03	1.1E-01	NA
Mercury (elemental)	1	0	0	0	1	0	0	NA
Mercuric chloride	1	1.1E-04	1.4E-06	3.4E-05	1	2.4E-02	2.4E-02	NA
Methyl mercury	1	1.2E-03	1.7E-05	5.1E-06	1	3.6E-03	3.6E-03	NA
PAHs								
2-Methylnaphthalene	1	2.4E-02	5.0E-03	2.9E-02	0.01	1.0E-02	1.7E-02	NA
7,12-Dimethylbenz(a)anthracene	1	3.9E-02	8.3E-03	4.8E-02	0.01	1.7E-02	2.9E-02	NA
Acenaphthene	1	2.5E-02	5.2E-03	3.0E-02	0.01	1.0E-02	1.8E-02	NA
Acenaphthylene	1	2.6E-02	5.5E-03	3.1E-02	0.01	1.1E-02	1.9E-02	NA
Benz(a)anthracene	1	3.9E-02	8.3E-03	4.8E-02	0.01	1.7E-02	2.9E-02	NA
Benzo(a)pyrene	1	3.8E-02	8.0E-03	4.6E-02	0.01	1.6E-02	2.8E-02	NA
Benzo(b)fluoranthene	1	3.9E-02	8.3E-03	4.8E-02	0.01	1.7E-02	2.9E-02	NA
Benzo(g,h,i)perylene	1	2.9E-02	6.1E-03	3.5E-02	0.01	1.2E-02	2.1E-02	NA
Benzo(k)fluoranthene	1	3.8E-02	8.0E-03	4.6E-02	0.01	1.6E-02	2.8E-02	NA
Chrysene	1	4.0E-02	8.4E-03	4.8E-02	0.01	1.7E-02	2.9E-02	NA
Dibenz(a,h)anthracene	1	3.1E-02	6.5E-03	3.8E-02	0.01	1.3E-02	2.3E-02	NA
Fluoranthene	1	4.0E-02	8.5E-03	4.9E-02	0.01	1.7E-02	3.0E-02	NA
Fluorene	1	2.9E-02	6.1E-03	3.5E-02	0.01	1.2E-02	2.1E-02	NA
Indeno(1,2,3-cd)pyrene	1	2.7E-02	5.8E-03	3.3E-02	0.01	1.2E-02	2.0E-02	NA
Dioxins								
OctaCDD, 1,2,3,4,6,7,8,9-	1	6.9E-03	1.4E-03	8.3E-03	1	2.9E-03	5.1E-03	NA
OctaCDF, 1,2,3,4,6,7,8,9-	1	8.8E-03	1.8E-03	1.1E-02	1	3.7E-03	6.5E-03	NA
HeptaCDD, 1,2,3,4,6,7,8-	1	8.8E-03	1.8E-03	1.1E-02	1	3.7E-03	6.5E-03	NA

Exhibit B-13. Animal Product Chemical-specific Inputs for Chemicals Included in MIRC

Compound Name	Soil Bio-Availability Factor (*Bs*) (unitless)	Biotransfer Factors (Ba_m) (day/kg FW tissue)[a] and Metabolism Factors (MF) (unitless)[b]						
		Mammal				Non-mammal		
		Beef (Ba_{beef})	Dairy (Ba_{dairy})	Pork (Ba_{pork})	*MF*	Eggs (Ba_{eggs})	Poultry ($Ba_{poultry}$)	*MF*
HeptaCDF, 1,2,3,4,6,7,8-	1	1.6E-02	3.5E-03	2.0E-02	1	6.9E-03	1.2E-02	NA
HeptaCDF, 1,2,3,4,7,8,9-	1	2.4E-02	5.1E-03	3.0E-02	1	1.0E-02	1.8E-02	NA
HexaCDD, 1,2,3,4,7,8-	1	1.1E-02	2.3E-03	1.3E-02	1	4.6E-03	8.1E-03	NA
HexaCDF, 1,2,3,4,7,8-	1	2.3E-02	4.8E-03	2.8E-02	1	9.6E-03	1.7E-02	NA
HexaCDD, 1,2,3,6,7,8-	1	6.8E-03	1.4E-03	8.2E-03	1	2.9E-03	5.0E-03	NA
HexaCDF, 1,2,3,6,7,8-	1	9.7E-03	2.0E-03	1.2E-02	1	4.1E-03	7.1E-03	NA
HexaCDD, 1,2,3,7,8,9 -	1	6.8E-03	1.4E-03	8.2E-03	1	2.9E-03	5.0E-03	NA
HexaCDF, 1,2,3,7,8,9-	1	1.4E-02	2.9E-03	1.7E-02	1	5.8E-03	1.0E-02	NA
HexaCDF, 2,3,4,6,7,8-	1	9.6E-03	2.0E-03	1.2E-02	1	4.1E-03	7.1E-03	NA
PentaCDD, 1,2,3,7,8-	1	1.8E-02	3.9E-03	2.2E-02	1	7.8E-03	1.4E-02	NA
PentaCDF, 1,2,3,7,8-	1	2.6E-02	5.5E-03	3.2E-02	1	1.1E-02	1.9E-02	NA
PentaCDF, 2,3,4,7,8-	1	3.1E-02	6.5E-03	3.8E-02	1	1.3E-02	2.3E-02	NA
TetraCDD, 2,3,7,8-	1	2.6E-02	5.5E-03	3.2E-02	1	1.1E-02	1.9E-02	NA
TetraCDF, 2,3,7,8-	1	3.6E-02	7.7E-03	4.4E-02	1	1.5E-02	2.7E-02	NA

Source: EPA 2005a, unless otherwise indicated. NA = not applicable.

[a]As discussed in HHRAP (EPA 2005a), Appendix A, biotransfer factors for mercury compounds were obtained from EPA 1997b. Considering speciation, fate, and transport of mercury from emission sources, elemental mercury is assumed to be vapor-phase and hence is assumed not to deposit to soil or transfer into aboveground plant parts. As a consequence, there is no transfer of elemental mercury into animal tissues. Biotransfer factors for cadmium compounds were obtained from EPA 1995b. Biotransfer factors for dioxins and PAHs were calculated from chemical octanol-water partitioning coefficients (K_{ow} values) using the correlation equation from RTI (2005) and assuming the following fat contents: milk - 4%; beef - 19%; pork - 23%; poultry -14%; and eggs - 8%.

[b]As discussed in HHRAP (EPA 2005a), EPA (1995c) recommends using a metabolism factor (MF) to account for metabolism of PAHs by mammals to offset the amount of bioaccumulation suggested by biotransfer factors. EPA has recommended an MF of 0.01 for bis(2-ethylhexyl)phthalate (BEHP) and 1.0 for all other chemicals (EPA 1995d). For MIRC, an MF of 0.01 is also used to calculate concentrations of PAHs in food products from mammalian species based on the work of Hofelt et al. (2001). This factor takes into account the P450-mediated metabolism of PAHs in mammals; applying this factor in our approach reduced the concentrations of chemicals in beef, pork, and dairy by two orders of magnitude.

Exhibit B-14. Soil and Plant Ingestion Rates for Animals

Animal	Soil Ingestion Rate – $Qs_{(m)}$ (kg/day)[a]	Plant Part Consumed by Animal	Plant Ingestion Rate – $Qp_{(l,m)}$ (kg/day)
Beef cattle[b]	0.5	Silage	2.5
		Forage	8.8
		Grain	0.47
Dairy cattle[c]	0.4	Silage	4.1
		Forage	13.2
		Grain	3.0
Swine[d]	0.37	Silage	1.4
		Grain	3.3
Chicken (eggs)[e]	0.022	Grain	0.2

Source: EPA 2005a HHRAP (Chapter 5).

[a]Beef cattle: NC DEHNR (1997) and EPA (1994b) recommended a soil ingestion rate for subsistence beef cattle of 0.5 kg/day based on Fries (1994) and NAS (1987). As discussed in HHRAP, Fries (1994) reported soil ingestion to be 4 percent of the total dry matter intake. NAS (1987) cited an average beef cattle weight of 590 kg, and a daily dry matter intake rate (non-lactating cows) of 2 percent of body weight. This results in a daily dry matter intake rate of 11.8 kg DW/day and a daily soil ingestion rate of about 0.5 kg/day.

Dairy cattle: NC DEHNR (1997) and EPA (1994b) recommended a soil ingestion rate for dairy cattle of 0.4 kg/day based on Fries (1994) and NAS (1987). As discussed in HHRAP, Fries (1994) reported soil ingestion to be 2 percent of the total dry matter intake. NAS (1987) cited an average beef cattle weight of 630 kg and a daily dry matter intake rate (non-lactating cows) of 3.2 percent of body weight. This resulted in a daily dry matter intake rate of 20 kg/day DW, and a daily soil ingestion rate of approximately 0.4 kg/day. Uncertainties associated with Qs include the lack of current empirical data to support soil ingestion rates for dairy cattle and the assumption of uniform contamination of soil ingested by cattle.

Swine: NC DEHNR (1997) recommended a soil ingestion rate for swine of 0.37, estimated by assuming a soil intake that is 8% of the plant ingestion rate of 4.3 kg DW/day. Uncertainties include the lack of current empirical data to support soil ingestion rates and the assumption of uniform contamination of the soil ingested by swine.

Chicken: HHRAP (EPA 2005a) assumes that chickens consume 10 percent of their total diet (which is approximately 0.2 kg/day grain) as soil, a percentage that is consistent with the study from Stephens *et al*. (1995). Uncertainties include the lack of current empirical data to support soil ingestion rates for chicken and the assumption of uniform contamination of soil ingested by chicken.

[b]The beef cattle ingestion rates of forage, silage, and grain are based on the total daily intake rate of about 12 kg DW/day (based on NAS [1987] reporting a daily dry matter intake that is 2 percent of an average beef cattle body weight of 590 kg) and are supported by NC DEHNR (1997), EPA (1994b and 1990), and Boone *et al*. (1981). The principal uncertainty associated with these *Qp* values is the variability between forage, silage, and grain ingestion rates for cattle.

[c]The dairy cattle ingestion rates of forage, silage, and grain are based on the total daily intake rate of about 20 kg DW/day (NAS 1987; EPA 1992) as recommended by NC DEHNR (1997). Uncertainties include the proportion of each food type in the diet, which varies from location to location. Assuming uniform contamination of plant materials consumed by cattle also introduces uncertainty.

[d]Swine are not grazing animals and are assumed not to eat forage (EPA 1998). EPA (1994b and 1998) and NC DEHNR (1997) recommended including only silage and grains in the diet of swine. EPA (1995c) recommended an ingestion rate of 4.7 kg DW/day for a swine, referencing NAS (1987). Assuming a diet of 70 percent grain and 30 percent silage (EPA 1990), HHRAP estimated ingestion rates of 3.3 kg DW/day (grain) and 1.4 kg DW/day (silage). Uncertainties associated with *Qp* include variability of the proportion of grain and silage in the diet, which varies from location to location.

[e]Chickens consume grain provided by the farmer. The daily quantity of grain feed consumed by chicken is assumed to be 0.2 kg/day (Ensminger (1980), Fries (1982), and NAS (1987). Uncertainties associated with this variable include the variability of actual grain ingestion rates from site to site. In addition, assuming uniform contamination of plant materials consumed by chicken introduces some uncertainty.

6.3. Adult and Non-Infant Exposure Parameter Values

The exposure parameters included in MIRC and their default and other value options are summarized in the following subsections. The default values were selected to result in a highly health protective screening scenario. Parameter value options were primarily obtained or estimated from EPA's *Exposure Factors Handbook* (EFH; EPA 2011a) and *Child-Specific Exposure Factors Handbook* (CSEFH; EPA 2008a). Where values were reported for age groupings other than those used in MIRC (see Section 2.3 above for MIRC age groups), time-weighted average values were estimated for the MIRC age groups from the available data.

In MIRC, ingestion rates for home-produced farm food items are included for exposed fruit, protected fruit, exposed vegetables, protected vegetables, root vegetables, beef, total dairy, pork, poultry, and eggs. Those ingestion rates are already normalized to body weight (i.e., $g_{wet\ weight}$/kg-day) (EPA 2011a). The body weight parameter values presented in Exhibit B-15, therefore, are not applied in the chemical intake (ADD) equations for these food types.

In MIRC, ingestion rates also are included for drinking water (mL/day), soil (mg/day), and fish (g/day). These ingestion rates, however, are on a per person basis (i.e., not normalized for body weight). The body weight parameter values presented in Exhibit B-15, therefore, are applied in the chemical intake (ADD) equations for these media.

6.3.1. Body Weights

Body weight (BW) options included in MIRC include mean, 5th, 10th, 50th, 90th, and 95th percentile values for adults and the five children's age groups: <1 year; 1–2 years; 3–5 years; 6–11 years; and 12–19 years. For its default screening assessment, EPA uses the mean BW for each age group. The BWs currently in the MIRC database are listed in Exhibit B-15.

In general, BW values for the five children's age groups were calculated from the summary data provided in Table 8-3 of EPA's 2008 CSEFH. For purposes of comparison, alternative BW values for children ages 12 through 19 years also were estimated using data from Portier *et al*. (2007). These values are listed in the last row of Exhibit B-15, but are not included in MIRC. The means calculated using the two methods for children ages 12 through 19 years were essentially identical at 64 kg. The other percentile values for this age group using the two methods differed by approximately 10 percent or less.

Exhibit B-15. Mean and Percentile Body Weight Estimates for Adults and Children

Lifestage (years)	Duration (years)	Body Weight (kg)					
		Mean	5th	10th	50th	90th	95th
Adult[a] (20-70)	50	80.0[a]	52.9	56	69.3	89.7	97.6
Child < 1[b]	1	7.83	6.03	6.38	7.76	9.24	9.66
Child 1-2[c]	2	12.6	9.9	10.4	12.5	14.9	15.6
Child 3-5[d]	3	18.6	13.5	14.4	17.8	23.6	26.2
Child 6-11[e]	6	36.0	22.1	24.0	33.5	51.2	58.6
Child 12-19[f]	8	64.2	39.5	45	64.2	83.5	89
[Child 12-19[g]	*8*	*64.3*	*41.1*	*44.6*	*60.9*	*88.5*	*98.4]*

[a]BW represents the recommended body weight from EPAs 2011 EFH. Although the 18 to 74 year age category in EPA's EFH does not match exactly the age 20 to 70 year categorization of adults in MIRC, the magnitude of error in the mean and percentile body weights is likely to be very small (i.e., less than 1%).
[b]Each BW represents a time-weighted average of body weights for age groups birth to <1 month, 1 to <3 months, 3 to <6 months, and 6 to <12 months from Table 8-3 of the 2008 CSEFH. Original sample sizes for each of these age groups can also be found in Table 8-3.
[c]Each BW represents a time-weighted average of body weights for age groups 1 to <2 years and 2 to <3 years from Table 8-3 of the 2008 CSEFH. Original sample sizes for each of these age groups can also be found in Table 8-3.
[d]BWs obtained directly from Table 8-3 of the 2008 CSEFH (age group 3 to <6 years).
[e]Each BW represents a time-weighted average of body weights for age groups 6 to <11 years and 11 to <16 years from Table 8-3 of the 2008 CSEFH. Original sample sizes for each of these age groups can also be found in Table 8-3.
[f]Mean BW estimated using Table 8-22 of the 2008 CSEFH, which is based on NHANES IV data as presented in Portier et al. (2007). This estimate was calculated as the average of the 8 single-year age groups from 12 to 13 years through 19 to 20 years. Values for the other percentiles were estimated using Portier et al., 2007.
[g]Each BW represents a time-weighted average of body weights for age groups 11 to <16 years and 16 to <21 years from Table 8-3 of the 2008 CSEFH. Estimated values include 11-year-olds and individuals through age 20, which contributes to uncertainty in the estimates for 12 to 19 years. Those values are provided for comparison purposes only and are not included in MIRC.

6.3.2. Water Ingestion Rates

MIRC also includes the option of calculating chemical ingestion via drinking water obtained from surface-water sources or from wells (i.e., from groundwater) in the contaminated area. Users have the option in MIRC to set drinking water ingestion rates to zero or to revise the drinking water ingestion rates in MIRC to better reflect site-specific water uses. The 2008 CSEFH recommends values for drinking water ingestion rates for children based on a study reported by Kahn and Stralka (2008). Table 3-4 of the CSEFH provides *per capita* estimates of community water ingestion rates by age categories. Community water ingestion includes both direct and indirect ingestion of water from the tap. *Direct ingestion* is defined as direct consumption of water as a beverage, while *indirect ingestion* includes water added during food or beverage preparation. The source of these data is the 1994-1996 and 1998 U.S. Department of Agriculture's (USDA's) *Continuing Survey of Food Intakes by Individuals* (CSFII) (USDA 2000). Exhibit B-16 includes the drinking water ingestion rates for children that are included in MIRC.

Mean and percentile adult drinking water ingestion rates were obtained from EPA (2004b), which presents estimated *per capita* water ingestion rates for various age categories based on data collected by the USDA's 1994–1996 and 1998 CSFII (USDA 2000). Adult ingestion rates, presented in Exhibit B-16, represent community water ingestion, both direct and indirect as defined above, for males and females combined, ages 20 years and older.

Exhibit B-16. Estimated Daily Per Capita Mean and Percentile Water Ingestion Rates for Children and Adults[a]

Lifestage (years)	Ingestion Rates, Community Water (mL/day)				
	Mean	50th	90th	95th	99th
Child <1[b]	504	482	969	1113	1440
Child 1-2[c]	332	255	687	903	1318
Child 3-5[d]	382	316	778	999	1592
Child 6-11[e]	532	417	1149	1499	2274
Child 12-19[f]	698	473	1641	2163	3467
Adult[g]	1219	981	2534	3087	4567

Sources: EPA 2004, 2008a

*The sample size does not meet minimum reporting requirements as described in EPA 2008a. For some of these MIRC age groupings, the values are based on the time-weighted average value for 2 or more age ranges from CSEFH Table 3-4. One or more age ranges within the group may not meet the minimum reporting requirements, but not necessarily all of them fall within this category.

[a]Source is Kahn and Stralka 2008, also presented in the CSEFH (EPA 2008a).

[b]Each IR represents a time-weighted average of ingestion rates for age groups birth to <1 month, 1 to <3 months, 3 to <6 months, and 6 to <12 months from Table 3-4 of the 2008 CSEFH.

[c]Each IR represents a time-weighted average of ingestion rates for age groups 1 to <2 years and 2 to <3 years from Table 3-4 of the 2008 CSEFH.

[d]Each IR represents the ingestion rate for age group 3 to <6 years from Table 3-4 of the 2008 CSEFH.

[e]Each IR represents the ingestion rate for age group 6 to <11 years from Table 3-4 of the 2008 CSEFH. This value represents a health protective (i.e., slightly low) estimate of IR for ages 6 through 11 years since 11-year olds are not included in this CSEFH age group.

[f]Each IR represents a time-weighted average of ingestion rates for age groups 11 to <16 years, 16 to <18, and 18 to <21 years from Table 3-4 of the 2008 CSEFH. Note that estimated values include 11-year-olds and individuals through age 20, which contributes to uncertainty in the estimates for 12 to 19 years.

[g]Adult drinking water ingestion rates were obtained from EPA (2004b), Appendix E, Part I, Table A1 for community water, both sexes (ages 20+), direct plus indirect water ingestion.

6.3.3. Local Food Ingestion Rates

MIRC includes mean, median, 90th, 95th, and 99th percentile food-specific ingestion rates (IRs) for consumers-only of farm food chain (FFC) media for adults and children. The mean and

percentile values are from EPA's analysis of data from the USDA's 1987 to 1988 *Nationwide Food Consumption Survey* (NFCS) (USDA 1993), as presented in Chapter 13 of the Agency's *Exposure Factors Handbook* (i.e., Intake Rates for Various Home Produced Food Items) (EPA 2011a). Consumers-only means that individuals who did not report eating a specified type of food during the three-day period covered by the food ingestion part of the survey were not included in the analysis of ingestion rates for that food type. The questionnaire included the options for a household to self-identify in one or more of five categories: as a household that gardens, raises animals, hunts, fishes, or farms. As of September 2008, that survey was the most recent NFCS available (EPA 2008a, CSEFH), and we are not aware of any that might be more recent.[29]

For the adult age group in MIRC, data were compiled on food-specific IRs separately for two types of households as indicated in the "Response to Questionnaire" (EPA 2011a, Chapter 13): (1) households that farm (F) and (2) households that garden or raise animals (HG for homegrown). This division reflects EPA's data analysis. EPA tabulated IRs for fruits and vegetables separately for households that farm and households that garden. Similarly, EPA tabulated IRs for animals and animal products for households that farm and for households that raise animals. Thus, the first type of household, F, represents farmers who may both grow crops and raise animals and who are likely to consume more homegrown/raised foods than the second type of household. The second type of household, HG, represents the non-farming households that may consume lower amounts of home-grown or raised foods (i.e., HG encompasses both households that garden and households that raise animals).

The food-specific ingestion rates are based on the amount of each food type that households that farm (F) or households that garden and raise animals (HG) produced and brought into their homes for consumption and the number of persons consuming the food. EPA averaged the actual consumption rate for home-grown foods over the 1-week survey period.

The default food-specific ingestion rates in MIRC for adults are those for farming households (F) in Exhibit B-17. The user can specify use of the non-farming household (HG) ingestion rates if they are more appropriate for the user's exposure scenario.

Exhibit B-17. Summary of Age-Group Specific Food Ingestion Rates for Farm Food Items

Product	Child (age in yr)					Adult (20–70 yrs)
	<1	1–2	3–5	6–11	12–19	
Mean ingestion rates (g/kg-day)						
Beef[a]	N/A	4.14	4.00	3.77	1.72	1.93
Dairy[b]	N/A	91.6	50.9	27.4	13.6	2.96
Eggs[a]	N/A	2.46	1.42	0.86	0.588	0.606
Exposed Fruit[a]	N/A	6.14	2.60	2.52	1.33	1.19
Exposed Vegetable[a]	N/A	3.48	1.74	1.39	1.07	1.38
Pork[a]	N/A	2.23	2.15	1.50	1.28	1.10
Poultry[a]	N/A	3.57	3.35	2.14	1.50	1.37

[29]Note that EPA's 2008 CSEFH does not distinguish between exposed and protected fruits and vegetables when recommending food ingestion rates based on the same data set for the same age categories. EPA's 1997 analysis for its EFH therefore remains the most appropriate data source for use in MIRC.

