Residual Risk Assessment for the Polymers & Resins I Neoprene Production Source Category in Support of the 2024 Risk and Technology Review Final Rule

EPA's Office of Air Quality Planning and Standards
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AirToxScreen	Air Toxics Screening Assessment
AERMOD	American Meteorological Society/EPA Regulatory Model
AEGL	Acute exposure guideline level
ASTDR	US Agency for Toxic Substances and Disease Registry
CalEPA	California Environmental Agency
CTE	Central Tendency Estimate
ERPG	Emergency Response Planning Guideline
HAP	Hazardous Air Pollutant(s)
HEM	Human Exposure Model
HI	Hazard index
HQ	Hazard quotient
IRIS	Integrated Risk Information System
MACT	Maximum Achievable Control Technology
MIR	Maximum Individual Risk
MOA	Mode of action
NAC	National Advisory Committee
NAAQS	National Ambient Air Quality Standards
NATA	National Air Toxics Assessment
NEI	National Emissions Inventory
NPRM	Notice of Proposed Rulemaking
PB-HAP	Persistent and Bioaccumulative – HAP
PAH	Polycyclic aromatic hydrocarbon
POM	Polycyclic organic matter
REL	Reference exposure level
RfC	Reference concentration
RfD	Reference dose
RTR	Risk and Technology Review

TOSHI	Target-organ-specific hazard index
TRIM	Total Risk Integrated Methodology
TRIM.FaTE	TRIM Environmental Fate, Transport, and Ecological Exposure
URE	Unit risk estimate

Executive Summary

This document describes the risk assessment that the U.S. Environmental Protection Agency (EPA) conducted to assess the human health and environmental risks posed by hazardous air pollutant (HAP) emissions from the Neoprene Production Industry. Section 112 of the Clean Air Act (CAA) establishes a two-stage regulatory process for addressing emissions of HAP from stationary sources. In the first stage, EPA must promulgate technology-based national emission standards for hazardous air pollutants (NESHAP) for categories of sources. EPA has completed this stage. For NESHAP that require maximum achievable control technology (MACT) standards, EPA is required to complete a second stage of the regulatory process – the residual risk review. In this second stage, EPA is required to assess the health and environmental risks that remain after implementation of the standards. EPA must also review each of the technology-based standards at least every eight years and revise them, as necessary, taking into account developments in practices, processes and control technologies. If appropriate based on the results of the risk and technology reviews, the Agency will revise the rule. For efficiency, the Agency includes the analyses in the same regulatory package and calls the rulemakings the Risk and Technology Review (RTR).

The specific source category results contained in this document are from the Neoprene Production Industry risk and technology review in support of EPA's 2024 final rule, *New Source Performance Standards for the Synthetic Organic Chemical Manufacturing Industry and National Emission Standards for Hazardous Air Pollutants for the Synthetic Organic Chemical Manufacturing Industry and Group I & II Polymers and Resins Industry*. The EPA is amending the NESHAP for this source category, under 40 CFR part 63, subpart U, to address the results of the RTR review of the MACT standards, required under Section 112. Neoprene Production is part of the Group I Polymers & Resins source categories. The Neoprene Production source category includes facilities that produce neoprene, which is a polymer of chloroprene. Neoprene was originally developed as an oil-resistant substitute for natural rubber, and its properties allow its use in a wide variety of applications, including wetsuits, gaskets and seals, hoses and tubing, plumbing fixtures, adhesives, and other products. Emission points include process vents, maintenance vents, wastewater, storage tanks, transfer racks, and equipment leaks. We determined that that there is only one facility in the Neoprene Production source category operating in the U.S. The total emissions of HAP for this facility are approximately 21 tons per year. The reported HAP emitted in the largest quantity are chloroprene, toluene, hydrochloric acid, methylene chloride, chloroform, and n-hexane. Emissions of these 6 pollutants make up over 99 percent of the total HAP emissions by mass. There are no reported emissions of persistent and bioaccumulative HAP (PB-HAP) from this facility. Emissions of environmental HAP are composed of hydrochloric acid (HCl).

The below table summarizes the results of the risk assessment for this facility in the Neoprene Production Source Category. The results of the chronic inhalation cancer risk assessment are estimated using modeling, which has been EPA's standard approach for residual risk analyses under CAA section 112 (f)(2) and applies to all risk results (both risk estimates and numbers of people exposed to such risks) presented here and in subsequent sections. Based on actual emissions from the source category, the modeled estimates indicate that the maximum lifetime individual cancer risk posed by the facility could be as high as 500-in-1 million, with chloroprene emissions from maintenance vents, storage tanks, wastewater, and equipment

leaks as the major contributors to the risk. The total estimated cancer incidence from this source category is one excess cancer case every 21 years. Approximately 1,000,000 people live within 50 kilometers of this Neoprene Production facility, and 690,000 people are estimated to have a cancer risk at or above 1-in-1 million from primarily the chloroprene emitted from this facility's source category emissions, with 2,000 people estimated to have a cancer risk above 100-in-1 million.

Risk Summary for the Neoprene Production Source Category

	Inhalation Cancer Risk		Population Cancer Risk			Max Chronic Individual Noncancer Risk		Max Acute Noncancer Risk		Multipathway Assessment
	Maximum Individual Risk (in 1 million)	Risk Driver	Cancer Incidence (cases per year)	>100 in 1 million	≥ 1 in 1 million	Hazard Index (TOSHI)	Risk Driver	Hazard Quotient	Risk Driver	Risk Driver and Health Endpoints
Baseline Actual Emissions										
Source Category	500	chloroprene	0.05	2,000	690,000	0.05	chloroprene	0.3	chloroform	---
Whole Facility	600	chloroprene	0.06	2,300	890,000	0.3	chlorine, chloroprene, nickel compounds, hydrochloric acid	---	---	---
Baseline Allowable Emissions (same as Baseline Actual Emissions)										
Source Category	500	chloroprene	0.05	2,000	690,000	0.05	chloroprene	0.3	chloroform	---
Post-Control Emissions										
Source Category	100	chloroprene	0.01	0	58,000	0.01	chloroprene, hydrochloric acid	0.3	chloroform	---

Regarding the noncancer risk assessment, the maximum chronic noncancer hazard index value for this facility could be up to 0.05 (for the respiratory hazard index) driven by emissions of chloroprene from maintenance vents, storage tanks, wastewater, and equipment leaks. Of the 1,000,000 people living within 50 kilometers of this facility, none are exposed to noncancer hazard index levels above 1, based on actual emissions from sources at this facility regulated under this source category. The maximum acute hazard quotient is less than 1.

Whole facility (or "facility-wide") emissions include those regulated under this source category plus all other emissions generated at the facility. The results of the chronic inhalation cancer risk assessment based on whole facility emissions are more uncertain and rely on the quality of the emissions data collected for source categories outside this regulatory review. These emissions sources may not undergo the same level of data quality review as those being assessed in this regulatory assessment. The maximum lifetime individual cancer risk posed by this facility, based on whole facility emissions, is 600-in-1 million. Chloroprene emissions drive the whole facility risk from in-category maintenance vents, storage tanks, wastewater, and equipment leaks, as well as from non-category maintenance vents and equipment leaks. The total estimated cancer incidence based on whole facility emissions is one excess cancer case every 18 years. Approximately 890,000 people are estimated to have cancer risks above 1-in-1 million from HAP emitted from all sources at the facility, with 2,300 people estimated to have a cancer risk above 100-in-1 million. Regarding the noncancer risk assessment, the

maximum chronic noncancer hazard index posed by whole facility emissions is estimated to be 0.3 (for the respiratory hazard index) driven primarily by emissions of chlorine from non-category sources (including process vents, equipment leaks, and storage tanks) and by non-category emissions of nickel compounds and hydrochloric acid, as well as by in-category emissions of chloroprene from maintenance vents. No one is exposed to noncancer hazard index levels above 1, based on whole facility emissions from the facility within this source category.

No PB-HAP are emitted as category emissions from this facility, therefore a multipathway risk assessment is not warranted. However, for dioxins we used the results of the SOCMI source category human health screening assessment at facilities with higher dioxin emission rates than the limits set in the Neoprene Production source category to qualitatively assess the potential for human health risks.[1] No facility exceeded a Tier 2 screening value for dioxins in the SOCMI source category multipathway risk screening assessment, including 4 HON facilities with dioxin emission rates higher than the standard in this action for dioxins for the Neoprene Production source category (and 1 HON facility with a dioxins emission rate approximately 20 times higher than the Neoprene Production emission limits set in this action).

We also conducted an environmental risk screening assessment for acid gases (i.e., HCl and HF) for the Neoprene Production source category; however, there were no reported emissions of HF at this facility. A screening-level evaluation of the potential adverse environmental risk associated with emissions of hydrochloric acid indicated that no ecological benchmarks were exceeded.

Potential differences between actual emission levels and the maximum emissions allowable under EPA's standards (i.e., "allowable emissions") were also determined for this facility. For this source category, baseline actual emissions are equal to allowable emissions. Therefore, the cancer and noncancer risk assessment results based on allowable emissions are the same as the risk assessment results based on actual emissions, summarized above.

In addition to the baseline source category and whole facility analyses, an analysis of post-control emissions was performed, a scenario which modeled chloroprene controls in this action. The results of the chronic inhalation cancer risk assessment based on these post-control emissions from the affected facility in the Neoprene Production source category indicate that the maximum lifetime individual cancer risk posed by neoprene production emissions from the facility could be as high as 100-in-1 million (compared to 500-in-1 million at baseline). Chloroprene emissions from maintenance vents, equipment leaks, process vents, and storage tanks are the major contributors to the post-control risk. The total estimated cancer incidence based on post-control emissions is one excess cancer case every 100 years. Approximately 58,000 people are estimated to have a cancer risk at or above 1-in-1 million from HAP emitted from this facility in the Neoprene Production source category under the post-control scenario, with no one estimated to have a cancer risk above 100-in-1 million. Regarding the noncancer risk assessment, the maximum chronic noncancer hazard index

[1] See *Residual Risk Assessment for the SOCMI Source Category in Support of the 2024 Risk and Technology Review Final Rule,* in Docket ID No. EPA-HQ-OAR-2022-0730.

posed by post-control Neoprene Production source category emissions is estimated to be 0.01 (for the respiratory hazard index) driven primarily by emissions of chloroprene from maintenance vents, equipment leaks, process vents, and storage tanks, as well as by hydrochloric acid from process vents. No one is exposed to noncancer hazard index levels above 1, based on post-control neoprene production emissions from this facility in the Neoprene Production source category. Similar to baseline emissions, the maximum acute hazard quotient is less than 1 based on post-control emissions.

This document summarizes the methods used to conduct the risk assessment of this source category as well as the results. Section 1 discusses the relevant regulatory framework including background on the Clean Air Act sections which require the EPA to conduct these source category risk assessments. Methods described in Section 2 include those used by EPA to develop refined estimates of chronic inhalation exposures and human health risks for cancer and noncancer endpoints, as well as those used to screen for acute health risks, chronic non-inhalation (i.e., multipathway) health risks, and adverse environmental effects. The source category-specific results for the risks are presented in Section 3. Section 4 contains a discussion of the uncertainties of the risk assessment, including uncertainties in the exposure assessment and in the dose-response values. The appendices to this risk report contain detailed descriptions of the methods used and the results.

1 Introduction

Section 112 of the Clean Air Act (CAA) establishes a two-stage regulatory process for addressing emissions of hazardous air pollutants (HAP) from stationary sources. In the first stage, section 112(d) requires the Environmental Protection Agency (EPA, or the Agency) to develop technology-based National Emission Standards for Hazardous Air Pollutants (NESHAP) for categories of sources (e.g., petroleum refineries, pulp and paper mills, etc.). EPA has completed this stage. For NESHAP that require maximum achievable control technology (MACT) standards, EPA is required to complete a second stage of the regulatory process – the residual risk review. In this second stage, EPA is required under section 112(f)(2) to assess the health and environmental risks that remain after implementation of the MACT standards. If additional risk reductions are necessary to protect public health with an ample margin of safety or to prevent an adverse environmental effect, EPA must develop standards to address these remaining risks. For each source category for which EPA issued MACT standards, the residual risk stage must be completed within eight years of promulgation of the initial technology-based standard.

Also, under section 112(d)(6), EPA must review each of the technology-based standards at least every eight years and revise it, as necessary, taking into account developments in practices, processes and control technologies. If appropriate based on the results of the risk and technology reviews, the Agency will revise the rule. For efficiency, the Agency includes the 112(f) and 112(d) analyses in the same regulatory package and calls the rulemakings the Risk and Technology Review (RTR).

In December 2006 we consulted with a panel from the EPA's Science Advisory Board (SAB) on the “Risk and Technology Review (RTR) Assessment Plan,” and in June 2007 we received

a letter with the results of that consultation. Subsequent to the consultation, in June 2009, EPA met with an SAB panel for a formal peer review of the "Risk and Technology Review (RTR) Assessment Methodologies" (USEPA, 2009a). We received the final SAB report on this review in May 2010 (USEPA, 2010a). Where appropriate, we responded to the SAB's key recommendations in developing our current risk assessments and continue our efforts to improve our assessments by incorporating updates that address the SAB's recommendations as they are developed and become available. Our responses to the key recommendations of the SAB are outlined in a memo entitled, "EPA's Actions in Response to Key Recommendations from the SAB Review of RTR risk Assessment Methodologies" (USEPA, 2010b). EPA has updated several aspects of the risk assessment methodologies contained in the 2009 document. In 2017, we submitted these updated methodologies to SAB for review. The updated methodologies are described in, *Screening Methodologies to Support Risk and Technology Reviews (RTR): A Case Study Analysis*. The SAB's findings for this review, *Review of EPA's draft technical report entitled Screening Methodologies to Support Risk and Technology Reviews (RTR): A Case Study Analysis* was submitted to EPA in September 2018.

This document contains the methods we use to conduct the risk assessment, the results of the residual risk assessment performed for the Neoprene Production source category, and a description of associated uncertainties.

2 Methods

A risk assessment consists of four steps: 1) hazard identification, 2) dose-response assessment, 3) exposure assessment, and 4) risk characterization. The first step, hazard identification, determines whether the pollutants of concern can be linked to the health effects in question (cancer and/or noncancer). Section 112 of the CAA identifies the HAP to be considered in the risk assessment for this source category. The second step is the dose-response assessment, which quantifies the relationship between the dose of a pollutant and the resultant health effects. Dose-response assessments are performed by EPA through the Integrated Risk Information System (IRIS) process as well as by other agencies, such as the Agency for Toxic Substances and Disease Registry (ATSDR). See Section 2.7 of this document for more information on dose-response assessments. The third and fourth steps, the exposure assessment and the risk characterization, respectively, are specific to the source category and are described throughout this report. The exposure assessment includes characterization of HAP emissions, environmental fate and transport, and population exposure for both inhalation and non-inhalation pathways. The fourth and final step, risk characterization, integrates all the information from the previous steps and describes the outcome of the assessment. This four-step approach to risk assessment was endorsed by the National Academy of Sciences in its publication "Science and Judgment in Risk Assessment" (NAS, 1994) and subsequently was adopted in the EPA's "Residual Risk Report to Congress" (USEPA, 1999).

The EPA conducts a risk assessment that provides estimates of the maximum individual risk (MIR) posed by the HAP emissions from each source in the source category, the hazard index (HI) for chronic exposures to HAP with potential to cause chronic (or long-term) noncancer health effects and the hazard quotient (HQ) for acute exposures to HAP with the potential to

cause noncancer health effects. The MIR is defined as the cancer risk associated with a lifetime of exposure at the highest concentration of HAP where people are likely to live. The HQ is the ratio of the potential exposure to the HAP to the level at or below which no adverse effects are expected; the HI is the sum of HQs for HAP that affect the same target organ or organ system. Hazard Quotient cannot be translated to a probability that adverse health effects will occur, and is unlikely to be proportional to risk. It is especially important to note that a Hazard Quotient exceeding 1 does not necessarily mean that adverse effects will occur.The risk assessment also provides estimates of the distribution of cancer risks within the exposed populations, cancer incidence and an evaluation of the potential for adverse environmental effects. The following sections describe how we estimate HAP emissions and conduct steps three and four of the risk assessment. The methods used to assess risks are consistent with those peer reviewed by a panel of the EPA's Science Advisory Board (SAB) in 2009 and described in their peer review report issued in 2010 (USEPA, 2010a).

2.1 Emissions and source data

To conduct the exposure assessment, EPA gathers the best available data on emissions, emissions release parameters, and other relevant source category-specific parameters. EPA determines the HAP emissions levels from emission points in the source category and identifies the emissions release characteristics of these emission points (e.g., stack height). EPA often begins with the National Emissions Inventory (NEI) database as the starting point for emissions and emissions release characteristics for the source category. The NEI database contains information about sources that emit HAP and it contains annual air pollutant emissions estimates. EPA's industry experts review the source category data for consistency and completeness. This includes an evaluation of facilities contained in the source category, the emissions units expected to be included for the processes in the source category, and the HAP compounds and emissions levels typically seen. If necessary, EPA will conduct a formal information collection request (CAA, Section 114) for emissions data and other data from the industry associated with the source category under review. Following the creation of the initial data set, the EPA performs the technology review and the residual risk assessment. If appropriate, based on the results of these reviews, the EPA proposes regulatory action for the source category in a Notice of Proposed Rulemaking (NPRM) published in a *Federal Register* notice. The NPRM data sets are available for public review in the rulemaking docket. Industry, state and local agencies, as well as the public have an opportunity to provide comments on the data, analyses, and results used to support the proposed action. EPA incorporates the comments, as appropriate, conducts any re-assessment, and summarizes and responds to comments before finalizing the action. Through source category-specific engineering reviews, information collection efforts, and public comment, EPA ensures that the data used to conduct risk assessments in support of the RTR rulemakings are of high quality.

In order to put the source category risks in context, we also examine the risks from the entire "facility," where the facility includes all HAP-emitting operations within a contiguous area and under common control. In other words, we examine the HAP emissions not only from the source category emission points of interest, but also from all other emission sources at the facility for which we have data. Using the most current available NEI data at the time of the

assessment, the EPA develops "facility-wide" emissions estimates. It is important to note that the NEI facility-wide inventory may not always reflect the level of detail or be representative of the same temporal period that is found in the source category-specific inventory. Further information on the NEI, which is developed from federal/state/local/tribal submitted data, can be found on the EPA's web site at: https://www.epa.gov/air-emissions-inventories/national-emissions-inventory.

Details on the development of the source data, emissions, and associated uncertainties in the data for the Neoprene Production source category can be found in Appendix 1 (*Emissions Inventory Support Documents*). Section 3 provides a summary of the processes and emissions associated with this source category.

2.2 Dispersion modeling for inhalation exposure assessment

For the residual risk analyses, we estimate both long- and short-term inhalation exposure concentrations and associated health risks from each facility in the source category. To do this, we use the Human Exposure Model 4 (HEM4 or HEM-AERMOD) modeling system – which combines the Human Exposure Model (HEM) with the American Meteorological Society/EPA Regulatory Model (AERMOD) dispersion modeling system. HEM4 performs three main operations: atmospheric dispersion modeling, estimation of individual human exposures and health risks, and estimation of population risks. The approach used in applying this modeling system is outlined below. Further details are provided in Appendix 2 to this document (*The HEM4 User's Guide*). This section focuses on the dispersion modeling component.

The dispersion model in the HEM4 modeling system, AERMOD version 21112 is a state-of-the-science Gaussian plume dispersion model that is preferred by EPA for modeling point, area, and volume sources of continuous air emissions from facility applications (USEPA, 2005a). Further details on AERMOD can be found in the AERMOD User's Guide (USEPA, 2021a) and the AERMOD Implementation Guide (USEPA, 2021b).[2] The model is used to develop annual average ambient concentrations through the simulation of hour-by-hour dispersion from the emission sources into the surrounding atmosphere. Unless data are available on the hours of operation for a source category, default hourly emission rates used for this simulation are generated by evenly dividing the total annual emission rate from the inventory into the 8,760 hours of the year.

The first step in the application of the HEM4 modeling system is to predict ambient concentrations at locations of interest. The AERMOD model options employed are summarized in Table 2.2-1 and are discussed further below.

[2] An explanation of the updates from the previous version of AERMOD can be found at https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod and corresponding updates to HEM can be found https://www.epa.gov/fera/human-exposure-model-users-guides.

Table 2.2-1. AERMOD version 21112 Model Options for RTR Modeling

Modeling Option	*Selected Parameter for chronic exposure*
Type of calculations	Hourly Ambient Concentration
Source types	Point Volume Area Polygon Line Buoyant Line
Receptor orientation	Polar (13 rings and 16 radials) Discrete (census block centroids) and user-supplied receptors
Terrain characterization	Actual from USGS 1/3-arc-second DEM data
Building downwash	Not Included
Plume deposition/depletion	Not Included
Urban source option	Site Specific (See Appendix 2)
Meteorology	1-year representative NWS from nearest site (838 stations); 791 stations contain 2019 met data, 47 stations contain 2016 through 2018 met data

In HEM4, meteorological data are ordinarily selected from a list of more than 800 National Weather Service (NWS) surface observation stations across the continental United States, Alaska, Hawaii, and Puerto Rico, and HEM4 defaults to the station closest to each modeled facility. We use data from other stations in special circumstances if we have reason to believe that other data are more representative for certain facilities. In this analysis, the distance between the modeled facility and the respective meteorological station was 17 miles (28 km). The meteorological data in HEM4's library are for a single year, and 2019 is the most recent full year of available data. EPA's Revisions to the Guideline on Air Quality Models addresses the regulatory application of air quality models for assessing criteria pollutants and requires five years of data to capture variability in weather patterns from year to year. We follow the guideline for air toxics modeling also; however, because dispersion model runtimes using five years of meteorological data would be too long for RTR source categories with many sources, we model only a single year. While the selection of a single year may result in under-prediction of long-term ambient levels at some locations, it may result in over-prediction at others. The sensitivity of model results to the selection of the nearest weather station and the use of one year of meteorological data is discussed in "Risk and Technology Review (RTR) Risk Assessment Methodologies" (USEPA, 2009a).

We use the AERMET meteorological data preprocessor and the Automated Surface Observing System (ASOS) surface data and Forecast Systems Laboratory (FSL) upper air data to generate nationwide surface and profile files for input into AERMOD. In 2021, the Agency released to the public on the EPA's Support Center for Regulatory Atmospheric Modeling (SCRAM) website both AERMET and AERMOD (version 21112). Appendix 3 to this document (*Meteorological Data for HEM Modeling*) provides a complete listing of meteorological stations and assumptions, along with further details used in processing the data through AERMET. EPA has posted the AERMET meteorological data (2019) used in this

analysis on the EPA's Fate, Exposure, and Risk Analysis (FERA) website under the Human Exposure Model (HEM) page.

The HEM4 modeling system estimates ambient concentrations at the geographic centroids of census blocks (using the 2010 Census) and at other receptor locations that can be specified by the user.[3] See Appendix 4 of this document (*Dispersion Model Receptor Revisions and Additions*) for a discussion of user receptors and centroid location changes specific to this source category. HEM4 accounts for the effects of multiple facilities when estimating concentration impacts at each block centroid. We typically combine the impacts of all facilities within the same source category and assess chronic exposure and risk for all census blocks[4] with at least one resident (i.e., locations where people may reasonably be assumed to reside rather than receptor points at the fenceline of a facility). We then calculate ambient concentrations as the annual average of all estimated short-term (one-hour) concentrations at each block centroid. We do not consider possible future residential use of currently uninhabited areas.

To assess the potential impacts from short-term exposures, we estimate reasonable worst-case one-hour concentrations (i.e., 99th percentile) at the census block centroids and at points closer to the facility (using either the polar receptors or user-specified receptors) that represent locations where people may be present for short periods[5]. Note that this is in contrast to the development of ambient concentrations for evaluating long-term exposures, which we perform only for occupied census blocks. Since short-term emission rates are needed to screen for the potential for hazard via acute exposures, and since the emission data typically contain only annual emission totals, we generally apply the assumption to all source categories that the maximum one-hour emission rate from any source is ten times the average annual hourly emission rate for that source. However, sources may emit on a more intermittent basis and source category-specific data may support the use of engineering judgement to determine peak hourly emissions for any given process. Further information on the factor used to estimate short-term emissions for this source category is provided in Appendix 1, and further discussion of the acute risk assessment can be found in Section 2.4.

We determine census block elevations for HEM4 nationally from the US Geological Survey 1/3 Arc Second National Elevation Dataset, which has a spatial resolution of about 10 meters. Each polar receptor is assigned the highest elevation of any census block in its neighborhood (all blocks closer to that polar receptor than any other polar receptor). If an elevation is not provided for an emission source, the model uses the average elevation of all polar receptors on the innermost polar ring. In addition to using receptor elevation to determine plume height, AERMOD adjusts the plume's flow if nearby elevated hills are expected to influence the wind

[3] We also estimate ambient concentrations for a grid of polar receptors that is specific to each facility, and these receptors are used to interpolate concentrations for census blocks in the outer part of the modeling domain, and for finding the maximum offsite concentrations.
[4] Census blocks, the finest resolution available in the census data, are typically comprised of approximately 50 people or about 20 households.
[5] Generally, we estimate these concentrations at locations no nearer than 100 meters from the center of the facility (note that for large facilities, this 100-meter ring could still contain locations inside the facility property).

patterns. For details on how hill heights are estimated and used in the AERMOD modeling, see Appendix 2 of this document.

2.3 Estimating chronic human inhalation exposure

We use the estimated annual average ambient air concentration of each HAP at each census block centroid or user-defined receptor as a surrogate for the lifetime inhalation exposure concentration of all the people who reside in the census block. The risk assessment does not consider either the short-term or long-term behavior (mobility) of the exposed populations and its potential influence on their exposure.

We do not address short-term human activity, including indoor air concentrations. Our experience with our national Air Toxics Screening Assessment (AirToxScreen), the successor to the National Air Toxics Assessment (NATA), which models daily human activity using EPA's HAPEM, suggests that given our current understanding of the ratio of exposure concentrations to ambient values, including short-term human activity in RTR analyses would, on average, reduce risk estimates by up to about 25 percent for particulate HAP and typically by much less for gaseous HAPs. To ensure the risk characterization is health protective, EPA risk assessors do not include this small potential reduction in exposure concentrations when calculating risks.