Exhibit B-17. Summary of Age-Group Specific Food Ingestion Rates for Farm Food Items

Product	Child (age in yr)					Adult (20–70 yrs)
	<1	1–2	3–5	6–11	12–19	
Protected Fruit[a]	N/A	16.6	12.4	8.50	2.96	5.19
Protected Vegetable[a]	N/A	2.46	1.30	1.10	0.78	0.862
Root Vegetable[a]	N/A	2.52	1.28	1.32	0.94	1.03
Water (mL/day)[c]	N/A	332	382	532	698	1218
Median ingestion rates (g/kg-day)						
Beef[a]	N/A	2.51	2.49	2.11	1.51	1.55
Dairy[b]	N/A	125	66.0	34.4	15.5	2.58
Eggs[a]	N/A	1.51	0.83	0.561	0.435	0.474
Exposed Fruit[a]	N/A	1.82	1.11	0.61	0.62	0.593
Exposed Vegetable[a]	N/A	1.89	1.16	0.64	0.66	0.812
Pork[a]	N/A	1.80	1.49	1.04	0.89	0.802
Poultry[a]	N/A	3.01	2.90	1.48	1.30	0.922
Protected Fruit[a]	N/A	7.59	5.94	3.63	1.23	2.08
Protected Vegetable[a]	N/A	1.94	1.04	0.79	0.58	0.564
Root Vegetable[a]	N/A	0.46	0.52	0.57	0.56	0.59
Water (mL/day)[c]	N/A	255	316	417	473	981
90th percentile ingestion rates (g/kg-day)[d]						
Beef[a]	N/A	9.49	8.83	11.4	3.53	4.41
Dairy[b]	N/A	185	92.5	57.4	30.9	6.16
Eggs[a]	N/A	4.90	3.06	1.90	1.30	1.31
Exposed Fruit[a]	N/A	12.7	5.41	6.98	3.41	2.37
Exposed Vegetable[a]	N/A	10.7	3.47	3.22	2.35	3.09
Pork[a]	N/A	4.90	4.83	3.72	3.69	2.23
Poultry[a]	N/A	7.17	6.52	4.51	3.13	2.69
Protected Fruit[a]	N/A	44.8	32.0	23.3	7.44	15.1
Protected Vegetable[a]	N/A	3.88	2.51	2.14	1.85	1.81
Root Vegetable[a]	N/A	7.25	4.26	3.83	2.26	2.49
Water (mL/day)[c]	N/A	687	778	1149	1640	2534
95th percentile ingestion rates (g/kg-day)						
Beef[a]	N/A	12.9	12.5	12.5	3.57	5.83
Dairy[b]	N/A	167	89.9	56.0	32.3	7.80
Eggs[a]	N/A	5.38	3.62	2.37	1.43	1.59
Exposed Fruit[a]	N/A	14.6	6.07	11.7	4.78	3.38
Exposed Vegetable[a]	N/A	11.9	6.29	5.47	3.78	4.46
Pork[a]	N/A	6.52	6.12	4.73	6.39	2.60
Poultry[a]	N/A	8.10	7.06	5.07	3.51	3.93
Protected Fruit[a]	N/A	48.3	35.1	26.9	11.4	19.2
Protected Vegetable[a]	N/A	9.42	5.10	3.12	2.20	2.83
Root Vegetable[a]	N/A	10.4	4.73	5.59	3.32	3.37

Exhibit B-17. Summary of Age-Group Specific Food Ingestion Rates for Farm Food Items

Product	Child (age in yr)					Adult (20–70 yrs)
	<1	1–2	3–5	6–11	12–19	
Water (mL/day)[c]	N/A	903	999	1499	2163	3087
99th percentile ingestion rates (g/kg-day)						
Beef[a]	N/A	20.9	19.8	13.3	4.28	6.84
Dairy[b]	N/A	180	87.2	54.8	34.7	9.20
Eggs[a]	N/A	16.2	11.2	8.19	4.77	1.83
Exposed Fruit[a]	N/A	25.2	32.5	15.7	5.9	13.0
Exposed Vegetable[a]	N/A	12.1	7.36	13.3	5.67	8.42
Pork[a]	N/A	8.71	9.74	6.61	4.29	3.87
Poultry[a]	N/A	9.63	10.24	6.12	4.60	4.93
Protected Fruit[a]	N/A	109	71.2	58.2	19.1	34.4
Protected Vegetable[a]	N/A	9.42	5.31	5.40	2.69	5.56
Root Vegetable[a]	N/A	10.4	4.73	7.47	5.13	7.57
Water (mL/day)[c]	N/A	1318	1592	2274	3467	4567

[a]Primary source for values was the 1987–1988 NFCS survey; compiled results are presented in Chapter 13 of 2011 Exposure Factors Handbook (EPA, 2011a). When data were unavailable for a particular age group, intake rate for all age groups was used multiplied by the age-specific ratio of intake based on national population intake rates from CSFII.
[b]Primary source for values was 1987–1988 NFCS survey, compiled results presented in Chapter 13 of 2011 Exposure Factors Handbook (EPA, 2011a). When data were unavailable for a particular age group, intake rate for all age groups was used multiplied by the age-specific ratio of intake based on national population intake rates from an NHANES 2003–2006 analysis in Chapter 11 of the Exposure Factors Handbook.
[c]Primary source for children less than 3 years of age was a Kahn and Stralka (2008) analysis of CSFII data, and from EPA's analysis of NHANES 2003–2006 data for children and adults greater than three. All data tables that were used and justifications for data sources are presented in Chapter 3 of the 2011 Exposure Factors' Handbook.
[d]Default ingestion rate percentile used in MIRC for Tier 1 assessments and chemical threshold calculations.

For children, EPA estimated food-specific IRs for four age categories (EPA 2011a): 1–2 years, 3–5 years, 6–11 years, and 12–19 years. Sample sizes were insufficient to distinguish IRs for children in different types of households; hence, for children, a single IR value represents both F and HG households for a given food type and age category (Exhibit B-17). For some food types and age categories, there were insufficient data for EPA to provide consumer-only intake rates (i.e., data set for the subpopulation consisted of fewer than 20 observations). The HHRAP methodology, Section 6.2.2.2, recommends a method by which to calculate the "missing" age-specific consumer-only ingestion rates, as explained below. Food-specific intake rates (IRs) for those child age groups and food items not included in Chapter 13 of the 2011 EFH, that is $IR_{age_group_x}$, were derived using the following information:

- Mean or percentile-specific consumer-only intake of the farm food item, as brought into the home, for the total NFCS survey population (from EFH Chapter 13) – IRCO_total;
- Mean or percentile-specific per capita intake of the food type from all sources, as consumed, for the specific child age group, from Chapter 3 of the CSFII Analysis of Food Intake Distributions (EPA 2003c) – IRPC, age_group_x; and
- Mean or percentile-specific per capita intake of the farm food item for the total CSFII survey population (from Chapter 3 of EPA 2003c) – IRPC_total.

The ratio of $IR_{PC,\ age_group_x}$ to IR_{PC_total} from the CSFII data shows the consumption rate of a particular food type by a specific age group relative to the consumption rate for that food type for the population as a whole. The ratio of $IR_{CO,\ age_group_x}$ to IR_{CO_total}, that is the consumption rate of a particular food type by a specific age group (consumers only) relative to the consumption rate for that food type for the NFCS survey population as a whole (consumers only), should be approximately the same. Given the assumption that the two ratios are equal, Equation B-56 was used to calculate the "missing" age-specific consumer-only *IRs*:

Equation B-56. Calculation of Age-Group-Specific and Food-Specific Ingestion Rates

$$IR_{CO,\ age_group_x} = \frac{IR_{CO_total} \times IR_{PC,\ age_group_x}}{IR_{PC_total}}$$

where:

$IR_{CO,\ age_group_x}$ = Mean or percentile-specific *consumer-only* intake of the food type from all sources, as consumed, for the specific child age group X

IR_{CO_total} = Mean or percentile-specific *consumer-only* intake of the farm food item, as brought into the home, for the <u>total</u> NFCS survey population

$IR_{PC,\ age_group_x}$ = Mean or percentile-specific *per capita* intake of the food type from all sources, as consumed, for the specific child age group X from the CSFII

IR_{PC_total} = Mean or percentile-specific *per capita* intake of the farm food item for the <u>total</u> CSFII survey population

In this discussion, *per capita* (as opposed to *consumer-only*) indicates the intake rates are based on the entire population rather than the subset of the population that ingests the particular food category (i.e., consumers). Here, the use of *per capita* ingestion rates is recommended by the HHRAP methodology because no consumer-only percentile-specific intakes are provided for the different age groups.

The above calculation implicitly assumes that the distribution of the consumption rate for a food type for a specific age group (consumers only) has the same shape as the distribution of the consumption rate for a food type for a specific age group in the general population (*per capita*). Otherwise, the separate calculation of each percentile might yield intake estimates that decrease as the percentile increases. This calculation artifact could occur if the shapes of the two distributions differ in the upper percentiles (or "tails") of the distributions.

In the instances where the above calculations were used to fill data gaps in the above exhibit, only the dairy child-specific age group intake estimates are not strictly increasing with increasing percentile. The distributions likely track better (and thus the above assumption of equal ratios is more reasonable) for lower percentiles, with deviations occurring due to outlier ingestion rates based on only a few respondents in the tails of the distributions. The MIRC defaults use the 90th percentile ingestion estimates, which are likely more reliable than the 95th or 99th percentile estimates in this particular calculation.

6.3.4. Local Fish Ingestion Rates

6.3.4.1. Screening Scenario

The USDA's 1987 to 1988 Nationwide Food Consumption Survey (NFCS) (USDA 1993, 1994a), as presented in Chapter 13 of the Agency's Exposure Factors Handbook (i.e., Intake Rates for

Various Home Produced Food Items) (EPA 2011a), includes family-caught fish ingestion rates by age category. There are several disadvantages, however, to using that data source to estimate fish ingestion rates. First, due to inadequate sample sizes, EPA did not report fish ingestion rates for children less than 6 years of age. Second, the NFCS data were collected more than two decades ago. Third, the reported fish ingestion rates are for ages 6 to 11 and 12 to 19 and are based on 29 and 21 individuals in each age category, respectively (EPA 2011a, Table 13-20). Finally, the ingestion rates from NFCS data are based on total weight of fish as brought into the home, and do not include losses from preparation of the fish (i.e., removal of inedible parts and, possibly, the skin). Estimates of preparation losses for fish intended to apply to the NFCS fish ingestion rate data are very uncertain and are based on a wide variety of freshwater, estuarine, and marine fish, and squid (EPA 2011a, Table 13-69). Additionally, when considering the multipathway screening methodology, it is important that potential health effects to those individuals who are most likely to have the greatest PB-HAP exposure are not underestimated and, therefore, ingestion rates that are reflective of subsistence fisher ingestion rates are desired. Therefore, a more recent survey was sought that included larger sample sizes, data for children younger than six years, ingestion rates for the parts of fish actually consumed, and ingestion rates reflective of subsistence fisher ingestion rates.

Taking all of these issues into consideration, the default adult fish ingestion rate selected for use in MIRC is 373 g/day, which is the estimated 99th percentile of fish ingestion rates for woman fishers as reported by Burger (2002). This rate is based upon ingestion of “wild-caught” fish, which includes freshwater, estuarine, and marine species, while our screening scenarios focus only on freshwater fish from lakes. This is notable because a number of studies indicate that fish ingestion rates are limited by species and habitat (i.e., lake, river, estuary, and ocean) and that the majority of the fish consumed in the United States are from river, marine and estuarine habitats versus lakes. Thus, although the fish ingestion rate for this group of subsistence fishers is not the highest fish ingestion rate available for use by EPA, we do believe it strikes the appropriate balance between being health protective and having screening scenarios so conservative that they are of limited use in the decision making process. This high-end fish ingestion rate is appropriate in the context of the conservative screening scenario used in the RTR process. This methodology is particularly applicable for national rulemakings given that it is very likely that subsistence woman fishers of child bearing age are located throughout the United States. Finally, we note that using a high-end subsistence fish ingestion rate is consistent with section 112 of the CAA, which focuses on risks associated with maximally exposed individuals.

Because Burger (2002) did not estimate fish ingestion rates for children, another data source was needed to develop ingestion rates for the child age categories that are used in MIRC. The child ingestion rates need to be consistent with the Burger adult ingestion rate, reflective of subsistence fisher ingestion rates, and based on adequate sample sizes. To satisfy these requirements, data on child ingestion rates from EPA’s *Estimated Per Capita Fish Consumption in the United States* (EPA 2002) were selected for use. Specifically, the estimated 99th percentile of *as-prepared*, *consumer-only* ingestion rates for finfish and shellfish were selected (see Section 4.2.1.1 Table 5 of EPA 2002).The original data were collected as part of the 1994–96 and 1998 USDA Continuing Survey of Intakes by Individuals (CSFII; USDA 2000). Values reflect “as prepared” ingestion rates for which cooking and preparation losses (*L1* and *L2*) did not need to be considered. “Total” fish as reported in this source represents consumption of finfish plus shellfish.

Because the child age categories used in MIRC differ from the CSFII age categories presented in EPA 2002, the CSFII data were adjusted for use in MIRC. The CSFII data did not provide ingestion rates for the 1–2 year age category. To estimate ingestion rates for this age group,

EPA used the ingestion rate for the 3–5 year age category scaled downward by the ratio of the mean body weight of the 1–2 year age group to the mean body weight of the 3–5 year age group. Because MIRC uses a 3–5 year age category, no adjustment was needed for CSFII data from that age category. For the 6–11 and 12–19 age categories, time-weighted average ingestion rates were calculated based on the CSFII ingestion rates. Exhibit B-18 provides the fish ingestion rates used in the screening assessment.

Exhibit B-18. Fish Ingestion Rates Used in Screening Assessment

	Ingestion Rates (g/day)					
	Infants <1 yr	**Child 1–2 yrs**	**Child 3–5 yrs**	**Child 6–11 yrs**	**Child 12–19 yrs**	**Adult 20–70 yrs**
	NA	107.7[a]	159.0[b]	268.2[c]	331.0[c]	373[d]

[a]A fish ingestion rate for ages 1-2 years was not available. The value represents the consumer-only fish ingestion rate for ages 3 to 5 from EPA (2002) (Section 4.2.1.1 Table 5 [freshwater/estuarine habitat]), scaled down by the ratio of the mean Child 1-2 body weight to the mean Child 3-5 body weight.
[b]This value represents the consumer-only fish ingestion rate for ages 3 to 5 from EPA (2002), Section 4.2.1.1 Table 5 (freshwater/estuarine habitat) rounded to the nearest full number.
[c]These values represent time-weighted average consumer-only fish ingestion rates based on ingestion rates from EPA (2002), Section 4.2.1.1 Table 5 (freshwater/estuarine habitat).
[d]This value represents the 99th percentile ingestion rate of wild caught fish for women as reported by Burger (2002).

6.3.4.2. Other Values Available in MIRC

EPA's (2002) analysis of freshwater and estuarine fish consumption from the USDA's Continuing Survey of Food Intake by Individuals (CSFII) for 1994-96 and 1998 was chosen to provide fish ingestion rate options by age category in MIRC. Although the fish consumption rates reported in the CSFII include all sources, commercial and self-caught, for purposes of screening level risk assessments, it was assumed that all freshwater and estuarine fish consumed are self-caught. The inclusion of commercially obtained and estuarine fish will overestimate locally caught freshwater fish ingestion rates for most populations in the United States; however, it also might underestimate locally caught fish ingestion rates for some populations (e.g., Native Americans, Asian and Pacific Island communities, rural African American communities). Because consumption of locally caught fish varies substantially from region to region in the United States and from one population or ethnic group to the next, users of MIRC are encouraged to use more locally relevant data whenever available.

For children, MIRC also includes values for the mean and the 90th, 95th, and 99th percentile fish *per-capita* ingestion rates (freshwater and estuarine fish only) based on EPA's analysis of 1994-96 and 1998 CSFII data (EPA 2002, 2008a). Those rates include individuals who eat fish and those who do not eat fish. As shown in EPA's 2008 CSEFH, Table 10-7, the 90th percentile *per capita* ingestion rates estimated from the two-day CSFII recall period are zero for some child age groups. Although not presented in CSEFH Table 10-7, median ingestion rates for all child age groups would be zero (considering the "consumer only" sample sizes [CSEFH Table 10-9] relative to the "*per-capita*" sample sizes in Table 10-7).

The high percentile fish ingestion rates that are zero result from the short duration of the CSFII recall period (two days) compared with the averaging time of interest (a year) and the relatively infrequent consumption of fish (e.g., on the order of once a week to once a month or less) compared with the near daily ingestion of other types of food products (e.g., dairy, produce, meat). Use of zero for fish ingestion rates, however, is not useful in MIRC. As a result, an alternative method was used to estimate fish ingestion rates for children and adults that could provide reasonable, non-zero values for all age groups and percentiles.

The alternative, age-group-specific fish ingestion rates were derived using values for each age group, *y*:

- Mean or other appropriate percentile consumer-only fish ingestion rates for age group *y*, IRCO,*y*, from EPA's Estimated Per Capita Fish Consumption in the United States (EPA 2002), Section 5.2.1.1, Table 5, for freshwater/estuarine habitat.[30]
- Fraction of the population consuming freshwater/estuarine fish, FPC,*y*, calculated as consumer-only sample size / U.S. population sample for age group *y*. The data to calculate those fractions are available in the 2008 CSEFH and EPA 2002.

Equation B-57 was used to calculate the alternative, *per capita* fish ingestion rates by age group ($IR_{PC,y}$):

Equation B-57. Calculation of Alternative Age-Group-Specific Fish Ingestion Rates

$$IR_{PC,y} = IR_{CO,y} \times F_{PC,y}$$

where:

$IR_{PC,y}$ = *Per capita* fish ingestion rate for age group *y* (g/day)

$IR_{CO,y}$ = *Consumer-only* fish ingestion rates for age group *y* (g/day) (EPA 2002, Section 5.2.1.1, Table 5, for freshwater/estuarine habitat)

$F_{PC,y}$ = Fraction of the population consuming freshwater/estuarine fish, calculated as consumer-only sample size / total U.S. population sample size for age group *y* (unitless) (2008 CSEFH, EPA 2002)

In the above, *per capita* (as opposed to *consumer-only*) indicates the intake rates are based on the entire population rather than the subset of the population that ingests the particular food category. Here, *per capita* ingestions are recommended by the HHRAP methodology because no consumer-only percentile-specific intakes are provided for the different age groups.

The mean and percentile consumer-only fish ingestion rates for children and adults and the fraction of the population consuming freshwater/estuarine fish used in calculating long-term *per capita* fish ingestion rates by age group are presented in Exhibit B-19 and Exhibit B-20. The mean and percentile *per capita* fish ingestion rates estimated using this methodology are summarized in Exhibit B-21 and are available in MIRC. The fish ingestion rates provided in Exhibit B-21 and included in MIRC are intended to represent the harvest and consumption of fish in surface waters in a hypothetical depositional area. For site-specific application of this tool, users should consider using more localized survey data to estimate more appropriate fish ingestion rates. The fishing season varies substantially across the United States by latitude, and fish consumption patterns also vary by type of water body (e.g., ponds, lakes, rivers, streams, estuaries, coastal marine), cultural heritage, and general geographic area. Therefore, use of more localized information is encouraged. Note that as indicated in Exhibit 16 and Exhibit 18, in developing the screening threshold emission rates, health protective fish ingestion rates for child and adult fish consumers that more closely represent exposures of a high-end recreational fisher were used.

[30]Most of these data also are provided in Table 10-9 of the CSEFH; the median values, however, are not presented in the CSEFH, and values for the mean and all other percentiles are slightly different due to rounding.

As noted in Section 6.4.3 of this attachment, if the user overwrites the fish IRs shown in Exhibit B-21 with fresh-weight as caught values (e.g., values obtained from a local creel survey), the user is advised to set non-zero values for the preparation and cooking loss factors L1 and L2 in Equation B-15. Suggested values are presented in Section 6.4.3.

Exhibit B-19. Daily Mean and Percentile *Consumer-Only* Fish Ingestion Rates for Children and Adults ($IR_{CO,y}$)[a]

Lifestage (years)	Ingestion Rates, All Fish (g/day)				
	Mean	50th	90th	95th	99th
Child <1	NA	NA	NA	NA	NA
Child 1-2[b]	27.31	15.61	64.46	87.60	138.76*
Child 3-5[c]	40.31	23.04	95.16	129.31	204.84*
Child 6-11[d]	61.49	28.46	156.86*	247.69*	385.64*
Child 12-19[e]	79.07	43.18	181.40*	211.15*	423.38*
Adult[f]	81.08	47.39	199.62*	278.91	505.65*

Sources: EPA 2002, 2008a

NA = not applicable; it is assumed that children < 1 year of age do not consume fish.

*Indicates that the sample size does not meet minimum reporting requirements as described in EPA 2002. Owing to the small sample sizes, these upper percentiles values are highly uncertain.

[a]*Per capita* fish ingestion (FI) rates for children by age group are available from Chapter 10 of the CSEFH (EPA 2008a); however, all 50th and some 90th percentile ingestion rates are zero. *Per capita* FI rates were therefore estimated as described in Equation B-57 to provide reasonable, non-zero values for all age groups and percentiles.

[b]A fish IR for ages 1-2 years was not available. The value represents the consumer-only fish ingestion rate for ages 3 to 5 from EPA (2002) (Section 5.2.1.1 Table 5 [freshwater/estuarine habitat]), scaled down by the ratio of the mean Child 1-2 body weight to the mean Child 3-5 body weight.

[c]These values represent the consumer-only fish ingestion rate for ages 3 to 5 from EPA (2002), Section 5.2.1.1 Table 5 (freshwater/estuarine habitat). Sample size = 442.

[d]These values represent the consumer-only fish ingestion rate for ages 6 to 10 from EPA (2002), Section 5.2.1.1 Table 5 (freshwater/estuarine habitat). Sample size = 147.

[e]These values represent the time-weighted average *per capita* fish ingestion rate for ages 11 to 15 and 16 to 17 years from EPA (2002), Section 5.1.1.1 Table 5 (freshwater/estuarine habitat); the value may underestimate ingestion rate for ages 12 to 19 years. Sample size = 135.

[f]These values represent the consumer-only fish ingestion rate for individuals 18 years and older from EPA (2002), Section 5.2.1.1 Table 4 (freshwater/estuarine habitat). Sample size = 1,633.

Exhibit B-20. Fraction of Population Consuming Freshwater/Estuarine Fish on a Single Day ($F_{PC,y}$)

Lifestage (years)	Fraction Consuming Fish
Child 3-5	0.0503[a]
Child 6-11	0.0440[b]
Child 12-19	0.0493[c]
Adult	0.08509[d]

Sources: EPA 2002, 2008a

[a]This value was calculated using the ages 3 to 5 sample size for consumers only divided by the sample size for the U.S. population divided by 2 to represent the proportion consuming fish on a single day (the consumers-only group includes individuals who consumed fish on at least one of two survey days) to match the one-day ingestion rate.

[b]As in footnote a, the value was calculated using the ages 6 to 10 sample size for consumers only divided by the sample size for U.S. population divided by 2.

[c]The value was calculated by summing the ages 11 to 15 and 16 to 17 sample sizes for consumers only and dividing by both by the sum of the sample sizes for U.S. population and by a factor of 2.

[d]The value was calculated using the ages 18 and older sample size for consumers only divided by the sample size for U.S. population from Section 5.1.1.1 Table 4. The result was divided by 2 to represent a one-day sampling period in order to match the one-day ingestion rate.

Exhibit B-21. Calculated Long-term Mean and Percentile *per capita* Fish Ingestion Rates for Children and Adults ($IR_{PC,y}$)

Lifestage (years)	Ingestion Rates, All Fish (g/day)				
	Mean	50th	90th	95th	99th
Child <1	NA	NA	NA	NA	NA
Child 1-2[a]	1.37	0.79	3.24	4.41	6.98
Child 3-5[b]	2.03	1.16	4.79	6.51	10.3
Child 6-11[c]	2.71	1.25	6.90	10.9	17.0
Child 12-19[d]	3.90	2.13	8.95	10.4	20.9
Adult[e]	6.90	4.03	16.99	23.73	43.02

Sources: EPA 2002, 2008a

NA = not applicable; it is assumed that children < 1 year of age do not consume fish.

[a]Values were calculated as (consumer-only IR for Child 1-2) x (fraction of population consuming fish for Child 3-5).

[b]Values were calculated as (consumer-only IR for Child 3-5) x (fraction of population consuming fish for Child 3-5).

[c]Values were calculated as (consumer-only IR for Child 6-11) x (fraction of population consuming fish for Child 6-11).

[d]Values were calculated as (consumer-only IR estimated for Child 12-19) x (fraction of population estimated to consume fish for Child 12-19).

[e]Values were calculated as (consumer-only IR for Adults) x (fraction of population consuming fish for Adults).

MIRC also includes values for the mean and the 90th percentile fish ingestion rates for recreational fishers, black and female recreational fishers, and fishers of Hispanic, Laotian, and Vietnamese descent which are shown in Exhibit B-22. These latter three populations are culturally or economically disposed to higher rates of fish ingestion than the general population. Recreational fisher values are from the EFH (EPA, 2011a). Black and female recreational fishers ingestion rates are presented in Burger (2002). The fish ingestion rates for Hispanic, Laotian, and Vietnamese populations were derived from a study by Shilling *et al*. (2010) of contaminated fish consumption in California's Central Valley Delta. Shilling *et al*. (2010) reported mean and 95th percentile ingestion rates for each subpopulation. In part due to the low sample size in the Shilling study (n of 30 to 45), 95th percentile values were believed to be unrealistically high. The 90th percentile ingestion rate estimates presented in Exhibit B-22 for Hispanic, Laotian, and Vietnamese fishers were derived by EPA using information from Shilling *et al*. (2010; EPA, 2010).

Exhibit B-22. Calculated Mean and 90th Percentile Per capita Fish Ingestion Rates for Populations of Recreational Fishers ($IR_{PC,y}$)

		Subpopulation					
Percentile	**Units**	**Recreational Fisher[a]**	**Female Recreational Fisher[b]**	**Black Recreational Fisher[b]**	**Hispanic Recreational Fisher[c]**	**Laotian Recreational Fisher[c]**	**Vietnamese Recreational Fisher[c]**
Ingestion of Fish							
Mean	g/day	8	39.1	171	25.8	47.2	27.1
90th	g/day	11	123	446	98	144.8	99.1

[a]1997 Exposure Factors Handbook (USEPA, 1997a)
[b]Burger (2002) weights are "as consumed" for locally caught fish.
[c]Shilling, F., A. White, L. Lippert, and M. Lubell. 2010. Contaminated fish consumption in California's Central Valley Delta. Environmental Research 110:334-344.

Applications to date of MIRC have used whole fish concentrations estimated by TRIM.FaTE. The proportion of lipid in TL3 and TL4 fish in TRIM.FaTE is assumed to be 5.7 percent (by weight) for the whole fish, based on information provided by Thomann (1989). The lipid content of the part(s) of the fish normally consumed is likely to be less than 5.7 percent. For example, EPA estimated a consumption-weighted mean lipid value for fillets of fish from TL3 to be 2.6 percent and from TL4 to be 3.0 percent (Table 6-9 in EPA 2003b). If a user of MIRC wishes to account for reduced chemical concentration in fillet compared with whole fish for lipophilic chemicals, the user can specify a "preparation" loss of chemical (see Section 6.4 of this attachment).

For lipophilic chemicals (e.g., log K_{ow} greater than 4), which partition primarily into the fatty tissues of fish, much of the higher concentration tissues might be stripped from the fish during preparation (e.g., belly fat, viscera which includes fat in liver, etc., fat under skin). The degree to which the concentration of chemical in a fillet is less than the average total concentration in the whole fish is chemical specific. Assuming the chemical concentration in the fillet is the same as in the whole fish may result in a health protective bias for highly lipophilic chemicals. For persons who prefer to consume fillets with the skin on and do not discard belly fat, assuming the same concentration of chemical in the fish consumed as in the whole fish also is protective.

6.3.5. Soil Ingestion Rates

Adult gardeners and farmers may incidentally ingest soils from gardening activities, and gardening and farming families might ingest soil particles that adhere to exposed fruits and exposed and belowground vegetables. Soils that are re-suspended in the air by wind can resettle on exposed fruits and vegetables. Children may incidentally ingest soils in those ways, but in addition, children playing outdoors may ingest soils directly or by hand-to-mouth activities during play. MIRC includes soil ingestion rate options by age group for these types of exposures. MIRC does not include options for children who may exhibit pica, or the recurrent ingestion of unusually high amounts of soil (i.e., on the order of 1,000 - 5,000 mg/day or more) (EPA 2008a).

Data on soil ingestion rates are sparse; the soil ingestion rates listed in Exhibit B-23 and included in MIRC are based on very limited data, as is evident from the values listed. The studies evaluated by EPA for children generally focused on children between the ages of 1 and 3 to 6 years and were not specific to families that garden or farm. The default ingestion rates in MIRC are the 90th percentile values, as for other ingestion rate parameters.

Exhibit B-23. Daily Mean and Percentile Soil Ingestion Rates for Children and Adults

Age Group (years)	Soil Ingestion Rate (mg/day)				
	Mean[a]	50th [a]	90th	95th	99th
Child < 1	NA				
Child 1-2	50	50	200[b]	200[b]	200[b]
Child 3-5	50	50	200[b]	200[b]	200[b]
Child 6-11	50	50	201[c]	331[d]	331[d]
Child 12-19	50	50	201[c]	331[d]	331[d]
Adult 20-70	20	20	201[c]	331[d]	331[d]

Sources: EPA 2008a, EPA 2011a
[a]For mean and 50th percentile soil ingestion rates for children, value represents a "central tendency" estimate from EPA's 2008 CSEFH, Table 5-1. For adults, value is the recommended mean value for adults from EPA's 2011 EFH, Chapter 5, Table 5-1.
[b]Values are the recommended "upper percentile" value for children from EPA's 2011 EFH, Chapter 4, Table 4-23. The 2008 CSEFH and 2011 EFH included a high-end value associated with pica only, but this value has not been used.
[c]Values are 90th percentile adult ingestion rates calculated in Stanek et al. 1997; used to represent older children and adults.
[d]Values are 95th percentile adult ingestion rates calculated in Stanek et al. 1997; used to represent older children and adults.

6.3.6. Total Food Ingestion Rates

Although not included in MIRC for deterministic screening-level exposure and risk assessments, total food ingestion rates would be included in any probabilistic module developed for MIRC. The total food ingestion rates presented in Exhibit B-24 will be used to normalize or to truncate the sum of food-specific ingestion rates to reasonable values. This procedure is particularly important when chemical intake from multiple upper-percentile food ingestion rates for different types of food are added together. Individuals representing the upper percentile ingestion rate for one food category might not be the same individuals who reported high percentile ingestion rates for one or any of the other food categories.

Exhibit B-24. Daily Mean and Percentile *Per Capita* Total Food Intake for Children and Adults

Lifestage (years)	Percent of Group Consuming Food	Mean	50th	90th	95th	99th
Total Food Intake (g/day, as consumed)						
Child < 1[a]	67.0% - 99.7% [h]	322	270	599	779	1152
Child 1-2[b]	100%	1,032	996	1537	1703	2143
Child 3-5[c]	100%	1,066	1,020	1,548	1,746	2,168
Child 6-11[d]	100%	1,118	1,052	1,642	1,825	2,218
Child 12-19[e]	100%	1,197	1,093	1,872	2,231	2,975
Adult[f]	100%	1,100	1,034	1,738	2,002	2,736
Total Food Intake (g/kg-day, as consumed)						
Child < 1[a]	67.0% - 99.7% [h]	39	34	72	95	147
Child 1-2[b]	100%	82	79	125	144	177
Child 3-5[c]	100%	61	57	91	102	132
Child 6-11[d]	100%	40	38	61	70	88
Child 12-19[e]	100%	21	19	34	40	51
Adult[g]	100%	14.8	13.9	23.7	27.6	35.5

Sources: EPA 2005e, 2008a

[a]These values represent a time-weighted average for age groups birth to <1 month (N=88), 1 to <3 months (N=245), 3 to <6 months (N=411), and 6 to <12 months (N=678) from Table 14-3 of the 2008 CSEFH.

These values represent a time-weighted average for age groups 1 to <2 years (N=1,002) and 2 to <3 years (N=994) from Table 14-3 of the 2008 CSEFH.

[c]These values were obtained from Table 14-3 of the 2008 CSEFH (age group 3 to <6 years, N=4,112).

[d]These values were obtained from Table 14-3 of the 2008 CSEFH (age group 6 to <11 years, N=1,553). These values represents a health protective (i.e., slightly low) estimate for ages 6 through 11 years since 11-year olds are not included in this CSEFH age group.

[e]These values represent a time-weighted average for age groups 11 to <16 years (N=975) and 16 to <21 (N=743) years from Table 14-3 of the 2008 CSEFH. Note that estimated values include 11-year-olds and individuals through age 20, which contributes to uncertainty in the estimates.

[f]These values represent a time-weighted average for age groups 20 to 39 years (N=2,950) and 40 to 69 years (N=4,818) from Table 5B of the 2005 EPA analysis of CSFII.

[g]These values represent a time-weighted average for age groups 20 to 39 years (N=2,950) and 40 to 69 years (N=4,818) from Table 5A of the 2005 EPA analysis of CSFII.

[h]Percents consuming foods from Table 14-3 of the 2008 CSEFH include: 67.0% (birth to <1 month); 74.7% (1 to <3 months); 93.7% (3 to <6 months); and 99.7% (6 to <12 months). Infants under the age of 1 that consume breast milk are classified as "non-consumers" of food.

6.4. Other Exposure Factor Values

The other exposure parameters included in the MIRC algorithms are exposure frequency (Section 6.4.1), fraction of the food type obtained from the contaminated area (Section 6.4.2), and reduction in the weight of the food types during preparation and cooking (Section 6.4.3). For the breast milk ingestion pathway, additional exposure parameters are included in the FFC algorithms (Section 6.5).

6.4.1. Exposure Frequency

The exposure frequency (EF) represents the number of days per year that an individual consumes home-produced food items that are contaminated with the chemical being evaluated. In MIRC, the default value for EF is 365 days/year for all exposure sources and all potential receptors. This assumption is consistent with the food ingestion rates used in MIRC (i.e., daily intake rates equivalent to annual totals divided by 365 days) and does not imply that residents necessarily consume home-produced food products every day of the year.

If the user wishes to evaluate daily intake rates based on shorter averaging times, the user can overwrite both the food-specific ingestion rates and the EF for each home-grown food product. Users of MIRC might want to specify a lower EF values for various food types where residents obtain some of their diet from commercial sources and where consumption of home grown produce is seasonal.

6.4.2. Fraction Contaminated

The fraction contaminated (FC) represents the fraction of each food product consumed that is contaminated by the chemical at a level consistent with environmental concentrations in the area of concern (e.g., area with maximum deposition rates). Obviously, the most health protective assumption is that all food products consumed (i.e., 100 percent) are from the location represented by the chemical concentrations input into MIRC.

For non-infant children and the adult age cohorts, MIRC includes the default FC of 1, assuming that 100 percent of the food product consumed is produced by households that farm, garden, or raise animals. The user can vary this default FC value for individual food products to tailor the assessment to a particular exposure scenario.

6.4.3. Preparation and Cooking Losses

Food preparation and cooking losses are included in the FFC exposure calculations to account for the amount of a food product as brought into the home that is not ingested due to loss during preparation, cooking, or post-cooking. These losses need to be accounted for in the ADD equations because the food ingestion rates calculated from the USDA 1987 to 1988 NFCS are based on the weight of home grown produce and animal products brought from the field into the house prior to any type of preparation. Not all of the produce or products were eventually ingested. In general, some parts of the produce and products are discarded during preparation while other parts might not be consumed even after cooking (e.g., bones). Thus, the actual food ingested is generally less than the amount brought into the home.

Three distinct types of preparation and cooking losses are included in the ingestion exposure algorithms in MIRC: (1) loss of parts of the food type from paring (i.e., removing the skin from vegetables and fruits) or other types of preparation (e.g., removing pits, coring, deboning), (2) additional loss of weight for the food type during cooking (e.g., evaporation of water), and (3) post-cooking losses (e.g., non-consumption of bones, draining cooking liquid [e.g., spinach]). MIRC includes mean values for these three types of preparation and cooking losses for exposed fruit, protected fruit, exposed vegetables, protected vegetables, root vegetables, beef, pork, poultry, and fish. Different types of losses apply to different types of foods. Therefore, the losses can be represented by only two parameters, *L1* and *L2*, the definitions of which vary according to the food type as explained in the endnotes in Exhibit B-25. All preparation and cooking loss parameter values were estimated as specified in the exhibit's endnotes from data presented in Chapter 13 of the EPA's 1997 and 2011 EFH (EPA 1997a and 2011a).

Exhibit B-25. Fraction Weight Losses from Preparation of Various Foods

Product	Mean Cooking, Paring, or Preparation Loss (Cooking Loss Type 1 [L1]) (unitless)[a]	Mean Net Post Cooking (Cooking Loss Type 2 [L2]) (unitless)[b]
Exposed Fruit[c]	0.244	0.305
Exposed Vegetable	0.162[d]	NA
Protected Fruit	0.29[e]	NA
Protected Vegetable	0.088[f]	NA
Root Vegetable[g]	0.075	0.22
Beef	0.27	0.24
Pork	0.28	0.36
Poultry	0.32	0.295[h]
Fish[i]	0.0	0.0

Source: EPA 1997a and 2011a
NA = Not Available
[a]For *fruits*, includes losses from draining cooked forms. For *vegetables*, includes losses due to paring, trimming, flowering the stalk, thawing, draining, scraping, shelling, slicing, husking, chopping, and dicing and gains from the addition of water, fat, or other ingredients. For *meats*, includes dripping and volatile losses during cooking.
[b]For *fruits*, includes losses from removal of skin or peel, core or pit, stems or caps, seeds and defects; may also include losses from removal of drained liquids from canned or frozen forms. For *vegetables*, includes losses from draining or removal of skin. For *meats*, includes losses from cutting, shrinkage, excess fat, bones, scraps, and juices.
[c]These values represent averages of means for all fruits with available data (except oranges) (Table 13-6).
[d]This value represents an average of means for all exposed vegetables with available data (Table 13-7). Exposed vegetables include asparagus, broccoli, cabbage, cucumber, lettuce, okra, peppers, snap beans, and tomatoes.
[e]This value was set equal to the value for oranges (Table 13-6).
[f]This value represents an average of means for all protected vegetables with available data (Table 13-7). Protected vegetables include pumpkin, corn, peas, and lima beans.
[g]These values represent averages of means for all root vegetables with available data (Table 13-7). Root vegetables include beets, carrots, onions, and potatoes.
[h]This value represents an average of means for chicken and turkey (Table 13-5).
[i]If the user changes fish ingestion rates to match a survey of the whole weight of fish brought into the home from the field (divided by the consumers of the fish), an appropriate value for L1 would be 0.31 and an appropriate L2 would be 0.11 (EPA 2011a).

There are substantial uncertainties associated with the L1 and L2 parameters, including the wide variation in values across produce types that were averaged together to recommend a central tendency value for each. For example, the L2 factor does not distinguish between weight loss during cooking by water evaporation, which might leave the chemical in the food (chemical not lost), and pouring the cooking liquid down the drain (chemical lost) or using the liquid to create a sauce (chemical not lost). In addition, the concentration of chemical might be highest in the skin, which often is discarded, and lower in the consumed portion of many bulky fruits and vegetables. Finally, the data EPA used to evaluate L1 included negative losses (i.e., weight gains) due to hydration of dried vegetables (e.g., peas and lima beans), which increases the range of L1 values across different vegetables.

Note that the default L1 and L2 values for fish are set to zero. That is because the data source for the fish ingestion rates is not the USDA's 1987 to 1988 NFCS (USDA 1993, 1994a) as reported in EPA's EFH, which reported food as brought into the home, as is the case for the other food categories. Instead, the fish IR data included in MIRC are based on parts actually consumed, and so no loss processes for preparation are needed.

If the user manually changes fish ingestion rates to match a local survey of the whole weight of fish brought into the home from the field (divided by number of persons consuming the fish), the user should also set the L1 and L2 parameter to non-zero values.

6.4.4. Food Preparation/Cooking Adjustment Factor (FPCAF) for Fish

In addition to estimating the weight of the food that is lost to preparation and cooking, there also can be changes in the chemical concentrations due to cooking. Because the fish consumption rates are “as consumed” and the fish concentration is based on uncooked fish, adjustments should be made to reflect the chemical concentrations in fish after cooking. In order to account for this phenomenon, an FPCAF can be applied to the uncooked fish concentration to estimate a concentration in cooked fish. The following sections discuss FPCAFs for each of the 4 PB-HAPs.

6.4.4.1. Mercury

In the U.S. EPA Revised Technical Support Document: National-Scale Assessment of Mercury Risk to Populations with High Consumption of Self-caught Freshwater Fish (EPA 2011b), a food preparation/cooking adjustment factor (FPCAF) of 1.5 was used to adjust methyl-mercury (MeHg) concentrations in consumed fish (i.e., a 50% increase in MeHg concentration due to cooking). Cooking fish typically increases MeHg levels per unit fish (as consumed) because MeHg concentrates in the muscle, while preparation involves removal primarily of non-muscle elements of the fish. The value is based on a study by Morgan et al. (1997).

6.4.4.2. Cadmium

Similar to mercury, cadmium will bind to muscle and will be retained during the cooking process. As such, the same FPCAF of 1.5 that is used for mercury is assumed for cadmium.

6.4.4.3. Dioxin

Dioxins are lipophilic and have been demonstrated to be lost during cooking. Based on a literature review, an FPCAF of 0.7 to is applied to account for these losses during the cooking process. A brief summary of supporting literature follows.

- Schecter et al. (1998) found that the mass of PCDD and PCDF in fresh catfish fillet (skin on) decreased by about 50 percent per serving portion during cooking. Given the simultaneous losses of moisture/fats during broiling of the catfish, the PCDDs and PCDFs concentrations decreased by 33 percent (i.e., multiply uncooked concentration in fresh fish by a factor of 0.66 = 0.70 to one significant digit).
- Reinert et al. (1972) reported higher losses of another highly lipophilic chemical, DDT, from cooking fish fillets of bloaters, yellow perch, lake trout, and coho salmon. Concentrations of DDT in fish fillet portions for lake trout and coho salmon, top predators, were reduced by 64 to 72 percent by frying or broiling, primarily through preferential loss of fat (and lipophilic DDT) during cooking. The investigators did not report skin on or off; however, they used steak cuts instead of flat fillets, which provide a smaller ratio of skin to muscle than is the case for fillets that constitute one side of the fish.
- Zabik and Zabik (1995) quantified the reduction in TCDD concentration of cooked, with the skin off, fillets compared with uncooked fillet with skin for fish harvested from the Great Lakes. Concentrations in the cooked fish with the skin off were reduced relative to the raw fillet with the skin on by approximately 44 percent for walleye, 80 percent for white bass, and 61 percent for lake trout. Comparing losses of TCDD for fillets cooked with the skin on versus fillets that were both skinned and cooked, Zabik and Zabik (1995) found reductions in TCDD concentrations of approximately 43 percent for Chinook Salmon cooked with the skin on and 57 percent for chinook salmon cooked with

the skin off. They found a 37 percent reduction of TCDD concentration for carp fillets cooked with the skin on and 54 percent reduction if the skin was removed.

The three studies listed above indicate that the 0.7 factor is not likely to overestimate loss of PCDD/PCDFs from fish during cooking (pan frying, broiling, grilling). Reductions in TCDD concentrations could be much higher with skin removal and trimming of fat.

6.4.4.4. PAHs

While it is reasonable to assume that there might be losses of lipophilic PAHs during the cooking process, there is insufficient information to distinguish what the net loss (or gain) during cooking might be because cooking can create PAHs from proteins in the tissue. The literature acknowledges these competing forces, but does not provide information to disentangle the gain and loss mechanisms. As such, a neutral approach was taken, which is to assume an adjustment factor of 1.0 (i.e., no adjustment) for PAHs.

6.5. Breast-Milk Infant Exposure Pathway Parameter Values

Values used for parameters in the breast-milk exposure pathway algorithms (see Section 3.4 of this attachment) can be scenario-specific, receptor-specific, and/or chemical-specific and might be empirically derived or estimated by an appropriate model. For parameters that are scenario-specific or for which empirical values are required, the default values provided in MIRC are listed. For parameters for which MIRC calculates values, the appropriate equation is listed. Scenario- and receptor-specific parameters are discussed in Section 6.5.1 and chemical-specific parameters are discussed in Section 6.5.2.

6.5.1. Receptor-specific Parameters

Receptor-specific values are needed for parameters that describe the characteristics or activities of the exposed individual. In this context, there are two relevant receptors: the mother and the infant. Exhibit B-26 lists the parameters and their default values. The text that follows describes the input value or value options for each exposure parameter required by MIRC to calculate the infant absorbed chemical intake rate, or DAI_{inf}. For parameter values that can be estimated when empirical values are not available, see the equation description in Section 3.4 of this attachment.

Exhibit B-26. Scenario- and Receptor-Specific Input Parameter Values Used to Estimate Infant Exposures via Breast Milk

Parameter	Description	Default Value
AT	Averaging time for infant's exposure via breast milk, i.e., duration of nursing (days)	=ED
BW_{inf}	Body weight of infant (kg) averaged over duration of nursing exposure	7.8
BW_{mat}	Body weight of mother (kg) averaged over duration of mother's exposure	66
DAI_{mat}	Daily absorbed intake of chemical by mother (mg/kg-day)	Equation B-36
ED	Exposure duration for infant, i.e., duration of breast feeding (days)	=AT
AT/ED	Averaging time divided by exposure duration	1.0
f_{bp}	Fraction of mother's whole blood that is plasma (unitless)	0.65
f_{fm}	Fraction of mother's body weight that is fat (unitless)	0.30
f_{mbm}	Fraction of fat in mother's breast milk (unitless)	0.04
f_{pm}	Fraction of mother's body weight that is plasma (unitless)	0.046
IR_{milk}	Mean infant milk ingestion rate over duration of nursing (kg/day)	0.709
t_{bf}	Duration of breast feeding (days)	365
t_{pn}	Duration of maternal chemical exposure prior to nursing (days)	3285

Averaging time (*AT*) and exposure duration (*ED*). AT refers to the time over which the infant's exposure to the chemical of concern is averaged. *ED* refers to the duration of the infant's exposure. For the exposure scenario considered for this age group, both *AT* and *ED* equal the duration of the nursing period, and they therefore cancel each other out in the infant average daily dose equation.

Infant body weight (BW_{inf}). The user selects a value for BW_{inf}, the time-weighted average body weight of the infant over the entire duration of breast feeding, based on the age at which the infant stops breast feeding. For example, if the infant breast feeds for one year, the user should select the body weight for an infant that is averaged from birth to the first birthday. Similarly, if an infant breast feeds for 6 months, the user should select the body weight for an infant that is averaged from birth to six months. Because the default breast feeding duration (t_{bf}) is one year (i.e., 365 days), the default infant body weight is 7.8 kg, which is the time-weighted average for the mean infant body weight between birth and the first birthday from EPA's 2008 *Child Specific Exposure Factors Handbook* (CSEFH; EPA 2008a). Exhibit B-27 presents additional values for the infant body weight parameter that the user can select instead of the MIRC default.