We do not address long-term migration or population growth or decrease over the 70-year modeling period. Instead, we assume that each person's predicted exposure is constant over the course of their lifetime, which is assumed to be 70 years. The assumption of not considering short- or long-term population mobility does not bias the estimate of the theoretical MIR (assumes a person stays in one location for 70 years) nor does it affect the estimate of cancer incidence since the total population number remains the same. It does, however, affect the shape of the distribution of individual risks across the affected population, shifting it toward higher estimated individual risks at the upper end and reducing the number of people estimated to be at lower risks, thereby increasing the estimated number of people at higher risk levels.

2.4 Acute risk screening and refined assessments

In establishing a scientifically defensible approach for the assessment of potential health risks due to acute exposures to HAP, we follow a similar approach to that for chronic health risk assessments under the residual risk program, in that we begin with a screening assessment and then, if appropriate, perform a refined assessment.

The approach for the acute health risk screening assessment is designed to eliminate from further consideration those facilities for which we have confidence that no acute adverse health effects of concern will occur. For this screening assessment, we use readily available data and conservative assumptions for emission rates, meteorology, and exposure location that, in combination, approximate a reasonable worst-case exposure.

The following are the steps we take and assumptions we make in the acute screening assessment:

- When available, we use peak 1-hour emission data obtained from data collection efforts or estimated based on the operating characteristics and engineering judgement of facility emission sources; otherwise, we use a default emission adjustment factor of 10 based on an analysis using a short-term emissions data set from a number of sources located in Texas (originally reported on by Allen *et al.* 2004) (see Appendix 5 of this document, *Technical Support Document for Acute Risk Screening Assessment*).
- We assume that the peak emissions occur at all emission points at the same time.
- For facilities with multiple emission points, 1-hour concentrations at each receptor are assumed to be the sum of the maximum concentrations due to each emission point, regardless of whether those maximum concentrations occurred during the same hour.
- Reasonable worst-case air dispersion[6] (from one year of local meteorology) is assumed to occur at the same time the peak emission rates occur. The recommended EPA local-scale dispersion model, AERMOD, is used for simulating atmospheric dispersion.
- A person is assumed to be at the location of the reasonable worst-case modeled impact, but no nearer to the source than 100 meters.

As a result of this screening assessment, the 99th percentile HAP concentration is compared to multiple acute dose-response values for the HAP being assessed to determine whether a possible acute health risk might exist. The acute dose-response values are described in section 2.7.2 of this report.

A facility will either be found to pose no potential acute health risks (i.e., it will "screen out") or will need to undergo a more refined assessment. When we identify levels of a HAP that exceed its acute health benchmarks, we perform a more refined assessment, if possible. Where we have used engineering judgement to estimate emissions, a refinement may be to obtain facility-specific data on HAP emissions. Other refinements may include the temporal pattern of emissions (number of working hours, batch vs continuous operation), the location of emission points, the boundaries of the facility, and/or the local meteorology. In some cases, all of these site-specific data are used to refine the assessment; in others, lesser amounts of site-specific data may be used to determine that acute exposures are not a concern, and significant additional data collection is not necessary. See Section 3 of this document for the approach used for this source category.

2.5 Multipathway human health risk assessment

Due to the potential for significant human health risks due to exposure via routes other than inhalation (e.g., ingestion), we determine whether any sources emit HAP known to be

[6] An explanation of reasonable worst-case air dispersion is provided in Appendix 5 of the report: *Technical Support Document for Acute Risk Screening Assessment*.

persistent and bioaccumulative in the environment (PB-HAP).[7] The set of PB-HAP compounds or compound classes initially identified for potential screening assessment (from EPA's Air Toxics Risk Assessment (ATRA) Library) included the following: cadmium compounds, chlordane, chlorinated dibenzodioxins and furans (dioxins), 1,1-dichloro-2,2-bis(p-chlorophenyl) ethylene (DDE), heptachlor, hexachlorobenzene, hexachlorocyclohexane, lead compounds, mercury compounds, methoxychlor, polychlorinated biphenyls (PCB), polycyclic organic matter (POM), toxaphene, and trifluralin. Of these, EPA identified cadmium compounds, dioxins, mercury compounds, lead, POM, as well as arsenic, as PB-HAP of primary concern, based on assessment of national emission totals, toxicity considerations, and bioaccumulation potential. We assess these six PB-HAP for human health risks due to non-inhalation exposure.

We use a tiered approach to evaluate emissions of these PB-HAP for potential non-inhalation risks. This approach is designed to eliminate from further consideration those facilities for which we have confidence that human health risks will not occur due to non-inhalation exposure to their PB-HAP emissions. The approach was developed for use with EPA's peer-reviewed Total Risk Integrated Methodology: Fate, Transport, and Ecological Exposure (TRIM.FaTE) model.

For each carcinogenic PB-HAP, we have derived a screening threshold emission rate at which the maximum excess lifetime cancer risk would be 1-in-1 million. For each PB-HAP that causes noncancer health effects, we have derived a screening threshold emission rate for which the maximum HQ would be 1. The ratio of facility emissions to the screening threshold emission rate is termed a "screening value;" facility emissions that exceed the screening threshold emission rate have a screening value greater than 1. A screening value greater than 1 in any of the tiered screening methods represents a high-end estimate of what the risk or hazard may be; it cannot be equated with a risk value or a HQ (or HI). For example, for a carcinogen, a screening value of 30 (i.e., facility emissions are 30 times above the screening threshold emission rate) means that we are confident that the cancer risk is lower than 30-in-1 million. Similarly, for a non-carcinogen, a screening value of 2 (i.e., facility emissions are 2 times above the screening threshold emission rate) can be interpreted to mean that we are confident that the noncancer HQ would be lower than 2.

For Tier 1, 2, and 3 assessments, we use hypothetical exposure scenarios to assess whether non-inhalation exposures pose a potential human health risk. Exposure scenarios were developed to simulate generic gardening and subsistence farming and subsistence fishing lifestyles. Each screening exposure scenario is designed to represent the upper end of the range of possible exposure levels, such that it is a conservative but not impossible scenario. The exposure scenarios were developed for use in conjunction with the TRIM.FaTE model. These hypothetical exposure scenarios and associated ingestion exposure pathways are shown in Table 2.5-1.

[7] Although the two-letter chemical symbol for lead is Pb, in this assessment PB-HAP refers to the many air pollutants known to be persistent and bioaccumulative in the environment. When this report is specifically referring to lead, the term is spelled out (i.e., the two-letter chemical symbol for lead is not used in this document).

Table 2.5-1. Multipathway Scenarios and Ingestion Pathways

Hypothetical Exposure Scenario	Fish	Breast Milk [a]	Beef/Pork /Chicken	Dairy Milk	Eggs	Soil	Fruits and Vegetables [b]
Combined Fisher and Farmer (Tier 1)	x	x	x	x	x	x	x
Fisher (Tier 2)	x	x					
Farmer [c] (Tier 2)		x	x	x	x	x	x
Gardener (urban or rural) (Tier 2)		x			x	x	x
Pollutants of Concern [d]	Hg, Cd, As, dioxin, POM	dioxin	As, dioxin, POM	As, dioxin, POM	As, dioxin, POM	As, dioxin, POM	As, dioxin, POM

[a] Health risks from the breast milk pathway are only associated with exposure to dioxins.
[b] Both protected and unprotected fruits and vegetables are included.
[c] This scenario may be included in a Tier 2 assessment in cases where the Tier 2 farmer scenario exceeds a level of concern and further screening is required to reflect alternative ingestion rates, that may be more common for the area (i.e., either in an urban or rural environment).
[d] The health endpoint for exposure to Hg (as methylmercury) and Cd is noncancer and the health endpoint for exposure to As (as inorganic arsenic), dioxin, and POM is cancer.

For the Tier 1 screening assessment, we determine whether the facility-specific emission rates for each emitted PB–HAP are high enough to create the potential for significant non-inhalation human health risks under reasonable worst-case conditions. We do this by comparing the facility-specific emission rates to the screening threshold emission rates for each PB-HAP for a hypothetical upper-end screening exposure scenario – the combined fisher and farmer scenario. The subsistence fisher scenario assumes a high-end fish consumption rate of 373 g/day for adults, a 99th percentile ingestion rate (Burger, 2002); fish consumption rates for other age groups are presented in Appendix 6. The farmer scenario involves an individual that lives for a 70-year lifetime on a farm near the source and consumes produce grown, and meat and animal products raised, on the farm. The ingestion rates used for these food groups, and for incidental soil ingestion, are set at the 90th percentile of EPA's Exposure Factors Handbook: 2011 Edition (USEPA, 2011) and are considered upper-bound levels. The fisher and farmer exposure scenarios are combined for the Tier 1 TRIM.FaTE model application. See Appendix 6 (*Technical Support Document for TRIM-Based Multipathway Tiered Screening Methodology for RTR*) for a complete discussion of the development and testing of the screening scenario and the screening threshold emission rates.

For those facilities with PB-HAP emissions that exceed the Tier 1 screening threshold emission rate, we conduct a Tier 2 multipathway screening assessment. For the Tier 2 screening assessment, we refine the assessment by using the facility locations and considering two separate exposure scenarios – the fisher scenario and the farmer scenario, with the home gardener scenario as appropriate (rural or urban classification) when the Tier 2 farmer scenario exceeds a level of concern. In some cases, if supported by site-specific information, the subsistence farmer scenario is retained throughout the screening and potentially throughout the site-specific multipathway assessment, if needed. For each facility, we use the Tier 1 PB-HAP screening threshold emission rate, but with adjustments based on the ingested media and based on an understanding of how exposure concentrations estimated for the screening scenario change with use of the local meteorology and environmental assumptions. For Tier 2, separate farmer and fisher scenarios replace the Tier 1 combined fisher and farmer scenario as more likely exposure scenarios. The farmer and gardener scenarios are primarily evaluated for exposure to carcinogenic PB-HAP (i.e., arsenic, dioxin, and POM) because the evaluated non-carcinogens (i.e., mercury and cadmium) do not readily accumulate in soil and the farm food chain, when compared to the amounts observed in fish tissue.

For the gardener scenario, the Tier 1 PB-HAP screening threshold emission rates are adjusted for the farmer to reflect exposure only through soil and farm produce (fruits, eggs, and vegetables), based on the rural/urban classification of the facility site (with urban gardeners growing and ingesting less home-grown produce than rural gardeners). The gardener scenarios (rural and urban) involve an individual that maintains a garden and consumes produce from this garden for 70 years at his/her residence. The evaluated locations of the gardener correspond to the maximum impacted residential receptor according to the RTR inhalation cancer assessment for each of the 8 wind octants (N, NE, E, SE, …) for all carcinogenic HAPs combined. The screening threshold emission rate can be different at each of these gardener locations, based on distance from the facility and based on local meteorology conditions. The ingestion rates used for the food groups are set at the 90th percentile and mean values for rural and urban, respectively, based on data from EPA's Exposure Factors Handbook: 2011 Edition (USEPA, 2011); both gardeners have incidental soil ingestion rates equal to those of the farmer. The largest of the gardener screening values is identified for each PB-HAP.

The fisher scenario is conducted for all of the currently evaluated PB-HAP, whose Tier 1 PB-HAP screening threshold emission rates are adjusted to reflect exposure only through fish ingestion. For the Tier 2 assessment, to fulfill the adult ingestion rate for the fisher scenario, if needed, more than one lake may be included in the modeling in order to reach a cumulative total of 373 acres and achieve the 373-g/day fish ingestion rate. A complete discussion of the bioassay studies used to support the assumption that the biological productivity limitation of each lake is 1 gram of fish caught and consumed per acre of water per day is provided in Appendix 6 of this document. The screening threshold emission rate can be different at each lake location, based on distance from the facility and based on local meteorology conditions.

If we need to include more than one lake in the Tier 2 screening assessment to achieve the 373 g/day ingestion rate, we begin with the lake with the highest modeled chemical concentration of a given PB-HAP group and "fish" up to the lake's biological productivity.

We then systematically proceed to other lakes based on concentration, until the 373 g/day target is met. A maximum travel radius of 50 km relative to the facility is used to maintain a realistic scenario for the fisher. 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 from each lake multiplied by the chemical concentration in fish). If the highest-concentration lake is at least 373 acres in size, the adult fisher catches and consumes 373 g/day of fish from that lake. If the cumulative size of multiple visited lakes exceeds 373 acres, the model includes from the final lake only the amount of fish necessary to satisfy the ingestion rate (i.e., to reach 373 g/day). If the total acreage of lakes within 50 km is less than 373 acres, the screening result reflects a reduced ingestion rate based on the smaller lake acreage. The order of fished lakes for a facility follows the order of PB-HAP concentration in fish from highest to lowest based on the facility's emissions. However, the resulting screening value calculations described above also potentially consider chemical inputs from emissions from multiple facilities. If a fished lake for one facility ("Facility A") is also within 50 km of another facility ("Facility B") in the source category, then the lake receives chemical input from emissions from two facilities. The order of fished lakes for Facility A considers only Facility A's chemical inputs to the lake, but the final fisher screening values for Facility A include the summed chemical inputs of Facility A and Facility B. If that lake was also fished for the Facility B scenario, then the same process would be applied to Facility B.

The Tier 2 assessment yields a facility-specific screening value for each PB-HAP for the fisher scenario, farmer scenario, and the gardener scenario if warranted. If information is available to identify subsistence farming operations, the Tier 2 assessment will also include a screening value for the farmer site-specific location. Tier 2 screening values are evaluated for the source category to determine whether further refined screening is necessary for those facilities that may pose a significant risk. A finding that a facility's emissions exceed the Tier 2 screening threshold emission rate does not necessarily mean that multipathway impacts are significant, only that we cannot rule out that possibility based on the results of the screening assessment. See Appendix 6 of this document for a complete discussion of the Tier 2 screening assessment.

For facilities for which the Tier 2 screening value(s) indicate a potential health risk to the public, we can conduct a Tier 3 multipathway screening assessment. The Tier 3 screening assessment has three individual stages; we progress through these stages until the facility's screening values indicate that the emissions are unlikely to pose health risks to the public, or until all three stages are complete.

The first stage of a Tier 3 screening assessment, the lake-assessment stage, is a refinement of the fisher scenario. We examine the fished lakes from Tier 2 and evaluate the existence, the potential purpose, the accessibility and fishability, and the suitability of the lakes for the models and methods used in the screening assessments. We do not reasonably expect a subsistence fisher to catch and consume fish from lakes or ponds that are for industrial or wastewater disposal; are covered in thick plant growth (e.g., swamps or marshes); are clearly closed to public use; or no longer exist (i.e., filled or drained). TRIM.FaTE is not configured to model chemical processes and environmental fate and transport mechanisms in saltwater or

brackish waters, nor is it configured to model the very large watersheds and water dynamics of rivers, bays or very large lakes (e.g., larger than 100,000 acres)[8]. We use aerial imagery and web inquires to evaluate whether any Tier 2 fished lakes meet these disqualifying criteria and, if so, remove those lakes from all future screening assessments. If we remove a lake from a facility's assessment, and the total acres of fished lakes drops below the target of 373 acres, we evaluate the previously unfished lake with the highest chemical concentration, and so on, until the sizes of the qualifying lakes collectively comprise at least 373 acres or all lakes have been evaluated. We then rerun the fisher screening scenario with the revised lake data set. If the PB-HAP emissions for a facility exceed the fisher screening threshold emission rate based on the revised lake data set, we can conduct the next stage of the Tier 3 screening assessment (i.e., the plume-rise screen); otherwise, the emissions are considered unlikely to pose significant health risks in the fisher scenario.

The second stage of a Tier 3 screening assessment, the plume-rise stage, is a refinement of the previously assessed scenarios (i.e., Tier 2 site-specific farmer [if known], Tier 2 gardener, Tier 3 lake-assessment fisher) where emissions exceeded screening threshold emission rates and may pose health risks. We use site-specific hourly meteorology and facility-specific emission-point characteristics to estimate the fraction of annual emissions that stay within TRIM.FaTE's mixing layer where exposure occurs (i.e., that do not exit the mixing layer). In Tiers 1 and 2, all chemicals are emitted inside the mixing layer and are available for ground-level exposure. In reality, meteorological conditions and emission-point characteristics can cause emissions occasionally to reach higher than the mixing layer. In TRIM.FaTE, any emissions exiting the mixing layer do not reenter the mixing layer, resulting in no ground-level exposure for those emissions. In this Tier 3 stage, we use thermodynamic equations with local hourly meteorology and facility stack parameters to calculate hourly plume-rise heights. The fraction of annual hours during which the plume-rise height is less than the mixing-layer height equals the fraction of annual emissions available for human exposure in the screening assessment. We calculate these fractions for the location of each fished lake and for each relevant farm/garden because lakes and farms/gardens can be in different directions from the facility; thus, these calculations are conditional on wind direction. The results of this stage of Tier 3 are revised fisher and/or farmer/gardener screening values for each relevant PB-HAP and facility, accounting for emissions deposited above the mixing layer. If the revised screening value still indicates potential health risks to the public, we can proceed to the final stage of the Tier 3 screening assessment (i.e., the time-series screen); otherwise, the PB-HAP emissions are considered unlikely to pose significant risks.

In the third and final stage of a Tier 3 screening assessment, the time-series assessment, we can conduct new runs of TRIM.FaTE for each relevant lake and/or garden location for a facility for every PB-HAP that represents a risk concern based upon the Tier 3 plume-rise assessment. For these model runs, we start with the screening configuration corresponding to the lake and/or garden location, and we use site-specific hourly meteorology and the hourly plume-rise values calculated in the Tier 3 plume-rise assessment. Allowing TRIM.FaTE- to

[8] Very large lakes and bays (i.e., those larger than 100,000 acres) are not included because their watersheds are too large and 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.

model chemical fate and transport with hour-by-hour changes in meteorology and plume rise produces a more accurate estimate of chemical concentrations in media of interest, as compared to the static values used in Tier 2 and the post-processing adjustments made in the Tier 3 plume-rise assessment. If a facility's model-estimated PB-HAP screening-level cancer risk is below 1-in-1 million (or screening-level HQ is below 1 for non-carcinogens), the emissions are considered unlikely to pose significant risks.

If a facility's PB-HAP Tier 3 screening results still indicate a potential health risk to the public and data are available, we may elect to conduct a more refined multipathway assessment. A refined assessment replaces some of the assumptions made in the screening with site-specific data. The refined assessment also uses the TRIM.FaTE model and facility-specific emission rates for each PB-HAP. Many variables are available to consider in a refined multipathway assessment, and we have developed a protocol to maintain consistency across source categories. This protocol can be found in Appendix 7 of this document (*Protocol for Site-Specific Multipathway Risk Assessment*) and details of the site-specific multipathway assessment can be found in Appendix 11 of this document (*Site-Specific Human Health Multipathway Residual Risk Assessment Report*).

Lead

We take a different approach for assessing lead compounds than we do for other HAP. In evaluating the potential multipathway risks from emissions of lead compounds, rather than developing a screening emission rate for them, we multiply the maximum annual estimated atmospheric concentration by 4, to represent a "worst case" 3-month concentration, and compare it to the national ambient air quality standard (NAAQS) for lead (0.15 ug/m^3, 3-month rolling average). Values below the NAAQS are considered to have a low potential for multipathway risks. Where values exceed the NAAQS, and where data are available to support doing so, further assessment is performed. We calculate 3-month rolling averages based on modeling and/or monitoring information. Any 3-month rolling average concentration that is above 0.15 ug/m^3 indicates a potential public health concern.

The primary NAAQS for lead, a public health policy standard, incorporates the Agency's most recent health evaluation of air effects of lead exposure for the purposes of setting a national ambient air quality standard. In setting this value, the Administrator promulgated a standard that was requisite to protect public health with an adequate margin of safety. We consider values below the level of the primary NAAQS to protect against multipathway risks because, as noted above, the primary NAAQS is set to protect public health with an adequate margin of safety. However, ambient air lead concentrations above the NAAQS are considered to pose the potential for increased risk to public health. We consider the lead NAAQS assessment to be a refined analysis given: 1) the numerous health studies, detailed risk and exposure analyses, and level of external peer and public review that went into the development of the primary NAAQS for lead, combined with 2) the site-specific dispersion modeling used in this assessment to estimate ambient lead concentrations due to the source category emissions.

The Administrator judged that the lead NAAQS would protect, with an adequate margin of safety, the health of children and other at-risk populations against an array of adverse health

effects, most notably including neurological effects, particularly neurobehavioral and neurocognitive effects, in children (73 FR 67007). The Administrator, in setting the standard, also recognized that no evidence or risk-based bright line indicated a single appropriate level. Instead, a collection of scientific evidence and other information was used to select the standard from a range of reasonable values (73 FR 67006).

It should be noted that the comparison to the Lead NAAQS described above does not account for possible population exposures to lead from sources *other* than the one being modeled, such as exposure via consumption of water from untreated local sources or ingestion of locally grown food.

We further note that comparing ambient lead concentrations to the secondary NAAQS for lead, also informs whether there is the potential for adverse environmental effects. This is because the secondary lead NAAQS, set to protect against adverse welfare effects (including adverse environmental effects), has the same averaging time, form, and level as the primary standard. Thus, ambient lead concentrations above the NAAQS for lead also indicate the potential for adverse environmental effects.

2.6 Environmental risk assessment

The EPA has developed a screening approach to examine the potential for adverse environmental effects, as required under section 112(f)(2)(A) of the CAA. The environmental screening assessment focuses on the following eight environmental HAP:

- Six persistent bioaccumulative HAP (PB-HAP) – cadmium, dioxins, POM, mercury (both inorganic mercury and methylmercury), arsenic, and lead;
- Two acid gases – hydrochloric acid (HCl) and hydrofluoric acid (HF).

HAP that persist and bioaccumulate are of particular environmental concern because they accumulate in the soil, sediment, and water. The acid gases – HCl and HF – were included due to their well-documented potential to cause direct damage to terrestrial plants. See Appendix 9 of this document (*Environmental Risk Screening Assessment*) for a more detailed discussion of the environmental risk screening assessment.

For the environmental risk screening assessment, EPA first determines whether any facilities in the source category emit any of the eight environmental HAP. If one or more of the environmental HAP are emitted by at least one facility in the source category, we proceed to the second step of the environmental risk screening assessment.

For cadmium, mercury, POM, arsenic, and dioxins, the environmental screening assessment consists of the same three tiers used in the multipathway human health risk assessment (see Section 2.5). In the first tier, the same TRIM.FaTE modeling used in human health risk assessment is conducted, using reasonable worst-case environmental conditions to identify screening threshold emission rates corresponding to ecological benchmarks for soil, fish, surface water, and sediment. For each facility and PB-HAP, facility emissions are compared to these screening threshold emission rates to determine the potential for significant impacts

on off-site ecological receptors. The ratio of facility emissions to the screening threshold emission rate is termed a "screening value." Facility emissions that exceed the screening threshold emission rate have a screening value greater than 1, and risks above levels of concern for ecological receptors are possible. Screening values below 1 indicate that risks to ecological receptors are likely below levels of concern.

For those facilities with PB-HAP emissions that exceed a Tier 1 screening threshold emission rate, we conduct a Tier 2 screening assessment. In Tier 2, the Tier 1 screening threshold emission rates are adjusted to account for local meteorology and environmental assumptions. For lake-related ecological receptors, actual locations of lakes within 50 km of the facility are identified, and the screening threshold emission rate can be different at each lake location based on distance from the facility and based on local meteorology conditions. After the screening value (i.e., ratio of facility emissions to screening threshold emission rate) is calculated at each lake, the largest screening value is identified. Screening threshold emission rates for soil receptors are evaluated at many locations surrounding the facility and are also impacted by distance from facility and local meteorology. For soil receptors in Tier 2, we are interested in the overall average screening value across all soil receptors (for a given facility and PB-HAP), and we are also interested in the total area in the vicinity of the facility where screening values are above 1 (for a given facility and PB-HAP). If a lake-related screening value is above 1, or the soil screening value is above 1 at any location, or the overall average soil screening value is above 1, it does not necessarily mean that the ecological effects are significant, but only that we cannot rule out that possibility. For facilities with Tier 2 screening values above 1, we can evaluate their emissions further in Tier 3.

Like in the multipathway human health risk assessment, in Tier 3 of the environmental screening assessment, we examine the suitability of the lakes around the facilities to support life and remove those that are not (e.g., lakes that have been filled in or are industrial ponds), adjust emissions for plume-rise, and conduct hour-by-hour time-series assessments. For the lake assessment, we remove from the screening any lakes that appear to be industrial, for wastewater disposal, or no longer exist. TRIM.FaTE is not configured to model chemical processes and environmental fate and transport mechanisms in saltwater or brackish waters, nor is it configured to model the very large watersheds and water dynamics of rivers or very large lakes (e.g., larger than 100,000 acres); these types of water bodies are also removed from the screening assessment. Unlike the multipathway human health risk assessment, we assume that if lakes that are swampy or are not publicly accessible, they still can support ecological life and some animals will still eat from them. After lakes are removed that meet these disqualifying criteria, lake-related receptors are rescreened. For the plume-rise assessment, as in the human health assessment, we adjust the facility's previously calculated screening value based on the fraction of facility emissions that remain in the mixing layer where exposure occurs, after accounting for plume rise (which is based on site-specific meteorology and facility-specific emission-point characteristics). If these Tier 3 adjustments still indicate that ecological risks could be above levels of concern (i.e., screening values are above 1), as in the human health assessment, we can conduct new TRIM.FaTE modeling using the screening configuration corresponding to the relevant lake and/or soil locations, site-specific hourly meteorology, and hourly plume-rise values. If such modeling results in screening-level media concentrations or doses above benchmark levels,

we may elect to conduct a more refined assessment using more site-specific information. If, after additional refinement, the media concentrations or doses are above benchmark levels, the facility may have the potential to cause adverse environmental effects.

For acid gases, the environmental screening assessment evaluates the potential phytotoxicity and reduced productivity of plants due to chronic exposure to acid gases. The environmental risk screening methodology for acid gases is a single-tier screening assessment that compares the average off-site ambient air concentration over the modeling domain to ecological benchmarks for each of the acid gases. For purposes of an ecological risk screening assessment, EPA identifies a potential for adverse environmental effects to plant communities from exposure to acid gases when the average off-site ambient air concentration over the modeling domain for a facility exceeds the ecological benchmark for that acid gas. In such cases, we further investigate factors such as the magnitude of the exceedance and the characteristics of the area of exceedance (e.g., land use of exceedance area, size of exceedance area) to determine whether the facility's emissions have the potential to cause adverse environmental effects.

Lead

For lead compounds, we currently do not have the ability to calculate media concentrations using the TRIM.FaTE model. However, air concentrations of lead are already calculated as part of the human health exposure and risk assessment using HEM4. To evaluate the potential for adverse environmental effects from lead, we compare the average annual modeled air concentrations of lead around each facility in the source category to the level of the secondary NAAQS for lead. The secondary lead NAAQS is a reasonable means of evaluating environmental risk because it is set to provide substantial protection against adverse welfare effects which can include "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being." [9] We investigate any modeled exceedances of the lead NAAQS in a manner similar to that noted above for acid gases.

2.7 Dose-response assessment

2.7.1 Sources of chronic dose-response information

Dose-response assessments (carcinogenic and non-carcinogenic) for chronic exposure (either by inhalation or ingestion) for the HAP reported in the emissions inventory for this source category are based on the EPA Office of Air Quality Planning and Standards' (OAQPS) existing recommendations for HAP (USEPA, 2021c). This information has been obtained

[9] A secondary standard, as defined in Section 109(b)(2), must "specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, based on criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air." Welfare effects as defined in section 302(h) (42 U.S.C. 7602(h)) include, but are not limited to, "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

from various sources and prioritized according to (1) conceptual consistency with EPA risk assessment guidelines and (2) level of peer review received. The prioritization process was aimed at incorporating into our assessments the best available science with respect to dose-response information. The recommendations are based on the following sources, in order of priority:

1) **U.S. Environmental Protection Agency (EPA).** EPA has developed dose-response assessments for chronic exposure for many HAP. These assessments typically provide a qualitative statement regarding the strength of scientific data and specify a reference concentration (RfC, for inhalation) or reference dose (RfD, for ingestion) to protect against effects other than cancer and/or a unit risk estimate (URE, for inhalation) or slope factor (SF, for ingestion) to estimate the probability of developing cancer. The RfC is defined as an "estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." The RfD is "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime." The URE is defined as "the upper-bound excess cancer risk estimated to result from continuous lifetime exposure to an agent at a concentration of 1 µg/m^3 in air." The SF is "an upper bound, approximating a 95 percent confidence limit, on the increased cancer risk from a lifetime exposure to an agent. This estimate, [is] usually expressed in units of proportion (of a population) affected per mg/kg-day…"

   EPA disseminates dose-response assessment information in several forms, based on the level of review. The Integrated Risk Information System (IRIS) is an EPA database that contains scientific health assessment information, including dose-response information. All IRIS assessments since 1996 have also undergone independent external peer review. The current IRIS process includes review by EPA scientists, interagency reviewers from other federal agencies, and the public, as well as peer review by independent scientists external to EPA. New IRIS values are developed and old IRIS values are updated as new health effects data become available. Refer to the IRIS Agenda for detailed information on status and scheduling of current individual IRIS assessments and updates. EPA's science policy approach, under the current carcinogen guidelines, is to use linear low-dose extrapolation as a default option for carcinogens for which the mode of action (MOA) has not been identified. We expect future EPA dose-response assessments to identify nonlinear MOAs where appropriate, and we will use those analyses (once they are peer reviewed) in our risk assessments. At this time, however, there are no available carcinogen dose-response assessments for inhalation exposure that are based on a nonlinear MOA.

2) **U.S. Agency for Toxic Substances and Disease Registry (ATSDR).** ATSDR, which is part of the US Department of Health and Human Services, develops and publishes Minimal Risk Levels (MRLs) for inhalation and oral exposure to many toxic substances. As stated on the ATSDR web site: "Following discussions with scientists

within the Department of Health and Human Services (HHS) and the EPA, ATSDR chose to adopt a practice similar to that of the EPA's Reference Dose (RfD) and Reference Concentration (RfC) for deriving substance specific health guidance levels for non-neoplastic endpoints." The MRL is defined as "an estimate of daily human exposure to a substance that is likely to be without an appreciable risk of adverse effects (other than cancer) over a specified duration of exposure." ATSDR describes MRLs as substance-specific estimates to be used by health assessors to select environmental contaminants for further evaluation.

3) **California Environmental Protection Agency (CalEPA).** The CalEPA Office of Environmental Health Hazard Assessment has developed dose-response assessments for many substances, based both on carcinogenicity and health effects other than cancer. The process for developing these assessments is similar to that used by EPA to develop IRIS values and incorporates significant external scientific peer review. The noncancer information includes available inhalation health risk guidance values expressed as chronic inhalation reference exposure levels (RELs). CalEPA defines the REL as a concentration level at (or below) which no health effects are anticipated, a concept that is substantially similar to EPA's noncancer dose-response assessment perspective. CalEPA's dose response assessments for carcinogens and noncarcinogens are available on-line.

For certain HAP, the dose-response information, based on this prioritization, is limited. To address data gaps, increase accuracy, and avoid underestimating risk, we made additional changes to some of the chronic inhalation exposure values. These important changes, outlined below and reflected in Appendix 8 (*Dose-Response Values Used in the RTR Risk Assessments*) to this document, are as follows:

1) **Acrolein.** The EPA derived an IRIS RfC for acrolein in 2003 (USEPA, 2003), which was based on a 1978 subchronic rodent study that identified a lowest-observed-adverse-effect level (LOAEL) for nasal lesions (Feron et al., 1978). In 2008, the California EPA derived a chronic reference exposure level for acrolein that was based on a more recent subchronic rodent study, which identified a no-observed-adverse-effect level (NOAEL) for nasal lesions (CalEPA, 2008; Dorman et al., 2008). Because both studies identified nasal lesions as the critical effect and because the Dorman et al. (2008) study identified a NOAEL, we have decided to use the CalEPA REL for acrolein in this RTR risk assessment. The EPA is in the process of updating the IRIS RfC for acrolein. If the RfC is updated prior to signature of the final rule, we will use it in the risk assessment for the final rule.

2) **Manganese**. The EPA considers the ATSDR MRL for manganese (Mn) the most appropriate chronic inhalation reference value to be used in RTR assessments. There is an existing IRIS RfC for Mn (USEPA, 1993a), and ATSDR published an assessment of Mn toxicity which includes a chronic inhalation reference value (i.e., an ATSDR Minimal Risk Level, MRL). (ATSDR, 2012). Both the 1993 IRIS RfC and the 2012 ATSDR MRL were based on the same study (Roels et al., 1992); however, ATSDR used updated dose-response modeling methodology (benchmark dose approach) and

considered recent pharmacokinetic findings to support their MRL derivation. Because of the updated methods, EPA has determined that the ATSDR MRL is the appropriate health reference value to use in RTR risk assessments.

3) **Polycyclic Organic Matter.** EPA has identified appropriate UREs for many individual compounds of POM, published in the sources used for RTR risk assessments. When an individual POM compound is reported in the emission inventory for the source category, we use the appropriate URE for that compound. However, if in the emission inventory for the source category a POM compound is reported for which EPA has not identified a URE, or when POM are not speciated into individual compounds, then EPA applies simplifying assumptions so that cancer risk can be quantitatively evaluated without substantially under- or over-estimating risk (which can occur if all reported POM emissions were assigned the same URE). To accomplish this, EPA places each POM compound into one of eight POM groups, generally defined by toxicity and the estimated emission profile of POM compounds. POM Groups 1 and 2 include unspeciated POM (emissions reported as "polycyclic organic matter") and individual POM compounds with no URE assigned from the sources used in RTR risk assessments. With two exceptions, both Groups 1 and 2 are assigned a URE equal to 5 percent of that for pure benzo[a]pyrene; the two exceptions are benzo[a]fluoranthene and generic "benzofluoranthenes", which received the URE of benzo[b]fluoranthene. POM Groups 3 through 7 comprise POM compounds for which UREs are available from the sources used for RTR risk assessments, except for benzo[b+k]fluoranthene and benzo[g,h,i]fluoranthene which receive the URE of benzo[b]fluoranthene. If reported emissions are for a specific compound in these groups, then EPA evaluates the cancer risk of the compound using its unique URE if one has been derived or its group URE if one has not been specifically derived. If the reported emissions are for a specific POM group rather than a compound within the group, then EPA evaluates the cancer risk of the POM group using a URE value that is close to the average of the UREs of the individual compounds within the group. POM Group 8 is composed of unspeciated polycyclic aromatic hydrocarbons (PAH) reported as 7-PAH and are assigned a URE equal to approximately 18 percent of that for pure benzo[a]pyrene. In addition, we have concluded that three PAHs—anthracene, phenanthrene and pyrene—are not carcinogenic and therefore no URE is assigned. Details of the analysis that led to this conclusion can be found in the document titled Development of a Relative Potency Factor (RPF) Approach for Polycyclic Aromatic Hydrocarbon (PAH) Mixtures: In Support of Summary Information of the Integrated Risk Information System (IRIS).

4) **Glycol Ethers.** Often in an emission inventory, the glycol ethers are reported only as the total mass for the entire group without distinguishing among individual glycol ether compounds. In other cases, emissions of individual glycol ether compounds that had not been assigned dose-response values were reported. To avoid underestimating the health hazard associated with glycol ethers, we protectively apply the RfC for ethylene glycol methyl ether (the most toxic glycol ether for which an assessment exists) to glycol ether emissions of unspecified composition.

5) **Lead.** We consider the primary NAAQS for lead, which incorporates an adequate margin of safety, to be protective of all potential health effects for the most susceptible populations. The NAAQS was developed using the EPA Integrated Exposure, Uptake, Biokinetic Model, using the best available toxicity and dose-response information on the noncancer adverse impacts of lead. The NAAQS for lead was set to protect the health of the most susceptible children and other potentially at-risk populations against an array of adverse health effects, most notably including neurological effects, particularly neurobehavioral and neurocognitive effects (which are the effects to which children are most sensitive). The lead NAAQS rolling 3-month average level of lead in total suspended particles is used in the RTR risk assessment as a screening value for chronic noncancer hazard.

6) **Nickel compounds.** To provide a conservative estimate of the potential cancer risks, the EPA considers the IRIS URE value for nickel subsulfide (which is considered the most potent carcinogen among all nickel compounds) to be the most appropriate value to be used in RTR assessments. Based on consistent views of major scientific bodies, such as the National Toxicology Program (NTP) in their 14th Report of the Carcinogens (RoC) (NTP, 2016), the International Agency for Research on Cancer (IARC, 1990), and other international agencies (WHO, 1991) that consider all nickel compounds to be carcinogenic, we currently consider all nickel compounds to have the potential of being carcinogenic to humans. The 14th RoC states that "the combined results of epidemiological studies, mechanistic studies, and carcinogenic studies in rodents support the concept that nickel compounds generate nickel ions in target cells at sites critical for carcinogenesis, thus allowing consideration and evaluation of these compounds as a single group." Although the precise nickel compound (or compounds) responsible for carcinogenic effects in humans is not always clear, studies indicate that nickel sulfate and the combinations of nickel sulfides and oxides encountered in industrial emissions of nickel mixtures cause cancer in humans (these studies are summarized in a review by Grimsrud et al., 2010). The major scientific bodies mentioned above have also recognized that there may be differences in the toxicity and/or carcinogenic potential across the different nickel compounds. For this reason, and given that there are two additional URE values[10] derived for exposure to mixtures of nickel compounds (as a group) that are 2-3 fold lower than the IRIS URE for nickel subsulfide, the EPA considers it reasonable, in some instances (e.g., when high quality data are available on the composition of nickel emissions from a specific source category), to use a value that is 50 percent of the IRIS URE for nickel subsulfide for providing an estimate of the lower end of the plausible range of cancer potency values for different mixtures of nickel compounds.

7) **Carbonyl Sulfide.** Although the health effects data for carbonyl sulfide (COS) are very limited, a series of studies (Morgan et. al., 2004; Herr et. al., 2007; Sills et. al.,

[10] Two UREs (other than the current IRIS values) have been derived for nickel compounds as a group: one developed by the California Department of Health Services (http://www.arb.ca.gov/toxics/id/summary/nickel_tech_b.pdf) and the other by the Texas Commission on Environmental Quality (http://www.tceq.texas.gov/assets/public/implementation/tox/dsd/facts/nickel_&_compounds.pdf).

2004) conducted by the National Toxicology Program have shown that the major concern regarding exposure to COS is its potential for neurotoxicity. These studies have shown consistently and at the same range of COS concentrations that the brain is a target organ for COS toxicity. Since appropriate health effects benchmarks have not been derived by our preferred sources of dose-response data including IRIS, ATSDR, and Cal EPA, the EPA has used the data from the above referenced studies to derive a chronic screening benchmark level for COS. A chronic screening level of 163 µg/m^3 was developed for COS from a No Observed Adverse Effects Level (NOAEL) of 200 ppm based on brain lesions and neurophysiological alterations in rodents. Additional details on the derivation of the chronic screening level for COS can be found in Appendix 8.

8) **Pollutant Groups.** In the case of HAP groups such as cyanide compounds, mercury compounds, antimony compounds and others, the most conservative dose-response value in the chemical group is used as a surrogate for other compounds in the group for which dose-response values are not available. This is done to examine, under conservative assumptions, whether those HAP that lack dose-response values may pose an unacceptable risk and require further examination.

9) **Mutagenic Mode of Action.** For carcinogenic chemicals acting via a mutagenic mode of action (i.e., chemicals that cause cancer by damaging genes), we estimate risks to reflect the increased carcinogenicity of such chemicals during childhood. This approach is explained in detail in the Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. Where available data do not support a chemical-specific evaluation of differences between adults and children, the Supplemental Guidance recommends using the following default adjustment factors for early-life exposures: increase the carcinogenic potency by 10-fold for children up to 2 years old and by 3-fold for children 2 to 15 years old. These adjustments have the aggregate effects of increasing by about 60 percent the estimated risk (a 1.6-fold increase) for a lifetime of constant inhalation exposure. EPA uses these default adjustments only for carcinogens known to be mutagenic for which data to evaluate adult and juvenile differences in toxicity are not available. The UREs for several HAP (see Appendix 8) were adjusted upward, by multiplying by a factor of 1.6, to account for the increased risk during childhood exposures. Although trichloroethylene is carcinogenic by a mutagenic mode of action, the age-dependent adjustment factor for the URE only applies to the portion of the slope factor reflecting risk of kidney cancer. For full lifetime exposure to a constant level of trichloroethylene exposure, the URE is adjusted upward by a factor of 1.12 (rather than 1.6 as discussed above). For more information on applying age-dependent adjustment factors in cases where exposure varies over the lifetime, see Toxicological Review of Trichloroethylene. The URE for vinyl chloride includes exposure from birth, although the IRIS assessment contains UREs for both exposure from birth and exposure during adulthood. This value already accounts for childhood exposure; thus, no additional factor is applied.

2.7.2 Sources of acute dose-response information

Hazard identification and dose-response assessment information for preliminary acute inhalation exposure assessments is based on the existing recommendations of OAQPS for HAP (USEPA, 2021d). When the benchmarks are available, the results from acute screening assessments are compared to both "no effects" reference levels for the general public, such as the California Reference Exposure Levels (RELs), and to emergency response levels, such as Acute Exposure Guideline Levels (AEGLs) and Emergency Response Planning Guidelines (ERPGs), with the recognition that the ultimate interpretation of any potential risks associated with an estimated exceedance of a particular reference level depends on the definition of that level and any limitations expressed therein. Comparisons among different available inhalation health effect reference values (both acute and chronic) for selected HAP can be found in an EPA document of graphical arrays (USEPA, 2009b).

California Acute Reference Exposure Levels (RELs). The California Environmental Protection Agency (CalEPA) has developed acute dose-response reference values for many substances, expressing the results as acute inhalation RELs.

> The acute REL is defined by CalEPA as "the concentration level at or below which no adverse health effects are anticipated for a specified exposure duration (OEHHA, 2019). RELs are based on the most sensitive, relevant, adverse health effect reported in the medical and toxicological literature. RELs are designed to protect the most sensitive individuals in the population by the inclusion of margins of safety. Since margins of safety are incorporated to address data gaps and uncertainties, exceeding the REL does not automatically indicate an adverse health impact." Acute RELs are developed for 1-hour (and 8-hour) exposures. The values incorporate uncertainty factors similar to those used in deriving EPA's inhalation RfCs for chronic exposures.

Acute Exposure Guideline Levels (AEGLs). AEGLs are developed by the National Advisory Committee (NAC) on Acute Exposure Guideline Levels (NAC/AEGL) for Hazardous Substances and then reviewed and published by the National Research Council. As described in the Committee's Standing Operating Procedures, AEGLs "represent threshold exposure limits for the general public and are applicable to emergency exposures ranging from 10 min to 8 h." Their intended application is "for conducting risk assessments to aid in the development of emergency preparedness and prevention plans, as well as real time emergency response actions, for accidental chemical releases at fixed facilities and from transport carriers." The document states that "the primary purpose of the AEGL program and the NAC/AEGL Committee is to develop guideline levels for once-in-a-lifetime, short-term exposures to airborne concentrations of acutely toxic, high-priority chemicals." In detailing the intended application of AEGL values, the document states, "It is anticipated that the AEGL values will be used for regulatory and nonregulatory purposes by U.S. Federal and State agencies, and possibly the international community in conjunction with chemical emergency response, planning, and prevention programs. More specifically, the AEGL values will be used for conducting various risk assessments to aid in the development of emergency preparedness and prevention plans, as well as real-time emergency response actions, for accidental chemical releases at fixed facilities and from transport carriers."

The NAC/AEGL defines AEGL-1 and AEGL-2 as:

> "AEGL-1 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure."
>
> "AEGL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape."
>
> "Airborne concentrations above AEGL-1 represent exposure levels that can produce mild and progressively increasing but transient and nondisabling odor, taste, and sensory irritation or certain asymptomatic, nonsensory effects. With increasing airborne concentrations above each AEGL, there is a progressive increase in the likelihood of occurrence and the severity of effects described for each corresponding AEGL. Although the AEGL values represent threshold levels for the general public, including susceptible subpopulations, such as infants, children, the elderly, persons with asthma, and those with other illnesses, it is recognized that individuals, subject to unique or idiosyncratic responses, could experience the effects described at concentrations below the corresponding AEGL."

Emergency Response Planning Guidelines (ERPGs). The American Industrial Hygiene Association (AIHA) has developed ERPGs for acute exposures at three different levels of severity. These guidelines represent concentrations for exposure of the general population (but not particularly sensitive persons) for up to 1 hour associated with effects expected to be mild or transient (ERPG-1), irreversible or serious (ERPG-2), and potentially life-threatening (ERPG-3).

ERPG values are described in their supporting documentation as follows: "ERPGs are air concentration guidelines for single exposures to agents and are intended for use as tools to assess the adequacy of accident prevention and emergency response plans, including transportation emergency planning, community emergency response plans, and incident prevention and mitigation."

ERPG-1 and ERPG-2 values are defined by AIHA's as follows:

> ERPG-1 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient health effects or without perceiving a clearly defined objectionable odor.
>
> ERPG-2 is the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other

serious adverse health effects or symptoms that could impair an individual's ability to take protective action.

2.8 Risk characterization

2.8.1 General

The final product of the risk assessment is the risk characterization, in which the information from the previous steps is integrated and an overall conclusion about risk is synthesized that is complete, informative, and useful for decision makers. In general, the nature of this risk characterization depends on the information available, the application of the risk information and the resources available. In all cases, major issues associated with determining the nature and extent of the risk are identified and discussed. Further, it is EPA's policy that a risk characterization be prepared in a manner that is clear, transparent, reasonable, and consistent with other risk characterizations of similar scope prepared across programs in the Agency. These principles of transparency and consistency have been reinforced by the Agency's *Risk Characterization Handbook* (USEPA, 2000a), in the Agency's information quality guidelines (USEPA, 2002a), and in the Office of Management and Budget (OMB) Memorandum on Updated Principles for Risk Analysis (OMB, 2007), and they are incorporated in these assessments.

Estimates of health risk are presented in the context of uncertainties and limitations in the data and methodology. Through our tiered, iterative analytical approach, we have attempted to reduce both uncertainty and bias to the greatest degree possible in these assessments, within the limitations of available time and resources. We provide summaries of risk metrics (including maximum individual cancer risks and noncancer hazards, as well as cancer incidence estimates) along with a discussion of the major uncertainties associated with their derivation to provide decision makers with the fullest picture of the assessment and its limitations.

For each carcinogenic HAP included in an assessment for which a potency estimate is available, individual and population cancer risks are calculated by multiplying the corresponding lifetime average exposure estimate by the appropriate URE. This calculated cancer risk is defined as the upper-bound probability of developing cancer over a 70-year period (i.e., the assumed human lifespan) at that exposure. Because UREs for most HAP are upper-bound estimates, actual risks at a given exposure level may be lower than predicted.

Increased cancer incidence for the entire population within the area of analysis is estimated by multiplying the estimated lifetime cancer risk for each census block by the number of people residing in that block, then summing the results for the entire modeled domain. This lifetime population incidence estimate is divided by 70 years to obtain an estimate of the number of cancer cases per year.

Unlike linear dose-response assessments for cancer, noncancer health hazards generally are not expressed as a probability of an adverse occurrence. Instead, the estimated human health risk for noncancer effects is expressed by comparing an exposure to a reference level as a

ratio. The hazard quotient (HQ) is the estimated exposure divided by a reference level (e.g., the RfC). For a given HAP, exposures at or below the reference level (HQ ≤ 1) are not likely to cause adverse health effects. As exposures increase above the reference level (HQs increasingly greater than 1), the potential for adverse effects increases. For exposures predicted to be above the RfC, the risk characterization includes the degree of confidence ascribed to the RfC values for the compound(s) of concern (i.e., high, medium, or low confidence) and discusses the impact of this on possible health interpretations.

The risk characterization for chronic effects other than cancer is developed using the HQ for inhalation, calculated for each HAP at each census block centroid. As discussed above, RfCs incorporate generally conservative uncertainty factors in the face of uncertain extrapolations, such that an HQ greater than 1 does not necessarily suggest the onset of adverse effects. The Hazard Index (HI) is the sum of hazard quotients for substances that affect the same target organ or organ system and is an approximation of the aggregate effect on a specific target organ (e.g., the lungs). The HQ and HI cannot be translated to a probability that adverse effects will occur, and it is unlikely to be proportional to adverse health effect outcomes in a population.

Screening for potentially significant acute inhalation exposures also follows the HQ approach. We divide the 99th percentile estimated acute exposure concentration by each available acute dose-response value to develop an array of HQs. In general, when none of these HQs is greater than one, there is no potential for acute risk. When one or more HQ is above 1, we evaluate additional information (e.g., proximity of the facility to potential exposure locations) to determine whether there is a potential for significant acute risks.

2.8.2 Mixtures

Since most or all receptors in these assessments receive exposures to multiple pollutants rather than a single pollutant, we estimate the aggregate health risks associated with exposure to all of the HAP from a particular source category.

To combine risks across multiple carcinogens, our assessments use the mixtures guidelines' default assumption of additivity of effects and combine risks by summing them using the independence formula in the mixtures guidelines (USEPA, 1986; USEPA, 2000b).

In assessing noncancer hazard from chronic exposures, in cases where different pollutants cause adverse health effects via completely different modes of action, it may be inappropriate to aggregate HQs. In consideration of these mode-of-action differences, the mixtures guidelines support aggregating effects of different substances in specific and limited ways. To conform to these guidelines, we aggregate noncancer HQs of HAP that act by similar toxic modes of action, or (where this information is absent) that affect the same target organ. This process creates, for each target organ, a target-organ-specific hazard index (TOSHI), defined as the sum of HQs for individual HAP that affect the same organ or organ system. For the RTRs, TOSHI calculations are based exclusively on effects occurring at the "critical dose" (i.e., the lowest dose that produces adverse health effects). Although HQs associated with some pollutants have been aggregated into more than one TOSHI, this has been done only in

cases where the critical dose affects more than one target organ. Because impacts on organs or systems that occur above the critical dose have not been included in the TOSHI calculations, some TOSHIs may have been underestimated. As with the HQ, the TOSHI should not be interpreted as a probability of adverse effects or as strict delineation of "safe" and "unsafe" levels. Rather, the TOSHI is another measure of the potential for adverse health outcomes associated with pollutant exposure and needs to be interpreted carefully by health scientists and risk managers.

Because of the conservative nature of the acute inhalation screening assessment and the variable nature of emissions and potential exposures, acute impacts are screened on an individual pollutant basis, not using the TOSHI approach.

3 Risk results for the Neoprene Production source category

3.1 Source category description and emissions

The Neoprene Production source category includes facilities that produce neoprene, which is a polymer of chloroprene. Neoprene was originally developed as an oil-resistant substitute for natural rubber, and its properties allow its use in a wide variety of applications, including wetsuits, gaskets and seals, hoses and tubing, plumbing fixtures, adhesives, and other products. Emission points include process vents, maintenance vents, wastewater, storage tanks, transfer racks, and equipment leaks. The MACT standards for the Neoprene Production source category are contained in 40 CFR part 63, subpart U. A complete description of the source category can be found in the text of the NPRM.

The emission estimates for this source category were obtained from a 2022 information collection request (ICR) survey, updated with more recent data from industry stakeholders, and reviewed to ensure quality control of facility and emission locations. We determined that that there is only one facility in the Neoprene Production source category operating in the U.S. that will be affected by the final rule. Emissions from this facility in the Neoprene Production source category are summarized in Table 3.1-1. The total HAP emissions from the facility are approximately 21 tons per year. The HAP emitted in the largest quantities are chloroprene, toluene, hydrochloric acid, methylene chloride, chloroform, and n-hexane. Emissions of these 6 HAP make up over 99 percent of the total emissions by mass. No PB-HAP are emitted from this facility. The environmental HAP hydrochloric acid is emitted from this facility and is included in the environmental risk screening assessment.