Exhibit B-27. Average Body Weight for Infants

Statistic	0 to < 6 months (kg)	0 to < 12 months (kg)	0 to < 18 months (kg)	0 to < 24 months (kg)
Mean	6.5	7.8[a]	9.0	9.6
5th percentile	5.0	6.0	7.0	7.5
10th percentile	5.3	6.4	7.4	7.8
15th percentile	5.5	6.7	7.7	8.2
25th percentile	5.8	7.0	8.1	8.7
50th percentile	6.4	7.8	8.9	9.5
75th percentile	7.1	8.6	9.9	10.5
85th percentile	7.4	9.0	10.3	11.0

Exhibit B-27. Average Body Weight for Infants

Statistic	0 to < 6 months (kg)	0 to < 12 months (kg)	0 to < 18 months (kg)	0 to < 24 months (kg)
Mean	6.5	7.8[a]	9.0	9.6
90th percentile	7.7	9.2	10.6	11.3
95th percentile	8.0	9.7	11.1	11.8

Source: EPA (2008a); each value is the time-weighted average from the data summaries presented in the CSEFH, Table 8-3.
[a]MIRC default

Maternal body weight (BW_{mat}). This parameter represents the body weight of the mother averaged over the entire duration of the mother's exposure to the chemical of concern. The maternal body weight is needed to calculate the biological elimination constant for the lipophilic chemical in lactating women (k_{fat_elac}). MIRC assumes that the mother will be pregnant for 9 months (i.e., 0.75 year) and will be lactating for 1 year. The MIRC default maternal body weight also assumes that the mother has been exposed for 10 years total. For 8.25 years, she is not pregnant or lactating, for 0.75 year she is pregnant, and for 1 year she is lactating. The MIRC default BW_{mat} of 66 kg is based on CSFII data compiled by EPA for non-lactating and non-pregnant women between the ages of 15 and 44 (i.e., women of child-bearing age), lactating women, and pregnant women (EPA 2004). Exhibit B-28 presents additional values for the maternal body weight parameter which the user may choose to use instead of the MIRC default. The BW_{mat} value is *not* the value that MIRC uses to estimate the mother's absorbed daily intake (DAI_{mat}). The daily ingestion rates for home-grown/raised food products in MIRC are for men and women combined, with the rates normalized to body weight. The ingestion rates for soil, water, and fish included in MIRC are not normalized to body weight but are based on both men and women. For those ingestion rates, MIRC uses an average body weight value for males and females to estimate the average daily dose (intake) of the chemical in mg/kg-day. These values are subject to the assumption that the body-weight normalized ingestion rates and resulting ADD values are applicable to nursing mothers.

Exhibit B-28. Time-weighted Average Body Weight for Mothers

Statistic	Weight (kg)
Mean	66.0[a]
5th	47.1
10th	50.2
25th	54.3
50th	62.0
75th	72.0
90th	85.7
95th	97.0

Source: EPA 2004
[a]MIRC default value

Exposure duration (*ED*). See discussion of *AT* and *ED* above.

Fraction of mother's whole blood that is plasma (f_{bp}). Steinbeck (1954) reported that plasma volume accounts for approximately 60 percent of the total blood volume in non-lactating human females (EPA 1998). Harrison (1967) and Ueland (1976) reported plasma volumes between 63 to 70 percent in postpartum women (EPA 1998). The default value in MIRC of 65 percent (0.65)

is the value recommended by EPA in its *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (MPE, EPA 1998).

Fraction of mother's body weight that is fat (f_{fm}). A limitation of using a steady-state, instead of a dynamic partitioning, model for lactational transfer of chemicals is that several key parameters change over the course of exposure. For example, Equation B-38, used to estimate the concentration of a lipophilic chemical in breast milk fat, assumes that the mother's body fat will remain constant over the entire duration of breast feeding (t_{bf}), which is unlikely to be true (EPA 2001a). Another limitation of the single analytic model is that chemical transfer rates from blood to milk are unlikely to be the same as the rate of mobilization of the chemical from fat stores to the blood (EPA 2001a). Studies cited in ATSDR's toxicological profile for chlorinated dibenzo-p-dioxins show a correlation between percent body fat and the elimination rate of dioxins, with longer half-lives for dioxins in individuals with a higher proportion of fat in their bodies (ATSDR 1998). In the context of a screening model, however, EPA recommends a default value for the fraction of a mother's body comprised of fat of 0.3 based on data and discussions presented by Smith (1987) and Sullivan *et al*. (1991) (EPA 1998). A fraction of 0.3 indicates that 30 percent of the mother's body weight is fat, which is a health protective value (EPA 2001a). To establish a health protective screening scenario, the MIRC default value for f_{fm} is 0.30**.**

Fraction of fat in mother's breast milk (f_{mbm}). The $C_{milkfat}$ model (Equation B-38) assumes that a constant fraction of breast milk is fat, even though there is evidence that indicates variation in the fat content of breast milk throughout lactation (Sim and McNeil 1992). Different studies suggest a fat content of breast milk in humans of between 1 and 5 percent (Jensen 1987, Schecter *et al*. 1994, Hong *et al*. 1994, McLachlan 1993, Bates *et al*. 1994, NAS 1991, Butte *et al*. 1984, Maxwell and Burmaster 1993, EPA 2011a, Smith 1987, Sullivan *et al*. 1991). The MIRC default value for f_{mbm} of 0.04 (i.e., 4 percent) is the value EPA recommended for MPE (EPA 1998).

Fraction of maternal weight that is plasma (f_{pm}). Altmann and Dittmer (1964) estimated that plasma volume for adult women ranged from 37 to 60 mL/kg of body weight and averaged about 45 mL/kg. Ueland (1976) observed that the average plasma volume of women 6 weeks postpartum was 45 mL/kg of body weight. Using a value of 1.026 for the specific gravity of plasma from Conley (1974), EPA estimated a value of 0.046 for the fraction of maternal weight that is plasma (EPA 1998). The MIRC default for f_{pm} therefore is 0.046.

Infant breast milk ingestion rate (IR_{milk}). Milk ingestion rates vary with several factors, including the age and size of the infant and use of other foods such as formula. Based on its review of a several studies, EPA recommended time-weighted average and upper percentile milk ingestion rates for infants that nurse for six and for twelve months (EPA 2011a, Table 15-3). To estimate an "average" value, EPA first estimated study-sample-size weighted average values for 1 through 12 months of age and then developed time-weighted average milk ingestion rates from those (EPA 2011a). EPA estimated an upper percentile (upper bound) value as the mean plus two standard deviations. MIRC converts the ingestion rates measured volumetrically (mL/day) to mass-based estimates (kg/day) assuming the density of human milk to be 1.03 g/mL (reported by NAS 1991 and recommended by EPA 2011a). The resulting values are shown in the first two rows of Exhibit B-29. The MIRC screening-level default of 980 mL/day is an upper-bound estimate based on a one-year nursing period.

Exhibit B-29 also includes the recommended values for four non-overlapping age categories from the CSEFH (EPA 2008a, Table 15-1). The values demonstrate that although infants grow substantially from birth to one year of age, the "upper bound" estimates of their milk ingestion rates are very close to 1 liter per day at all stages of development in the first year.

Exhibit B-29. Infant Breast Milk Intake Rates

Age Category	Average (mL/d)	Average (kg/d)	"Upper Bound" (mL/d)	"Upper Bound" (kg/d)	Reference
1 to 6 months	742	0.764	1,033	1.064	EPA 2011a[†]
0 to < 12 months	688	0.709	980[a]	1.01[a]	EPA 2011a[†]
0 to < 1 month	510	0.525	950	0.979	EPA 2008a[††]
1 to < 3 months	690	0.711	980	1.01	EPA 2008a[†]
3 to < 6 months	770	0.793	1,000	1.03	EPA 2008a[†]
6 to < 12 months	620	0.639	1,000	1.03	EPA 2008a[†]

[a]MIRC default; [†] Based on review of multiple studies; [††] Based on a single study

Duration of breast feeding (t_{bf}). This parameter is equal to the infant's exposure duration (*ED*) and the infant's averaging time (*AT*). In its MPE Methodology, EPA asserts a health protective value for the duration of breast feeding of 1 year (i.e., 365 days) and a central tendency estimate of 6 months (180 days) (EPA 1998). Reviewers of MPE noted that 365 days may be overly health protective, given that only 20 percent of infants are breast fed for 6 months, at which point alternative foods are introduced, at least in addition to breast milk (EPA 2001a). Nonetheless, to establish a health protective screening scenario, the MIRC default for t_{bf} is 365 days.

Duration of the mother's exposure to the chemical of concern prior to nursing (t_{pn}). The model shown as Equation B-38 includes this parameter to reduce the over-estimate of chemical concentration in milk fat that occurs if the model is applied to a chemical with a long biological half-life (e.g., many years). The factor is needed for applications of the model to scenarios with a brief exposure duration (e.g., beginning a few months prior to the start of nursing) relative to the chemical half-life. As the duration of an exposure scenario increases to meet and exceed the chemical half-life, however, the overestimate that occurs without this parameter is reduced. For example, assume a chemical biological half-life of 8 years and a nursing period of 1 year. If exposure of the mother starts at the beginning of nursing, using Equation B-38 without the t_{pn} term results in an over-estimate of the concentration of the chemical in breast milk by a factor of 28.1 compared with the prediction using Equation B-38 with the t_{pn} term (EPA 1998, Table 9-6). However, at longer pre-natal exposures of the mother, the magnitude of the over-estimate is reduced: for a 10-year exposure, the magnitude of the overestimate without the t_{pn} term is 2.28, and for a 30-year exposure, the overestimate is reduced to 1.39.

For purposes of the screening-level assessment, we assume an exposure duration equal to the MIRC default half-life for dioxins, or 10 years. Only 3,285 days of that period are pre-natal (i.e., 3650 minus 365 days, assuming 1 year lactation period). Although longer exposure periods are possible for the screening scenario, there is sufficient uncertainty in the model to merit accepting a health protective bias for this parameter value.

6.5.2. Chemical-Specific Parameter Values

The chemical-specific parameters in the breast-milk pathway in MIRC are listed in Exhibit B-30. Note that the parameters for which values are needed are different for the lipophilic chemicals (i.e., dioxins), for which lactational transfer is assumed to occur via milk fat, and inorganic chemicals, for which the transfer is assumed to occur via the aqueous phase of breast milk (i.e., mercury). All dioxin congeners were assumed to manifest identical values as TCDD in regard to breast milk-related parameters.

Exhibit B-30. Chemical-specific Input Parameter Values for Breast Milk Exposure Pathway

Parameter and Description		2,3,7,8-TCDD	MeHg
AE_{inf}	Infant absorption efficiency of the chemical by the oral route of exposure (i.e., fraction of ingested chemical that is absorbed by the infant; unitless)	1.0 (default)	1.0 (default)
AE_{mat}	Maternal absorption efficiency of the chemical by the oral route of exposure (i.e., fraction of ingested chemical that is absorbed by the mother; unitless)	1.0 (default)	1.0 (default)
f_{bl}	Fraction of steady-state total body burden of hydrophilic chemical in mother that is in the mother's whole blood compartment (unitless)	NA	0.059 (Kershaw *et al*. 1980)[a]
f_f	Fraction of steady-state lipophilic chemical body burden in mother that is stored in body fat (unitless)	≥0.90 (ATSDR 1992)	NA
f_{pl}	Fraction of steady-state total hydrophilic chemical body burden in mother that is in the blood plasma compartment (unitless)	NA	Not yet identified[b]
h	Biological half-life for chemical in non-lactating women (days)	3650 (EPA 1994c)	50 (Sherlock *et al*. 1984)
k_{aq_elac}	Rate constant for total elimination of hydrophilic chemicals by lactating women (per day)	NA	= k_{elim}
k_{elim}	Rate constant for elimination of chemical for non-lactating women (per day; related to chemical half-life)	1.9E-04[b]	1.4E-02 [c]
k_{fat_elac}	Rate constant for total elimination of lipophilic chemicals by lactating women (per day)	Est. using Equation B-41	NA
Pc_{bm}	Partition coefficient for hydrophilic chemical between maternal *blood plasma* and aqueous phase of breast milk (g milk/g plasma; model assumption)	NA	1.0 (model assumption)
Pc_{RBC}	Partition coefficient for hydrophilic or protein-bound chemical between *red blood cells* (RBC) and *plasma* in maternal blood (mL whole blood/mL RBC)	NA	40 (Hollins *et al*. 1975)

NA = not applicable. ND = not yet determined from literature.
[a]This value is based on a single-dose study and may not be appropriate for a chronic exposure model.
[b]An empirical value for this variable is currently missing for application of model.
[c]This value was calculated from biological half-life (*h*) using Equation B-40.

Absorption efficiency of the chemical by the oral route of exposure for the infant (AE_{inf}). The models included in MIRC assume that the AE_{inf} from the lipid phase of breast milk is equal to the AE_{inf} from the aqueous phase of the milk. Reviewers of the model stated that this assumption may not be valid and that ideally, the equation DAI_{inf} would include variables for the AE_{inf} from the breast milk fat and the AE_{inf} from the aqueous phase of breast milk (EPA 2001a). However, since the MIRC assumption is that chemicals will partition to either the lipid or aqueous phase of milk, it is not necessary at this time to have multiple AE_{inf} values for a given chemical. If data on the AE from the mother or an adult but not for the infant are available, data for the adult may be used for AE_{inf}. Reviewers also recommended that chemical-specific values come from studies that account for absorption of the chemical from milk, because absorption from other matrices (e.g., solid foods) may not be relevant (EPA 2001a). If chemical-specific data are not available

for adults or infants, a health protective default value for AE_{inf} for a screening level assessment is 1.0, which assumes 100 percent absorption (EPA 1998).

The default value for AE_{inf} in MIRC for both MeHg and dioxin is 1.0. For ingested lipophilic chemicals, it is reasonable to assume that absorption will be high (EPA 2004c). ATSDR (1998) reported that dioxins are well absorbed by the oral route of exposure, with one human experiment indicating more than 86 percent absorption. It is EPA policy to assume 100 percent absorption for chemicals with reported *AEs* of 50 percent or higher (EPA 2004c). MeHg also is well absorbed, with measured values as high as 95 percent, and so a value of 100 percent is used in MIRC (EPA 2001b).

Absorption efficiency of the chemical by the oral route of exposure for the mother (AE_{mat}). The default value for both dioxins and MeHg is 1.0, as described in the previous paragraph.

Fraction of total maternal chemical body burden that is in the whole blood (f_{bl}). The default value for MeHg in MIRC, 0.059, is from Kershaw *et al*. (1980), which reported kinetics of blood deposition and clearance of MeHg in humans. Individuals consumed one meal of fish that contained between 18 and 22 µg Hg/kg body weight. The fraction of the dose deposited in the blood volume after mercury was fully distributed in tissues was 5.9 percent or 0.059. This study used a single-dose and thus may not be appropriate for a chronic exposure analysis.

Fraction of total maternal chemical body burden that is in body fat (f_f). Based on ATSDR's *Toxicological Profile for Selected PCBs* (ATSDR 1992) and Sullivan *et al*. (1991), EPA concluded that the "fraction of ingested contaminant stored in fat may be >90%" for lipophilic chemicals such as PCBs and dioxins (EPA 1998). This statement was interpreted to mean that 90 percent of the maternal body burden of chemical at "steady state" is located in body fat for dioxins at steady state.

Fraction of total maternal chemical body burden that is in blood plasma (f_{pl}). For hydrophilic chemicals, this parameter represents the steady-state fraction of the total chemical in the body that is circulating in the blood plasma. Values for f_{pl} may be available for some chemicals in the scientific literature. No value for this parameter for methyl mercury has been identified from the literature at this time. A value can be calculated using Equation B-43. However, this equation requires a reliable value for f_{bl}, and the value found for mercury may not be appropriate for a chronic exposure analysis (see above).

Chemical half-life in non-lactating women (*h*). In general, highly lipophilic chemicals tend to have relatively long biological half-lives. EPA estimates that the half-life for dioxins is between 7 and 10 years (EPA 1994a). ATSDR estimates that the half-life for 2,3,7,8-TCDD in particular may be as long as 12 years (ATSDR 1998). To establish a health protective screening scenario, the MIRC default half-life for dioxins is set to 10 years or 3650 days.

The half-life for methylmercury is on the order of weeks, not years. Greenwood *et al*. (1978) measured blood clearance rates for MeHg in lactating Iraqi women exposed accidentally to MeHg via bread prepared from wheat treated with a fungicide that contained MeHg. The data indicated a mean half-life for MeHg of approximately 42 days. Sherlock *et al*. (1984) reported an average measured half-life for MeHg of 50 days with a range of 42-70 days. The MIRC default for MeHg is set to the longer average half-life of 50 days.

Chemical elimination rate constant for lactating women – aqueous (k_{aq_elac}). The parameter k_{aq_elac} is equal to k_{elim} plus the loss rate for the chemical in the aqueous phase of breast-milk during lactation. EPA has yet to propose a term for the additional elimination of a chemical in the aqueous phase of milk from breast feeding. In the absence of empirical values, a

reasonable assumption for water soluble chemicals is that k_{aq_elac} is equal to k_{elim} as discussed for Equation B-43. The extent to which k_{elim} is an underestimate of k_{aq_elac} for a given chemical will determine the extent of health protective bias in k_{aq_elac}.

Chemical elimination rate constant for non-lactating women (k_{elim}). Although values for this parameter often are reported directly in the literature, MIRC estimates k_{elim} from chemical half-life assuming first-order kinetics as shown in Equation B-40. For example, for a biological half-life of 3,650 days for dioxins, k_{elim} is estimated to be 1.9E-04 per day. Assuming a biological half-life of 50 days for MeHg, the value for k_{elim} is estimated to be 0.014 per day.

Rate constant for total elimination of lipophilic chemicals by lactating women (k_{fat_elac}). Although values for this parameter might be found in the scientific literature for some chemicals, in MIRC, k_{fat_elac} for dioxins is calculated from Equation B-41. When the parameters in that equation are set to the default values in MIRC for dioxins, MIRC estimates a value of 0.0015 per day for k_{fat_elac}.

Partition coefficient for chemical between maternal blood plasma and aqueous phase of breast milk (Pc_{bm}). The aqueous model, presented in Equation B-42, assumes that the concentrations in the plasma and aqueous phase of breast milk are directly proportional (EPA 1998). Therefore, the default value for this parameter for MeHg in MIRC is 1.0.

Partition coefficient for chemical between red blood cells and plasma in maternal blood (Pc_{RBC}). Chemical-specific values for this parameter should be located in the scientific literature. If chemical-specific values are unavailable and it is assumed that there is equal distribution of the chemical in the plasma and red blood cells, EPA suggests a default value of 1.0 (EPA 1998). For MeHg, MIRC includes a value of 40 based on Hollins *et al*. (1975) study of cats exposed to MeHg, which reported a ratio of radio-labeled mercury in red blood cells to plasma of 97.7 to 2.3 (i.e., ratio of 42.5).

7. Summary of MIRC Default Exposure Parameter Settings

The default settings included in MIRC are intended to be characteristic of a health protective (but plausible) exposure scenario that results in a negligible or extremely low chance of underestimating risk. These default parameter values were used to derive the screening threshold emission rates used for screening emissions of PB-HAPs from sources included in RTR risk assessments. These values are the default, or initial setting, for parameter values in MIRC as described in Section 6 of this attachment. This section summarizes the default parameter values used to calculate screening thresholds.

This chapter is organized to present the chemical- and scenario-specific inputs to MIRC by data type. The screening-level analysis uses 90th percentile ingestion rates for soil, breast milk, and farm food items and 99th percentile ingestion rates for fish (presented in Section 7.1) and population-specific characteristic assumptions (presented in Section 7.2), that are generally health protective in nature. Screening thresholds were derived for five RTR chemical species: benzo(a)pyrene, cadmium, mercuric chloride, methyl mercury, and 2,3,7,8-TCDD; Section 7.3 presents chemical-specific parameter inputs for these five chemicals. Finally, Section 7.4 presents default parameter values for the nursing infant exposure scenario, which applied only to dioxin and methyl mercury as discussed in Section 3.4.

7.1. Default Ingestion Rates

The screening-level (or default) values for ingestion rates for soil, breast milk, and for each farm food item are equal to the 90th percentile of the distribution of national data for that ingestion

medium. In general, these values were obtained from the 2011 Exposure Factors Handbook or the 2008 Child-Specific Exposure Factors Handbook (see Exhibit B-31). Fish ingestion rates are also available from these sources; however, as described in Section 6.3.4, these sources were not used to obtain fish ingestion rates.

7.1.1. Fish Ingestion Rates

The adult fish ingestion rate was obtained from Burger (2002), a study that examined daily consumption of wild-caught fish for high-end recreationalists (white, black and female) in South Carolina. For female high-end consumers of wild-caught fish, Burger identified average and higher-percentile consumption rates as follows: 39.1 g/day (mean), 123 g/day (90th percentile), 172 g/day (95th percentile), and 373 g/day (99th percentile). As shown in Exhibit B-31 and discussed in Section 6.3.4, for adults, the rate of fish ingestion assumed in the screening scenario is 373 g/day, which corresponds to the 99th percentile value estimated by Burger for adult females. This value was selected to be representative of subsistence fishers.

For the child age groups, as discussed in Section 6.3.4, the baseline fish ingestion rates for the screening scenario are based on “as prepared” total freshwater/estuarine fish ingestion rates at the 99th percentile of the distribution for the *consumer-only* population (i.e., inclusive only of people who consume fish, rather than per-capita rates, which include both consumers and non-consumers), as estimated in EPA (2002), Section 4.2.1.1. Some adjustments were necessary because the age groups evaluated for RTR (which correspond to the age groups for which farm food ingestion rates are available) do not all directly correspond to the age groups in the EPA (2002) report. As described in Section 6.3.4, these adjustments convert the available age-specific data on fish ingestion rates to the age-specific values needed for MIRC.

For the screening-level fish ingestion exposure scenario, the consumer evaluated is an individual who regularly consumes a large amount of fish that he or she has caught locally over the course of a 70-year lifetime. Modeled exposures are intended to encompass those of a subsistence fisher whose diet comprises a substantial proportion of fish. The scenario is not, however, intended to represent the maximum possible exposure an individual subsistence fisher might experience.

Although the fish ingestion rates presented here are representative of the 99th percentile of the evaluated data set, the use of these inputs (compared with 90th percentile values used for other food types) is not considered to be inconsistent. This is due to the idiosyncrasies of the survey data on fish consumption, the fact that the data sets for homegrown foods and fish are not parallel, and the consideration of rates appropriate for subsistence fishers, as described above.

As discussed above, EPA believes that use of these fish ingestion rates strikes the appropriate balance between being health protective and having screening scenarios so conservative that they are of limited use in the decision making process. This high-end fish ingestion rate is appropriate in the context of the conservative screening scenario used in the RTR process and is applicable for national rulemakings given that it is very likely that subsistence woman fishers of child bearing age are located throughout the United States. Using a high-end subsistence fish ingestion rate also is consistent with section 112 of the CAA, which focuses on risks associated with maximally exposed individuals.

7.1.2. Farm Food Chain Ingestion

The default settings assume that all food types are obtained from the area of chemical deposition specified by the user (i.e., fraction of food from contaminated area = 1.0).