The emissions for this source category are estimates of actual emissions on an annual basis. The risk results presented in the following sections are based on these actual emissions. Facility-wide emissions were also estimated and the risk results based on those emissions are presented below as well. Details on the development of the actual and facility-wide emission estimates and the source of the data for this source category can be found in Appendix 1.

For the chronic inhalation risk assessment, the emissions inventory for the Neoprene Production source category includes emissions of 12 HAP and all 12 of these have available chronic inhalation dose-response values. Of these, four are classified as known, probable, or

possible carcinogens, with quantitative cancer dose-response values available and 12 HAP have quantitative noncancer dose-response values available. These HAP, their emissions and dose-response values are listed in Table 3.1-1 and the source of each dose-response value is listed in Appendix 8.

For the acute inhalation risk assessment, for the Neoprene Production source category, maximum hourly emissions estimates were available, so we did not use a default acute emissions multiplier of 10 (as described in Section 2.4), but rather, we used process level-specific acute emissions multipliers, generally ranging from a factor of 2 to 10 as was done in past chemical and petrochemical residual risk reviews such as for the 2015 the Petroleum Refinery Sector rule, 2020 MON rule, 2020 EMACT rule, and 2020 OLD rule, where similar emission sources and standards exist. See Appendix 1 to this document for a detailed description of how the maximum hourly emissions were developed for this source category.

The emissions inventory for the Neoprene Production source category includes emissions of 11 HAP with relevant and available quantitative acute dose-response values. These HAP, their emissions and acute and chronic dose-response values are listed in Table 3.1-1 and the source of each dose-response value is listed in Appendix 8.

As mentioned previously, when we identify acute impacts which exceed their relevant dose-response values, we refine our acute screening estimates to the extent possible. For the Neoprene Production source category, the acute screening results indicate the peak emissions are considered unlikely to pose significant risk and further refinement was not warranted. The acute results for the source category are summarized in the following section and detailed information is contained in Appendix 10 to this document (*Detailed Risk Modeling Results*).

Regarding a multipathway risk assessment, there are no PB-HAP identified in the emissions inventory from this facility in the Neoprene Production source category, therefore a multipathway risk assessment is not warranted.

For the environmental risk assessment, the acid gas hydrochloric acid was screened for potential adverse environmental effects as described in Section 2.5. The benchmark value and a detailed discussion of the approach for this assessment can be found in Appendix 9. The results of the environmental assessment for the source category are summarized in the following section and detailed information is contained in Appendix 10 to this document.

Table 3.1-1 Summary of Emissions from the Neoprene Production Source Category and Dose-Response Values Used in the Residual Risk Assessment

HAP	Emissions (tpy)	Number of Facilities Reporting HAP (1 facility in data set)	Prioritized Inhalation Dose-Response Value Identified by OAQPS			PB-HAP Oral Benchmark Values for Cancer (1/(mg/kg/d)) and/or Noncancer (mg/kg/d)[a]
			Unit Risk Estimate for Cancer (1/(µg/m^3))	Reference Concentration for Noncancer (mg/m^3)	Health Benchmark Values for Acute Noncancer (mg/m^3)	
Chloroprene	18	1	0.00048[b]	0.02		
Toluene	2	1		5	190 (ERPG-1)	
Hydrochloric Acid	0.6	1		0.02	2.1 (REL)	
Methylene Chloride	0.2	1	0.000000016[b]	0.6	14 (REL)	
Chloroform	0.2	1		0.098	0.15 (REL)	
n-Hexane	0.2	1		0.7	10000 (AEGL-2 (1-hr))	
Tetrachloroethene	0.04	1	0.00000026	0.04	20 (REL)	
Xylenes (mixed)	0.04	1		0.1	22 (REL)	
Methyl Chloride	0.03	1		0.09	310 (ERPG-1)	
Formaldehyde	0.007	1	0.000013	0.0098	0.055 (REL)	
Carbon Disulfide	0.004	1		0.7	3.1 (ERPG-1)	
Glycol Ethers	0.004	1		0.02	0.093 (REL)	

Notes:
[a] Benchmark values are provided only for PB-HAPs for which multipathway risk is assessed (via TRIM). There may be other PB-HAPs in this table, even though no benchmark is presented.
[b] Age-dependent adjustment factor (ADAF) has been applied to the Unit Risk Estimate (URE).

3.2 Baseline risk characterization

This section presents the results of the risk assessment for the Neoprene Production source category based on the modeling methods described in the previous sections. All baseline risk results are developed using the best estimates of actual HAP emissions summarized in the previous section. The basic chronic inhalation risk estimates presented here are the maximum individual lifetime cancer risk, the maximum chronic hazard index, and the cancer incidence. We also present results from our acute inhalation screening assessment in the form of maximum acute hazard quotients for the reasonable worst-case exposure scenario, as well as the results of our preliminary screening assessment for potential non-inhalation risks and environmental risk from PB-HAP. Also presented are the HAP "drivers," which are the HAP that collectively contribute 90 percent of the maximum cancer risk or maximum hazard at the highest exposure location. A detailed summary of the facility-specific inhalation and multipathway risk assessment results is available in Appendix 10 of this document.

3.2.1 Risk assessment results based on actual emissions

Inhalation

Table 3.2-1 summarizes the chronic and acute inhalation risk results for this source category based upon baseline actual emissions. The results of the chronic inhalation cancer risk assessment are that the maximum lifetime individual cancer risk posed by the facility could be as high as 500-in-1 million, with chloroprene emissions from maintenance vents, storage tanks, wastewater, and equipment leaks as the major contributors to the risk. The total estimated cancer incidence from this source category is one excess cancer case every 21 years. Approximately 1,000,000 people live within 50 kilometers of this Neoprene Production facility, and 690,000 people are estimated to have a cancer risk at or above 1-in-1 million from primarily the chloroprene emitted from this facility's source category emissions, with 47,000 of those people estimated to have a cancer risk at or above 10-in-1 million, 4,600 people estimated to have a cancer risk at or above 100-in-1 million, and 2,000 people estimated to have a cancer risk above 100-in-1 million. The maximum chronic noncancer hazard index value for this facility based on source category emissions could be up to 0.05 (respiratory) driven by emissions of chloroprene from maintenance vents, storage tanks, wastewater, and equipment leaks, and no one is exposed to TOSHI levels above 1.

Maximum acute HQs were calculated for every HAP that has an acute dose-response value, as shown in Table 3.1-1. Since none of the screening HQs were greater than 1, further refinement of the estimates was not warranted. Based on actual baseline emissions, the highest screening acute HQ of 0.3 (based on the acute REL for chloroform) is shown in Table 3.2-2. Acute HQ estimates for each pollutant at the facility are provided in Appendix 10 of this document.

Table 3.2-1. Source Category Level Inhalation Risks for Neoprene Production Based on Actual Emissions

Result		HAP "Drivers"
Facilities in Source Category		
Number of Facilities Estimated to be in Source Category	1	n/a
Number of Facilities Modeled in Risk Assessment	1	n/a
Cancer Risks		
Maximum Individual Lifetime Cancer Risk (in 1 million)	500	chloroprene
Number of Facilities with Maximum Individual Lifetime Cancer Risk:		
Greater than or equal to 1,000-in-1 million	0	n/a
Greater than 100-in-1 million	1	chloroprene
Greater than or equal to 100-in-1 million	1	chloroprene
Greater than or equal to 10-in-1 million	1	chloroprene
Greater than or equal to 1-in-1 million	1	chloroprene
Chronic Noncancer Risks		
Maximum Respiratory Hazard Index	0.05	chloroprene
Number of Facilities with Maximum Respiratory Hazard Index:		
Greater than 1	0	n/a

Table 3.2-1. Source Category Level Inhalation Risks for Neoprene Production Based on Actual Emissions

Result		HAP "Drivers"
Acute Noncancer Screening Results		
Maximum Acute Hazard Quotient	0.3	chloroform (REL)
Number of Facilities with Potential for Acute Effects	0	n/a
Population Exposure		
Number of People Living Within 50 Kilometers of Facilities Modeled	1,000,000	n/a
Number of People Exposed to Cancer Risk:		
Greater than or equal to 1,000-in-1 million	0	n/a
Greater than 100-in-1 million	2,000	n/a
Greater than or equal to 100-in-1 million	4,600	n/a
Greater than or equal to 10-in-1 million	47,000	n/a
Greater than or equal to 1-in-1million	690,000	n/a
Number of People Exposed to Noncancer Respiratory Hazard Index:		
Greater than 1	0	n/a
Estimated Cancer Incidence (excess cancer cases per year)	0.05	n/a
Contribution of HAP to Cancer Incidence		
chloroprene	100%	n/a
formaldehyde	<0.001%	n/a
tetrachloroethene	<0.001%	n/a
methylene chloride	<0.0001%	n/a

Facility-wide Inhalation

The facility-wide chronic MIR and TOSHI, available in Appendix 10, are based on emissions from all sources at the identified facility (both MACT and non-MACT sources). The results of the facility-wide assessment for cancer risks, as compared to the Neoprene Production source category assessment, are summarized in Table 3.2-2. The results indicate that the facility has a facility-wide cancer MIR above 100-in-1 million. The maximum facility-wide cancer MIR is 600-in-1 million, mainly driven by chloroprene emissions from in-category maintenance vents, storage tanks, wastewater, and equipment leaks, as well as from non-category maintenance vents and equipment leaks. The total estimated cancer incidence from the whole facility is one excess cancer case every 18 years. Approximately 890,000 people are estimated to have cancer risks at or above 1-in-1 million from exposure to HAP emitted from both MACT and non-MACT sources at the facility in this source category, with 48,000 of those people estimated to have cancer risks at or above 10-in-1 million, 5,800 people estimated to have cancer risks at or above 100-in-1 million, and 2,300 people estimated to have cancer risks above 100-in-1 million. The maximum facility wide TOSHI for the source category is estimated to be 0.3 (for the respiratory hazard index), mainly driven by emissions of chlorine from non-category sources (including process vents, equipment leaks, and storage tanks) and by non-category emissions of nickel compounds and hydrochloric acid, as well as by in-category emissions of chloroprene from maintenance vents. No people are exposed to

noncancer hazard index levels above 1, based on facility-wide emissions from the facility in this source category.

Table 3.2-2 Source Category Contribution to Facility-Wide Cancer Risks Based on Actual Emissions

Neoprene Production	Number of Facilities Binned by Facility-Wide MIR (in 1 million)				
Source Category MIR Contribution to Facility-Wide MIR	**<1**	**1≤ MIR<10**	**10≤ MIR<100**	**≥ 100**	**Total**
> 90%	0	0	0	0	0
50-90%	0	0	0	1	1
10-50%	0	0	0	0	0
< 10%	0	0	0	0	0
Total	0	0	0	1	1

Multipathway

We did not identify reported PB-HAP emissions from the Neoprene Production source category, therefore a multipathway assessment is not warranted. As such, Appendix 11 of this document is intentionally blank.

Environmental

As mentioned above, because we did not identify reported PB-HAP emissions, we did not undertake the environmental risk screening assessment of PB-HAP for the Neoprene Production source category. Furthermore, we conducted an environmental risk screening assessment for acid gases (*i.e.*, HCl and HF) for the Neoprene Production source category; however, there were no reported emissions of hydrofluoric acid (HF) at this facility. For hydrochloric acid (HCl), the average modeled concentration around the facility (*i.e.*, the average concentration of all off-site data points in the modeling domain) did not exceed any ecological benchmark. In addition, each individual modeled concentration of HCl (*i.e.*, each off-site data point in the modeling domain) was below the ecological benchmarks for the facility.

3.2.2 Risk assessment results based on allowable emissions

Inhalation

Potential differences between actual emissions levels and the maximum emissions allowable under the MACT standards (i.e., MACT-allowable emissions) were also determined for this Neoprene Production facility. For this category, baseline actual emissions are equal to allowable emissions, and therefore the cancer and noncancer risk assessment results based on allowable emissions are the same as the risk assessment results based on baseline actual emissions, summarized above in Section 3.2.1.

3.3 Post-control risk characterization

Chloroprene emissions are primarily driving the baseline risks. Given this, using the same risk assessment methods described above, we estimated what the risks would be if chloroprene emissions were controlled from heat exchange systems, process vents, storage vessels, wastewater, and equipment leaks at Neoprene Production processes. The results of the chronic inhalation cancer risk assessment based on these post-control emissions from this facility in the source category are summarized in Table 3.3-1. Based on this scenario, we estimate that the cancer MIR for the Neoprene Production source category would be reduced from 500-in-1 million (i.e., pre-control) to approximately 100-in-1 million (i.e., post-control), with chloroprene emissions from maintenance vents, equipment leaks, process vents, and storage tanks driving the post-control risk. There is an estimated reduction in cancer incidence to 0.01 excess cancer cases per year (post-control), from 0.05 excess cancer cases per year (pre-control). In addition, the number of people estimated to have a cancer risk greater than or equal to 1-in-1 million would be reduced from 690,000 (pre-control) to 58,000 (post-control) from Neoprene Production source category emissions. The number of people estimated to have a cancer risk greater than or equal to 10-in-1 million would be reduced from 47,000 (pre-control) to 16,000 (post-control) from Neoprene Production source category emissions. The number of people estimated to have a cancer risk greater than or equal to 100-in-1 million would be reduced from 4,600 (pre-control) to 270 (post-control) from Neoprene Production source category emissions. Finally, the number of people estimated to have a cancer risk greater than 100-in-1 million would be reduced from 2,000 (pre-control) to 0 (post-control) from Neoprene Production source category emissions.

Regarding noncancer risk, the maximum chronic noncancer hazard index posed by post-control emissions is estimated to be 0.01 (for the respiratory hazard index) driven primarily by emissions of chloroprene from maintenance vents, equipment leaks, process vents, and storage tanks, as well as by hydrochloric acid from process vents. No one is exposed to noncancer hazard index levels above 1, based on post-control neoprene production emissions from this facility in the Neoprene Production source category. Similar to baseline emissions, the maximum acute hazard quotient is less than 1 based on post-control emissions.

As noted for the baseline assessment, no PB-HAP are emitted from this source category post-control, therefore a multipathway assessment is not warranted. Likewise, the post-control emissions of hydrochloric acid indicated that no ecological benchmarks are exceeded.

Table 3.3-1. Source Category Level Inhalation Risks for Neoprene Production Based on Post-Control Emissions

Result		HAP "Drivers"
Cancer Risks		
Maximum Individual Lifetime Cancer Risk (in 1 million)	100	chloroprene
Number of Facilities with Maximum Individual Lifetime Cancer Risk:		
Greater than or equal to 1,000-in-1 million	0	n/a
Greater than 100-in-1 million	0	n/a
Greater than or equal to 100-in-1 million	1	chloroprene

Table 3.3-1. Source Category Level Inhalation Risks for Neoprene Production Based on Post-Control Emissions

Result		HAP "Drivers"
Greater than or equal to 10-in-1 million	1	chloroprene
Greater than or equal to 1-in-1 million	1	chloroprene
Chronic Noncancer Risks		
Maximum Respiratory Hazard Index	0.01	chloroprene, hydrochloric acid
Number of Facilities with Maximum Respiratory Hazard Index:		
Greater than 1	0	n/a
Acute Noncancer Screening Results		
Maximum Acute Hazard Quotient	0.3	chloroform (REL)
Number of Facilities with Potential for Acute Effects	0	n/a
Population Exposure		
Number of People Living Within 50 Kilometers of Facilities Modeled	1,000,000	n/a
Number of People Exposed to Cancer Risk:		
Greater than or equal to 1,000-in-1 million	0	n/a
Greater than 100-in-1 million	0	n/a
Greater than or equal to 100-in-1 million	270	n/a
Greater than or equal to 10-in-1 million	16,000	n/a
Greater than or equal to 1-in-1million	58,000	n/a
Number of People Exposed to Noncancer Respiratory Hazard Index:		
Greater than 1	0	n/a
Estimated Cancer Incidence (excess cancer cases per year)	0.01	n/a
Contribution of HAP to Cancer Incidence		
chloroprene	100%	n/a
formaldehyde	<0.01%	n/a
tetrachloroethene	<0.001%	n/a
methylene chloride	<0.001%	n/a

4 General discussion of uncertainties in the risk assessment

The uncertainties in virtually all of the RTR risk assessments can be divided into three areas: 1) uncertainties in the emission data sets, 2) exposure modeling uncertainties, and 3) uncertainties in the dose-response relationships. Uncertainties in the emission estimates and in the air quality models lead to uncertainty in air concentrations. Uncertainty in exposure modeling can arise due to uncertain activity patterns, the locations of individuals within a census tract, and the microenvironmental concentrations as reflected in the exposure model. Finally, uncertainty in the shape of the relationship between exposure and effects, the URE and the RfC, also contributes to uncertainties in the risk assessment. These three areas of uncertainty are discussed below.

4.1 Emissions inventory uncertainties

Although the development of the RTR emissions data set involves an extensive quality assurance/quality control process, the accuracy of emission values will vary depending on certain factors, for example, the source of the data, the degree to which data are incomplete or missing, the degree to which assumptions made to complete the data sets are accurate, and the extent to which there are errors in these emission estimates. The emission estimates used in the risk assessment generally are annual totals for certain years, and they do not reflect short-term fluctuations during the course of a year or variations from year to year.

For the acute screening assessment, therefore, in the absence of available specific estimates or measurements, we use estimates of peak hourly emission rates. These estimates typically are calculated by first estimating the average annual hourly emissions rates by evenly dividing the total annual emission rate from the inventory into the 8,760 hours of the year. An emission adjustment factor that is intended to account for emission fluctuations during normal facility operations is then applied to these average annual hourly emission rates. The adjustment factor can be based on actual fluctuations seen in the available emission data for sources in a category or on engineering judgment; in the absence of such information, a default factor is applied.

To prepare the emissions data set, EPA gathers the best available data on emissions, emission release parameters, and other relevant source category-specific parameters. EPA often begins with its National Emissions Inventory (NEI) database as the starting point for emission rates, emissions release characteristics, and locations of the emission release points for each facility in the source category. The NEI is a composite of emission measurements and estimates produced by state and local regulatory agencies, industry, and EPA. EPA's industry experts then review the data for consistency and completeness and conduct extensive quality assurance/quality control checks. Available information, which may include compliance data, information from project files, permits, and other sources regarding facilities and emission sources, are also incorporated into the data set. This additional information may be incorporated in addition to the NEI data or in place of the NEI data, depending on EPA's evaluation of the quality of the various sources of data. In order to fill data gaps, EPA may conduct a formal information collection request (ICR) under the authority of section 114 of the Clean Air Act to obtain current, complete emissions data and other data from the facility owners and operators associated with the source category under review.

Uncertainty in the emissions data set stems from data gaps, default assumptions, and the emission models used to develop emissions inventory estimates. A variety of methods, such as emission factors, material balances, engineering judgement, air permit information and source testing, are used to develop emission estimates. Other parameters that are part of the emissions data set, including facility location and emission point parameters, may also be a source of uncertainty. Some release point locations use an average facility location instead of the location of each specific unit within the facility. In some instances, default release point parameters may be in the inventory. Where fugitive release parameters are not available, default values are included. Another potential source of emission estimate uncertainty may be low or poor quality data (e.g., out-of-date parameter values). For more information on the

uncertainties in the emission estimates for this source category see Appendix 1 *(Emissions Inventory Support Documents*) of this document.

4.2 Exposure modeling uncertainties

4.2.1 Inhalation exposure modeling

Although every effort is made to identify all of the relevant facilities and emission points, as well as to develop accurate estimates of the annual emission rates for all relevant HAP, the uncertainties in our emission inventory likely dominate the uncertainties in the exposure assessment. The ambient air modeling uncertainties are considered relatively small in comparison, since we are using EPA's refined local dispersion model with site-specific parameters and reasonably representative meteorology. These uncertainties include the fact that the population exposure estimates do not account for short- or long-term population mobility and do not address processes like deposition, plume depletion, and atmospheric degredation. Additionally, estimates of maximum individual risk (MIR) contain uncertainty because they are derived at census block centroid locations rather than actual residences. This uncertainty is known to create potential underestimates and overestimates of the actual MIR values for individual facilities; however, overall, it is not thought to have a significant impact on the estimated MIR for a source category. We also do not factor in the possibility of a source closure occurring during the 70-year chronic exposure period, leading to a potential upward bias in both the MIR and population risk estimates. Nor do we factor in the possibility of population growth during the 70-year chronic exposure period, which could lead to a potential downward bias in both the MIR and population risk estimates. Finally, we do not factor in time an individual spends indoors.

We did not include the effects of human mobility on exposures in the assessment. Specifically, short-term mobility and long-term mobility between census blocks in the modeling domain were not considered. (Short-term mobility is movement from one micro-environment to another over the course of hours or days. Long-term mobility is movement from one residence to another over the course of a lifetime.) The approach of not considering short or long-term population mobility does not bias the estimate of the theoretical MIR (by definition), nor does it affect the estimate of cancer incidence because the total population number remains the same. It does, however, affect the shape of the distribution of individual risks across the affected population, shifting it toward higher estimated individual risks at the upper end and reducing the number of people estimated to be at lower risks, thereby increasing the estimated number of people at specific high risk levels (e.g., 1-in-10 thousand or 1-in-1 million). We also do not account for population growth or decline and instead assume populations are constant over the next 70 years. This approach does not bias the estimate of the theoretical MIR but may underestimate cancer incidence in areas with population growth or overestimate it in areas with population decline.

In addition, the assessment predicted the chronic exposures at the centroid of each populated census block as surrogates for the exposure concentrations for all people living in that block. Using the census block centroid to predict chronic exposures tends to over-predict exposures for people in the census block who live farther from the facility and under-predict exposures for people in the census block who live closer to the facility. Thus, using the census block

centroid to predict chronic exposures may lead to a potential understatement or overstatement of the true maximum impact, but is an unbiased estimate of average risk and incidence. We reduce this uncertainty by analyzing large census blocks near facilities using aerial imagery and adjusting the location of the block centroid to better represent the population in the block, as well as adding additional receptor locations where the block population is not well represented by a single location.

The assessment evaluates the cancer inhalation risks associated with pollutant exposures over a 70-year period, which is the assumed lifetime of an individual. In reality, both the length of time that modeled emission sources at facilities actually operate (i.e., more or less than 70 years) and the domestic growth or decline of the modeled industry (i.e., the increase or decrease in the number or size of domestic facilities) will influence the future risks posed by a given source or source category. Depending on the characteristics of the industry, these factors will, in most cases, result in an overestimate both in individual risk levels and in the total estimated number of cancer cases. However, in the unlikely scenario where a facility maintains, or even increases, its emissions levels over a period of more than 70 years, residents live beyond 70 years at the same location, and the residents spend more of their days at that location, then the cancer inhalation risks could potentially be underestimated. However, annual cancer incidence estimates from exposures to emissions from these sources would not be affected by the length of time an emissions source operates.

The exposure estimates used in these analyses assume chronic exposures to ambient (outdoor) levels of pollutants. Because most people spend the majority of their time indoors, actual exposures may not be as high, depending on the characteristics of the pollutants modeled. For many of the HAP, indoor levels are roughly equivalent to ambient levels, but for very reactive pollutants or larger particles, indoor levels are typically lower.

A sensitivity analysis, discussed in "Risk and Technology Review (RTR) Risk Assessment Methodologies" (USEPA, 2009a), found that the selection of the meteorology data set location could have an impact on the risk estimates. The analysis found that cancer MIR derived using different meteorological stations varied by as much as 63 percent below to 51 percent above the value derived using the nearest meteorological station. Cancer incidence estimated using different meteorological stations varied by as much as 68 percent below to 120 percent above the value estimated using the nearest meteorological station. Similarly, air concentrations estimated using different meteorological stations varied by as much as 49 percent below to 21 percent above the value estimated using the nearest meteorological station. Since this analysis was performed EPA has increased the number of meteorological stations used in our risk assessments; thus, we expect variability to be reduced.

For the acute screening assessment, the results are intentionally biased high, and thus health-protective, by assuming the co-occurrence of independent factors, such as hourly emission rates, meteorology and human activity patterns. Furthermore, in cases where multiple acute dose-response values for a pollutant are considered scientifically acceptable, we choose the most conservative of these dose-response values, erring on the side of overestimating potential health risks from acute exposures. In cases where these results indicate the potential

for exceeding acute HQs, we refine our assessment by developing a better understanding of the geography of the facility relative to potential exposure locations.

4.2.2 Multipathway exposure modeling

In modeling the fate and transport of pollutants through the environment and the non-inhalation exposure (i.e., ingestion) to these pollutants, TRIM.FaTE uses simplified representations of many complex real-world processes. This simplified representation introduces uncertainty. Uncertainties arise from model assumptions and structure, as reflected in the algorithms that describe the environmental movement of pollutants, and in the input values for numerous environmental parameters.

Uncertainty in the algorithms is inherent to any model attempting to represent complex processes in the real world. How persistent, bioaccumulative chemicals such as mercury, cadmium, arsenic, PAHs, and dioxins behave in the environment is highly complex, and many natural processes are represented in a simplified manner by TRIM.FaTE, including, for example:

- gaseous and particulate deposition from air;
- biogeochemical cycling in the aquatic environment, particularly mercury transformations through methylation and demethylation at the sediment-surface interface;
- mixing processes in air, water, and sediment;
- suspended and benthic sediment dynamics in lakes; and
- biotic processes such as growth, reproduction, and predation.

Even though some processes, such as diffusion, are known to follow second-order dynamics, the TRIM.FaTE model represents all fate and transport processes in terms of first-order differential equations. TRIM.FaTE also does not explicitly deal with lateral or vertical dispersion in the air compartments. Some algorithms, such as those addressing methylation and sediment transport, for example, do not consider all of the factors known to affect the process. Biotic processes including chemical absorption, chemical elimination, growth, reproduction, predation, and death have been represented relatively simplistically in the model. Although the model's algorithms have been validated and are based on professional judgment, some level of uncertainty results from such simplifications.

The input values for parameters are also associated with uncertainty. Algorithms that describe the environmental movement of pollutants depend on numerous environmental parameters for which the values might be naturally variable and for which available data are often limited. Examples of parameters for which input values are variable and uncertain include aquatic food web structure (e.g., diet of each fish species), biokinetic parameters that influence bioaccumulation (e.g., assimilation efficiencies and elimination rates), topographic characteristics (e.g., lake depth, runoff rates, and erosion rates), meteorological parameters (e.g., evaporation and precipitation rates), chemical transformation rates (e.g., methylation and demethylation rates, in the case of mercury), and human exposure parameters (especially fish consumption rates).

For TRIM.FaTE modeling, we use central tendency values and combinations of values that would lead to estimates of reasonable maximum exposures to bound risk estimates. We have conducted analyses of the sensitivity of risk estimates to parameter input values. For those parameters to which the model is particularly sensitive, we have continued to collect additional data to better quantify the variability and distribution of input values.
A more comprehensive explanation of the uncertainties related to fate, transport, and exposure modeling using TRIM.FaTE is provided in Appendix 6 (*Technical Support Document for TRIM-Based Multipathway Tiered Screening Methodology for RTR)* of this report for the tiered assessments and Appendix 11 (*Site-Specific Human Health Multipathway Residual Risk Assessment Report)* of this report for a site-specific assessment if one was conducted.

4.2.3 Environmental risk screening assessment

For each source category, we generally rely on site-specific levels of environmental HAP emissions to perform an environmental screening assessment. The environmental screening assessment is based on the outputs from models that estimate environmental HAP concentrations. The same models, specifically the TRIM.FaTE multipathway model and the AERMOD air dispersion model, are used to estimate environmental HAP concentrations for both the human multipathway screening analysis and for the environmental screening analysis. Therefore, both screening assessments have similar modeling uncertainties. Two important types of uncertainty associated with the use of these models in RTR environmental screening assessments (and inherent to any assessment that relies on environmental modeling) are model uncertainty and input uncertainty.

Model uncertainty concerns whether the selected models are appropriate for the assessment being conducted and whether they adequately represent the movement and accumulation of environmental HAP emissions in the environment. For example, does the model adequately describe the movement of the pollutant through the soil? This type of uncertainty is difficult to quantify. However, based on feedback received from previous EPA SAB reviews and other reviews, we are confident that the models used in the screening assessments are appropriate and state-of-the-art for the environmental risk assessments conducted in support of our RTR analyses.

Input uncertainty is concerned with how accurately the models have been configured and parameterized for the assessment at hand. For Tier 1 of the environmental screening assessment for PB-HAP, we configured the models to avoid underestimating exposure and risk to reduce the likelihood that the results indicate the risks are lower than they actually are. This was accomplished by selecting upper-end values from nationally-representative datasets for the more influential parameters in the environmental model, including selection and spatial configuration of the area of interest, the location and size of any bodies of water, meteorology, surface water and soil characteristics, and structure of the aquatic food web. In Tier 1, we use the maximum facility-specific emissions for the PB-HAP (other than lead compounds, which were evaluated by comparison to the Secondary Lead NAAQS) that are included in the environmental screening assessment and each of the media when comparing to

ecological benchmarks. This is consistent with the conservative design of the Tier 1 screening assessment. In Tier 2 of the environmental screening assessment for PB-HAP, we refine the model inputs to account for meteorological patterns in the vicinity of the facility versus using upper-end national values, and we identify the locations of water bodies near the facility location. By refining the screening approach in Tier 2 to account for local geographical and meteorological data, we decrease the likelihood that concentrations in environmental media are overestimated, thereby increasing the usefulness of the screening assessment. To better represent widespread impacts, the modeled soil concentrations are averaged in Tier 2 to obtain one average soil concentration value for each facility and for each PB-HAP. For PB-HAP concentrations in water, sediment, and fish tissue, the highest value for each facility for each pollutant is used.

For the environmental screening assessment for acid gases, we employ a single-tiered approach. We use the modeled air concentrations and compare those with ecological benchmarks.

For both Tiers 1 and 2 of the environmental screening assessment, our approach to addressing model input uncertainty is generally cautious. We choose model inputs from the upper end of the range of possible values for the influential parameters used in the models, and we assume that the exposed individual exhibits ingestion behavior that would lead to a high total exposure. This approach reduces the likelihood of not identifying potential risks for adverse environmental impacts.

4.3 Uncertainties in the dose-response relationships

In the sections that follow, separate discussions are provided on uncertainty associated with cancer potency factors and for noncancer reference values. Cancer potency values are derived for chronic (lifetime) exposures. Noncancer dose-response values are generally derived for chronic exposures (up to a lifetime) but may also be derived for acute (less than 24 hours), short-term (from 24 hours up to 30 days), and subchronic (30 days up to 10 percent of lifetime) exposure durations, all of which are derived based on an assumption of continuous exposure throughout the duration specified. For the purposes of assessing all potential health risks associated with the emissions included in an assessment, we rely on both chronic (cancer and noncancer) and acute (noncancer) dose-response values, which are described in more detail below.

Although every effort is made to identify peer-reviewed dose-response values for all HAP emitted by the source category included in an assessment, some HAP have no peer-reviewed values. Since exposures to these pollutants cannot be included in a quantitative risk estimate, an understatement of risk for these pollutants at estimated exposure levels is possible. To help alleviate this potential underestimate, where we conclude similarity with a HAP for which a dose-response assessment value is available, we use that value as a surrogate for the assessment of the HAP for which no value is available. To the extent use of surrogates indicates appreciable risk, we may identify a need to increase priority for a new IRIS assessment of that substance. We additionally note that, generally speaking, HAP of greatest concern due to environmental exposures and hazards are those for which dose-response

assessments have been performed, reducing the likelihood of understating risk. Further, HAP not included in the quantitative assessment are assessed qualitatively and considered in the risk characterization that informs the risk management decisions, including with regard to consideration of HAP reductions achieved by various control options.

Additionally, chronic dose-response values for certain compounds included in the assessment may be under EPA IRIS review. In those cases, revised assessments may determine in the future that these pollutants are more or less potent than currently thought.

For a group of compounds that are unspeciated (e.g., glycol ethers), we conservatively use the most protective reference value of an individual compound in that group to estimate risk. Similarly, for an individual compound in a group (e.g., ethylene glycol diethyl ether) that does not have a specified reference value, we apply the most protective reference value from the other compounds in the group to estimate risk.

Cancer assessment

The discussion of dose-response uncertainties in the estimation of cancer risk below focuses on the uncertainties associated with the specific approach currently used by the EPA to develop cancer potency factors. In general, these same uncertainties attend the development of cancer potency factors by CalEPA, the source of peer-reviewed cancer potency factors used where EPA-developed values are not yet available. To place this discussion in context, we provide a quote from the EPA's *Guidelines for Carcinogen Risk Assessment* (herein referred to as *Cancer Guidelines*). (USEPA, 2005d) "The primary goal of EPA actions is protection of human health; accordingly, as an Agency policy, risk assessment procedures, including default options that are used in the absence of scientific data to the contrary, should be health protective." The approach adopted in this document is consistent with this approach as described in the *Cancer Guidelines*.

For cancer endpoints EPA usually derives an oral slope factor for ingestion and a unit risk value for inhalation exposures. These values allow estimation of a lifetime probability of developing cancer given long-term exposures to the pollutant. Depending on the pollutant being evaluated, EPA relies on both animal bioassay and epidemiological studies to characterize cancer risk. As a science policy approach, consistent with the *Cancer Guidelines*, EPA uses animal cancer bioassays as indicators of potential human health risk when other human cancer risk data are unavailable.

Extrapolation of study data to estimate potential risks to human populations is based upon EPA's assessment of the scientific database for a pollutant using EPA's guidance documents and other peer-reviewed methodologies. The EPA *Cancer Guidelines* describe the Agency's recommendations for methodologies for cancer risk assessment. EPA believes that cancer risk estimates developed following the procedures described in the *Cancer Guidelines* and outlined below generally provide an upper bound estimate of risk. That is, EPA's upper bound estimates represent a plausible upper limit to the true value of a quantity (although this is usually not a true statistical confidence limit). In some circumstances, the true risk could be as

low as zero; however, in other circumstances the risk could also be greater.[11] When developing an upper bound estimate of risk and to provide risk values that do not underestimate risk, EPA generally relies on conservative default approaches. [12] EPA also uses the upper bound (rather than lower bound or central tendency) estimates in its assessments, although it is noted that this approach can have limitations for some uses (e.g. priority setting, expected benefits analysis).

Such health risk assessments have associated uncertainties, some which may be considered quantitatively, and others which generally are expressed qualitatively. Uncertainties may vary substantially among cancer risk assessments associated with exposures to different pollutants, since the assessments employ different databases with different strengths and limitations and the procedures employed may differ in how well they represent actual biological processes for the assessed substance. Some of the major sources of uncertainty and variability in deriving cancer risk values are described more fully below.

(1) The qualitative similarities or differences between tumor responses observed in experimental animal bioassays and those which would occur in humans are a source of uncertainty in cancer risk assessments. In general, EPA does not assume that tumor locations observed in an experimental animal bioassay are necessarily predictive of the locations at which tumors would occur in humans. However, unless scientific support is available to show otherwise, EPA assumes that tumors in animals are relevant for humans, regardless of target organ concordance.[13] For a specific pollutant, qualitative differences in species responses can lead to either under-estimation or over-estimation of human cancer risks.

(2) Uncertainties regarding the most appropriate dose metric for an assessment can also lead to differences in risk predictions. For example, the measure of dose is commonly expressed in units of mg/kg/d ingested or the inhaled concentration of the pollutant. However, data may support development of a pharmacokinetic model for the absorption, distribution, metabolism and excretion of an agent, which may result in improved dose metrics (e.g., average blood concentration of the pollutant or the quantity of agent metabolized in the body). Quantitative uncertainties result when the appropriate choice of a dose metric is uncertain or when dose

[11] The exception to this is the URE for benzene, which is considered to cover a range of values, each end of which is considered to be equally plausible, and which is based on maximum likelihood estimates.

[12] According to the NRC report Science and Judgment in Risk Assessment (NRC, 1994) "[Default] options are generic approaches, based on general scientific knowledge and policy judgment, that are applied to various elements of the risk-assessment process when the correct scientific model is unknown or uncertain." The 1983 NRC report Risk Assessment in the Federal Government: Managing the Process defined default option as "the option chosen on the basis of risk assessment policy that appears to be the best choice in the absence of data to the contrary" (NRC, 1983a, p. 63). Therefore, default options are not rules that bind the Agency; rather, the Agency may depart from them in evaluating the risks posed by a specific substance when it believes this to be appropriate. In keeping with EPA's goal of protecting public health and the environment, default assumptions are used to ensure that risk to chemicals is not underestimated (although defaults are not intended to overtly overestimate risk). See EPA 2004 *An Examination of EPA Risk Assessment Principles and Practices*, EPA/100/B-04/001.

[13] From EPA's *Guidelines for Carcinogen Risk Assessment* (USEPA, 2005d), pages A-5 and A-3, respectively: "Target organ concordance is not a prerequisite for evaluating the implications of animal study results for humans." and "The default option is that positive effects in animal cancer studies indicate that the agent under study can have carcinogenic potential in humans."

metric estimates are themselves uncertain (e.g., as can occur when alternative pharmacokinetic models are available for a compound). Uncertainty in dose estimates may lead to either over or underestimation of risk.

(3) For the quantitative extrapolation of cancer risk estimates from experimental animals to humans, EPA uses scaling methodologies (relating expected response to differences in physical size of the species), which introduce another source of uncertainty. These methodologies are based on both biological data on differences in rates of process according to species size and empirical comparisons of toxicity between experimental animals and humans. For a particular pollutant, the quantitative difference in cancer potency between experimental animals and humans may be either greater than or less than that estimated by baseline scientific scaling predictions due to uncertainties associated with limitations in the test data and the correctness of scaled estimates.

(4) EPA cancer risk estimates, whether based on epidemiological or experimental animal data, are generally developed using a benchmark dose (BMD) analysis to estimate a dose at which there is a specified excess risk of cancer, which is used as the point of departure (or POD) for the remainder of the calculation. Statistical uncertainty in developing a POD using a benchmark dose (BMD) approach is generally addressed though use of the 95 percent lower confidence limit on the dose at which the specified excess risk occurs (the BMDL), decreasing the likelihood of understating risk. EPA has generally utilized the multistage model for estimation of the BMDL using cancer bioassay data (see further discussion below).

(5) Extrapolation from high to low doses is an important source of uncertainty in cancer risk assessment. EPA uses different approaches to low dose risk assessment (i.e., developing estimates of risk for exposures to environmental doses of an agent from observations in experimental or epidemiological studies at higher dose) depending on the available data and understanding of a pollutant's mode of action (i.e., the manner in which a pollutant causes cancer). EPA's *Cancer Guidelines* express a preference for the use of reliable, compound-specific, biologically-based risk models when feasible; however, such models are rarely available. The mode of action for a pollutant (i.e., the manner in which a pollutant causes cancer) is a key consideration in determining how risks should be estimated for low-dose exposure. A reference value is calculated when the available mode of action data show the response to be nonlinear (e.g., as in a threshold response). A linear low-dose (straight line from POD) approach is used when available mode of action data support a linear (e.g., nonthreshold) response or as the most common default approach when a compound's mode of action is unknown. Linear extrapolation can be supported by both pollutant-specific data and broader scientific considerations. For example, EPA's *Cancer Guidelines* generally consider a linear dose-response to be appropriate for pollutants that interact with DNA and induce mutations. Pollutants whose effects are additive to background biological processes in cancer development can also be predicted to have low-dose linear responses, although the slope of this relationship may not be the same as the slope estimated by the straight line approach.

EPA most frequently utilizes a linear low-dose extrapolation approach as a baseline science-policy choice (a "default") when available data do not allow a compound-specific determination. This approach is designed to not underestimate risk in the face of uncertainty

and variability. EPA believes that linear dose-response models, when appropriately applied as part of EPA's cancer risk assessment process, provide an upper bound estimate of risk and generally provide a health protective approach. Note that another source of uncertainty is the characterization of low-dose nonlinear, non-threshold relationships. The National Academy of Sciences (NAS, 1994) has encouraged the exploration of sigmoidal type functions (e.g., log-probit models) in representing dose-response relationships due to the variability in response within human populations. Another National Research Council report (NRC, 2006) suggests that models based on distributions of individual thresholds are likely to lead to sigmoidal-shaped dose-response functions for a population. This report notes sources of variability in the human population: "One might expect these individual tolerances to vary extensively in humans depending on genetics, coincident exposures, nutritional status, and various other susceptibility factors..." Thus, if a distribution of thresholds approach is considered for a carcinogen risk assessment, application would depend on ability of modeling to reflect the degree of variability in response in human populations (as opposed to responses in bioassays with genetically more uniform rodents). Note also that low dose linearity in risk can arise for reasons separate from population variability: due to the nature of a mode of action and additivity of a chemical's effect on top of background chemical exposures and biological processes.

As noted above, EPA's current approach to cancer risk assessment typically utilizes a straight line approach from the BMDL. This is equivalent to using an upper confidence limit on the slope of the straight line extrapolation. The impact of the choice of the BMDL on bottom line risk estimates can be quantified by comparing risk estimates using the BMDL value to central estimate BMD values, although these differences are generally not a large contributor to uncertainty in risk assessment (Subramaniam et. al., 2006). It is important to note that earlier EPA assessments, including the majority of those for which risk values exist today, were generally developed using the multistage model to extrapolate down to environmental dose levels and did not involve the use of a POD. Subramaniam et. al. (2006) also provide comparisons indicating that slopes based on straight line extrapolation from a POD do not show large differences from those based on the upper confidence limit of the multistage model.

(6) Cancer risk estimates do not generally make specific adjustments to reflect the variability in response within the human population — resulting in another source of uncertainty in assessments. In the diverse human population, some individuals are likely to be more sensitive to the action of a carcinogen than the typical individual, although compound-specific data to evaluate this variability are generally not available. There may also be important life stage differences in the quantitative potency of carcinogens and, with the exception of the recommendations in EPA's Supplemental Cancer Guidance for carcinogens with a mutagenic mode of action, risk assessments do not generally quantitatively address life stage differences. However, one approach used commonly in EPA assessments that may help address variability in response is to extrapolate human response from results observed in the most sensitive species and sex tested, resulting typically in the highest URE which can be supported by reliable data, thus supporting estimates that are designed not to underestimate risk in the face of uncertainty and variability.

Chronic noncancer assessment

Chronic noncancer reference values represent chronic exposure levels that are intended to be health-protective. That is, EPA and other organizations, such as the Agency for Toxic substances and disease Registry (ATSDR), which develop noncancer dose-response values use an approach that is intended not to underestimate risk in the face of uncertainty and variability. When there are gaps in the available information, uncertainty factors (UFs) are applied to derive reference values that are intended to be protective against appreciable risk of deleterious effects. Uncertainty factors are commonly default values[14] (e.g., factors of 10 or 3) used in the absence of compound-specific data; where data are available, uncertainty factors may also be developed using compound-specific information. When data are limited, more assumptions are needed and more default factors are used. Thus, there may be a greater tendency to overestimate risk—in the sense that further study might support development of reference values that are higher (i.e., less potent) because fewer default assumptions are needed. However, for some pollutants it is possible that risks may be underestimated.

For noncancer endpoints related to chronic exposures, EPA derives a reference dose (RfD) for exposures via ingestion, and a reference concentration (RfC) for inhalation exposures. As stated in the IRIS Glossary, these values provide an estimate (with uncertainty spanning perhaps an order of magnitude) of daily oral exposure (RfD) or of a continuous inhalation exposure (RfC) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. To derive values that are intended to be "without appreciable risk," EPA's methodology relies upon an uncertainty factor (UF) approach (USEPA, 1993b; USEPA, 1994) which includes consideration of both uncertainty and variability.

EPA begins by evaluating all of the available peer-reviewed literature to determine noncancer endpoints of concern, evaluating the quality, strengths and limitations of the available studies. EPA typically chooses the relevant endpoint that occurs at the lowest dose, often using statistical modeling of the available data, and then determines the appropriate POD for derivation of the reference value. A POD is determined by (in order of preference): (1) a statistical estimation using the BMD approach; (2) use of the dose or concentration at which the toxic response was not significantly elevated (no observed adverse effect level—NOAEL); or (3) use of the lowest observed adverse effect level (LOAEL).

[14] According to the NRC report *Science and Judgment in Risk Assessment* (NRC, 1994) "[Default] options are generic approaches, based on general scientific knowledge and policy judgment, that are applied to various elements of the risk-assessment process when the correct scientific model is unknown or uncertain." The 1983 NRC report *Risk Assessment in the Federal Government: Managing the Process* defined *default option* as "the option chosen on the basis of risk assessment policy that appears to be the best choice in the absence of data to the contrary" (NRC, 1983a, p. 63). Therefore, default options are not rules that bind the Agency; rather, the Agency may depart from them in evaluating the risks posed by a specific substance when it believes this to be appropriate. In keeping with EPA's goal of protecting public health and the environment, default assumptions are used to ensure that risk to chemicals is not underestimated (although defaults are not intended to overtly overestimate risk). See EPA 2004 *An examination of EPA Risk Assessment Principles and Practices*, EPA/100/B-04/001.

A series of downward adjustments using default UFs is then applied to the POD to estimate the reference value (USEPA, 2002b). While collectively termed "UFs", these factors account for a number of different quantitative considerations when utilizing observed animal (usually rodent) or human toxicity data in a risk assessment. The UFs are intended to account for: (1) variation in susceptibility among the members of the human population (i.e., inter-individual variability); (2) uncertainty in extrapolating from experimental animal data to humans (i.e., interspecies differences); (3) uncertainty in extrapolating from data obtained in a study with less-than-lifetime exposure (i.e., extrapolating from subchronic to chronic exposure); (4) uncertainty in extrapolating from a LOAEL in the absence of a NOAEL; and (5) uncertainty when the database is incomplete or there are problems with applicability of available studies. When scientifically sound, peer-reviewed assessment-specific data are not available, default adjustment values are selected for the individual UFs. For each type of uncertainty (when relevant to the assessment), EPA typically applies an UF value of 10 or 3 with the cumulative UF value leading to a downward adjustment of 10-3000-fold from the selected POD. An UF of 3 is used when the data do not support the use of a 10-fold factor. If an extrapolation step or adjustment is not relevant to an assessment (e.g., if applying human toxicity data and an interspecies extrapolation is not required) the associated UF is not used. The major adjustment steps are described more fully below.

1) Heterogeneity among humans is a key source of variability as well as uncertainty. Uncertainty related to human variation is considered in extrapolating doses from a subset or smaller-sized population, often of one sex or of a narrow range of life stages (typical of occupational epidemiologic studies), to a larger, more diverse population. In the absence of pollutant-specific data on human variation, a 10-fold UF is used to account for uncertainty associated with human variation. Human variation may be larger or smaller; however, data to examine the potential magnitude of human variability are often unavailable. In some situations, a smaller UF of 3 may be applied to reflect a known lack of significant variability among humans.

2) Extrapolation from results of studies in experimental animals to humans is a necessary step for the majority of chemical risk assessments. When interpreting animal data, the concentration at the POD (e.g. NOAEL, BMDL) in an animal model (e.g. rodents) is extrapolated to estimate the human response. While there is long-standing scientific support for the use of animal studies as indicators of potential toxicity to humans, there are uncertainties in such extrapolations. In the absence of data to the contrary, the typical approach is to use the most relevant endpoint from the most sensitive species and the most sensitive sex in assessing risks to the average human. Typically, compound specific data to evaluate relative sensitivity in humans versus rodents are lacking, thus leading to uncertainty in this extrapolation. Size-related differences (allometric relationships) indicate that typically humans are more sensitive than rodents when compared on a mg/kg/day basis. The default choice of 10 for the interspecies UF is consistent with these differences. For a specific chemical, differences in species responses may be greater or less than this value.

Pharmacokinetic models are useful to examine species differences in pharmacokinetic processing and associated uncertainties; however, such dosimetric adjustments are not always possible. Information may not be available to quantitatively assess toxicokinetic or

toxicodynamic differences between animals and humans, and in many cases a 10-fold UF (with separate factors of 3 for toxicokinetic and toxicodynamic components) is used to account for expected species differences and associated uncertainty in extrapolating from laboratory animals to humans in the derivation of a reference value. If information on one or the other of these components is available and accounted for in the cross-species extrapolation, a UF of 3 may be used for the remaining component.

3) In the case of reference values for chronic exposures where only data from shorter durations are available (e.g., 90-day subchronic studies in rodents) or when such data are judged more appropriate for development of an RfC, an additional UF of 3 or 10-fold is typically applied unless the available scientific information supports use of a different value.

4) Toxicity data are typically limited as to the dose or exposure levels that have been tested in individual studies; in an animal study, for example, treatment groups may differ in exposure by up to an order of magnitude. The preferred approach to arrive at a POD is to use BMD analysis; however, this approach requires adequate quantitative results for a meaningful analysis, which is not always possible. Use of a NOAEL is the next preferred approach after BMD analysis in determining a POD for deriving a health effect reference value. However, many studies lack a dose or exposure level at which an adverse effect is not observed (i.e., a NOAEL is not identified). When using data limited to a LOAEL, a UF of 10 or 3-fold is often applied.

5) The database UF is intended to account for the potential for deriving an underprotective RfD/RfC due to a data gap preventing complete characterization of the chemical's toxicity. In the absence of studies for a known or suspected endpoint of concern, a UF of 10 or 3-fold is typically applied.

Acute noncancer assessment

Many of the UFs used to account for variability and uncertainty in the development of acute reference values are quite similar to those developed for chronic durations. For acute reference values, though, individual UF values may be less than 10. UFs are applied based on chemical- or health effect-specific information or based on the purpose of the reference value. The UFs applied in acute reference value derivation include: 1) heterogeneity among humans; 2) uncertainty in extrapolating from animals to humans; 3) uncertainty in LOAEL to NOAEL adjustments; and 4) uncertainty in accounting for an incomplete database on toxic effects of potential concern. Additional adjustments are often applied to account for uncertainty in extrapolation from observations at one exposure duration (e.g., 4 hours) to arrive at a POD for derivation of an acute reference value at another exposure duration (e.g., 1 hour).

Not all acute dose-response values are developed for the same purpose and care must be taken when interpreting the results of an acute assessment of human health effects relative to the reference value or values being exceeded. Where relevant to the estimated exposures, the lack of dose-response values at different levels of severity should be factored into the risk characterization as potential uncertainties.

Environmental Risk Screening Assessment

Uncertainty also exists in the ecological benchmarks for the environmental risk screening assessment. We established a hierarchy of preferred benchmark sources to allow selection of benchmarks for each environmental HAP at each ecological assessment endpoint. In general, EPA benchmarks used at a programmatic level (e.g., Office of Water, Superfund Program) were used if available. If not, we used EPA benchmarks used in regional programs (e.g., Superfund Program). If benchmarks were not available at a programmatic or regional level, we used benchmarks developed by other agencies (e.g., NOAA) or by state agencies.

In all cases (except for lead compounds, which were evaluated through a comparison to the NAAQS), we searched for benchmarks at the following three effect levels, as described in Section 2.6 of this report and in Appendix 9 (*Environmental Risk Screening Assessment*) of this report: a no-effect level (i.e., NOAEL), threshold-effect level (i.e., LOAEL), and probable-effect level (i.e., PEL).

For some ecological assessment endpoint/environmental HAP combinations, we could identify benchmarks for all three effect levels, but for most we could not. In one case, where different agencies derived significantly different numbers to represent a threshold for effect, we included both. In several cases, only a single benchmark was available. In cases where multiple effect levels were available for a particular PB-HAP and assessment endpoint, we used all of the available effect levels to help us determine whether risk exists if risks could be considered significant and widespread.

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Appendix 1
Emissions Inventory Support Documents

MEMORANDUM

TO: Andrew Bouchard, U.S. EPA/OAQPS/SPPD – EPA Office of Air Quality Planning and Standards

FROM: Eastern Research Group, Inc.