For estimates of screening threshold emission rates for PB-HAPS, environmental concentrations and air deposition rates were estimated using TRIM.FaTE for the area of maximal deposition in the vicinity of a hypothetical facility, and thus represent risks estimated for a maximally exposed individual/farm/family.

Exhibit B-31 also includes a sum of the 90th percentile ingestion rates for homegrown food categories and 99th percentile fish ingestion to show the implied total food ingestion rate associated with setting multiple food-type-specific ingestion rates at upper percentiles. Because these upper percentile values for each farm food category are likely to reflect different individuals, it is likely that addition of multiple upper percentile intake values will exceed the total food ingestion rates expected for the general population. This sum is shown on the third row from the bottom (Total Food: Homegrown Only).

The second row from the bottom presents the 90th percentile of the distribution of *individual total food ingestion rates* from the USDA's 1994-96 and 1998 *Continuing Survey of Food Intakes by Individuals* (CSFII) (USDA 2000) data sets, as analyzed by EPA (EPA 2005e). The total ingestion rate for the farming households (third row from bottom) takes into account the cooking losses typical of each food category to provide a better comparison with the 90th percentile individual total food ingestion rates from CSFII (which are based on consumption of prepared foods). The final row of Exhibit B-31 shows the likely magnitude of the overestimates by age category by presenting the ratio of the two preceding rows. The values in this row demonstrate the potential for overestimating intake by using upper percentile values for all food groups. This bias may be considered when evaluating the results estimated by MIRC.

Exhibit B-31. Farm Food Category Ingestion Rates for Health Protective Screening Scenario for Farming Households

Product	Screening-Level Consumer Ingestion Rate						Units
	Infants <1 yr	Child 1–2 yrs	Child 3–5 yrs	Child 6–11 yrs	Child 12–19 yrs	Adult 20–70 yrs	
Farm Food Item							
Beef[a]	NA	9.49	8.83	11.4	3.53	4.41	g/kg-day
Dairy[b]	NA	185	92.5	57.4	30.9	6.16	g/kg-day
Eggs[a]	NA	4.90	3.06	1.90	1.30	1.31	g/kg-day
Exposed Fruit[a]	NA	12.7	5.41	6.98	3.41	2.37	g/kg-day
Exposed Vegetable[a]	NA	10.7	3.47	3.22	2.35	3.09	g/kg-day
Pork[a]	NA	4.90	4.83	3.72	3.69	2.23	g/kg-day
Poultry[a]	NA	7.17	6.52	4.51	3.13	2.69	g/kg-day
Protected Fruit[a]	NA	44.8	32.0	23.3	7.44	15.1	g/kg-day
Protected Vegetable[a]	NA	3.88	2.51	2.14	1.85	1.81	g/kg-day
Root Vegetable[a]	NA	7.25	4.26	3.83	2.26	2.49	g/kg-day
Other							
Breast milk[c]	1.01	NA	NA	NA	NA	NA	kg/day
Soil (dry)	NA	200[d]	200[d]	201[e]	201[e]	201[e]	mg/day
Fish (per individual)[f]	NA	107.7[g]	159.0[g]	268.2[h]	331.0[h]	373	g/day

Exhibit B-31. Farm Food Category Ingestion Rates for Health Protective Screening Scenario for Farming Households

Product	Screening-Level Consumer Ingestion Rate						Units
	Infants <1 yr	Child 1–2 yrs	Child 3–5 yrs	Child 6–11 yrs	Child 12–19 yrs	Adult 20–70 yrs	
Total Food Ingestion Rates for Comparison Only (not in MIRC; excludes soil and water)							
Total Food: Homegrown only[i]	NA	259	142	99	51	35.5	g/kg-day
Total Food: All Sources[j]	NA	125	91	61	34	23.7	g/kg-day
Overestimate (ratio of Homegrown/Total)	NA	2.1	1.6	1.6	1.5	1.3	(unitless)

Sources: EPA 2011a, EPA 2008a, unless otherwise noted.
NA = not applicable
[a]Primary source for values was the 1987–1988 NFCS survey; compiled results are presented in Chapter 13 of the 2011 Exposure Factors Handbook (EPA, 2011a). When data were unavailable for a particular age group, the intake rate for all age groups was multiplied by the age-specific ratio of intake based on national population intake rates from CSFII.
[b]Primary source for values was 1987–1988 NFCS survey, compiled results are presented in Chapter 13 of the 2011 Exposure Factors Handbook (EPA, 2011a). When data were unavailable for a particular age group, the intake rate for all age groups was multiplied by the age-specific ratio of intake based on national population intake rates from an NHANES 2003–2006 analysis in Chapter 11 of the Exposure Factors Handbook.
[c]Infants are assumed to consume only breast milk for one year.
[d]These values are the recommended "upper percentile" value for children from EPA's 2011 EFH, Chapter 4, Table 4-23. The 2008 CSEFH and 2011 EFH included a high-end value associated with pica only, but this value has not been used.
[e]These values are 90th percentile adult ingestion rates calculated in Stanek et al. 1997, and they are used to represent older children and adults.
[f]The ingestion rate for adults was obtained from Burger (2002) and is the 99th percentile value for adult females considered high-end recreationists; this value is believed to be representative of subsistence fishers. The 99th percentile values for children were derived based on EPA's Estimated Per Capita Fish Consumption in the United States (2002)—Section 4.2.1.1 Table 5 (for child age categories) adjusted and scaled. Values reflect "as prepared" ingestion rates.
[g]The fish ingestion rate for children aged 3–5 years was obtained directly from Section 4.2.1.1, Table 5 in the EPA (2002) report (value presented is rounded); for these children, the RTR age-group range matches the EPA (2002) age category. Fish ingestion rates for children less than 3 years old, however, were not provided. Therefore, for children aged 1–2 years, the fish ingestion rate was calculated using the ingestion rate for children aged 3–5 years scaled downward by the ratio of the mean body weight of children aged 1–2 years to the mean body weight of children aged 3–5-years.
[h]Time-weighted average ingestion rates were calculated using the EPA (2002) fish ingestion estimates in order to adjust for the differences between the age group ranges used for the RTR screening and those presented in the 2002 EPA report.
[i]Sum of post-cooking food ingestion rates. This estimate is calculated by multiplying the food ingestion rates on previous rows (excluding soil and water) by $(1-L_1)x(1-L_2)$, where L_1 and L_2 are the loss rates from Exhibit B-25. The rows are then summed to get the total post-cooking ingestion rate.
[j]90th percentile total food intake rates from EPA 2008a and 2005e based on CSFII data 1994-96 and 1998; see Section 6.3.6 of this document.

7.2. Default Screening-Level Population-Specific Parameter Values

The screening-level values for body weights (BWs) for the RTR screening threshold analysis, which serve as the default values in MIRC, are mean values and are presented in Exhibit B-32. As stated in Section 6 of this attachment, EPA recommends using the mean BW for each age group when using upper percentile values for medium ingestion rates. Use of the mean body weights introduces no bias toward over- or underestimating risk.

Exhibit B-32. Mean Body Weight Estimates for Adults and Children[a]

Lifestage (years)	Duration (years)	Mean Body Weight (kg)
Adult[b] (20-70)	50	80.0
Child < 1[c]	1	7.83
Child 1-2[c]	2	12.6
Child 3-5[d]	3	18.6

Exhibit B-32. Mean Body Weight Estimates for Adults and Children[a]

Lifestage (years)	Duration (years)	Mean Body Weight (kg)
Child 6-11[e]	6	36.0
Child 12-19[f]	8	64.2

[a]Sources: EPA 1997, 2008a
[b] EPA-recommended value (EPA 2011a).
[d]These values were obtained directly from Table 8-3 of the 2008 CSEFH.
[e]Each BW represents a time-weighted average of BWs for age groups 6 to <11 years and 11 to <16 years from Table 8-3 of the 2008 CSEFH. Original sample sizes for each of these age groups can also be found in Table 8-3.
[f]These values were calculated as time-weighted average BW for age groups 11 to <16 years and 16 to <21 years from Table 8-3 of the 2008 CSEFH. The direction of the possible bias is unknown. The values match the estimate based on Table 8-22 of the NHANES IV data as presented by Portier et al. (2007).

7.3. Default Chemical-Specific Parameter Values for Screening Analysis

Exhibit B-33 presents chemical-specific parameter values for input to MIRC for the screening-level analysis. Values for bioavailability when ingested in soil (*Bs*), mammalian metabolism factors (*MF*), correction factors for belowground produce ($VG_{rootveg}$), wet deposition fractions (*Fw*), air to plant transfer factors (Bv_{AG}), root concentration factors (*RCF*), and soil-water partition coefficient (*Kds*) are presented in Exhibit B-33.

Exhibit B-33. Chemical-Specific Parameter Values for Input to MIRC[a]

Parameter	Description	Benzo(a)-pyrene	Cadmium	Mercuric chloride	Methyl mercury	2,3,7,8-TCDD	Units
Bs	Soil bioavailability factor for livestock	1	1	1	1	1	unitless
MF	Mammalian metabolism factor	0.01	1	1	1	1	unitless
VGrootveg	Empirical correction factor for belowground produce, i.e., tuber or root vegetable, to account for possible overestimate of the transfer of chemicals from the outside to the inside of bulky tubers or roots (based on carrots and potatoes)	0.01	1	1	0.01	0.01	unitless
Fw	Fraction of wet deposition that adheres to plant surfaces; 0.2 for anions, 0.6 for cations and most organics	0.6	0.6	0.6	0.6	0.6	unitless

Exhibit B-33. Chemical-Specific Parameter Values for Input to MIRC[a]

Parameter	Description	Benzo(a)-pyrene	Cadmium	Mercuric chloride	Methyl mercury	2,3,7,8-TCDD	Units
BvAG	Air-to-plant biotransfer factor for aboveground produce for vapor-phase chemical in air	174,523	0	1,800	0	65,500	[mg/g produce DW]/[mg/g air]
RCF	Chemical-specific root concentration factor for tubers and root produce	9,180	0	0	0	40,002	L soil pore water/kg root WW
Kds	Chemical-specific soil/water partition coefficient	7,750	75	58,000	7,000	31,126	L soil pore water/kg soil DW

[a]Values presented in this exhibit are also presented in previous exhibits; however exact values used in the assessment are presented here, rather than values restricted by significant figures. In addition, only values for those chemicals that are specifically used in the screening assessment are provided here.

Only single estimates were developed for each of these parameters for HHRAP (EPA 2005a), and the potential direction and magnitude of bias toward over- or underestimating risks were not investigated in this assessment. The inputs that are both chemical-specific and plant-type-specific, as presented in Exhibit B-11, are *not* repeated here. Again, only single estimates were developed for these parameters and the potential direction and magnitude of bias toward over- or underestimating risks were not investigated. Finally, Exhibit B-34 presents biotransfer factors for each of the chemicals and animal types for which screening threshold emissions were calculated.

Exhibit B-34. Chemical and Animal-Type Specific Biotransfer Factor (Ba) Values for Input to MIRC

([mg chemical/kg WW tissue or dairy] / [mg chemical intake/day] = day/kg WW tissue or dairy)

Chemical	Beef	Dairy	Pork	Eggs	Poultry
Benzo(a)pyrene	3.8E-02	8.0E-03	4.6E-02	1.6E-02	2.8E-02
Cadmium	1.2E-04	6.5E-06	1.9E-04	2.5E-03	1.1E-01
Mercuric chloride	1.1E-04	1.4E-06	3.4E-05	2.4E-02	2.4E-02
Methyl mercury	1.2E-03	1.7E-05	5.1E-06	3.6E-03	3.6E-03
2,3,7,8-TCDD	3.6E-02	7.7E-03	4.4E-02	1.5E-02	2.7E-02

7.4. Screening-Level Parameter Values for Nursing Infant Exposure

MIRC is configured to evaluate risk to nursing infants exposed to dioxins and to methylmercury (MeHg) in their mother's milk for a family farming and catching fish in the area of maximal air deposition of chemical. Input values were summarized in Section 6.5 of this attachment.

7.4.1. Dioxins

For dioxins, chemical intake via breast milk by nursing infants was estimated using the model presented in EPA's *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (MPE, EPA 1998). The assumption that lactational transfer of dioxins to the infant occurs via the lipid-phase of milk appears reasonable. The

following screening-level assumptions used in that model should bias the results toward health-protective estimates of risks.

- Duration of nursing is a full year and no other foods or liquids are consumed by the infant; a more "typical" value would be six months.
- Absorption efficiency of dioxin in food or milk by mother and infant are 100 percent; this assumption might overestimate absorption but probably by no more than 15 percent (see Section 6.5.2).
- The fat content of human milk is assumed to be 4 percent, a value toward the high end of the reported range of values (1 to 5 percent).
- The maternal chemical intake is estimated using upper percentile ingestion rates for the different homegrown foods (see discussion for Exhibit B-31); this assumption might overestimate total ingestion of homegrown foods by a factor of more than 2 (see Exhibit B-31).
- If the fraction of the maternal body burden of dioxin that is in the body fat compartment is greater than 90 percent, as suggested by ATSDR (1998), then actual exposures of the infant may be less than estimated.

There also are parameter values and model assumptions for the lipid-phase breast-milk pathway for which possible bias is unknown.

- The accuracy of the model is unknown; it has not been verified or validated with empirical data.
- Using a half-life of 10 years for dioxins may over- or under-estimate risks.

Finally, there is one assumption that might possibly introduce some bias toward underestimating risks. The model results are sensitive to the biological half-life of the chemical in the mother relative to the length of her exposure prior to the lactation period. Using an exposure duration for the mother equal to the assumed half-life for dioxins, 10 years, may underestimate the duration of exposure of the mother.

7.4.2. Methyl Mercury

For MeHg, empirical data from a single human study (Fujita and Takabatake 1977) was used in conjunction with a physiologically based pharmacokinetic (PBPK) model of lactational transfer of MeHg developed and partially validated by Byczkowski and Lipscomb (2001) to support a very simple predictive model. Both the human data and the PBPK model indicated that for relatively low MeHg exposures, the concentration of MeHg in the nursing infant's blood is similar to its concentration in the mother's blood. The PBPK model suggested in addition that the average daily dose of MeHg absorbed from milk by the nursing infant (DAI_{inf}) is indistinguishable from the dose of MeHg absorbed by its mother from her food (DAI_{mat}). The data are limited, and the model includes various assumptions; however, there is no known directional bias in the estimates.

8. References

Altman, P.L., and D.S. Dittmer, Eds. 1964. Biology Data Book. Volume 1. Bethesda, MD. 263-264 (As cited in EPA 1998).

Amin-Zaki, L., S. Elhassani, M.A. Majeed, T.W. Clarkson, R.A. Doherty, M.R. Greenwood, and T. Giovanoli-Jakubczak. 1976. Perinatal methylmercury poisoning in Iraq. Am. J. Diseases in Children 130: 1070-1076 (As cited in Byczkowski and Lipscomb 2001).

ATSDR (Agency for Toxic Substances and Disease Registry). 1992. Toxicological profile for selected PCBs (Arochlor- 1260, 1254, 1248, 1242, 1232, 1221, and 1016). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service (As cited in EPA 1998).

ATSDR. 1998. Toxicological profile for chlorinated dibenzo-p-dioxins. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Bacci E., M. Cerejeira, C. Gaggi, G. Chemello, D. Calamari, and M. Vighi. 1992. Chlorinated dioxins: Volatilization from soils and bioconcentration in plant leaves. *Bull. Environ. Contam. Toxicol.* 48: 401-408.

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. Review and analysis of parameters and assessing transport of environmentally released radionuclides through agriculture. ORNL-5786. Oak Ridge National Laboratory. Oak Ridge, Tennessee. September.

Bates, M.N., D.S. Hannah, S.J. Buckland, J.A. Taucher, and T. van Mannen. 1994. Chlorinated organic contaminants in breast milk of New Zealand women*. Environmental Health Perspectives* 102(Supplement 1): 211-217.

Belcher, G.D., and C.C. Travis. 1989. Modeling support for the RURA and municipal waste combustion projects: Final report on sensitivity and uncertainty analysis for the terrestrial food chain model. Interagency Agreement No. 1824-A020-A1, Office of Risk Analysis, Health and Safety Research Division, Oak Ridge National Laboratory. Oak Ridge, Tennessee. October.

Boone, F.W., Y.C. Ng, and J.M. Palm. 1981. Terrestrial pathways of radionuclide particulates. *Health Physics* 41:735-747.

Briggs, G.G., R.H. Bromilow, and A.A. Evans. 1982. Relationships between lipophilicity and root uptake and translocation of non-ionized chemicals by barley. *Pesticide Science* 13: 495-504 (As cited in EPA 2005a, Appendix A-2).

Burger J. 2002. Daily consumption of wild fish and game: Exposures of high end recreationalists. *International Journal of Environmental Health Research* 12:343-354.

Butte, N.F., C. Garza, E.O. Smith, and B.L. Nichols. 1984. Human milk intake and growth in exclusively breast-fed infants. *The Journal of Pediatrics* 104(2):187-195.

Byczkowski, J.Z., and J.C. Lipscomb. 2001. Physiologically based pharmacokinetic modeling of the lactational transfer of methylmercury. *Risk Analysis* 21(5): 869-882.

Chamberlain, A.C. 1970. Interception and retention of radioactive aerosols by vegetation. *Atmospheric Environment* 4: 57-78.

Clewell, H.J, J.M. Gearhart, R.P. Gentry, T.R Covington, C.B. VanLandingham, C.B. Crump, and A.M. Shipp. 1999. Evaluation of the uncertainty in an oral reference dose for methylmercury due to interindividual variability in pharmacokinetics. *Risk Analysis* 19: 547-558 (As cited in Byczkowski and Lipscomb 2001).

Conley, C.L. 1974. The blood. Medical Physiology 13(2). V.B. Moutcasle, Ed. 1997. The C.V. Mosby Company, St. Louis, MO. 1027-1046 (As cited in EPA 1998).

Ensminger, M.E. 1980. Poultry Science. Interstate Printers and Publishers, Inc. Danville, Illinois.

Fries, G. F. 1982. Potential polychlorinated biphenyl residues in animal products from application of contaminated sewage sludge to land. *J. Environ. Qual.* 11:14.

Fries, G.F. 1994. Personal communication between G.F. Fries, U.S. Department of Agriculture, and Glenn Rice and Jennifer Windholtz, U.S. Environmental Protection Agency, Office of Research and Development. Agricultural Research Service. March.

Fujita, M., and E. Takabatake. 1977. Mercury levels in human maternal and neonatal blood, hair and milk. *Bull. Environ. Contam. Toxicol.* 18(2): 205-209.

Gearhart, J.M., H.J. Clewell III, K.S. Crump, A.M. Shipp, and A. Silvers. 1995. Pharmacokinetic dose estimates of mercury in children and dose-response curves of performance tests in a large epidemiological study. *Water, Air, Soil Pollut.* 80: 49-58 (As cited in Byczkowski and Lipscomb 2001).

Gearhart, J., T. Covington, and H. Clewell III. 1996. Application of a physiologically based pharmacokinetic model for MeHg in a dose reconstruction of the Iraqi accidental exposures. Paper presented at the Fourth International Conference on Mercury as a Global Pollutant, Congress Centre, Hamburg, Germany; August (As cited in Byczkowski and Lipscomb 2001).

Greenwood, M.R., T.W. Clarkson, R.A. Doherty, A.H. Gates, L. Amin-Zaki, S. Elhassani, and M.A. Majeed. 1978. Blood clearance half-times in lactating and nonlactating members of a population exposed to mercury. *Environ. Res.* 16: 48-54.

Harrison, K.A. 1967. Blood volume changes in severe anemia in pregnancy. *Lancet* 1(7480):20-25.

Hofelt, C.S., M. Honeycutt, J.T. McCoy, and L.C. Haws. 2001. Development of a metabolism factor for polycyclic aromatic hydrocarbons for use in multipathway risk assessments of hazardous waste combustion facilities. *Reg. Toxicol. Pharmacol*. 33:60-65.

Hoffman, F.O., K.M. Thiessen, M.L. Frank, and B.G. Blaylock. 1992. Quantification of the interception and initial retention of radioactive contaminants deposited on pasture grass by simulated rain. *Atmospheric Environ.* 26a(18): 3313-3321.

Hollins, J.G., R.F. Willes, F.R. Bryce, S.M. Charbonneau, and I.C. Munro. 1975. The whole body retention and tissue distribution of Hg methylmercury in adult cats. *Toxicol. App. Pharmacol.* 33: 438-449.

Hong, C.S., J. Xiao, A.C. Casey, B. Bush, E.F. Fitzgerald, and S.A. Hwang. 1994. Mono-ortho and non-ortho-substituted polychlorinated biphenyls in human milk from Mohawk and control women: Effects of maternal factors and previous lactation. *Arch. Environ. Contam. Toxicol.* 27(3): 431-437.

Jensen, A.A. 1987. Polychlorinated biphenyls (PCBs), polychlorodibenzo-p-dioxins (PCDDs) and polychlorodibenzofurans (PCDFs) in human milk, blood and adipose tissue. *Sci. Total Environ.* 64(3): 259-293.

Kahn, H., and K. Stralka. 2008. Estimated daily average *per capita* water ingestion by child and adult age categories based on USDA's 1994-96 and 1998 continuing survey of food intakes individuals. *J. Expo. Anal. Environ. Epidemiol.* 1-9.

Kershaw, T.G., T.W. Clarkson , and P.H. Dhahir . 1980. The relationship between blood levels and dose of methylmercury in man. *Arch. Environ. Health* 35(1): 28-36.

Lorber, M. 1995. Development of an air-to-plant vapor phase transfer for dioxins and furans. Presented at the 15th International Symposium on Chlorinated Dioxins and Related Compounds. August 21-25, 1995 in Edmonton, Canada. Abstract in *Organohalogen Compounds* 24:179-186.

Lorber, M., and P. Pinsky. 2000. An evaluation of three empirical air-to-leaf models for polychlorinated dibenzo-p-dioxins and dibenzofurans. *Chemosphere* 41(6):931-41.

Maxwell, N.I., and D.E. Burmaster. 1993. A simulation model to estimate a distribution of lipid intake from breast milk during the first year of life. *Journal of Exposure Analysis and Environmental Epidemiology* 3(4): 383-406.

McLachlan, M.S. 1993. Digestive tract absorption of polychlorinated dibenzo-p-dioxins, dibenzofurans and biphenyls in a nursing infant. *Toxicology and Applied Pharmacology* 123(1): 68-72.

Miller, C.W., and F.O. Hoffman. 1983. An examination of the environmental half-time for radionuclides deposited on vegetation. *Health Physics* 45(3): 731-744.

Morgan, J.N., M.R. Berry, and R.L. Graves. 1997. Effects of Commonly Used Cooking Practices on Total Mercury Concentration in Fish and Their Impact on Exposure Assessments. *Journal of Exposure Analysis and Environmental Epidemiology* 7(1):119-133.

NAS (National Academy of Sciences). 1987. Predicting Feed intake of Food-Producing Animals. National Research Council, Committee on Animal Nutrition, Washington, D.C.

NAS. 1991. Nutrition During Lactation. National Academies Press. Washington, DC.

NC DEHNR (North Carolina Department of Health, Environment, and Natural Resources). 1997. North Carolina Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units. January.

Portier K., J. Tolson, and S. Roberts. 2007. Body weight distributions for risk assessment. *Risk Anal.* 27(1): 11-26.

Reinert, RE; Stewart, D; Seagran, HL. 1972. Effects of dressing and cooking on DDT concentrations in certain fish from Lake Michigan. Journal of Fisheries Research Board of Canada. 29(5): 525-529.

RTI. 2005. Methodology for predicting cattle biotransfer factors. Prepared for U.S. Environmental Protection Agency (EPA) Office of Solid Waste. EPA Contract No. 68-W-03-042. September. Available at: http://www3.epa.gov/epawaste/hazard/tsd/td/combust/finalmact/ssra/btfreportfull05.pdf.

Schecter, A., P. Fürst, C. Fürst, O. Päpke, M. Ball, J. Ryan, H. Cau, L. Dai, H. Quynh, H.Q. Cuong, N. Phuong, P. Phiet, A. Beim, J. Constable, J. Startin, M. Samedy, and Y. Seng. 1994. Chlorinated dioxins and dibenzofurans in human tissue from general populations: A selective review. *Environmental Health Perspectives* 102(Supplement 1): 159-171.

Sherlock, J., D. Hislop, G. Newton, G. Topping, and K. Whittle. 1984. Elevation of mercury in human blood from controlled ingestion of methylmercury in fish. *Human Toxicology* 3: 117-131 (As cited in USFDA 2009).

Shilling, F., White, A. Lippert, L, and M. Lubell. 2010. Contaminated fish consumption in California's Central Valley Delta. *Environmental Research* 110: 334-344.

Shor, R.W., C.F. Baes, and R.D. Sharp. 1982. Agricultural production in the United States by county: A compilation of information from the 1974 census of agriculture for use in terrestrial food-chain transport and assessment models. Oak Ridge National Laboratory Publication. ORNL-5786

Sim, M.R. and J.J. McNeil. 1992. Monitoring chemical exposure using breast milk: A methodological review. *American Journal of Epidemiology* 136(1): 1-11.

Smith, A.H. 1987. Infant exposure assessment for breast milk dioxins and furans derived from waste incineration emissions. *Risk Analysis* 7:347-353.

Stanek, E.J., E.J. Calabrese, R. Barnes, P. Pekow. 1997. Soil ingestion in adults – results of a second pilot study. *Toxicol. Environ. Safety* 36:249-257.

Steinbeck, A.W. 1954. Plasma and blood volumes of normal Australian females. Australian *Journal of Experimental Biology and Medical Science* 32(1): 95-9.

Stephens, R.D., M. Petreas, and G.H. Hayward. 1995. Biotransfer and bioaccumulation of dioxins and furans from soil: Chickens as a model for foraging animals. *Science Total Environment* 175: 253-273. July 20.

Sullivan, M.J., S.R. Custance, and C.F. Miller. 1991. Infant exposure to dioxin in mother's milk resulting from maternal ingestion of contaminated fish. *Chemosphere* 23(8-10): 1387-1396.

Thomann, R.V. 1989. Bioaccumulation model of organic-chemical distribution in aquatic food-chains. *Environ. Sci. Technol*. 23(6): 699-707.

Travis, C.C., and A.D. Arms. 1988. Bioconcentration of organics in beef, milk, and vegetation. *Environ. Sci. Technol.* 22:271-274.

Travis, C.C., H.A. Hattemer-Frey and A.A. Arms. 1988. Relationship between dietary intake of organic chemicals and their concentrations in human adipose tissue and breast milk. Arch. Environ. Contam. Toxicol. 17:473-478.

Ueland, K. 1976. Maternal cardiovascular dynamics. VII. Maternal cardiovascular dynamics. Intrapartum blood volume changes. *Am. J. Obstetrics Gynecol*. 126(6): 671-677.

USDA (U.S. Department of Agriculture). 1992. Changes in Food Consumption and Expenditures in American Households during the 1980's. USDA, Washington, D.C. Statistical Bulletin o. 849. (As cited in EPA 1997)

USDA. 1993. Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1987-88. Nationwide Food Consumption Survey 1987-88, NFCS Report No. 87-I-1. (As cited in EPA 1997)

USDA. 1994a. Food Consumption and Dietary Levels of Households in the United States, 1987-88. Agricultural Research Service, Report No. 87-H-1. (As cited in EPA 1997)

USDA. 1994b. Vegetables 1993 Summary. National Agricultural Statistics Service, Agricultural Statistics Board. Washington, D.C. Vg 1-2 (94). Jan.

USDA. 1994c. Noncitrus Fruits and Nuts 1993 Summary. National Agricultural Statistics Service, Agricultural Statistics Board, Washington, D.C. Fr Nt 1-3 (94).

USDA. 2000. 1994–96, 1998 Continuing Survey of Food Intakes by Individuals (CSFII). CD-ROM. Agricultural Research Service, Beltsville Human Nutrition Research Center, Beltsville, MD. Available from the National Technical Information Service, Springfield, VA, Accession Number PB-2000500027. (As cited in EPA 2008a, Chapter 14)

EPA (US. Environmental Protection Agency). 1990. Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions. Environmental Criteria and Assessment Office. ORD.EPA-600-90-003. January.

EPA. 1992. Technical Support Document for the Land Application of Sewage Sludge: Volumes I and II. EPA 822/R-93-001a. Office of Water. Washington, D.C.

EPA. 1994a. Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

EPA. 1994b. Estimating Exposure to Dioxin-Like Compounds. Volume II: Properties, Sources, Occurrence, and Background Exposures. External Review Draft. Office of Research and Development. Washington, DC. EPA/600/6-88/005Cc. June.

EPA. 1994c. Estimating Exposure to Dioxin-Like Compounds. External Review Draft. Office of Research and Development, Washington, D.C. EPA/600/6-88/005Cb. June. Available at: http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=438673.

EPA. 1995a. Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project. Volumes I and II. Office of Solid Waste. March 3.

EPA. 1995b. Memorandum Regarding Further Studies for Modeling the Indirect Exposure Impacts from Combustor Emissions. From Mathew Lorber, Exposure Assessment Group, and Glenn Rice, Indirect Exposure Team, Environmental Criteria and Assessment Office. Washington, D.C. January 20.

EPA. 1995c. Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions. Office of Research and Development. Washington, D.C. January 20.

EPA. 1995d. Waste Technologies Industries Screening Human Health Risk Assessment (SHHRA): Evaluation of Potential Risk from Exposure to Routine Operating Emissions. Volume V. External Review Draft. U.S. EPA Region 5, Chicago, Illinois.

EPA. 1996. Soil Screening Guidance: User's Guide. Office of Solid Waste and Emergency Response, Washington D.C. EPA/540/R-96/018, April 1996.

EPA. 1997a. Exposure Factors Handbook. Volumes I, II, and III. Office of Research and Development, Washington, D.C. EPA-600-P-95-002Fa,b,c. August. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12464.

EPA. 1997b. Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment. Office of Air Quality Planning and Standards and Office of Research and Development. EPA-452/R-97-005. December.

EPA. 1997c. Parameter Guidance Document. National Center for Environmental Assessment, NCEA-0238.

EPA. 1998. Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions. National Center for Environmental Assessment, Cincinnati, OH. EPA-600-R-98-137. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=55525.

EPA. 1999. 1999 National-Scale Air Toxics Assessment Results; Approach for Modeling POM. Available at: http://archive.epa.gov/nata2002/web/pdf/pom_approach.pdf.

EPA. 2001a. Peer Review of EPA's Hazardous Waste Identification Rule Risk Assessment Model: Breast milk exposure model for the HWIR 3MRA Model. Prepared by Eastern Research Group for EPA Office of Solid Wastes. 68-W5-0057.

EPA. 2001b. Water Quality Criterion for the Protection of Human Health: Methylmercury. Office of Water, Office of Science and Technology. Washington D.C. EPA-823-R-01-001. January. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/health/upload/2009_01_15_criteria_methylmercury_mercury-criterion.pdf.

EPA. 2002. Estimated *Per capita* Fish Consumption in the United States. Office of Water, Office of Science and Technology, Washington, D.C. EPA-821- C- 02-003. August. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/health/upload/consumption_report.pdf.

EPA. 2003a. Chapter 10 In: Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Modeling System, Volume II: Site-based, Regional, and National Data. SAB Review Draft. EP-530/D-03-001b. Office of Research and Development, Athens, GA, and Research Triangle Park, NC, and Office of Solid Waste, Washington, D.C. July. Available at: http://www.epa.gov/osw/hazard/wastetypes/wasteid/hwirwste/risk03.htm.

EPA. 2003b. Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000): Technical Support Document. Volume 2: Development of National Bioaccumulation Factors. Office of Water, Office of Science and Technology, Washington, D.C. EPA-822-R-03-030. December. Available at: http://water.epa.gov/scitech/swguidance/standards/criteria/health/methodology/.

EPA. 2003c. CSFII Analysis of Food Intake Distributions. Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. EPA-600-R-03-29. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=56610.

EPA. 2004. Estimated *Per capita* Water Ingestion and Body Weight in the United States – An Update. Office of Water, Office of Science and Technology, Washington, D.C. EPA-822-R-00-001. October. Available at: http://water.epa.gov/action/advisories/drinking/upload/2005_05_06_criteria_drinking_percapita_2004.pdf.

EPA. 2004c. Risk Assessment Guidance for Superfund. Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final. Office of Superfund Remediation and Technology Innovation, Washington, D.C. EPA/540/R/99/005; OSWER 9285.7-02EP; NTIS PB99-963312. July.

EPA. 2005a. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Office of Solid Waste and Emergency Response, Washington, DC. EPA-530-R-05-006. September. Available at: http://www.epa.gov/osw/hazard/tsd/td/combust/risk.htm.

EPA. 2005b. Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants. Risk Assessment Forum. Washington, DC. November. EPA/630/P-03/003F. Available at: http://www2.epa.gov/sites/production/files/2013-09/documents/agegroups.pdf.

EPA. 2005c. Guidelines for Carcinogen Risk Assessment. Risk Assessment Forum, Washington, DC. EPA/630/P-03/001F. March. Available from: http://www2.epa.gov/sites/production/files/2013-09/documents/cancer_guidelines_final_3-25-05.pdf.

EPA. 2005d. Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. Risk Assessment Forum: Washington, D.C. EPA-630/R-03-003F. March. Available at: http://www.epa.gov/ttn/atw/childrens_supplement_final.pdf.

EPA. 2005e. Analysis of Total Food Intake and Composition of Individual's Diet Based on the U.S. Department of Agriculture's 1994-96, 1998 Continuing Survey of Food Intakes By Individuals (CSFII) (Final). Office of Research and Development, National Center for Environmental Assessment, Washington, D.C. EPA/600/R-05/062F. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=132173.

EPA. 2007a. Prioritized Chronic Dose-Response Values for Screening Risk Assessments (Table 1). Office of Air Quality Planning and Standards; June 12, 2007. Available at: http://www.epa.gov/ttn/atw/toxsource/summary.html.

EPA. 2007b. Toxicological Review of 1,1,1-Trichloroethane (CAS No. 71-55-6) In Support of Summary Information on the Integrated Risk Information System (IRIS). Office of Research and Development, Washington, DC. EPA/635/R-03/006. August. Available at: http://www.epa.gov/iris.

EPA. 2008a. Child-Specific Exposure Factors Handbook. Office of Research and Development, Washington, D.C. EPA/600/R-06/096F. September. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=199243 .

EPA. 2008b. Draft Report on EPA OAQPS Risk and Technology Review Methodologies: For Review by the EPA Science Advisory Board; Case Studies – MACT I Petroleum Refining Sources, Portland Cement Manufacturing. Office of Air Quality Planning and Standards, Office of Air and Radiation, Research Triangle Park, NC. July 14, 2008.

EPA. 2010. U.S. EPA. Development of a Relative Potency Factor (RPF) Approach for Polycyclic Aromatic Hydrocarbon (PAH) Mixtures (External Review Draft). Washington, DC, EPA/635/R-08/012A February. Available at: http://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=194584

EPA. 2011a. Exposure Factors Handbook: 2011 Edition. Office of Research and Development, Washington, D.C. EPA/600/R-090/052F. September. Available at: http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252.

EPA. 2011b. Revised Technical Support Document: National-Scale Assessment of Mercury Risk to Populations with High Consumption of Self-caught Freshwater Fish; In Support of the Appropriate and Necessary Finding for Coal- and Oil-Fired Electric Generating Units. Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-452/R-11-009. December.

Van den Berg, M., L.S. Birnbaum, M. Denison, M. De vito, W. Farlans, M. Feeley, H. Fiedler, H. Hakansson, A. Hanberg, L.. Haws, M. Rose, S. Safe, D. Schrenk, C. Tohyama, A. Tritscher, J. tuomisto, M. Tysklind, N. Walker, and R.E. Peterson. 2006. The 2005 World Health Organization reevaluation of human and mammalian toxic equivalency factors for dioxins and dioxin-like compounds. *Toxicol Sci.* 93(2): 223-41.

Zabik, ME; Zabik, MJ. 1995. Tetra-chlorodibenzo-p-dioxin residue reduction by cooking/processing of fish fillets harvested from the Great Lakes. Bulletin of Environmental Contamination and Toxicology. 55:264-269.

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Attachment C. Dermal Risk Screening

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Exhibits, Attachment C

Exhibit C-1. Cancer Slope Factors and Reference Doses Based on Absorbed Dose C-2

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Non-inhalation exposure to PB-HAPs can occur by way of the dermal pathway through contact with PB-HAP-contaminated soil and water. However, dermal absorption of chemicals that are originally airborne is generally a relatively minor pathway of exposure compared to other exposure pathways (EPA 2006, Cal/EPA 2000). This section demonstrates that for the conservative tiered screening scenario developed for RTR multipathway evaluation, the dermal exposure route is not a significant risk pathway when compared to the ingestion pathway. In general, the RTR multipathway assessment followed the protocol for evaluating a reasonable maximum exposure as described in EPA's *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Model, Part E, Supplemental Guidance for Dermal Risk Assessment* (EPA 2004).

1. Hazard Identification and Dose Response Assessment

To assess the potential contribution of dermal exposure to non-inhalation exposure, we evaluated the potential for cancer and chronic non-cancer effects for the four PB-HAPs currently assessed in the multipathway screening evaluation for RTR: cadmium, divalent mercury, 2,3,7,8-TCDD, and benzo(a)pyrene. EPA has not developed carcinogenic potency slope factors (CSFs) and non-cancer reference doses (RfDs) specifically for evaluating potential human health concerns associated with dermal exposure to PB-HAPs. Instead, dermal toxicity values can be derived from oral toxicity values via route-to-route extrapolation by adjusting for gastrointestinal (GI) absorption. EPA recommends making this adjustment only when GI absorption of the chemical is significantly less than 100% (i.e., less than 50 percent). Otherwise, a default value of complete (100 percent) oral absorption is assumed, and no adjustment is made (EPA 2004).

The absorbed cancer slope factor (CSF_{ABS}) is based on the oral cancer slope factor (CSF_O) and the fraction of the contaminant absorbed in the gastrointestinal track (ABS_{GI}), as follows:

$$CSF_{ABS} = \frac{CSF_o}{ABS_{GI}}$$

where:

CSF_{ABS} = Absorbed slope factor $(mg/kg\text{-}day)^{-1}$

CSF_o = Oral slope factor $(mg/kg\text{-}day)^{-1}$

ABS_{GI} = Fraction of chemical absorbed in gastrointestinal tract (unitless)

The absorbed reference dose (RfD_{ABS}) is based on the oral reference dose (RFD_O) and the fraction of the contaminant absorbed in the gastrointestinal tract (ABS_{GI}), as shown below.

$$RfD_{ABS} = RfD_o \times ABS_{GI}$$

where:

RfD_{ABS} = Absorbed reference dose (mg/kg-day)

RfD_o = Oral reference dose (mg/kg-day)

ABS_{GI} = Fraction of chemical absorbed in gastrointestinal tract (unitless)

The GI absorptions for 2,3,7,8-TCDD and all polycyclic aromatic hydrocarbons (PAHs) (which includes benzo[a]pyrene) were estimated to be greater than 50 percent. Therefore, as shown in Exhibit C-1, no adjustments to the available oral CSFs were required. For cadmium and divalent mercury, adjustments were made based on absorption data provided in RAGS Part E, Exhibit 4-1. The RfDs for dermal exposure to cadmium and divalent mercury are also shown in Exhibit C-1.

Exhibit C-1. Cancer Slope Factors and Reference Doses Based on Absorbed Dose

PB-HAP	Fraction of Contaminant Absorbed in GI Tract (ABS_{GI}) (unitless)	Absorbed Cancer Slope Factor (CSF_{ABS})[a] $(mg/kg\text{-}day)^{-1}$	Absorbed Reference Dose (RfD_{ABS})[a] (mg/kg-day)
Cadmium Compounds	0.05	NA	2.5E-05
Divalent Mercury	0.07	NA	2.1E-05
2,3,7,8-TCDD	No adjustment required [b]	1.5E+05	1.0E-09
Benzo[a]pyrene	No adjustment required [b]	1.0E+01	NA

NA = Not applicable
[a]Oral dose response values are presented in Appendix 2. Only the resulting adjusted dose response values are presented in this table.
[b]According to RAGS Part E, Exhibit 4-1, GI absorption is expected to be greater than 50%.

2. Dermal Exposure Estimation

Dermal exposures and risks resulting from absorption of the chemical through the skin from contact with contaminated water and soil were evaluated for the RTR screening scenario. Individuals were assumed to be exposed on a fraction of their bodies (i.e., their head, forearms, hands, lower legs, and feet) to contaminated soil from the TRIM.FaTE surface soil parcel with the highest concentration (N1) on a daily basis. For the water evaluation, individuals were assumed to be exposed to contaminated surface water with the same PB-HAP concentration as the TRIM.FaTE screening scenario lake over their entire bodies on a daily basis.

2.1. Equations for Estimating Dermal Exposure

The general equation used to estimate dermal absorbed dose (DAD) for water or soil is shown below, and is expressed in milligrams of PB-HAP per kilogram of receptor body weight per day (mg/kg-day). DADs are calculated separately for the water and soil pathways and then added together for each age group.

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT}$$

where:

DA_{event} = Absorbed dose per event; chemical-specific; equation for DA_{event} also differs depending on water or soil contact (mg/cm^2-event)

EV = Event frequency (events/day)

ED = Exposure duration (years)

EF	=	Exposure frequency (days/year)
SA	=	Skin surface area available for contact (cm^2)
BW	=	Body weight (kg)
AT	=	Averaging time; for non-cancer effects, equals ED x 365 days/year; for cancer effects, equals 70 years x 365 days/year (days)

DA_{event} is estimated to be the total dose absorbed through the skin at the end of exposure and the equation for calculation is different for organic and inorganic chemicals in water and for soil. The equations for calculating these chemical-specific DA_{event} values for water contact are provided in RAGS Part E, Chapter 3 (see Equations 3.2 – 3.4). For soil, the equation for calculating these chemical-specific DA_{event} values is provided in RAGS Part E, Chapter 3 (see Equation 3.12).

$$\textit{Water – Organic Chemicals:}\ DA_{event} = C_w \times 2 \times FA \times K_p \sqrt{\frac{6 \times \tau_{event} \times t_{event}}{\pi}}$$

$$\textit{Water – Inorganic Chemicals:}\ DA_{event} = C_w \times K_p \times t_{event}$$

$$\textit{Soil – All Chemicals:}\ DA_{event} = C_s \times AF \times ABS \times CF$$

where:

DA_{event}	=	Absorbed dose per event (mg/cm^2-event)
C_w C_s	=	Chemical concentration in water (mg/cm^3) or soil (mg/kg)
K_p	=	Chemical-specific dermal permeability coefficient of compound in water (cm/hr)
FA	=	Chemical-specific fraction absorbed; accounts for loss due to the regular shedding of skin cells of some chemical originally dissolved into skin (unitless)
τ_{event}	=	Chemical-specific lag time per event (hr/event)
t_{event}	=	Receptor-specific event duration (hr/event)
AF	=	Receptor- and activity-specific adherence factor of soil to skin (mg/cm^2-event)
ABS	=	Chemical-specific dermal absorption fraction (unitless)
CF	=	Conversion factor (10^{-6} kg/mg)

2.2. Exposure Factors and Assumptions

The exposure parameters included in this assessment and their default and other value options are summarized in this subsection. Default values were selected to result in a highly conservative estimate of exposure (i.e., exposures are likely overestimated). Parameter values were primarily obtained or estimated from RAGS Part E (EPA 2004) and the Child-Specific Exposure Factors Handbook (CSEFH, EPA 2008). Receptor-and scenario-specific exposure assumptions are discussed first, and a discussion of chemical-specific parameters values follows. Estimated water and soil exposure concentrations are presented at the end of this subsection.

2.3. Receptor-Specific Parameters

Dermal exposures and risks were estimated for the same age groups used in the ingestion exposure assessment: adults (ages 20 to 70 years) and five child age groups: <1 year; 1 to 2 years; 3 to 5 years; 6 to 11 years; and 12 to 19 years. The body weight values used in the ingestion exposure assessment were used in the dermal exposure assessment.

Body surface areas (SAs) for water and soil exposures for adults were calculated using Appendix C, Exhibit C-1, of RAGS Part E. For children, SAs for water and soil exposures for the five children's age groups were estimated using Tables 7-1 and 7-2 of the CSEFH, respectively. For SA (water), individuals were assumed to shower or bathe in the water with 100 percent of their body exposed. For SA (soil), it was assumed that individuals were exposed on a fraction of their total body, specifically their head, forearms, hands, lower legs, and feet. Based on information provided in RAGS Part E, the SA for forearms was calculated using the SA for arms and assuming a forearm-to-arm ratio of 0.45, and the SA for lower legs was estimated using the SA for legs and assuming a lower leg-to-leg ratio of 0.4.

Values for body SA by age group are summarized in Exhibit C-2.

Exhibit C-2. Receptor-Specific Body Surface Area Assumed to be Exposed to Chemicals

Age Group[a] (years)	Surface Area for Water Exposure (cm^2)	Surface Area for Soil Exposure (cm^2)
Adult 20-70	18,150[g]	6,878[h]
Child <1[b]	3,992	1,772
Child 1-2[c]	5,700	2,405
Child 3-5[d]	7,600	3,354
Child 6-11[e]	10,800	4,501
Child 12-19[f]	17,150	6,906

[a]Sources for the child groups included Table 7-1 (total body surface area for SA-Water), and Table 7-2 (fraction of total body surface area for SA-Soil) of the 2008 CSEFH.
[b]Represents a time-weighted average for age groups birth to <1 month, 1 to <3 months, 3 to <6 months, and 6 to <12 months.
[c]Represents a time-weighted average for age groups 1 to <2 years and 2 to <3 years.
[d]Values for age group 3 to <6 years in the 2008 CSEFH.
[e]Values for age group 6 to <11 years in the 2008 CSEFH. Represents a conservative (i.e., slightly low) estimate for ages 6 through 11 years since 11-year olds are not included in this CSEFH age group.
[f]Represents a time-weighted average for age groups 11 to <16 years and 16 to <21 years. Note that estimated values include 11-year-olds and individuals through age 20, which contributes to uncertainty in the estimates for 12 to 19 years.
[g]Represents the average total surface area of adults from Table C-1 of RAGS Part E.
[h]Represents the average surface area of adults for head, forearms, hands, lower legs, and feet from Table C-1 of RAGS Part E.

2.4. Scenario-Specific Parameters

Exhibit C-3 summarizes the exposure values related to frequency and duration of contact. In general, these are the recommended defaults for calculating a reasonable maximum exposure (RME) for a residential scenario as proposed by EPA in RAGS Part E, Chapter 3.