DATE: March 2023

SUBJECT: Emissions Data Used in Technology Review Modeling Files for Facilities Located in the SOCMI and Neoprene Production Source Categories that are Associated with Processes Subject to HON and P&R I

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is proposing amendments to the National Emission Standards for Hazardous Air Pollutants (NESHAP) for three subparts in 40 CFR 63 (subparts F, G, and H) that apply to the Synthetic Organic Chemical Manufacturing Industry (SOCMI) and for one subpart in 40 CFR 63 (subpart I) that applies to equipment leaks from certain non-SOCMI processes located at chemical plants. These four NESHAP are more commonly referred together as the Hazardous Organic NESHAP (HON). The emissions sources affected by the current HON includes heat exchange systems and maintenance wastewater regulated under NESHAP subpart F; process vents, storage vessels, transfer racks, and wastewater streams regulated under NESHAP subpart G; equipment leaks associated with SOCMI processes regulated under NESHAP subpart H; and equipment leaks from certain non-SOCMI processes at chemical plants regulated under NESHAP subpart I.

The Group I Polymers and Resins NESHAP (P&R I, codified at 40 CFR 63, subpart U) regulates the following elastomer product source categories:

- Butyl rubber
- Epichlorohydrin elastomer
- Ethylene propylene rubber
- Halobutyl rubber
- Hypalon™
- Neoprene
- Nitrile butadiene latex
- Nitrile butadiene rubber
- Polybutadiene rubber/styrene butadiene rubber by solution
- Polysulfide rubber
- Styrene butadiene latex
- Styrene butadiene rubber by emulsion

The EPA conducted a residual risk and technology review for the HON in 2006 and Neoprene Production source category in P&R I in 2008, concluding that there was no need to revise the standards under either CAA section 112(f) or 112(d)(6). As part of the residual risk review, the EPA conducted a risk assessment, and based on the results of the risk assessment, determined that the current level of control called for by the existing MACT standards both reduced HAP emissions to levels that presented an acceptable level of risk and protected public health with an ample margin of safety (see 71 FR 76603, December 21, 2006 and 73 FR 76220, December 16, 2008, for additional details). This action constitutes another 112(d)(6) technology review for the SOCMI (HON) and Neoprene Production source categories. We note that although there is no statutory CAA obligation under CAA section 112(f) for the EPA to conduct a second residual risk review of the SOCMI and Neoprene Production source categories, the EPA retains discretion to revisit its residual risk reviews where the Agency deems that is warranted. For the SOCMI source category, the EPA is concerned about the risks posed from ethylene oxide and chloroprene, due to the fact that revisions to the EPA's Integrated Risk Information System (IRIS) inhalation unit risk estimate (URE) for ethylene oxide were finalized in 2016 showing it to be more toxic than previously known as well as because of the development of the EPA's IRIS inhalation URE for chloroprene in 2010. Similarly, for the Neoprene Production source category, the EPA is concerned about the risks posed from chloroprene due to the development of the EPA's IRIS inhalation URE for chloroprene in 2010. Thus, since the EPA was unable to consider these factors in its residual risk review for the SOCMI source category in 2006 and Neoprene source category in 2008, it is conducting a risk assessment in this action so that the results of the risk assessment can be considered to ensure that the MACT standards continue to provide an ample margin of safety to protect public health. This memorandum describes the methodology used to develop the risk modeling file used for this additional review.

2.0 INITIAL FACILITIES LIST DEVELOPMENT

The list of existing facilities potentially subject to the HON and Neoprene Production standards was initially developed using several sources. First, the EPA compiled a list of facilities representing the chemical manufacturing sector from the 2017 National Emissions Inventory (NEI) and in the Toxics Release Inventory (TRI) with a primary facility North American Industry Classification System (NAICS) code beginning with 325. Second, this list was supplemented with information from the Office of Enforcement and Compliance Assurance's (OECA) Enforcement and Compliance History Online (ECHO) tool[1] as well as other internal chemical sector facility lists from the EPA's recent petrochemical sector RTR rulemakings (e.g., Miscellaneous Organic Chemical Manufacturing NESHAP (40 CFR part 63, subpart FFFF), Organic Liquids Distribution NESHAP (40 CFR part 63, subpart EEEE), Ethylene Production NESHAP (40 CFR part 63, subparts XX and YY), Petroleum Refineries NESHAP (40 CFR part 63, subparts CC and UUU)).[2] Third, the list was overlaid with the

[1] See *https://echo.epa.gov/facilities/facility-search?srch=adv.*

[2] See 85 FR 49084, August 12, 2020, 85 FR 40740, July 7, 2020, 85 FR 40386, July 6, 2020, and 80 FR 75178, December 1, 2015, respectively.

facility list the EPA used for the latest review of the HON back in 2006 and Neoprene Production back in 2008.

To determine which facilities on the comprehensive chemical manufacturing sector facility list were subject to the HON and P&R I standards for Neoprene Production, the EPA obtained title V air permits from publicly available online State databases (where available). In cases where an online database was incomplete or did not exist, the EPA contacted the Region and/or State for help in obtaining the air permits or determining whether a facility was subject to the HON. The EPA also conducted internet searches to determine the status of the facility (e.g., whether the facility was still open, permanently closed, and/or sold). In some cases where a permit could not be obtained, the EPA assumed that the facility was subject to the HON.

Lastly, the EPA shared a draft of the compiled facility list with the American Chemistry Council (ACC) in October 2021. Based on feedback provided by ACC, a facility list consisting of 207 hazardous organic chemical manufacturing facilities subject to the HON standards, herein referred to as "HON facilities," was finalized and used to assess impacts for this rulemaking. The list of facilities located in the United States that are major sources of HAP and part of the SOCMI source category with processes subject to HON is available in the memorandum titled: "Lists of Facilities Subject to the HON, Group I and Group II Polymers and Resins NESHAPs, and NSPS subparts VV, VVa, III, NNN, and RRR" (ERG, 2023a). For the 207 HON facilities, only 195 had reported HAP emissions in the 2017 NEI, and we note that two facilities included in the 207 are new/under construction and were not operating in 2017. We also note that one facility was identified as a Neoprene Production facility (which is also subject to the HON).

3.0 PROCEDURES USED TO OBTAIN BASELINE EMISSIONS

For each HON and Neoprene Production facility (see Section 2.0 of this memorandum), we gathered emissions data from the January 2021 version of the 2017 NEI. The 2017 NEI was the most vetted and recent publicly available data set at the time of this analysis. However, in a few instances where facility-specific data was not available in the 2017 NEI, we attempted to obtain data from a more recent data set (i.e., from 2018 NEI or 2019 or 2020 state submittals to the Emissions Inventory System (EIS) for NEI). The more recent data are not part of a larger, publicly available, triennial NEI; and therefore, have not undergone the same level of review as the 2017 NEI data set.[3] Ultimately, the EPA deemed this data set as the baseline emissions for the HON source category (and improvements to this baseline emissions data set are discussed in Section 4 of this memorandum).

We then reviewed description data fields for each NEI record in the baseline emissions data set associated with any ethylene oxide emitting HON facility.[4] For each of these specific NEI records, we allocated the record to one of the emission process groups identified in Table 1 using information provided in the description data fields for each emission unit, process, release

[3] Refer to the 2017 NEI Technical Support Document for detailed discussion on the types of review and augmentation performed for 2017 NEI (*https://www.epa.gov/sites/default/files/2021-02/documents/nei2017_tsd_full_jan2021.pdf*).

[4] Although EPA conducts whole facility risk assessments of all HON facilities, it was anticipated that HON facilities emitting ethylene oxide would likely require a more elaborate review of specific emission process groups.

point, and standard classification code (SCC). We used automated queries (see Appendix A) for much of this task; however, assignments were also made manually.

Table 1. Emission Process Groups Related to Ethylene Oxide Emitting HON Facilities

Emission Process Group Description[1]
Bottoms Receiver
Equipment Leak
Heat Exchange System
Hotwell
Nitrogen Inert System
Process Vent[2]
Storage Tank
Surge Control Vessel
Transfer Rack
Wastewater
Control Device (UnknownEPG)[3]
Flare[4]
Non-CMATTR Source Category Process Group[5]
Unknown[6]

[1] If discernible, we differentiated between maintenance and non-maintenance activities for each emission process group.

[2] If discernible, we identified analyzer vents separate from process vents.

[3] Although a specific control device (e.g., carbon adsorber, incinerator, or thermal oxidizer) could often be determined using the various description data fields associated with the NEI record, we could not determine the emission process group associated with the control device, including whether the record involves co-mingled emissions from more than one emission process group due to a shared control device.

[4] If discernible, we differentiated between emergency and non-emergency flaring activities, as well as the emission process group associated with the flare, and whether the flare is operating in a Texas county subject to specific flare control requirements for highly reactive volatile organic compounds.

[5] These are instances where we determined the NEI record is either: (1) entirely outside the HON source category (e.g., abrasive blasting operations, degreasers, emergency generators, marine loading operations, painting operations, etc), or (2) already considered in a previous EPA residual risk review for the Organic Liquid Distribution (OLD) NESHAP, Ethylene Production (EMACT) NESHAP, or Miscellaneous Organic NESHAP (MON).

[6] These are instances when the description data fields of the NEI record are not descriptive enough to assign an emission process group.

4.0 PROCEDURES USED TO IMPROVE DATA

4.1 Responses to Section 114 Request

A CAA section 114 information collection request (ICR) was developed and sent to nine entities (comprising of 18 facilities[5] which we identified through initial review of the source category) (ERG, 2023b). Many of these entities were chosen because they have some facilities that produce, use, and emit ethylene oxide or chloroprene, which are pollutants with considerable concern for cancer risk for the HON source category.

The first CAA section 114 ICR, sent on June 15, 2021, went to Denka Performance Elastomers, LLC to gather information about emissions from their chemical plant and the various

[5] The ICR originally encompassed 22 facilities; however, the EPA reduced this number to 18 facilities based on a March 3, 2022 petition that the EPA received from industry.

NESHAP they are subject to, including the HON (and others such as the Group I Polymers and Resins NESHAP (40 CFR part 63, subpart U)). In addition, on January 19, 2022, eight other entities (BASF Corporation, The Dow Chemical Company, Eastman Chemical Company, Formosa Plastics Corporation, Huntsman Petrochemical, Indorama Ventures Oxides and Derivatives, Sasol Chemicals, and Union Carbide Corporation) received CAA section 114 ICRs to ask for additional information about their HON processes, processes subject to other chemical sector NESHAP, and SOCMI New Source Performance Standards (NSPS) that apply to emission sources at their chemical manufacturing facilities. These CAA section 114 ICRs sought to gather specific information about various emission sources, emission inventories (using the 2017 NEI as a baseline), and chemical manufacturing production processes via a questionnaire (Component 1) as well as emissions data via requests for historical data, stack testing, and fugitive emissions testing with fenceline monitoring (Component 2). For more information regarding the CAA section 114 ICRs, please refer to the memorandum entitled "Data Received from Information Collection Request for Chemical Manufacturers." (ERG, 2023b).

The EPA requested facilities (those that were part of the January 19, 2022 CAA section 114 ICR) review their NEI records for completeness and accuracy, given that these records formed the underlying basis of our emissions modeling input files for the residual risk review. The NEI records were sent to entities in separate Microsoft Excel worksheet(s) via email requesting review (and revise, if necessary) emission values, emission release point parameters, coordinates, emission unit descriptions, periods of operation, and emission process group assignments. We used all this information to reevaluate our emission process group assignments (see Table 1) for each NEI record in the modeling file (i.e., records associated with any ethylene oxide emitting HON facility). We also used this information to update emission release point parameter data. In other words, we used the CAA section 114 response data wherever possible (in lieu of the 2017 NEI), unless it failed our QA checks (see Section 5.0 of this memorandum). For example, if a CAA section 114 response indicates the emission release point is associated with a process vent, but the modeling file says a storage vessel, we updated the modeling file to reflect a process vent. Also, as another example, if a CAA section 114 response indicates a stack height of 10 feet, but the modeling file says the stack height is 7 feet, we updated the modeling file to reflect the stack height of 10 feet.

Once each of the steps discussed above were complete, we performed an overall review of the RTR emissions modeling file to determine if the data for each facility were both complete and representative.

4.1.1 Stack Test Data for Dioxins and Furans & Chlorine

We reviewed stack test data from nine HON facilities that tested for, among other things, dioxins and furans (D/F) in 2010, 2011, and 2014 and that formed the basis of our proposed emission standard for these pollutants. These stack test reports are available in the rulemaking docket (EPA-HQ-OAR-2022-0730). Upon review of the records in 2017 NEI for these nine facilities, we found that emission records for these pollutants were missing. Accordingly, we added records consistent with this stack test data for each incinerator/thermal oxidizer that controls emissions from a vinyl chloride monomer (VCM)/ethylene dichloride (EDC) chemical manufacturing process unit that was stack tested for D/F emissions at these nine HON facilities.

A list of these facilities and the number of incinerator/thermal oxidizer at each facility for which emissions data for D/F emissions were added can be found in the table 2 below.

Table 2. D/F Emitting HON Facilities

Facility Name in 2017 NEI	**# of Incinerators or thermal oxidizers at Facility**	**Additional Notes**
Formosa Plastics Corp Louisiana	2	
DEER PARK VCM PLANT	2	This is the Oxyvinyls plant.
Shintech Louisiana LLC - Shintech Plaquemine Plant	2	
Axiall LLC - Westlake Lake Charles North	2	Formerly Georgia Gulf-Lake Charles as it relates to stack test data.
Westlake Vinyls Co LP	1	
Axiall LLC - Plaquemine Facility	2	Westlake acquired Axiall.
Eagle US 2 LLC - Lake Charles Complex	4	Formerly PPG Lake Charles as it relates to stack test data.
BLUE CUBE OPERATIONS FREEPORT	2	Formerly Dow Oyster Creek as it relates to stack test data.
FORMOSA POINT COMFORT PLANT	3	

For chlorine, Formosa Plastics Corp Louisiana had reported higher than expected emissions from their VCM production Incinerators A & B of 16.0 tons/yr and 21.3 tons/yr, respectively. Following a brief conference call with the company on October 5, 2022, the company conveyed that these reported values to the 2017 NEI were based on emissions stack testing that occurred in 1992, well before the HON was finalized in 1994. More recent stack testing for Incinerator B was conducted in 2014 (and was also tested for D/F emissions and is in the docket for this action). This post-HON compliance test is much more recent and represents post-HON controls and much more current operations. It shows that the annual average chlorine emissions for this incinerator are actually 0.56 tons/yr. Thus, the emissions for chlorine for Incinerators A & B were revised to this annual emissions value.

4.1.2 CAA Section 114 and Other Ethylene Oxide Specific Revisions

After EPA reviewed CAA section 114 ICR data, we reviewed ethylene oxide records to determine whether the emissions were associated with HON processes or non-HON processes and updated the regulatory code in the risk modeling input files to account for this review. We also reviewed the 2021 EPA Region 6 emissions modeling[6] and reviewed reported upset emissions data, and made minor revisions to ethylene oxide emissions records. Amendments were made to the ethylene oxide emissions records for select emission sources at the following facilities:

Huntsman Petrochemical – Conroe Plant

Eastman Chemical Company – Texas Operations

Union Carbide Corporation – Seadrift Operations

Indorama Ventures – Port Neches Operations

As part of the CAA section 114 ICR data submission, Huntsman Petrochemical suggested an amendment to the reported ethylene oxide emissions associated with the Pump P-G-125 seal flush. The reported ethylene oxide emissions in the 2017 NEI, assumed a continuous annual operation of 8,760 hours per year. At the request of Huntsman Petrochemical, we amended the ethylene oxide emissions to reflect eight hours of operation. The emissions from this operation are associated maintenance activities on the pump, rather than a continuous operation.

As part of EPA's review of reported emissions upset data, ethylene oxide emissions were amended for the model at the Eastman Chemical Company, Texas Operations and Union Carbide Corporation, Seadrift Operations facilities. At the Eastman facility, we added upset emissions associated with a control valve as reported to the Texas Commission on Environmental Quality (TCEQ) in Incident Report 254349, to the NEI emissions record for Cooling Tower 56U-501. Similarly, at the Seadrift Operations we added ethylene oxide upset emissions associated with a leak in the condenser (heat exchange) system, reported to the TCEQ in Incident Report 293911. The emissions in the model reflect, estimated releases under a 45 day window of repair consistent with the HON. EPA estimated the release using an average of the attached emissions models, and added a new record to the model associated with the release. This is discussed further in our memorandum, entitled "Analysis of Control Options for Heat Exchange Systems to Reduce Residual Risk of Ethylene Oxide in the SOCMI Source Category for Processes Subject to HON" (ERG, 2023b).

Table 3 below includes the emission unit specific amendments made at the Huntsman Conroe, Eastman Texas Operations, and Union Carbide Corporation Seadrift facilities:

Table 3. Adjusted Ethylene Oxide Emissions (Relative To 2017 NEI) For Certain Facilities

[6] *https://www.epa.gov/system/files/documents/2021-07/region-6-risk-assessment-of-ethylene-oxide-emitting-facilities-in-texas-and-louisian-jul-8-2021.pdf*

Company Name	Conroe Facility	Emission Unit	Ethylene oxide Emissions (tpy)		Data Source
			2017 NEI	Adjusted	
Huntsman Petrochemical	Conroe Facility	Pump Seal P-G-125	0.5618	0.0039	CAA Section 114 ICR Data Submission
Eastman Chemical Company	Texas Operations	Cooling Tower 56U-501	0.57	0.8849	TCEQ Incident Report 254349
Union Carbide Corporation	Seadrift	Oxide Glycol Heat Exchange System	NA	6.52	TCEQ Incident Report 293911

Additionally, in an attempt to better include upset releases at the Port Neches facility, we utilized model values reflective of 2018 emissions data collected by EPA Region 6 and compiled in the 2018 NEI. This data was used in lieu of the 2017 NEI records for Port Neches. In correspondence with the facility regarding these upsets, we also received updated stack test characteristics for the Port Neches regenerator and reabsorber vents (see Appendix C); therefore, we used this information in lieu of the stack test characteristics in the 2017 NEI records.

Finally, although other emissions revisions were suggested by facilities as part of the CAA section 114 ICR responses, we did not use this data. Instead, we continued to use emissions reported in the 2017 NEI because there was insufficient information provided to support the suggested changes from industry.

4.1.3 CAA Section 114 and Chloroprene Specific Revisions

EPA reviewed CAA section 114 ICR data from Denka Performance Elastomers, LLC. In particular, EPA requested emission inventories from the past 5 years (i.e., 2016-2020) from the facility's operations as part of this request. As 2017 NEI data did not represent current controls being employed at Denka Performance Elastomers, LLC, EPA chose to use the most current data it had available and that is reflective of current operations and emissions. Given concerns about decreased production and emissions in 2020 from the COVID-19 pandemic, EPA elected to use Denka's 2019 emissions inventory submitted as part of the CAA section 114 request in its risk assessment for the HON and Neoprene Production source categories in lieu of the 2017 NEI data. EPA also reviewed chloroprene emission records to determine whether the emissions were associated with HON processes, neoprene processes, or other non-HON and non-neoprene processes and updated the regulatory code in the risk modeling input files to account for this review.

5.0 EMISSION RELEASE POINT QA STEPS

The emission release point parameters in the modeling file are stack height, exit gas temperature, stack diameter, exit gas velocity, and exit gas flow rate. As described in Section 3.0 above, priority was given to emission release point parameters provided in the CAA section 114 responses. If emission release point parameters from the CAA section 114 responses were missing or out of range, then the original NEI parameters were retained. If the emission release point parameters from the NEI data were missing or outside of typical QA range checks, then the missing or out of range parameters were calculated where possible. An example of this calculation is using reported diameter and velocity to calculate a missing exit gas flow rate. If it was not possible to calculate a missing value, then a surrogate value was assigned based on the SCC.[7] All diameters, velocities, and flow rates for fugitive releases were set to default values of 0.003 feet (ft), 0.0003 feet per second (ft/sec), and 0 actual cubic feet per second (acfs), respectively. If height and/or temperature were not available for fugitive sources, default values of 10 ft for stack height and 72 degrees Fahrenheit for temperature were assigned.

6.0 WHOLE FACILITY EMISSIONS ESTIMATES

Our analyses and data quality review efforts were primarily focused on emissions of ethylene oxide and chloroprene, given that this is of central relevance to the residual risk review. A simpler cursory review of the whole facility emissions was also done to ensure that any emissions of major risk driving pollutants was reflective of best available emissions data.

7.0 ACUTE EMISSIONS MULTIPLIER & MACT-ALLOWABLE EMISSIONS

To develop estimates of acute exposures, the Agency generally assumes the 1-hr emissions rate for any emission point could be 10 times higher than its average hourly emissions (calculated by dividing the actual annual emissions by 8,760 hours per year) in situations where the EPA lacks sufficient information on hourly emissions for given emissions sources. The basis for this assumption was derived from an analysis of short-term release information collected from a Texas study of facilities in a four-county area (Harris, Galveston, Chambers, and Brazoria Counties, Texas) which was then compared against routine emissions rates for an entire facility. The conclusions for this analysis were that the ratio of hourly emissions from any single release event to the average annual volatile organic compound (VOC) release rate for an entire facility was seldom greater than a factor of 10. We used additional knowledge of the emission point release characteristics to refine the default factor for the SOCMI and Neoprene Production source categories. The acute multipliers we used are in Table 5 which are based on the acute multipliers that we used for the MON source category (EPA, 2020). These values were also used in other more recent risk reviews previously discussed in this memorandum such as for Petroleum Refineries and Ethylene Production sources.

Table 5. Acute Multipliers

Emissions Source	Acute Multiplier
Bottoms Receiver	6
Equipment Leak	2

[7] In certain instances where we added a record to the modeling file due to information received from the Section 114, the SCC may not have been included. For these records, we assigned a default SCC based on the emission process group assignment.

Emissions Source	Acute Multiplier
Heat Exchange System	2
Hotwell	6
Nitrogen Inert System	6
Process Vent	6
Storage Tank	4
Surge Control Vessel	6
Transfer Rack	10
Wastewater	4
Control Device (UnknownEPG)	10
Flare	10
Unknown	10

8.0 Quality Assurance (QA) Procedures

In addition to the procedures used to improve the modeling file data described in Section 4.0 above, Appendix B to this memo describes the general procedures used to review and correct RTR modeling files that were also conducted in the QA of our modeling file.

9.0 REFERENCES

EPA, 2020. Residual Risk Assessment for the Miscellaneous Organic Chemical Manufacturing Source Category in Support of the 2020 Risk and Technology Review Final Rule. EPA Docket No. EPA-HQ-OAR-2018-0746-0189.

ERG, 2023a. Lists of Facilities Subject to the HON, Group I and Group II Polymers and Resins NESHAPs, and NSPS subparts VV, VVa, III, NNN, and RRR. March 2023. EPA Docket No. EPA-HQ-OAR-2022-0730.

ERG, 2023b. Analysis of Control Options for Heat Exchange Systems to Reduce Residual Risk of Ethylene Oxide in the SOCMI Source Category for Processes Subject to HON. EPA Docket No. EPA-HQ-OAR-2022-0730.

ERG. 2023b. Data Received from Information Collection Request for Chemical Manufacturers. March 2023. EPA Docket No. EPA-HQ-OAR-2022-0730.

Appendix A

The following automated queries were used to assign an emission process group.

(These queries were run in the order presented below. If no query is provided below for a specific emission process group, then the assignment was made manually.)

- If the record was assigned to EMACT, MON, or OLD, we left it alone, and labeled it as a “Non-CMATTR Source Category Process Group” emission process group.

- To be assigned to the “Process Vents” emission process group, we searched emission unit description, process description, and scc description:
    - Like "*oxidation*" Or Like "*distillation*" Or Like "*reactor*"
    - Like "*vent*" And Not Like "*solvent*"

- To be assigned to the “Equipment Leak” emission process group, we searched emission unit description, process description, release point description, and scc description:
    - Like "*fug*"

- To be assigned to the “Heat Exchange System” emission process group, we searched emission unit description, process description, release point description, and scc description:
    - Like "*cool*"

- To be assigned to the “Storage Tank” emission process group, we searched scc description:
    - Like "*storage*" And Not Like "*wastewater*"

- To be assigned to the “Transfer Rack” emission process group, we searched emission unit description, process description, and scc description:
    - Like "*transfer*" (for emission unit description)
    - Like “*trans*” (for process description)
    - Like “*load*” (for scc description)

- To be assigned to the “Wastewater” emission process group, we searched emission unit description and scc description:
    - Like "*wastewater*"

- To differentiate between maintenance and non-maintenance activities for each emission process group, we searched emission unit description, process description, release point description, and scc description:
    - Like "*maintenance*"

- To be assigned to the “Non-CMATTR Source Category Process Group” emission process group, we searched emission unit description, process description, release point description, and scc description:

    - Like "*boiler*"
    - Like "*coating*"
    - Like "*cracking*"
    - Like "*marine*"
    - Like "*barge*"
    - Like "*paint*"
    - Like "*gasoline*"
    - Like "generator*"
    - Like "*diesel*"
    - Like "*heater*"
    - Like "*compressor*"
    - Like "*combustion*"
    - Like "*engine*"
    - Like "*groundwater*"
    - Like "*abrasive*"
    - Like "*dust*"(excluded from scc description search)
    - Like "*silo*"
    - Like "*hopper*"
    - Like "*degreaser*"
    - Like "*R&D*"
    - Like "*pilot plant*"
    - Like "*baghouse*"
    - Like "*bag filter*"
    - Like "*fabric filter*
    - Like "*bagfilter*"
    - Like "*fabricfilter*"
    - Like "*HEPA*"

Appendix B

RTR QA Documentation

INTRODUCTION

This document provides an overview of the QA checks and corrections implemented in Risk and Technology Review (RTR) modeling files.

The QA checks conducted by the EPA are intended to identify clearly incorrect data and missing data, and in any instance where a value was replaced or a default value was applied, those data are in the record. Note that use of defaults or replacement of incorrect data are functions that occur throughout various data systems (*e.g.*, the NEI), and any changes made through the QA process serve to improve the accuracy of the data.