Exhibit C-3. Scenario-Specific Exposure Values for Water and Soil Contact

Exposure Parameter	Receptor	Value	Source
Water Contact			
Event Duration (t_{event}) (hr/event)	Child	1	Reasonable maximum exposure scenario for showering/bathing from RAGS Part E, Exhibit 3-2
	Adult	0.58	
Soil Contact			
Soil Adherence Factor (AF) (mg/cm^2)	Child	0.2	For children, value is geometric mean value for children playing (wet soil) and for adults, value is geometric mean value for an adult farmer from RAGS Part E, Exhibit 3-3
	Adult	0.1	
Both Media			
Event Frequency (EV) (events/day)	All	1	Reasonable maximum exposure scenario from RAGS Part E, Exhibits 3-2 and 3-5.
Exposure Frequency (EF) (days/year)	All	350	
Exposure Duration (ED) (years)	Child <1	1	Represents the number of years included in the age group; also used in ingestion exposure calculations.
	Child 1-2	2	
	Child 3-5	3	
	Child 6-11	6	
	Child 12-19	8	
	Adult 20-70	50	
Averaging Time (AT) (days)	For cancer assessment, an AT equal to a lifetime (70 years) × 365 days/year is used. Same value used in ingestion exposure calculations. For non-cancer assessment, an AT equal to the exposure duration (ED) × 365 days/year is used, so AT will vary by receptor group. Same value used in ingestion exposure calculations.		

2.5. Chemical-Specific Parameters

The chemical-specific parameters required to quantitatively evaluate dermal pathway exposures are listed in Exhibit C-4. For the water concentration in the dermal analysis, the modeled TRIM.FaTE chemical concentration in the screening scenario pond at the screening threshold emission rate was used. For the soil concentration, the modeled TRIM.FaTE chemical concentration in surface soil in parcel N1 (untilled soil, closest to facility) of the screening scenario at threshold emission rate was used. This same soil concentration was also used in ingestion exposure calculations for soil ingestion.

Dermal absorption of chemicals in water is based on the use of a dermal permeability coefficient (K_p), which measures the rate that a chemical penetrates the skin. Dermal absorption of soil-bound chemicals is based on the use of a dermal absorption fraction (ABS), which is a measure of how much of a chemical the skin absorbs through contact with soil.

Exhibit C-4. Chemical-Specific Dermal Exposure Values for Water and Soil Contact

PB-HAP	Cadmium	Divalent Mercury	2,3,7,8-TCDD	Benzo[a] pyrene	Source
Chemical concentration in Water (Cw) (mg/cm^3)	2.4E-08	1.9E-09	2.6E-18	2.1E-13	TRIM.FaTE modeled concentration in screening scenario pond
Chemical concentration in Soil (Cs) (mg/kg)	6.9E-02	6.3E-02	2.2E-10	1.4E-04	TRIM.FaTE modeled concentration in surface soil in parcel N1 in screening scenario
Permeability coefficient in water (Kp) (cm/hour)	0.001	0.001	0.81	0.7	Values from RAGS Part E, Exhibits B-3 (organics) and B-4 (inorganics)
Fraction absorbed water (FA) (unitless)	NA	NA	0.5	1.00	Values from RAGS Part E, Exhibits B-3; only used for organic chemicals
Lag time per event (event) (hr/event)	NA	NA	6.82	2.69	Values from RAGS Part E, Exhibits B-3; only used for organic chemicals
Dermal absorption fraction (ABS) from soil (unitless)	0.001	0.045[a]	0.03	0.13	Values from RAGS Part E, Exhibit 3-4, unless otherwise noted

[a]Value obtained from Bioavailability in Environmental Risk Assessment (Hrudey et al. 1996).

3. Screening-Level Cancer Risks and Non-Cancer Hazard Quotients

Toxicity values were used in conjunction with exposure information to evaluate the potential for cancer risks and non-cancer health hazards. Risk estimation methods are presented below.

3.1. Dermal Cancer Risk

Cancer risk for the dermal route was calculated as the product of the age-specific *DAD*s and the absorbed CSF for each chemical, as follows:

$$\textit{Dermal Cancer Risk} = DAD \times CSF_{ABS}$$

where:

DAD = Dermal Absorbed Dose (mg/kg-day)

CSF_{ABS} = Absorbed cancer slope factor $(mg/kg\text{-}day)^{-1}$

Lifetime dermal cancer risks were calculated for 2,3,7,8-TCDD and benzo[a]pyrene. The total risk accounts for dermal exposures that an individual might receive from these PB-HAPs in water plus soil over his or her lifetime (70 years).

3.2. Dermal Hazard Quotient

Dermal hazard quotient (HQ) was estimated as the ratio of age-specific *DAD*s to the absorbed RfD for each chemical, as shown below:

$$Dermal\ HQ = DAD / RfD_{ABS}$$

where:

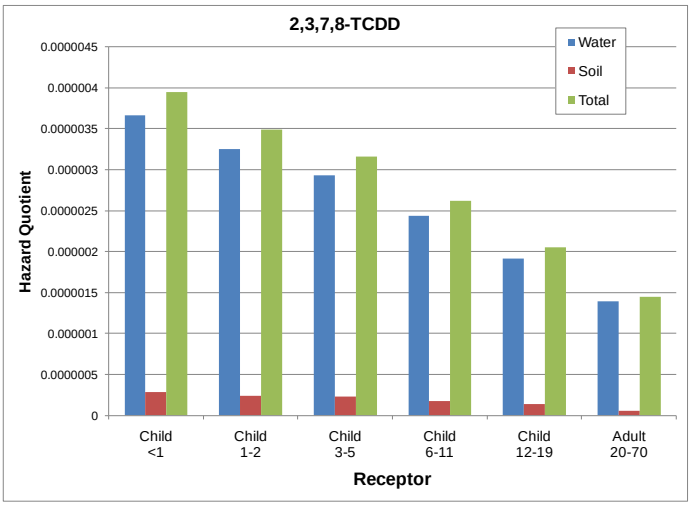
DAD	=	Dermal Absorbed Dose (mg/kg-day)
RfD_{ABS}	=	Absorbed reference dose (mg/kg-day)

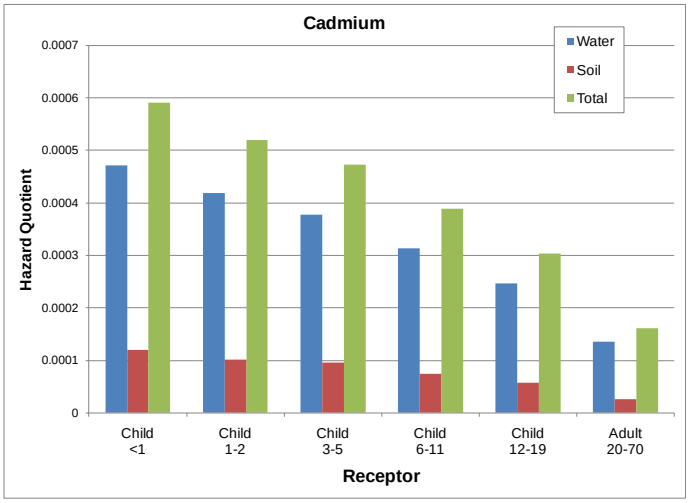
The aggregate HQ accounts for exposures that an individual in a receptor group may receive from the PB-HAP in water and soil over the exposure duration. Non-cancer hazard is not additive *across* the age groups evaluated here.

4. Dermal Screening Results

Exhibit C-5 presents a summary of estimated dermal non-cancer hazards by age group. A summary of estimated lifetime dermal cancer risks is provided in Exhibit C-6. The highest HQ value was 0.006 (representing divalent mercury exposure for children less than 1 year of age) or less. This is approximately 170 times less than the potential ingestion hazard quotients associated with the screening scenario (i.e. emissions of divalent mercury in the screening scenario resulted in an ingestion hazard quotient of 1). The highest estimated individual lifetime cancer risk associated with potential dermal exposures was 4.1E-09 for benzo[a]pyrene; this value is approximately 240 times smaller than the ingestion risk (i.e., 1E-06) estimated for the same screening threshold emission rate.

Exhibit C-5. Summary of Dermal Non-Cancer Hazards





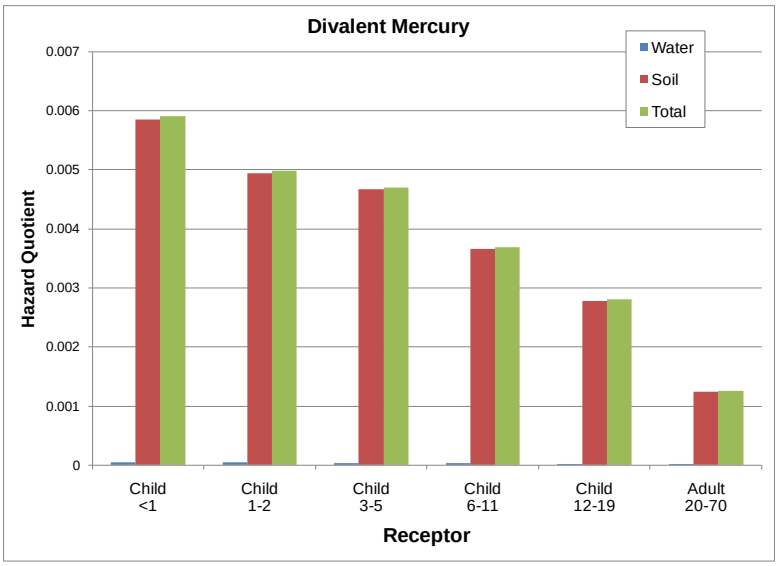


Exhibit C-6. Summary of Dermal Cancer Risks

PB-HAP	Dermal Lifetime Cancer Risk	Magnitude of Difference[a]
2,3,7,8-TCDD		
Water	2.64E-10	>3,700
Soil	1.49E-11	>67,300
Total	2.79E-10	>3,500
Benzo[a]pyrene		
Water	1.50E-09	>600
Soil	2.63E-09	>300
Total	4.12E-09	>200

[a]Represents the magnitude of difference between the estimated dermal risk and the potential ingestion risk associated with the screening scenario.

Based on these results and taking into consideration the extremely conservative nature of the dermal exposure calculations, it was assumed that it is not necessary to incorporate dermal exposures in calculating multipathway screening threshold levels. Specifically, the daily exposure durations of 0.58 hour for adults and 1 hour for children used to calculate dermal exposure from water are highly conservative and assume that the individual is bathing in surface water taken directly from a contaminated lake or is swimming in the lake for 350 days of the year. The exposure frequency of 350 days and corresponding skin surface area available for contact with contaminated soils (i.e., head, hands, arms, legs, and feet) likely also grossly overestimates dermal exposure to soil.

5. References

Cal/EPA (California Environmental Protection Agency) Office of Environmental Health Hazard Assessment (OEHHA). 2000. Air Toxics Hot Spots Program Risk Assessment Guidelines; Part IV, Exposure Assessment and Stochastic Analysis Technical Support Document. Section 6, Dermal Exposure Assessment. September. Available at: http://www.oehha.ca.gov/air/hot_spots/pdf/chap6.pdf.

Hrudey, S.E., W. Chen, and C.G. Roussex, 1996. Bioavailability in environmental risk assessment. CRC Press, Inc, Lewis publishers.

EPA (Environmental Protection Agency). 2004. Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). EPA/540/R99/005. Available at: http://www2.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-e.

EPA. 2006. Risk and Technology Review (RTR) Assessment Plan. Office of Air and Radiation. November 20. Available at: http://www.epa.gov/sab/panels/consul_risk_and_tech_assessment_plan.htm.

EPA. 2008. Child-Specific Exposure Factors Handbook. Office of Research and Development, Washington, D.C. EPA/600/R-06/096F. September. Available at: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=199243.

Attachment D. Summary of TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

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Exhibits, Attachment D

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment D-1

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Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Meteorological Parameters				
Wind direction (% of time wind blows toward the lake and farm)	In previous runs, direct deposition accounted for the bulk of chemical input onto farms and into lakes. Because wind direction is strongly correlated to direct deposition in a given location, media concentrations are potentially highly sensitive to this parameter. Also, because the percentage of time the prevailing wind blows in the direction of lakes and farms can vary considerably across locations, differences in this parameter might also result in significant changes in important environmental concentrations.	**Highly Significant**: Previous sensitivity analyses have confirmed this to be a very sensitive parameter in the Tier 1 Screening modeling set-up. Changing the fraction of time the wind blows toward the lake and farm by a factor of two corresponds to a change in the risk by a factor of two. **Low Effort to Implement:** This variable is relatively straightforward to vary in the Tier 2 screening scenarios.	**Low to Moderate:** The average fraction of time the wind blows in a given direction can be estimated for any surface meteorological station. Then, facilities can be linked to the closest surface meteorological station.	**High**
Wind speed	Wind speed can affect the location of the "peak" concentration and deposition patterns in a given model configuration, as well as the risk-distance profile.	**Highly Significant**: Previous sensitivity analyses have confirmed this to be a very sensitive parameter. However, wind speed does not vary widely across U.S. locations which could reduce its potential influence. **Low Effort to Implement:** This variable is relatively straightforward to vary in the Tier 2 screening scenarios.	**Low to Moderate:** The annually-averaged wind speed can be estimated for any surface meteorological station. Then, facilities can be linked to the closest surface meteorological station.	**High**

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Precipitation	Chemicals for which wet vapor or wet particle deposition processes are important are likely to be sensitive to the assumed level of precipitation.	**Highly Significant**: Previous sensitivity analyses have indicated a relatively high sensitivity of risk to precipitation for most PB-HAPs (PAHs, cadmium, and mercury). **Moderate Effort to Implement:** In implementing changes in precipitation in TRIM, care must be taken to also preserve the overall water balance in the model.	**Low to Moderate:** The annually-averaged precipitation rate can be estimated for the subset of surface meteorological stations that capture rainfall data. Then, facilities can be linked to the closest surface meteorological station with available data.	**High**

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Mixing height	Greater mixing heights increase the dispersion of pollutants in the atmosphere and consequently reduce deposition to the ground in the areas around the stack. This is likely to be a highly sensitive parameter if there is a sizeable variation in mixing heights between facilities.	**Highly Significant**: Previous sensitivity analyses have shown risk to be very sensitive to mixing height. **Low Effort to Implement:** This variable is relatively straightforward to vary in the Tier 2 screening scenarios.	**Moderate to High:** Mixing height estimates are available for upper air meteorological stations, and this set of stations is more limited than the set of surface meteorological stations. Each surface station can be linked to the closest upper air station to estimate the average mixing height. Then, facilities can be linked to the closest surface meteorological station. The relative uncertainty in mixing height for a given facility is high, given diurnal variations in mixing height and the smaller number of upper air stations.	**High**

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Configurational Parameters				
Distance of lake from stack	Deposition is known to decrease with distance from stack, although this relationship also depends on meteorological parameters such as wind speed and wind direction.	**Significance Difficult to Determine:** Limited results from previous TRIM model runs show an inconclusive relationship between risk and distance from stack, possibly as a result of limited statistical power. Some studies in the literature show a definite decreasing risk gradient with distance but others report too many confounding factors to isolate the precise relationship. **Moderate Effort to Implement:** This variable requires updates to the layout coordinates and requires more effort to vary in the Tier 2 screening scenarios than the meteorological parameters.	**Low:** The lakes within a given radius of each facility can be found using ArcGIS™.	**High**
Distance of farm from stack	Deposition is known to decrease with distance from stack, although this relationship also depends on meteorological parameters such as wind speed and wind direction.	**Significance Difficult to Determine:** Limited results from previous TRIM model runs show an inconclusive relationship between risk and distance from stack, possibly as a result of limited statistical power. Some studies in the literature show a definite decreasing risk gradient with distance but others report too many confounding factors to isolate the precise relationship. **Moderate Effort to Implement:** This variable requires updates to the layout coordinates and requires more effort to vary in the Tier 2 screening scenarios than the meteorological parameters.	**High:** Although the distance to the farm will likely affect risk, it is difficult to determine the precise land parcels near each facility that are actually used for farming now or in the future.	**Medium**

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Watershed: lake area ratio	A higher watershed:lake area ratio potentially increases the chemical input of water-soluble or particle-attached chemicals into the lake. But the associated higher flush rate will likely reduce this effect.	**Significance Difficult to Determine**: Changes in the watershed to lake ratio affect risk, but the interaction depends on other variables involved in the water balance. **Moderate Effort to Implement:** In implementing changes in the watershed:lake ratios in TRIM, care must be taken to also preserve the overall water balance in the model.	**High:** The portion of land serving as a watershed to a particular lake is difficult to determine.	**Medium**
Area and depth of lake	A higher lake area would capture more deposition but this effect might be counterbalanced by the ensuing larger volume of water, which reduces chemical concentration. Similarly, a deeper lake would also reduce concentrations, but this effect might be counterbalanced by the ensuing lower flush rates at a constant level of precipitation/runoff.	**Significance Difficult to Determine**: The impact of these parameters is inconclusive based on current studies using the TRIM model. **Moderate Effort to Implement:** The lake area variable requires updates to the layout coordinates and requires more effort to vary in the Tier 2 screening scenarios than the meteorological parameters. In implementing changes in these variables in TRIM, care must be taken to also preserve the overall water balance in the model.	**High:** While the area of lakes near a facility can be determined using GIS, the depth cannot.	**Medium**

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Physical Parameters				
Flush rate	A higher flush rate out of the lake would result in a higher rate of chemical output from the lake, assuming constant inflow and volume.	**Significance Difficult to Determine**: The impact of this parameter is inconclusive based on current studies using the TRIM model. **Moderate Effort to Implement:** In implementing changes in the flush rate in TRIM, care must be taken to also preserve the overall water balance in the model.	**High:** The flush rate of a lake cannot be determined easily for any lake found near a facility. In addition, erosion rates, watershed information, and lake depth needed to estimate the flushing rate are not readily available.	**Medium**
Runoff rate and fraction	A higher runoff rate (or fraction) would likely result in greater chemical input into the lake for some chemicals but also potentially a higher flush rate out of the lake.	**Significance Difficult to Determine**: The impact of this parameter is inconclusive based on current studies using the TRIM model. **Moderate Effort to Implement:** In implementing changes in the runoff rate and fraction in TRIM, care must be taken to also preserve the overall water balance in the model.	**High:** As with the flush rate, the runoff rate and fraction for any lake near a facility cannot be readily determined.	**Medium**
Erosion rate and fraction	A higher erosion rate would likely result in greater chemical input into the lake for particle-bound chemicals. It would also result in greater chemical transport onto farmlands, but this might be counterbalanced by equally greater erosion off farmland.	**Highly Significant**: Previous analyses have shown risk to be sensitive to this parameter for some chemicals. **Moderate Effort to Implement:** In implementing changes in the erosion rate and fraction in TRIM, care must be taken to also preserve the overall water balance in the model.	**High:** As with the flush rate, the erosion rate and fraction for any lake near a facility cannot be readily determined.	**Medium**

Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM	Assessment of Parameter Significance and Ease in Implementation	Uncertainty in Site-Specific Data for Facilities	Priority for Inclusion
Chemical Parameters				
Methylation/ demethylation rates (Hg)	For Hg, methylation and demethylation rates in lake sediment and surface water are potentially sensitive parameters affecting risk. A literature survey has indicated a relatively high range for rate constants describing these processes.	**Highly Significant**: Previous analyses run in TRIM have confirmed the high sensitivity of these parameters for Hg. **Low Effort to Implement:** This variable is relatively straightforward to vary in the Tier 2 screening scenarios.	**High:** The specific methylation / demethylation rates for mercury in the vicinity of a specific facility cannot be readily determined.	**Low**
Total phosphorus levels in the lake	The total phosphorus content of a lake is used as part of the TRIM.FaTE parameterization process to estimate the biomass content of different trophic levels. These biomass levels affect the biomagnification of chemicals up the food chain and potentially risk to human consumers of fish.	**Not Significant**: Previous analyses have shown limited sensitivity to total phosphorus levels. This is likely because the empirical equations predicting biomass in each trophic level depend in similar ways on the level of total phosphorus. So changes in total phosphorus do not significantly affect the ratio of biomass between the different trophic levels. **Low Effort to Implement:** This variable is relatively straightforward to vary in the Tier 2 screening scenarios.	**High:** The total phosphorus levels in lakes near a specific facility cannot be readily determined.	**Low**

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Attachment E. Analysis of Lake Size and Sustainable Fish Population

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1. Introduction

Identifying the smallest size of a lake that might maintain self-sustaining populations of fish from trophic levels (TL) 3 and 4 and is sufficient to support at least one fisher at a specified fish ingestion rate requires consideration of many factors. Some factors depend on assumptions about the behavior of fishers who consume fish from a lake (see Section 2 below). Other factors depend upon the general biology of fish populations in North American ecoregions (see Section 3). Based on evaluation of these factors, a set of assumptions was developed to support the estimation of minimum lake sizes that are needed to sustain a particular total human ingestion rate in grams/day (see Section 4). Then, equations were developed (see Section 5) that were used to create Exhibit 26 (in Section 3.4 of the main body of the report), which was used to determine the threshold lake size of 25 acres.

2. Fisher Behavior

Several assumptions regarding fisher behavior are important for estimating a minimum lake size that is fishable. The first is a conservative assumption that fishers (and their family members) consume about 50:50 top carnivore fish from both the benthos and from the water column. Benthic carnivores (BC), such as catfish and chub that consume benthic invertebrates and small benthic fish, can grow to large sizes (e.g., 2 kg). Assuming a diet of 50 percent benthic invertebrates and 50 percent small benthic fish (e.g., young of the year that feed on algae or detritus), the BC fish category would represent trophic level (TL) 3.5. Pelagic piscivores—water column carnivores (WCC)—include species such as largemouth bass, lake trout, pickerel, and walleye. The WCC are modeled as TL 4, with 100 percent of their diet comprised of water column omnivores (WCO, e.g., pan fish such as bluegill and white perch), and the diet of the WCO is assumed to be 100 percent minnow-sized fish that feed on zooplankton and algae . The assumption of 50:50 WCC and BC consumption is conservative, because smaller, pan fish, are not included. Although fishers might prefer to catch and consume the pelagic (TL4) game fish species, their generally lower abundance compared with fish that also consume benthic invertebrates dictates that fishers will more often capture the benthic (TL3.5) carnivores. Some TL2 (herbivorous) fish such as carp attain “catchable” size, but they generally are not popular fish for consumption and are not considered here. .

A second assumption is that fishers and their family members consume only the fillet portion of a fish. According to Ebert et al. (1993), the edible fraction of fish as a proportion of total fresh body weight is 0.4 for salmon, 0.78 for smelt, and 0.3 for all other species. EPA recommends use of 0.30 for the consumable fraction of fish (USEPA, 1989). For this assessment, a 0.33 edible fraction for TL4 fish was assumed. That factor is roughly one-third, which we considered preferable to 0.30 to account for some proportion of salmon likely in the diet. This factor is used in the lake size analysis to estimate total fish biomass required to support specified human fish consumption rates.

A third assumption relates to ingestion rates of the fisher or fisher family. Fish ingestion rates used for the purpose of the Tier 2 assessment are the same as those in Tier 1 and are consistent with subsistence fisher ingestion rates (see Exhibit 18).

The final assumption is that the lake must support a sustainable fishery despite fish harvesting by humans; in other words, the lake shouldn’t be “fished out” by the harvest rate required to meet the subsistence fisher fish ingestion rate. The productivity of any particular fishery (local population of a species of fish) and the proportion of adult fish that can be harvested for human consumption are difficult values to estimate, and models to predict sustainable harvests of different fisheries are numerous and complex. Species-specific parameters of key to such models include fecundity with age and size; survivorship of eggs, fry, and juveniles to sexual

maturity (recruitment); natural predation pressures; and temporal variation in food availability. For the purpose of this analysis, simplifying assumptions are required. In the analysis by Håkanson and Boulion (2004), which included a survey of 122 lakes, the authors noted that a typical loss from fishing by birds, mammals, and humans would be approximately 10 percent of the fish biomass in the prey fish compartment (TL3) and 10 percent of the biomass in the predator fish compartment (TL4). The authors also found that as overall lake productivity increased, the biomass of prey (TL3) fish increased more rapidly than the biomass of predator (TL4) fish. For our lake size analysis, we assumed that fishers can harvest 10 percent of the biomass of pelagic WCC fish without diminishing the fish population size.

3. Fish Biology

Fish life histories also are key to estimating the minimum surface area of a pond or lake that could support a sustainable fish population of WCC. The productivity and trophic structure of fish communities in ponds and lakes across the United States are varied. Thus, any set of assumptions is unlikely to all hold true at any given location. Nonetheless, three factors are important to any estimate of a minimum lake surface area for sustainable pelagic TL4 fishing: the general productivity of a lake (expressed as grams of fish wet weight per meter squared, g ww/m^2); the maximum likely proportion of the total fish biomass in a lake that is comprised of the top trophic level fish; and the minimum viable population (MVP) size required for the fish species to be self-sustaining in the short term (for at least a few decades).

3.1. Lake Productivity

The general productivity of a lake depends on many factors, including latitude, seasonal temperatures, and nutrients supporting the base of the food web. For lakes at approximately the same latitude in the same climate, nutrients play a key role in the total fish biomass that a lake might support. In a regression analysis of data on total phosphorus (TP) and fish biomass for 31 lakes across North America, Europe, and Russia, Nürnberg (1996) summarized the "limits" among three TP-defined lake trophic status categories with respect to total fish wet weight biomass per unit area:

Oligo-meso (TP = 10 µg/L)	=	1.9 g ww/m^2
Meso-eutro (TP = 30 µg/L)	=	3.7 g ww/m^2
Eutro-hypereutro (TP = 100 µg/L)	=	8.5 g ww/m^2

Nürnberg (1996) also summarized total fish biomass limits from Bachmann et al. (1996) for the same lake trophic status categories based on a sample of 60 lakes in Florida:

Oligo-meso (TP = 10 µg/L)	=	7.4 g ww/m^2
Meso-eutro (TP = 30 µg/L)	=	10.6 g ww/m^2
Eutro-hypereutro (TP = 100 µg/L)	=	15.6 g ww/m^2

As might be expected, for the same TP concentrations, standing fish biomass per unit area in the Florida lakes is two to three times higher than standing fish biomass for more northerly lakes with shorter growing seasons.

Hanson and Legget (1982) estimated the relationship between TP and standing stock of fish using a regression model based on samples from 21 lakes ranging in surface area from 0.1–25,000 hectares (~0.25–62,000 acres) and located between 0° and 56° N latitude and

121° E to 122° W longitude. Their linear regression relating TP to total fish standing biomass (B) had a correlation coefficient (r^2) of 0.84:

$$B = 0.792 + 0.072\ (TP)$$

where:

B = total fish biomass (kg/hectare)

TP = total phosphorous (µg/L)

The regression model of Hanson and Legget (1982) predicted total fish biomass densities in lakes of 3.0–9.5 g ww/m^2 for TP concentrations ranging from 10–50 µg/L for oligo-mesotrophic to mid-range eutrophic lakes. Another regression model from Hoyer and Canfield (1991) predicted fish biomass densities in streams of 2.6–6.6 g ww/m^2 over the same range of TP concentrations.

In general, for very small lakes, relatively low fish productivity is likely. For example, Demers et al. (2001) found fish standing biomass values of 2.73 and 3.81 g ww/m^2 in two lakes of 27 and 22 acres (11 and 9 hectares), respectively, in south-central Ontario. Brönmark and Weisner (1996) reported on aquatic communities from a sample of 44 small ponds in southern Sweden (most were less than 5 hectares ≈ 12 acres). They found no fish in 5 of the smaller ponds (mean surface area of 0.20 ± 0.097 acres)—which also exhibited lower TP concentrations than the larger ponds—and no piscivorous fish in another 11 of the 44 ponds (mean surface area of 0.46 ± 0.27 acres). For the 28 ponds with piscivorous (TL4) fish present, the mean pond surface area was 1.4 (±1.3 SD) acres.

Scientists have also examined the relationship between TP and total fish biomass in reservoirs. Yurk and Ney (1989) examined the relationship between TP and standing stock of fish in 22 reservoirs in southern Appalachia sampled in 1973. Their logarithmic regression relating TP to total fish standing biomass (B) used the following equation and had an r^2 of 0.75:

$$Log_{10}\ (B) = 1.07 + 1.14 \times Log_{10}\ (TP)$$

Use of the equations from Hanson and Legget (1982) and Yurk and Ney (1989) yielded similar predications of total fish biomass at low to intermediate TP concentrations. At low TP (e.g., 10 µg/L), predictions of total fish biomass were 3.0 g ww/m^2 (Yurk and Ney, 1989) and 1.6 g ww/m^2 (Hanson and Legget, 1982); at high TP (e.g., 100 µg/L), fish biomass predicted by the two models were 15.5 and 22.4 g ww/m^2, respectively.

Ideally, one would have data indicating TP levels in lakes in the vicinity of facilities for a Tier 2 assessment. Such data, however, are rarely readily available. For purposes of the screening assessment, therefore, we assume that fish productivity per unit area is independent of lake size over a wide range of lake sizes and that TP levels are unknown.

Leidy and Jenkins (1977) reported analyses of several large data sets to support modeling of fish productivity and carrying capacity in reservoirs across the United States for the National Reservoir Research Program. The analyses included studies of fish standing biomass by species in 61 reservoirs across the midwestern and eastern United States sampled at different times between 1952 and 1975. Only reservoirs of at least 500 acres (202 hectares) in size were included, with some exceeding 65,000 acres (in the Missouri drainage basin). Considering all 61 reservoirs, the mean biomass density of fish was 41.3 (± 30.4 SD) g ww/m^2. The minimum

and maximum total fish biomass densities were 3.2 and 133.2 g ww/m^2, respectively, and the median value was 30.9 g ww/m^2. Reservoirs typically have large drainage basins, which in some areas can receive excess TP from large expanses of agricultural areas.

In summary, the fish productivity in lakes and reservoirs can vary by more than three orders of magnitude. The reservoirs surveyed by Leidy and Jenkins (1977) in general were much larger (and were often more shallow and nutrient rich) than the natural lakes surveyed by others discussed above. The mean standing fish biomass of approximately 41.3 g ww/m^2 from the reservoir survey is likely to be higher than a mean value for representative samples of natural lakes in the United States. For the purpose of estimating the minimum lake size that would support a sustainable WCC fishery, we rounded that value down to a single significant digit of 40 g ww/m^2 as the upper limit for total fish biomass in a lake. That standing biomass is higher than predicted by the regression models of Hanson and Legget (1982), Yurk and Ney (1989), and Nürnberg (1996) at a high total phosphorus of 100 µg/L (where phosphorous is the limiting nutrient). Less productive lakes would support fewer fish per unit area, and, therefore, would have to be larger to support a specified fish ingestion rate.

3.2. Proportion of Fish Biomass by Trophic Level

As indicated previously, for the Tier 2 assessment, the proportion of fish in a fisher's diet that consists of WCC (TL4) and BC (TL3.5) is assumed to be 50:50 by biomass (not numbers) for lakes that support the four trophic levels. In smaller lakes, TL4 fish are likely to be missing or rare, with TL3 fish in the water column (e.g., sunfish) being the highest trophic level supported by the primary productivity (algal/plant production) in some lakes. As a "rule of thumb" in ecology, 10 percent or less of the energy produced at one trophic level usually can be converted to biomass in the next trophic level (i.e., approximately 90 percent loss of energy) per trophic step. However, with different species having different energy assimilation efficiencies and with smaller species generally having higher turnover rates than larger species, the 10 percent energy rule does not necessarily translate into a standing biomass pyramid of similar proportions. In this section, the proportion of fish (based on biomass) that might be expected in the WCC and the BC fish compartments relative to total standing fish biomass are examined assuming that the lake is large enough to support WCC (pelagic TL4 fish).

Examination of several studies of fish biomass by trophic level indicated that top trophic level fish might comprise up to 20 percent of the standing fish biomass in many locations. Ploskey and Jenkins (1982) estimated that piscivorous fish, both those that are generally free-swimming or pelagic (e.g., pike, gar, walleye) and those that rest and forage primarily in the benthos (e.g., various species of catfish, suckers) comprise 22 percent of the total fish biomass in DeGray Lake, Arkansas (averaged across several years). Leidy and Jenkins (1977) estimated that 18 percent of the fish biomass across the 61 reservoirs they examined was piscivorous (minimum of 14 percent and maximum 24 percent). Demers et al. (2001) categorized 2 percent and 15 percent of the total fish biomass in two small lakes of 27 and 22 acres in size, respectively, as piscivorous/benthivorous fish (e.g., largemouth bass, creek chub); primary benthivores (e.g., catfish, suckers) dominated at >70 percent in both lakes.

One of the more recent food web models for freshwater lakes is that of Håkanson and Boulion (2004). They designed their model to predict productivity and standing crop of prey and predatory fishes in lakes of northern Europe. The authors acknowledged that fish feeding patterns are complicated by the fact that fish change their feeding preferences as they age. Some fish species consume zooplankton or benthic invertebrates in their first year, and switch to small fish and then to larger fish as they mature and grow in size.

Håkanson and Boulion (2004) created a "distribution coefficient" to indicate what proportion of the total fish biomass in a lake is prey versus predatory fish. Based on data from 122 lakes in Europe and North America, they concluded that 27 percent by biomass is a "normal" portion of predatory fish in a balanced system. They noted further, however, that for eutrophic lakes with TP levels >100 µg/L, the proportion of fish represented by piscivores declines to less than 20 percent. The piscivores included both benthic and pelagic species. We note that most benthic piscivores also consume benthic macroinvertebrates.

Based on the information above, the top trophic level fish are assumed to comprise 21 percent of the total fish biomass. With the bulk of productivity in lakes originating from detritus in the benthos, the total biomass of strictly pelagic game fish is expected to be less than that of benthic fish. Therefore, for purpose of this lake size analysis, the piscivorous/benthivorous fish were separated into two compartments, with 17.5 percent of the total fish biomass in a benthic carnivore (TL3.5 or BC) compartment and 3.5 percent of the total in a pelagic piscivore (WCC) compartment. Thus, the TL4 fish, when present, represent the limiting compartment for fish harvesting and consumption.

3.3. Minimum Viable Population Size

The final step in estimating the minimum lake size that can support sustainable fishing of its WCC fish species is to invoke the concept of minimum viable population (MVP) size. MVP is a concept used frequently in conservation biology for animals and is defined as the smallest population that will persist for a specified duration (e.g., 100 years) with a given probability (e.g., 95 percent). MVP for any given species and location depends on many attributes of the species biology (e.g., body size, reproductive rate, home range size, corridors between populations, variability in environmental characteristics that impact fecundity and survival). At lower numbers, the likelihood of population extinction increases due to environmental and demographic stochasticity (Menzie et al., 2008). As for fisheries biology, entire text books have been dedicated to applied population ecology with population simulations incorporating demographic and life-history characteristics, spatial separation of habitat patches and metapopulations, the probability of local catastrophes, genetic variation (e.g., drift), and other factors with predictions of time-to-extinction or probability of extinction within specified time periods (e.g., Soulé, 1987; Akçakaya et al., 1999). Consideration of such models in population-level ecological risk assessment has begun, but faces many challenges (Barnthouse et al., 2008). Moreover, that level of effort is beyond the resources available for screening-level assessments.

Much of the initial work on MVP investigated the genetic minima required for short-term survival, continuing adaptation to environmental change, and ultimately evolution. Inbreeding has been considered the primary threat to short-term survival and genetic drift the principal threat to losing the genetic variation required for adaptation (Shaffer, 1987). Several analyses (Senner, 1980; Franklin, 1980; Soulé, 1980; Frankel and Soulé, 1981; Lande and Barrowclough, 1987) have led to the conclusion that minimum effective population sizes on the order of 50 are required for short-term survival (e.g., several generations, decades), while effective population sizes on the order of 500 are necessary to provide adequate genetic variation for continuing adaptation over the long term (e.g., tens of generations, centuries for some animals) (Shaffer, 1981; 1987). Effective population size, N_e, is a measure of the rate of genetic drift (loss of genetic diversity or inbreeding), and its definition generally depends on the population in question (Rieman and Allendorft, 2001). N_e can be estimated mathematically based on stochastic behavior of gene frequencies in a diploid population. Simple models assume a fixed population size, constant fecundity, specified sex ratio, and no overlap between generations (see studies cited in NRC, 1986). For animals with 50:50 sex ratios, the effective population size is essentially the same as the actual breeding adult population size (Ewens et al., 1987). One of the most extensive

population viability analyses in the United States has been conducted on the spotted owl (Boyce, 1993). Given the number and complexity of factors that influence MVP, however, including the definitions of time horizon (e.g., 100 years) and probability of survival (e.g., 95 percent), population biologists caution against using a "rule of thumb" for MVP across circumstances (Ewens et al., 1987).

Note that the MVP is appropriate for a single species of fish, not for generic categories of fish such as WCC or TL4. For this Tier 2 assessment, the MVP of 50 associated with short-term population survival was assumed for a TL4 fish species isolated in a lake. In reality, short-term extirpations from a lake can be countered by purposeful introductions from other lakes or during flooding events. Thus, an MVP of 500 was not considered necessary for game fish in lakes.

4. Summary of Assumptions for the Lake Size Analysis

The following assumptions were used in processing lake data for the Tier 2 assessment and in estimating the relationship between fish ingestion and sustainable harvest rates and lake size (see Section 3.4.1 of Attachment B).

1. Piscivorous fish (WCC and BC), when present, comprise approximately 21 percent of the standing biomass of fish (ignoring seasonal changes). The BC fish represent 17.5 percent of the standing fish biomass; WCCs account for 3.5 percent of the total fish biomass. Thus, WCC fish, when present, represent the limiting compartment for fish harvesting and consumption.
2. Humans can harvest 10 percent of the biomass of a fish compartment without threatening the population due to overharvesting.
3. The MVP size for a single WCC species is at least 50 adult fish for a local population to survive over the short term (more than a decade).
4. Only 33 percent of the fish is edible fillet muscle.

5. Equations Used to Determine Lake Fish Populations

The standing biomass of WCC (TL4) fish supported in Lake X can be calculated as the total standing biomass of fish (Total SB) multiplied by 0.035, based on the assumption that TL4 fish represent approximately 3.5 percent of the standing biomass in Lake X.

$$WCC\ SB = Total\ SB\ x\ Fraction\ WCC \qquad \textit{(Equation 1)}$$

where:

WCC SB = Standing biomass of WCC fish (g wet weight [ww]/m^2) in Lake X

Total SB = Total standing biomass of fish (g ww/m^2) in Lake X

Fraction WCC = Fraction of WCC fish in Lake X (i.e., 0.035)

Using WCC SB and the size of Lake X (Lake Size), the total number of WCC fish supported in Lake X can be calculated using Equation 2 below.

$$No.WCC = \frac{Lake\ Size\ x\ WCC\ SB\ x\ CF}{BW_a} \qquad \textit{(Equation 2)}$$

where:

No. WCC = Total number of WCC fish in Lake X

Lake Size = Size of Lake X (acres)

WCC SB = Standing biomass of WCC fish (g ww/m^2; from Equation 1)

CF = 4047 (unit conversion factor m^2/acre)

BW_a = Body weight of adult TL4 fish (2000 g; assumed)

The likely annual productivity of WCC fish (kg/year) in Lake X can be estimated using Equation 3.

$$Productivity\ WCC = \frac{Lake\ Size\ x\ WCC\ SB\ x\ CF1}{CF2} \quad \textit{(Equation 3)}$$

where:

Productivity WCC= Likely annual productivity of WCC fish in Lake X (kg/year)

Lake Size = Size of the Lake X (acres)

WCC SB = Standing biomass of WCC fish (g ww/m^2; from Equation 1)

CF1 = 4047 (unit conversion factor 1, m^2/acre)

CF2 = 1000 (unit conversion factor 2, g/kg)

The maximum fish ingestion rate (g/day) for WCCs plus BCs associated with sustainable fishing can be predicted using Equation 4. It assumes that the fishers consume 50 percent WCC and 50 percent BC, represented by the factor of 2 in Equation 4.

$$Max\ Sustain\ IR\ (BC + WCC) = \frac{2\ x\ Productivity\ WCC\ x\ FF\ x\ HF\ x\ CF1}{CF2} \quad \textit{(Equation 4)}$$

where:

Max Sustain IR (BC + WCC) = Predicted maximum sustainable ingestion rate for BC and WCCfish (g/day)

Productivity WCC = Likely annual productivity of WCC fish in Lake X (kg/year; from Equation 3)

FF = Fillet fraction; represents the assumed edible portion of fish (0.33; unitless)

HF = Annual harvest fraction (0.10; unitless)

CF1 = 1000 (unit conversion factor 1, g/kg)

CF2 = 365 (unit conversion factor 2, days/year)

6. References

Akçakaya, H.R., Burgman, M.A., and Ginzburg, L.R. 1999. Applied Population Ecology: Principles and Computer Exercises using RAMAS EcoLab. Sunderland, MA: Sinauer Associates, Inc. Publishers.

Bachmann, RW; Jones, BL; Fox, DD; Hoyer, M; Bull, LA; Canfield, DE. 1996. Relations between trophic state indicators and fish in Florida (USA) lakes. Canadian Journal of Fisheries and Aquatic Sciences. 53:842-855.

Barnthouse, L.W., Munns, W.R. Jr., and Sorensen, M.T. 2008. Population-Level Ecological Risk Assessment. Boca Raton, FL: CRC Taylor & Francis Group; Pnesacola, FL: Society of Environmental Toxicology and Chemistry (SETAC).

Boyce, M.S. 1993. Population viability analysis: adaptive management for threatened and endangered species. In: Wildlife Management Institute, Transactions of the 58th North American Wildlife and Natural Resources Conferences. Proceedings WWRC-93-19, pp. 520-527.

Brönmark, C. and S.E.B. Weisner. 1996. Decoupling of cascading trophic interactions in a freshwater benthic food chain. Oecologia 108: 534-541.

Demers, E., McQueen, D.J., Ramcharan, C.W., and A. Perez-Fuentetaja. 2001. Did piscivores regulate changes in fish community structure? Advanc. Limnol. 56: 49-80.

Ebert, E., N. Harrington, K. Boyle, J. Knight, and R. Keenan. 1993. Estimating consumption of freshwater fish among Maine anglers. N. Am. J. Fisheries Manage. 13: 737-745.

Ewens, W.J., Brockwell, P.J., Gani, J.M., and Resnick, S.I. 1987. Minimum viable population sizes in the presence of catastrophes. In: M.E. Soulé (ed.) Viable Populations for Conservation. United Kingdom, Cambridge: Cambridge University Press, pp. 59-68.

Frankel, O.H., and Soulé, M.E. 1981. Conservation and evolution. United Kingdom, Cambridge: Cambridge University Press.

Franklin, I.R. 1980. Evolutionary change in small populations. In: M.E. Soulé and B.A. Wilcox (eds.) Conservation Biology: An Evolutionary-Ecological Perspective. Sunderland, MA: Sinauer Associates; pp. 135-150. As cited by Shaffer, 1987.

Håkanson, L. and V.V. Boulion. 2004. Modeling production and biomasses of prey and predatory fish in lakes. Hydrobiologia 511: 125–150.

Hanson, J.M., and W.C. Leggett. 1982. Empirical prediction of fish biomass and yield. Can. J. Fish. Aquat. Sci. 39: 257-263.

Hoyer, M.V., and D.E. Canfield, Jr. 1991. A phosphorus-fish standing crop relationship for streams? Lake Reserv. Manage. 7: 25-32.

Lande, R., and Barrowclough, G.F. 1987. Effective population size, genetic variation, and their use in population management. In: M.E. Soulé (ed.) Viable Populations for Conservation. United Kingdom, Cambridge: Cambridge University Press, pp. 87-123.

Leidy, G.R., and Jenkins, R.M. 1977. The development of fishery compartments and population rate coefficients for use in reservoir ecosystem modeling. Contract Report Y-77-1 prepared

by the National Reservoir Research Program, U.S. Fish and Wildlife Service, for the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, USA.

Menzie, C., Bettinger, N., Fritz, A., Kapustka, L., Regan, H., Moller, V., and Noel, H. 2008. Population protection goals. In: Barnthouse, L.W., Munns, W.R. Jr., and Sorensen, M.T. 2008. Population-Level Ecological Risk Assessment. Boca Raton, FL: CRC Taylor & Francis Group; Pnesacola, FL: Society of Environmental Toxicology and Chemistry (SETAC), pp. 41-68.

NRC (National Research Council). 1986. Ecological Knowledge and Environmental Problem Solving. Committee on the Applications of Ecological Theory to Environmental Problems. Washington, DC: National Academies of Science Press.

Nürnberg, G.K. 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Journal of Lake and Reservoir Management 12(4): 432-447.

Ploskey, G.R., and R.M. Jenkins. 1982. Biomass model of reservoir fish and fish-food interactions, with implications for management. North American Journal of Fisheries Management 2(2): 105-121.

Rieman, B.E., and Allendorf, F.W. 2001. Effective population size and genetic conservation criteria for bull trout. N. A. J. Fisheries Manage. 21:756-764.

Senner, J.W. 1980. Inbreeding depression and the survival of zoo populations. In: M.E. Soulé and B.A. Wilcox (eds.) Conservation Biology: An Evolutionary-Ecological Perspective. Sunderland, MA: Sinauer Associates; pp. 209-244. As cited by Shaffer, 1987.

Scaffer, M.L. 1981. Minimum population sizes for species conservation. Bioscience 31: 131-134.

Shaffer, M. 1987. Minimum viable populations: coping with uncertainty. In: M.E. Soulé (ed.) Viable Populations for Conservation. United Kingdom, Cambridge: Cambridge University Press, pp. 69-86.

Soulé, M.E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. In: M.E. Soulé and B.A. Wilcox (eds.) Conservation Biology: An Evolutionary-Ecological Perspective. Sunderland, MA: Sinauer Associates; pp. 151-170. As cited by Shaffer, 1987.

Soulé, M.E. (ed.) 1987. Viable Populations for Conservation. United Kingdom, Cambridge: Cambridge University Press.

USEPA (US Environmental Protection Agency). 1989. Assessing human health risks from chemically contaminated fish and shellfish: a guidance manual. EPA-503/8-89-002. Washington, DC.

Yurk, J.J., and J.J. Ney. 1989. Phosphorus-fish community biomass relationships in southern Appalachian reservoirs: can lakes be too clean for fish? Lake and Reservoir Management 5(2): 83-90.

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