GENERAL QA OF MODELING FILE FIELDS

The following modeling file fields should not be null after a file is developed. EPA checks for null entries in these fields and populates them where possible using existing EPA data sets, facility-specific information, and/or valid codes from lookup tables:

- FRS ID – cannot always be populated
- SPPD Facility ID
- Region
- State Abbreviation
- County Name
- State County FIPS
- Tribal Code
- Facility Name
- Location Address
- City
- Zip Code
- NAICS Code (NAICS Primary)
- Facility Category Code
- Emission Unit ID
- Process ID
- SCC
- Regulatory Code
- Emission Process Group
- Emission Release Point ID
- Emission Release Point Type Code
- Stack Height (ft)
- Stack Default Flag
- Pollutant Code

- Actual Emissions (tpy)
- Start Date
- End Date
- Data Source Code
- Emission Calc Method Code

Similarly, the following fields are primary keys and must be populated. If identifier fields are not populated, EPA assigns IDs as needed:

- SPPD Facility ID
- Emission Unit ID
- Process ID
- Emission Release Point ID
- Pollutant Code

Additional Checks for Invalid and Null Values

EPA checks to see if the fields listed below are populated with invalid information or are null. EPA uses code lookup tables to QA and augment reported values for data fields that use codes.

- Control Measure Code
- Control Status Code
- Emission Calc Method Code
- Emission Release Point Type Code
- Facility Category Code
- Location Default Flag
- NAICS Code (NAICS Primary)
- North American Datum
- Pollutant Code
- Regulatory Code
- SCC
- Stack Default Flag - use Stack Default Code to populate
- Start/End Dates – must be in YYYYMMDD format
- State County FIPS
- Tribal Code

EMISSION RELEASE POINT AND FUGITIVE RELEASE QA

The first step for stack and fugitive parameter review is to QA the Emission Release Point Type Code. RTR modelers use the Emission Release Point Type Code to determine how to model the release. If the Emission Release Point Type Code is incorrect, it can greatly affect risk results. In

RTR modeling files, the Emission Release Point Type Code identifies the type of release. Emission Release Point Type Codes in RTR modeling files include the following:

Emission Release Point Type Codes
1-Fugitive General
2-Vertical Stack
3-Horizontal Stack
4-Goose Neck Stack
5-Vertical with rain cap Stack
6-Downward-facing vent Stack
7-Fugitive Area (Reserved for historical data)
8-Low Flow Vent
9-Fugitive Two-dimensional
10-Fugitive Three-dimensional

Low Flow Vent source (<10sqft) is an emission release from a single point. Examples include a single roof or wall vent for building fugitives.

Required parameters are:

- release height (ft),
- exit gas temperature >50F,
- stack diameter (default is 0.1 (ft),
- exit gas velocity (ft/sec) (default is 0.1 ft/sec),
- exit gas flow rate (cu ft/sec) (default is 0.0008 cu ft/sec), and
- lat/lon of release

Fugitive two-dimensional source (>10sqft) is an emission release on one plane. For example, an elongated roof vent or a wastewater holding pond.

Instructions for populating the required parameters of a two-dimensional release:

Pick the midpoints of two opposing sides of the source, and enter the lat/lon of these midpoints. A width is also required, which is the distance between the remaining two sides of the source (that is, the width is perpendicular to the line between the two midpoints). For irregularly shaped sources, first create a rectangle that best approximates the shape of the actual source, then determine the parameters described above. Also, estimate the height where the release occurs.

See the examples of fugitive two-dimensional sources in Figures 1 and 2.

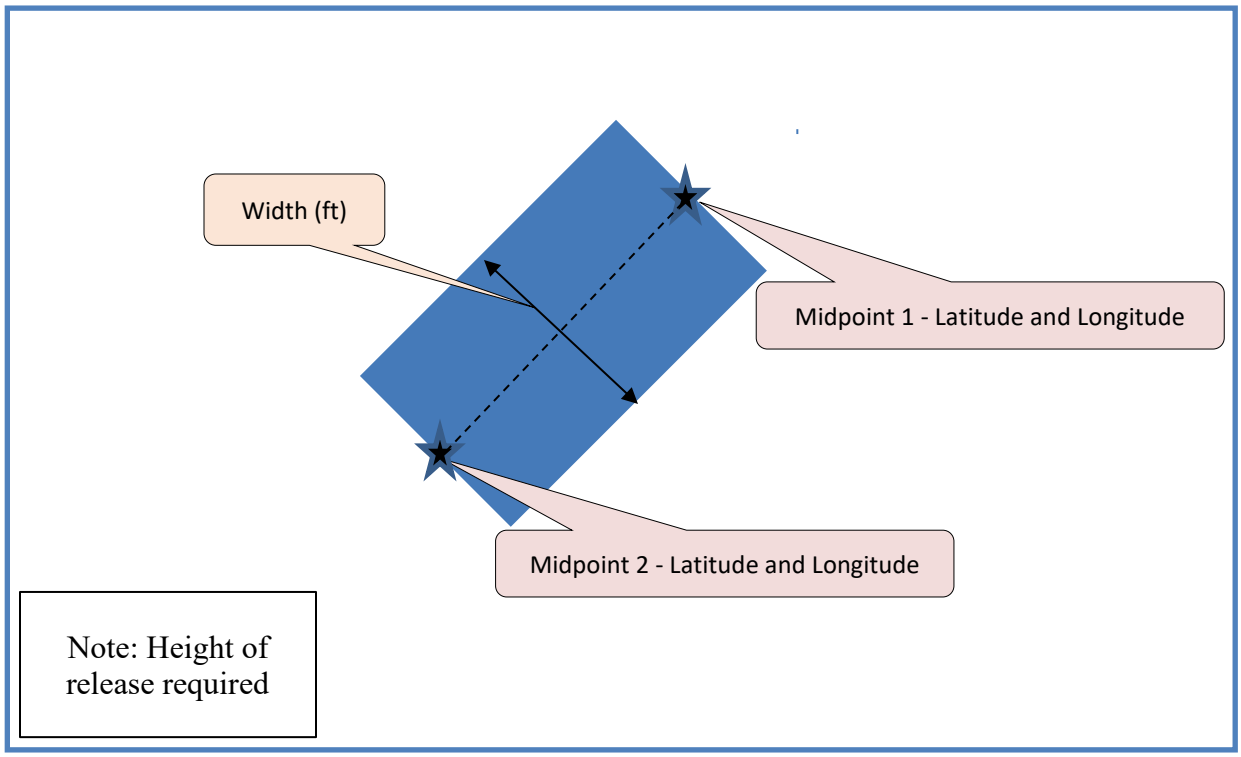

Figure 1. Example 1 of Fugitive Two-dimensional Source

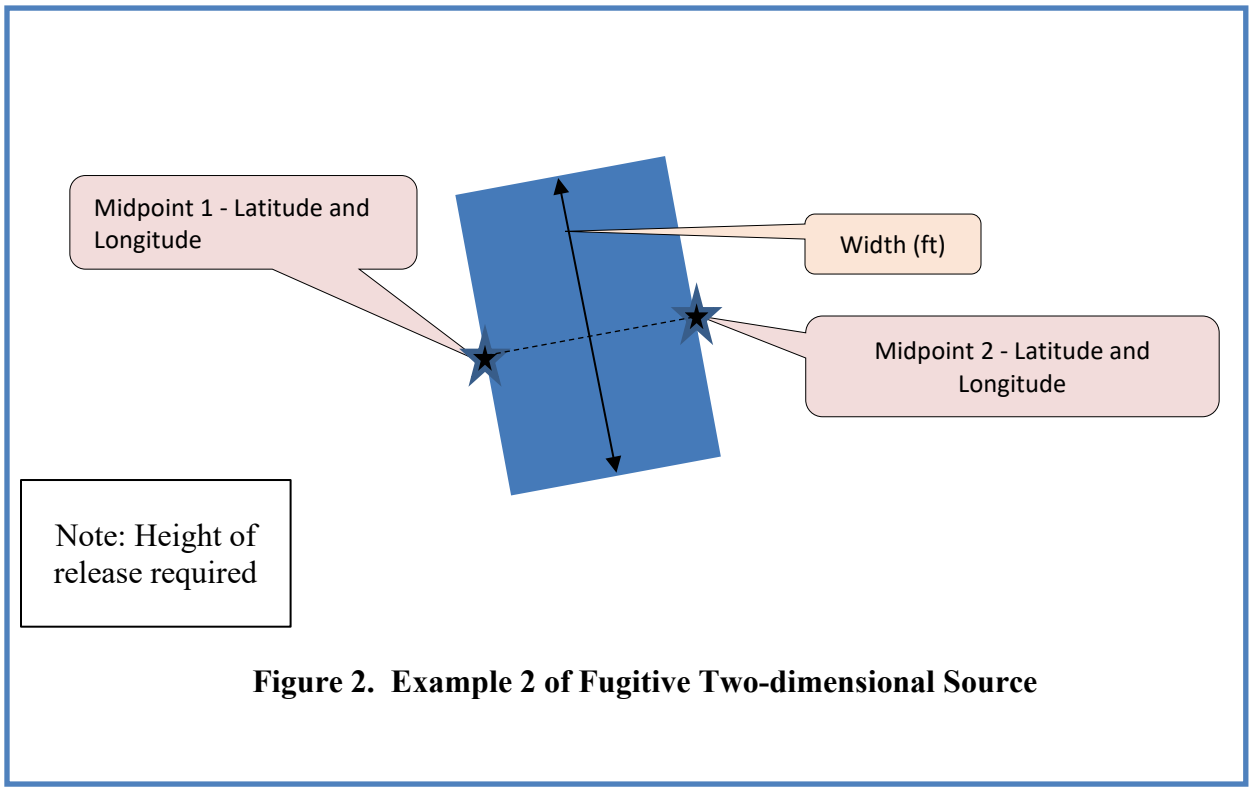

Figure 2. Example 2 of Fugitive Two-dimensional Source

Fugitive three-dimensional source has multiple release vents, a few examples would be a building with many wall and roof vents or an outdoor material storage pile.

Required parameters are:

- side length (ft) [length and width are equal with three-dimensional sources]
- lat/lon is the center of the footprint of the square and
- height of the three-dimensional source

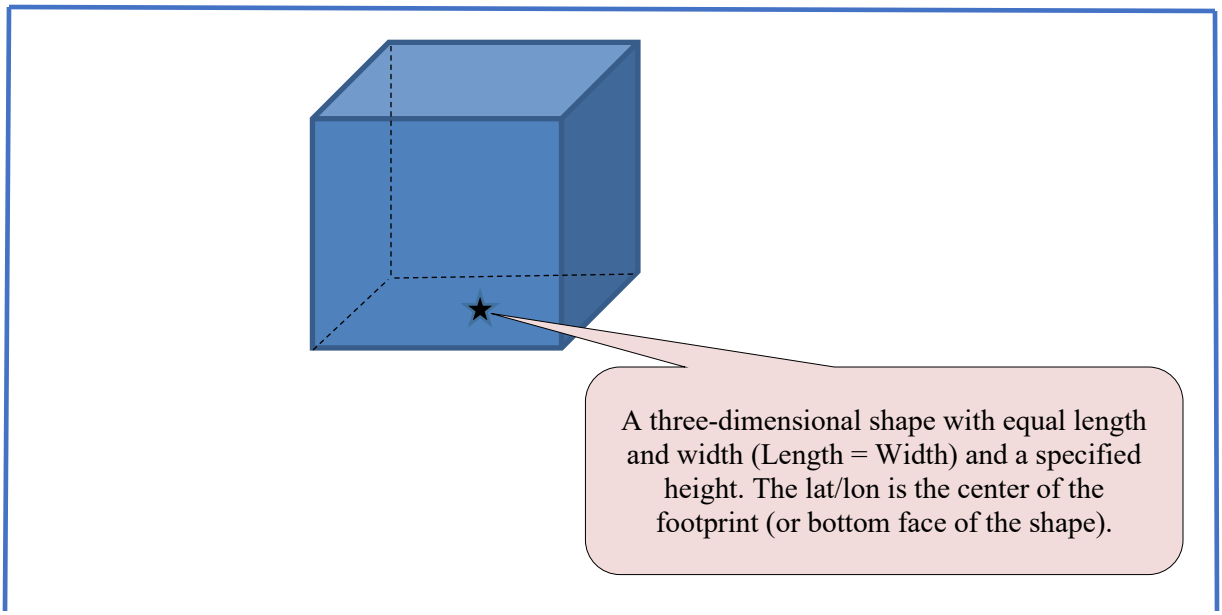

Figure 3. Depiction of Fugitive Three-dimensional Source Parameters

Fugitive area source (>10 sqft) is an alternative way of representing a fugitive two-dimensional source. It is an emission release on one plane. For example, an elongated roof vent or a wastewater holding pond.

Required parameters description:

- Enter the coordinates of the southwest corner of the release. The figure below shows examples of how fugitive area source rectangles are created. The red dashed lines represent the coordinate plane with north towards the top. The purple SW points to the southwest corner to show correct location of fugitive coordinates.
- The X and Y represent fugitive length and width.
- The rotation of each angle is also shown. You may wish to review your coordinates and fugitive areas in a GIS program or Google Earth to verify the accuracy.

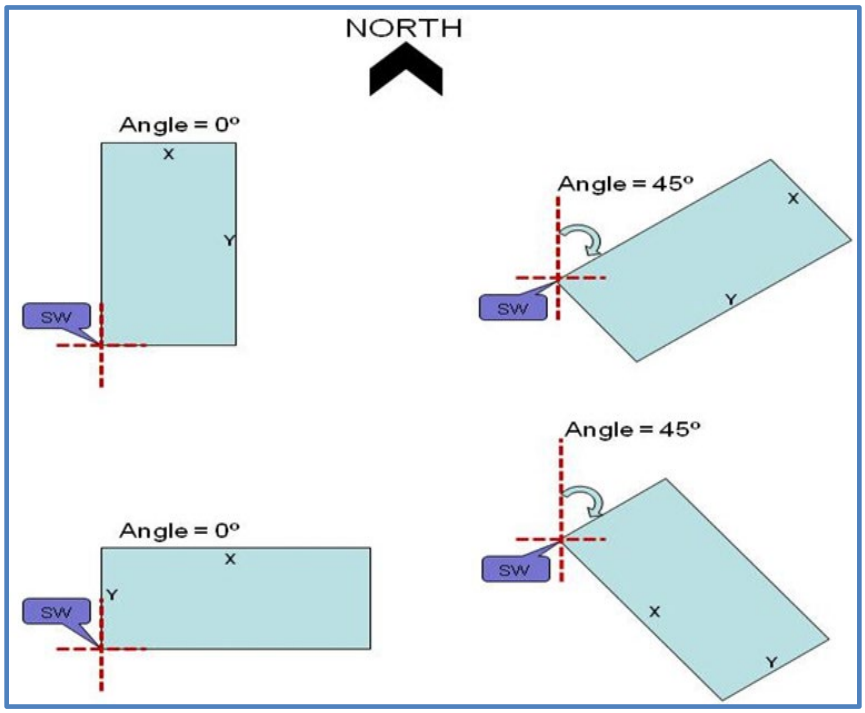

Figure 4. Depiction of Fugitive Area Source Parameters

Quality assurance (QA) range checks implemented by EPA include range checks for release parameters (stack height, exit gas temperature, stack diameter, and exit gas velocity). The acceptable QA ranges are shown below. If values are outside of these ranges, then the record is examined to see if it is in fact correct for the facility or if it appears to be incorrect.

- Height: 1 – 1300 ft
- Temperature: 30 – 1800 °F (temperatures should be >250 °F for combustion sources)
- Diameter: 0.1 – 100 ft
- Velocity: 0.1 – 200 ft/sec
- Stack height > diameter

When stack parameters are missing or incorrect, the missing or incorrect value is replaced with a calculated value where possible. For example, valid diameter and velocity can be used to calculate a missing or invalid exit gas flow rate. If it is not possible to calculate a replacement stack parameter value, average stack parameters for similar emission units at the same facility are used as default parameters. If there are no similar emission units at the same facility, then average stack parameters for the source category are used as default parameters. The reported flow rate is compared to the calculated flow rate using the reported diameter and velocity. If the reported flow rate is not within ten percent of the calculated flow rate, then all three related parameters are examined to determine which values are correct.

For fugitive releases including low flow vents that have missing or out of range height and/or temperature, the default values of 10 ft for stack height and 72 degrees Fahrenheit for

temperature are assigned. For a low flow vent, the default diameter and velocity are set to the minimum values of the QA range checks (i.e., 0.1 ft for diameter and 0.1 ft/sec for velocity.

The stack default flag description field in the emissions modeling file indicates which stack parameters are original or are revised for each modeling file record. If stack parameters were reviewed and accepted or revised by industry, then those are considered “original” values.

Table 1 below summarizes the required parameters and QA range check values for each release type.

Finally, coordinates and fugitive dimensions are plotted and reviewed using ArcGIS Online maps to verify accuracy.

Release Parameter	Point (Stack) Source	Low Flow Vent Source	Fugitive Three-Dimensional Source	Fugitive Two-Dimensional Source	Fugitive Area (Reserved for Historical Data)
Fugitive Length (ft)	NA	NA	NA – only a single side required	NA	Required (Between 1 and 10,000)
Fugitive Width (ft)	NA	NA	Required (Between 1 and 10,000)	Required (Between 1 and 10,000)	Required (Between 1 and 10,000)
Fugitive Angle	NA	NA	NA	NA	Required (Between 0 – 90)
Stack Diameter (ft)	Required (Between 0.1 – 100)	0.1 (Default)	NA	NA	NA
Exit Gas Velocity (ft/sec)	Required (Between 0.1 – 200)	0.1 (Default)	NA	NA	NA
Exit Gas Flow Rate (cu ft/sec)	Calculated based on velocity and stack diameter (assuming round stack)	0.0008 (Calculated Default = $(\pi R^2)V$	NA	NA	NA
Release Height (ft)	Required (Between 1 – 1300)	Required (Between 1 – 1300) Use 1 for ground-level releases	Required >0 (Top of Three-Dimensional Source)	Release height required >0	Required (Between 1 – 1300) Use 1 for ground-level releases
Exit Gas Temperature (F)	Required (Between 30 – 1800)	Required (Between 30 – 1800)	NA	NA	NA
Latitude (decimal degrees), Longitude (decimal degrees)	Required	Required	Required, center of source footprint	Two sets of lat/long for the midpoints of opposing sides of source	Required Southwest corner of source
Examples	APCD stack, powered building vent	Single roof vent/opening/window for building fugitives	Entire building with multiple release point on walls and/or roof, outdoor storage pile	Wastewater holding pond, building with elongated roof vent, haul road	Wastewater holding pond, building with elongated roof vent, haul road

Appendix C

Stack Test Characteristics

(Provided to the EPA on 12/8/2022 by Port Neches Facility for regenerator and reabsorber vents.)

Emission Source	Stack Parameters		Exit Gas Conditions		Coordinates	
	Height (ft)	Diameter (ft)	Velocity (ft/s)	Temp (F)	Lat	Long
F4 Regenerator Vent	183	1.3	242.6	204.7	29.96257	-93.93254
F6 Regenerator Vent	186	1.67	202.4	193	29.96537	-93.93144
F8 Regenerator Vent	150	1.67	118.4	202.7	29.96268	-93.9336
F4 Reabsorber Vent	43.6	0.33	Varies[1,2]	100	29.96562	-93.93186
F6 Reabsorber Vent	64.3	0.67	Varies[1,2]	100	29.96354	-93.93392
F8 Reabsorber Vent	97.8	0.5	Varies[1,2]	100	29.96233	-93.93309

Notes:

1. This emission point is a safety release and does not have a continuous flow to determine normal velocity. Max and average numbers have been provided below based on actual emission events.

Emission Source	Exit Gas Velocity (ft/s)	
	Max	Avg
F4 Reabsorber Vent	77	43
F6 Reabsorber Vent	54	30
F8 Reabsrober Vent	56	31

2. This emission point is a safety release and does not have a continuous flow. The release hours provided below were determined by the amount of time the reabsorber vent opened to atmosphere in 2021 during an emission event.

Emission Source	Release Hours
F4 Reabsorber Vent	5.13
F6 Reabsorber Vent	4.82
F8 Reabsrober Vent	49.4

Appendix 2
Technical Support Document for HEM4 Modeling

The HEM4 User's Guide

Instructions for using the Human Exposure Model 4
for Single and Multiple Facility Exposure and Risk Modeling

Open-Source Version 1.0

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1. Introduction

The Human Exposure Model 4 (HEM4) Open Source Version 1.0 is a streamlined, but rigorous tool you can use for estimating ambient concentrations, human exposures and health risks that may result from air pollution emissions from complex industrial facilities. HEM4 can be used to model impacts from a single facility or from multiple facilities located across the entire United States (U.S.) and its territories, as well as anywhere in the world. HEM4 is designed for use by the U.S. Environmental Protection Agency (EPA), states, local agencies, industry and other stakeholders, and is currently used in the Risk & Technology Review (RTR) assessments by EPA of entire source categories. In RTR assessments, HEM4 – like its predecessor, HEM-3 – is used to model emissions and the resulting ambient concentrations from hundreds of facilities, located both near as well as thousands of miles away from each other. The model then predicts the potential exposures and inhalation health risks posed by these emissions, including in zones with combined impacts from multiple nearby facilities. Compared to HEM-3, HEM4 incorporates additional front-end and back-end features and capabilities in the model platform, including additional modeling options, risk summary reports that summarize the cancer risk and noncancer health impacts for your modeled group of facilities, and multiple output viewing and analysis tools. Unlike HEM-3, HEM4 also enables the user to model concentrations, risk and health impacts for their own receptors inside *or* outside the U.S. HEM4 is available for download at http://www.epa.gov/fera/download-human-exposure-model-hem.

1.1 Organization of the HEM4 User's Guide

This User's Guide is organized into 10 sections plus an appendix:

Section 1	Provides a brief introduction to HEM4, including the main features and requirements of the model and a comparison to HEM-3
Section 2	Provides instructions for installing HEM4, including descriptions of the data libraries provided during installation
Section 3	Provides instructions for preparing the input data files needed by HEM4
Section 4	Provides step-by-step instructions for running HEM4
Section 5	Describes the calculations performed by HEM4 for each modeled facility
Section 6	Describes the facility-specific outputs produced by HEM4
Section 7	Describes the risk summary reports produced for each run group
Section 8	Explains how to understand the basic risk results
Section 9	Discusses quality assurance remodeling
Section 10	References
Section 11	Appendix A: Sample HEM4 Output Files

1.2 Main Features of HEM4

HEM4 performs three main operations: dispersion modeling, estimation of population exposure, and estimation of human health risks. For dispersion modeling, the American Meteorological Society - U.S. EPA Regulatory Model (AERMOD) is run by HEM4 as a compiled executable program. AERMOD is a state-of-the-science Gaussian plume dispersion model that EPA prefers for most industrial source modeling applications for air toxics applications (EPA 2005). AERMOD was developed under the auspices of the American Meteorological Society - Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) as summarized on EPA's AERMOD website. (See https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod for all AERMOD model documentation as well as links to AERMOD's preprocessors, AERMET, AERMAP, AERSCREEN, AERSURFACE and BPIPPRIM and post-processor, LEADPOST.)

This version 1.0 of HEM4 incorporates AERMOD version 19191 which was originally made available to the public in August 2019 (EPA 2019a, EPA 2019b). AERMOD can handle a wide range of different source types that may be associated with an industrial source complex, including stack sources, area sources, and volume sources. Additionally, AERMOD is capable of modeling polygon, line and buoyant line source types. AERMOD can also optionally model emissions that vary in time or with wind speed, deposition with or without plume depletion, and other complex plume processes such as building downwash.

HEM4 supplies AERMOD with meteorological data pre-processed by AERMET and required for AERMOD's dispersion calculations. HEM4's Meteorology Library contains meteorological ("met") data from over 800 observation stations across the continental U.S., Alaska, Hawaii, and Puerto Rico. Section 2.4 provides information on how to download the met data used by HEM4, discusses how the met files were processed and the data contained in each, and includes a national map of the locations for all 2019 met stations.

HEM4 runs AERMOD as many times as is necessary to address the gaseous pollutants and particulate matter emitted from each modeled facility. AERMOD outputs annual average ambient concentrations at discretely modeled receptor locations, through the simulation of hour-by-hour dispersions from the emission sources into the surrounding atmosphere.

For U.S. emission sources, after running AERMOD for dispersion modeling, HEM4 estimates population exposure and human health risks by drawing on additional data libraries that are provided with the model, including a U.S. Census Library and a Chemical (Pollutant) Health Effects Library. The Census Library of census block internal point ("centroid") locations and populations provides the basis of human exposure calculations. The model includes location and population data from the 2010 U.S. Census. HEM4 draws upon the Census Library to identify all census block locations within the study domain as defined by the default modeling radius around each facility or a radius that you specify. The Census Library includes locations and populations, elevations, and controlling hill heights for all of the approximately 6.3 million populated blocks tabulated in the 2010 U.S. Census (Census 2010). Section 2.3 provides information on how to download the census data and discusses the data contained in HEM4's Census Library.

Alternatively, HEM4 can model without the U.S. Census Library by using Alternate Receptors that the user can provide within the U.S. or anywhere in the world.

HEM4 uses the Chemical Health Effects Library of pollutant unit risk estimates (URE) and reference concentrations (RfCs) to calculate population cancer risks and noncancer health hazards. These risk factors and RfCs are based on the latest values recommended by the EPA for hazardous air pollutants (HAP) and other toxic air pollutants. More information on how EPA uses these dose-response values in risk assessments, including the source for these values, is provided in EPA's Dose-Response Assessment webpage (EPA 2018a) and in Section 2.2.

Using the air concentration results from AERMOD in combination with the data supplied by HEM4's Census and Chemical Health Effects Libraries, HEM4 estimates cancer risks and noncancer "risks" (health hazard indices) due to inhalation exposure at U.S. Census block locations and at other receptor locations that you may specify. As noted above, HEM4 (unlike the previous HEM-3 version of the model) can also be used outside the U.S., without U.S. Census block receptors, to predict concentrations and risk anywhere in the world at receptors specified by the user surrounding emission sources. The predicted risk estimates are generally conservative with respect to the modeled emissions because they are not adjusted for attenuating exposure factors (such as indoor/outdoor concentration ratios, daily hours spent away from the residential receptor site, and years of lifetime spent living elsewhere than the current residential receptor site).

HEM4 computes cancer risks using the EPA's UREs for HAP and other toxic air pollutants. The resulting estimates reflect the risk of developing cancer for an individual breathing the ambient air at a given receptor site 24 hours per day over a 70-year lifetime. HEM4 estimates noncancer "risk" (or health hazards) using hazard quotients (HQs) and hazard indices for 14 "target" organs or systems. The HQ for a given pollutant and receptor site is the ratio of the ambient concentration of the pollutant to the RfC at which (and below which) no adverse effects are expected. The chronic hazard index (HI) for a given target organ is the sum of HQs for substances that affect that organ. HEM4 computes target organ-specific hazard indices (TOSHIs) for the following 14 organ systems: the respiratory system; the liver; the neurological system; developmental effects; the reproductive system; the kidneys; the ocular system; the endocrine system; the hematological system; the immunological system; the skeletal system; the spleen; the thyroid; and whole body effects. Like the cancer risk estimates, noncancer hazard indices are not adjusted for attenuating exposure factors and are therefore considered conservative estimates.

Optionally, HEM4 can estimate acute (short-term, such as hourly) concentrations for each pollutant and receptor site, including the location of the maximum acute concentration for each pollutant emitted from the facility. In addition, the model outputs a listing of the associated acute benchmarks for each pollutant (at or below which certain acute adverse effects are not expected). From these acute concentrations and benchmarks, the ratio of the maximum acute concentration to the associated benchmark is computed to determine the maximum acute HQ for each pollutant of concern. Acute noncancer HQs, like chronic noncancer TOSHIs and cancer risk are conservative estimates in HEM4. Section 2.2.1 discusses the terms URE, RfC, HQ, HI and TOSHI in more detail.

HEM4 estimates the predicted lifetime cancer risk, chronic noncancer TOSHIs, annual concentrations, and (optionally) acute concentrations at every receptor location, and also identifies receptor locations where the impact is highest. For these locations, the model gives the concentrations of the modeled pollutants (HAP) emitted from each emission source driving the overall cancer risks, chronic TOSHIs, and acute impacts. The model also estimates the number of people exposed to various cancer risk levels and TOSHI levels.

HEM4 provides these results for each individual modeled facility and also consolidates facility-specific results into output files that provide results for all modeled facilities. HEM4's post-processors, the risk summary programs, produce additional outputs of combined and summarized results that are useful in capturing the risk and health hazards, as well as the pollutant and emission source drivers of these impacts, for a group of modeled facilities as a whole (e.g., an entire source category of facilities modeled under the EPA's RTR program). HEM4 provides a browser-based option of viewing all the summarized results in graphical form, including an interactive map of the facilities modeled, pie and bar charts of overall cancer incidence, population risks, and pollutant and source risk drivers, and an interactive table of the main results for each facility.

1.3 Differences between HEM4 and 2019 Version of HEM-3

HEM was originally developed as a screening tool for exposure assessment in the 1980s (EPA 1986). The original model was upgraded to run in a Windows™ environment, eventually called HEM-3, and regularly improved and re-released by EPA in several HEM-3 versions over the years, including most recently in 2007, 2014, 2017 and 2019. HEM4 is written in the open-source software language Python™, while HEM-3 is written in the FoxPro® language, last published by Microsoft® in 2007 and now unsupported. In addition, HEM4 includes improved and streamlined user interfaces as well as enhanced graphical output capabilities compared to HEM-3, as listed below, and summarized in Figure 1.

- HEM4 bases model selection options primarily on the data in your input files, rather than on responses to user interface questions, which is less prone to user error.
- HEM4 can model impacts anywhere in the world with user-provided "alternate receptors", in addition to U.S. Census block receptors.
- HEM4 includes an integrated processor to change the U.S. Census database you use to model by zeroing out block populations, moving blocks, and/or deleting blocks.
- HEM4 will default to using the full year of selected met data, but you may instead model with a specified period of met data by indicating a start and end date and even hour.
- HEM4 allows you to specify the exact location of the facility center or use the center location calculated by the model.
- HEM4 allows you to specify polar ring distances or use the polar ring locations calculated by the model.
- HEM4 allows you to choose Method 1 or Method 2 for particle deposition. Method 2 requires less knowledge of the particle size distribution of your emissions compared to Method 1, which requires a detailed particle size input file.
- HEM4 allows you to choose a different acute high value for each facility (e.g., maximum, 99th percentile, 98th percentile), rather than modeling each facility with the same maximum acute value.

- HEM4 includes the Risk Summary Report programs (previously called the RTR Summary Programs) integrated into the model itself, rather than as an add-on suite of programs.

- HEM4's Risk Summary Reports are enhanced. The HI Histogram output accounts for all 14 TOSHIs (not just three). The Incidence Drivers output is now sorted in descending order of pollutant-specific incidence and includes the pollutant's percentage contribution to total incidence. The Source Type Risk Histogram output includes the maximum overall risk histogram and incidence for all modeled facilities in your run group, in addition to the histogram and incidence specific to each source type.

- HEM4 performs consistency checks on your input files and includes more specific and instructive error messages, to aid you in rectifying any errors or inconsistencies in your input files before the model run begins.

- In addition to spreadsheet output files, HEM4 includes enhanced capabilities for visualization and analysis of outputs, including browser-based interactive tables, graphs, and mapping options.

- Note: In addition to the enhancements listed above, HEM4 has maintained all the capabilities of the 2019 HEM-3 version, which included numerous enhancements compared to the previous versions.

Model Feature	HEM4	2019 HEM-3
Software language	Written in open-source Python™ language	Written in Microsoft FoxPro® language, now unsupported
Minimal user interface	Model options based primarily on data in input files; less prone to user error	Model options based on input files as well as responses to user interface questions; more prone to user error
Receptor enhancement and flexibility	Modeling can occur anywhere in the world because users can specify alternate populated receptors in lieu of U.S. Census blocks	Only U.S. modeling was possible because U.S. Census receptor data was required for any model run
Census database revisions	Census blocks may be revised or removed using an integrated processor	Census database could not be edited by user
Meteorological Period Options	Period start and end fields allow you to specify exactly what met period HEM4 should instruct AERMOD to use for your modeling run, down to the year, month, day and even hour	HEM-3 always used the default annual period of met data
Facility center	User may specify the location of the facility center	The facility center was always calculated by model based on source locations

Model Feature	HEM4	2019 HEM-3
Polar ring distances	User may specify polar ring distances or use defaults	Polar ring distances were set by default only
Particle deposition	User can choose AERMOD's Method 1 or 2 to model particle deposition. Method 2 requires less particle data.	Particle deposition was always modeled via AERMOD Method 1, which requires detailed particle size distribution data
Acute high value	User can specify a different percentile to use as the acute high value for each facility	The same maximum value had to be used for every facility in the modeling run
Risk Summary Programs	Risk Summary Programs are integrated into HEM4	RTR Summary Programs were a separate executable
Risk Summary Report Enhancements	The HI Histogram output accounts for all 14 TOSHIs. The Incidence Drivers output is sorted in descending order of pollutant-specific incidence and includes the pollutant's percentage contribution to total incidence. The Source Type Risk Histogram output includes the maximum overall histogram for the run group.	HEM-3 accounted for only 3 TOSHIs in the HI Histogram output. HEM-3's Incidence Drivers output was unsorted and did not include the percentage that each pollutant contributes to the total incidence. HEM-3's Source Type Risk Histogram did not include the maximum overall column for the run.
Error messages	Input file inconsistency checks are automatically made prior to model run with more specific and instructive error messages to aid user in correcting errors pre-run	Error messages were not specific enough and did not capture many input file inconsistencies prior to runs
Graphical outputs	Browser-based interactive tables, graphs, and mapping options for visualization and analysis of outputs, in addition to spreadsheet-based output files	Graphical output options were not available in HEM-3

Figure 1. Summary of Key Improvements for HEM4 versus 2019 HEM-3

1.4 Strengths and Limitations of HEM4

HEM4 is designed to perform detailed and rigorous analyses of chronic and acute air pollution risks for populations located near industrial emission sources. The model was previously updated with the goal of simplifying the running of AERMOD without sacrificing any of AERMOD's strengths. In keeping with this goal, you can specify complex emission source configurations, including point sources for stacks, area and volume sources for fugitive emissions, obliquely oriented area sources for roadways, line sources for airport runways, buoyant line sources for roof vents, and polygon sources for a variety of area source shapes

including entire census blocks and tracts. The model identifies all receptors located near each facility, including census blocks (if in the U.S.) and alternate receptors. You can also specify the locations of individual houses, schools, facility boundaries, monitors, or other user-defined receptors to model. HEM4 can account for impacts of terrain, building downwash effects, pollutant deposition and plume depletion, and temporally-varying emissions. HEM4 also analyzes multiple pollutants concurrently, with the capability of including particulate and gaseous pollutants in the same model run.

However, HEM4's framework has some limitations. First, AERMOD, like all air pollutant dispersion models, is subject to uncertainties. Likewise, pollutant UREs for cancer, RfCs for noncancer HI, and benchmarks for acute health effects are subject to uncertainties. Another limitation of HEM4 is that, when modeling with census block receptors in the U.S., the model estimates pollutant concentrations and risks for the block centroid, as defined by the U.S. Census Bureau. Values calculated for this internal point are not representative of the range of values over the entire block, and may not represent where most people reside within a block. Further, these values do not account for the movement of people from their home census blocks to other census blocks, due to commuting or other daily activities. In addition, as previously noted, HEM4 calculates outdoor concentrations of air pollutants. These concentrations do not account for indoor sources of pollution, or the reduction of outdoor pollution in indoor air.

HEM4 performs several tests on user input data—including ensuring consistency of input files and some parameters—before using AERMOD to calculate air pollution impacts. However, there are some potential problems users may introduce to their input files that HEM4 may not detect in these initial tests. To avoid this, carefully review the model input guidelines to make sure that the contents and format of your input files meet these guidelines before launching HEM4.

1.5 Requirements for Running HEM4

You can use HEM4 on any Windows™-based personal computer running Windows 98™ or later. Disk space requirements will depend on the number of census and meteorological files that you use. To model an individual facility, the model requires, at minimum, 10 megabytes (MB) of disk space for a small facility and 1 to 2 gigabytes (GB) for a large, complex facility. Furthermore, disk space requirements can be 10 to 20 times larger (than 2 GB) for complex facilities located in densely populated urban areas (i.e., with many receptors), depending on the modeling options you choose. The full census and meteorological libraries that you can download in addition to the model require about 3.3 GB of space. The HEM4 model also will need a minimum of 8 GB of random-access memory (RAM). Once installed, you can use HEM4 to model risks and exposures for any location in the U.S. or around the world, and for a wide range of emission source configurations.

For each model analysis, you should provide emission rates for all HAP and emission source locations in the form of Excel™ spreadsheet files. HEM4 requires separate estimates of emission rates of each pollutant, from each emission source, for each facility to be modeled. The model also requires detailed information on each emission source, including location, release height, emission velocity and temperature for point (stack) sources, and the configuration of non-point emission sources (e.g., area sources which emit with negligible velocity at ambient temperature). You will be able to design the model receptor network around each facility to be modeled via an input spreadsheet file. You can also use an optional spreadsheet file to provide the dimensions of buildings near emission sources, for use in

computing building downwash effects. When modeling particulate emissions, you can use an optional spreadsheet file to provide particle size information and deposition parameters. If you opt to model deposition of gaseous emissions, you will need to provide additional spreadsheet input files describing the land use and vegetation surrounding the facility. You will be prompted to indicate the location of your input spreadsheet files through user input screens, which are discussed in more detail in Section 4, *Step-by-Step Instructions for Running HEM4*.

This user's guide is designed to provide all the information you will need to run HEM4. However, some of the options for running HEM4 draw on advanced features of AERMOD. If unfamiliar with the AERMOD dispersion model, you may need to refer to the AERMOD documentation (available at https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod.) in order to develop some of the inputs needed for HEM4 (EPA 2019a, EPA 2019b). This is particularly true for some of the more complex modeling options, such as plume deposition and depletion, building downwash, temporal and wind speed emission variations, and complex source configurations.

2. Installing HEM4

This section provides instructions for downloading and installing the HEM4 model and required data libraries from the EPA's HEM Download Page.

2.1 Downloading the HEM4 Program

The HEM4 model is available from EPA's HEM Download webpage at http://www.epa.gov/fera/download-human-exposure-model-hem. This site includes general installation instructions, including hardware and software requirements, as well as links to download and install HEM4. Download the HEM4 zip install package under "Software available for download." HEM4 can be installed anywhere on your PC and the root folder is not required to be named HEM4. However, **for the purposes of this User's Guide, it is assumed the root folder will be named "HEM4".** HEM4 is started by running the executable file ending in ".exe". **Note**: The HEM4 source code is available on github.com/USEPA/HEM4.

In addition to user-supplied inputs describing the nature and location of the emissions (discussed in Section 3.1), HEM4 relies upon several data libraries that supply other required inputs for a modeling run. To complete the installation of HEM4, download the following data libraries:

- the Chemical Health Effects Library containing the pollutant (hazardous air pollutant, HAP)-specific dose response values and benchmark values for affected organs, a.k.a. "Toxicity Value Files" (Note: upon installation, HEM4's resources folder will include a Dose Response Library and Target Organ Endpoints table);
- the Census Library containing nationwide files that provide the population numbers and terrain elevation data surrounding a facility location (based on the 2010 Census); Note: upon installation, HEM4's census folder will include the census files needed to run the template/sample files only; and
- the Meteorological Library containing met station files (a surface and profile file for each station) with data for over 800 stations nationwide; Note: upon installation, HEM4's AERMOD MetData folder will include the meteorological files needed to run the template/sample files only.

You will find links to these data libraries on the HEM Download Page. The following sections provide instructions for downloading these files, along with a brief description of each of these data libraries.

2.2 Downloading Chemical Health Effects Data

HEM4 uses a chemical health effects library of pollutant unit risk estimates (UREs) and reference concentrations (RfCs) to calculate risks. To download these values, click on the "Toxicity Value Files" link on EPA's HEM Download Page (http://www.epa.gov/fera/download-human-exposure-model-hem). Before initiating a modeling run, always check for updated versions of these files on the HEM Download Page. When updated files become available, copy these into the "resources" folder under the HEM4 directory that you selected during installation. Be sure to unzip the files and verify they are located in the specified folder when finished. The folder for chemical health effects data is "HEM4\resources."

2.2.1 Description of Chemical Health Effects Library

For each pollutant or HAP, the Chemical Health Effects Library includes the following parameters, where available:

- URE for cancer;
- RfC for chronic noncancer health effects;
- reference benchmark concentration for acute health effects; and
- target organs affected by the pollutant (for chronic noncancer effects).

These parameters are based on the EPA's database of recommended dose response values for HAP (EPA 2018a), which is updated periodically, consistent with continued research on these parameters. The URE represents the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent (HAP) at a concentration of 1 microgram per cubic meter ($\mu g/m^3$) in air. For example, if the URE is 1.5×10^{-6} per $\mu g/m^3$, then 1.5 excess cancer cases are expected per 1 million people, if all 1 million people were exposed daily for a lifetime to 1 microgram of the pollutant in 1 cubic meter of air. UREs are considered plausible upper limits to the true value; the true risk is likely to be less but could be greater (EPA 2018b).

The RfC is a concentration estimate of a continuous inhalation exposure to the human population that is likely to be without an appreciable "risk" of deleterious noncancer health effects during a lifetime (including to sensitive subgroups such as children, asthmatics and the elderly). No adverse effects are expected to result from exposure if the ratio of the potential exposure concentration to the RfC, defined as the hazard quotient (HQ), is less than one (1). Note that the uncertainty of the RfC estimates can span an order of magnitude. (EPA 2018b). Target organs are those organs (e.g., kidney) or organ systems (e.g., respiratory) which may be impacted with chronic noncancer health effects by exposure to the pollutant in question. The hazard index (HI) is the sum of hazard quotients for substances that affect the same target organ or organ system, also known as the target organ specific hazard index (TOSHI).

The reference concentrations for acute health effects include both "no effects" reference levels for the general public, such as the California Reference Exposure Levels (RELs), and emergency response levels, such as Acute Exposure Guideline Levels (AEGLs) and

Emergency Response Planning Guidelines (ERPGs). A more in-depth discussion of the development and use of the health reference values may be found in the EPA's Air Toxics Risk Assessment Library (EPA 2017), available for download at http://www.epa.gov/fera/risk-assessment-and-modeling-air-toxics-risk-assessment-reference-library.

You can add pollutants and associated health effect values, as needed, to the two Excel™ spreadsheets comprising HEM4's Chemical Health Effects Library: the Dose Response Library file and the Target Organ Endpoints file. These files are located in HEM4's resources folder:

- HEM4\resources\Dose_Response_Library.xlsx; and
- HEM4\resources\Target_Organ_Endpoints.xlsx.

The Dose Response Library file includes a listing of HAP and other toxic pollutants and the various URE values, RfC values, and acute benchmark values associated with these pollutants. The Target Organ Endpoints file includes a listing of HAP and other toxic pollutants and the organs or organ systems that may be impacted with chronic noncancer health effects, by exposure to these pollutants above the RfC level.

Note that each pollutant you list in your facility-specific input files (discussed in Section 3.1) needs to match exactly (the spelling of) a pollutant name in HEM4's Dose Response Library file, and there can be no extra pollutants listed in your facility-specific input files that are not also listed in the Dose Response Library file. The Target Organ Endpoints file need not contain every pollutant listed in your inputs. You should ensure, however, that every pollutant in your input files that has chronic noncancer health effects associated with it – and that you wish to model as such – has an RfC value in the Dose Response Library file and is also listed in the Target Organ Endpoints file, with the impacted organs and organ systems checked. Note: **Only pollutants with RfC values need to be listed in the Target Organ Endpoints file**.

2.3 Downloading Census Data

You will need census files for the region or regions you wish to model. You can obtain nationwide files from the 2010 Census on the HEM Download Page (http://www.epa.gov/fera/download-human-exposure-model-hem) of EPA's FERA website.

Nationwide files are provided on a state-by-state basis in JavaScript Object Notation format (.json). HEM4 will access census files to cover the area within 50 kilometers of each facility you are modeling. Multiple states may be needed to model a particular facility if the facility is located within 50 kilometers of a state boundary.

Download, unzip and copy the nationwide census files into the census folder under the HEM4 folder you selected during installation. Once unzipped, check to be sure that these files are now located in the specified folders when finished. The census folder is "HEM4\census".

Do not delete the Census_key.json file (HEM4\census\Census_key.json). This file is required for HEM4 modeling runs. Note that the Illinois and North Carolina files for the 2010 Census are also included with the installation package to allow running of the template input files (discussed in Section 3) with or without downloading of all nationwide census files.

2.3.1 Description of Census Library

The HEM4 Census Library includes census block identification codes, locations, populations, elevations, and controlling hill heights for the over 6 million populated census blocks identified in the 2010 Census. The location coordinates reflect an internal point selected by the Census Bureau to be roughly in the center of the block. For complex shapes, the internal point may not be in the geographic center of the block, but they are still referred to as "centroids" in this guide. Locations and population data for census blocks in the 50 states, Puerto Rico, and the Virgin Islands are extracted from the U.S. Census Bureau website for Census 2010 (Census 2010).

HEM4's census database includes elevation and controlling hill height data, in addition to the population and location data supplied by the Census Bureau. U.S. Geological Survey data were used to estimate the elevation of each census block in the continental U.S. and Hawaii. The elevation data contained within the 2010 Census files were derived from North American Digital Elevation Model (DEM) data at a resolution of 1/3 of an arc second, or about 10 meters (USGS 2015). Using the ArcGIS® 10 analysis tool, elevation was estimated for each census block in Alaska and the U.S. Virgin Islands. The point locations of the census blocks in Alaska and the U.S. Virgin Islands were overlaid with a raster layer of DEM elevations (in meters) (USGS 2000). An elevation value was assigned to each census block point based on the closest point in the ArcGIS elevation raster file. HEM4 uses these block elevations to estimate the elevation of each nearby polar grid receptor and the elevation of each source, if the user does not provide source elevations, as discussed later in this guide.

An algorithm used in AERMAP, the AERMOD terrain processor (EPA 2018c), is used to determine controlling hill heights. These values are used for flow calculations within AERMOD. To save run time and resources, the HEM4 census block elevation database is substituted for the DEM data generally used in AERMAP. As noted above, the census block elevations were originally derived from the DEM database. To determine the controlling hill height for each census block, a cone is projected away from the block centroid location, representing a 10% elevation grade. The controlling hill height is selected based on the highest elevation above that 10% grade (in accordance with the AERMAP methodology). The distance cutoff for this calculation is 100 kilometers. (This corresponds to an elevation difference at a 10% grade of 10,000 meters, which considerably exceeds the maximum elevation difference in North America.)

In addition to census block location, population, elevation and controlling hill height data, the HEM4 Census Library also includes the locations for over 125,000 schools and 1,000 monitors. School location data is for public and private schools, spanning pre-kindergarten through high school, and are from the NCES 2009 data (NCES 2009a, NCES 2009b). You can obtain monitoring locations from the Air Toxics Data section of the EPA's Technology Transfer Network Ambient Monitoring Technology Information Center (EPA 2018d). Note that the precision of the latitude/longitude location of these monitors varies and, in some cases, is precise to only two decimal places (roughly ± 600 meters), making comparison with HEM4 modeling results inexact.

2.4 Downloading Meteorological Data

You can obtain nationwide meteorological data files from the HEM Download Page (http://www.epa.gov/fera/download-human-exposure-model-hem). Each set of meteorological

files contains surface data and upper air data and is named beginning with the state abbreviation for the state in which the station is located. Generally, the closest set of stations will be most representative of the meteorology in the modeling domain. However, there are several situations where a different combination of meteorological stations will be more representative. For instance, if the modeling domain is located on the Gulf of Mexico, a surface station near the Gulf may be more representative than an inland station, even if there is a closer inland station.

Download the nationwide meteorological files into the "MetData" folder in the "aermod" folder under the HEM4 folder you selected during installation. Unzip the meteorological files. After unzipping, verify they are located in the specified folder. The meteorological folder is "HEM4\aermod\MetData." AERMOD uses two files for each meteorological station and these files have extensions of SFC (surface data) and PFL (profile data).

Note that when you download the HEM4 model (as described in Section 2.1), the installation package will place an Excel™ spreadsheet named "*metlib_AERMOD.xlsx*" in your "HEM4\resources" folder. This spreadsheet lists all the SFC and PFL met stations that are provided in the nationwide meteorological data files (those available on the HEM Download Page on the date you download the model). You may edit this spreadsheet to include additional met station files, but you must provide the new met station data as both SFC and PFL files in your "HEM4\aermod\MetData" folder. Be careful that the SFC and PFL file names match the new rows you have added to the metlib_AERMOD.xlsx spreadsheet in your resources folder. You may also edit rows in this spreadsheet or delete met station entries entirely. (A Python error message will be displayed if HEM4 cannot locate the metlib_AERMOD.xlsx spreadsheet in your resources folder.)

2.4.1 Description of Meteorological Library

AERMOD requires surface and upper air meteorological data that meet specific format requirements. HEM4 includes a library of meteorological data from National Weather Service (NWS) observation stations. The current HEM4 AERMOD Meteorological Library includes over 800 nationwide locations, depicted in Figure 2.

USEPA meteorologists obtained calendar year 2019 Integrated Surface Hourly Data (ISHD) for over 800 Automated Surface Observation System (ASOS) (http://www.nws.noaa.gov/asos/) stations spanning the entire US, as well as Puerto Rico and the US Virgin Islands, from the National Centers for Environmental Information (NCEI) (formerly, the National Climatic Data Center (NCDC)). The AERMOD meteorological processor, AERMET (EPA 2019c) and its supporting modeling system (AERSURFACE and AERMINUTE) were used to process the meteorological data.

To estimate the boundary layer parameters required by AERMOD, AERMET requires hourly surface weather observations (which may include hourly values calculated from 1-minute data) and the full (*i.e.*, meteorological variables reported at all levels) twice-daily upper air soundings. The surface and upper air stations are paired to produce the required input data for AERMOD. To support AERMET, ASOS 1-minute data for each surface station were obtained from NCEI in a DSI 6405 format. Further, upper air sounding data for the same time period for over 80 observation sites were obtained from the National Oceanic & Atmospheric Administration (NOAA) Earth System Research Laboratory's (ESRL) online Radiosonde Database (see http://www.esrl.noaa.gov/raobs/General_Information.html). These datasets were produced by ESRL in Forecast Systems Laboratory (FSL) format.

AERMET Processing

Utilizing the AERMET meteorological data pre-processor, and the ASOS surface and FSL upper air stations, surface and profile files for input into AERMOD were generated nationwide. The surface stations were paired with representative upper air stations by taking the upper air station closest to each surface station. The AERSURFACE tool was used to estimate the surface characteristics for input into AERMET utilizing land cover data surrounding the surface station. In addition, the AERMINUTE pre-processor was used to process 1-minute ASOS wind data for input into AERMET. The following provides more detail regarding the pre-processors, AERMET and AERMINUTE, used to generate the AERMOD meteorological data.

- AERMET Options: Version 19191 used to process ASOS site data; surface data in NCEI TD-3505 (ISHD) format; upper air data in FSL (all levels, tenths m/s) format; used the ADJ_U* non-Default BETA option to adjust the friction velocity (u* or ustar) for low wind speed stable conditions.

- AERMINUTE Options: Version 15272 used for 1-minute ASOS data in TD-6405 format where available.

The surface files were examined for completeness. If more than 10 percent of the data were missing, the station was not considered suitable for the HEM4 meteorological database. In all, 838 met station pairs were found suitable and are included in the HEM4 meteorological library, as depicted in Figure 2. Of these 838 met stations, 791 stations contain 2019 met data, while the rest are 2016 through 2018.

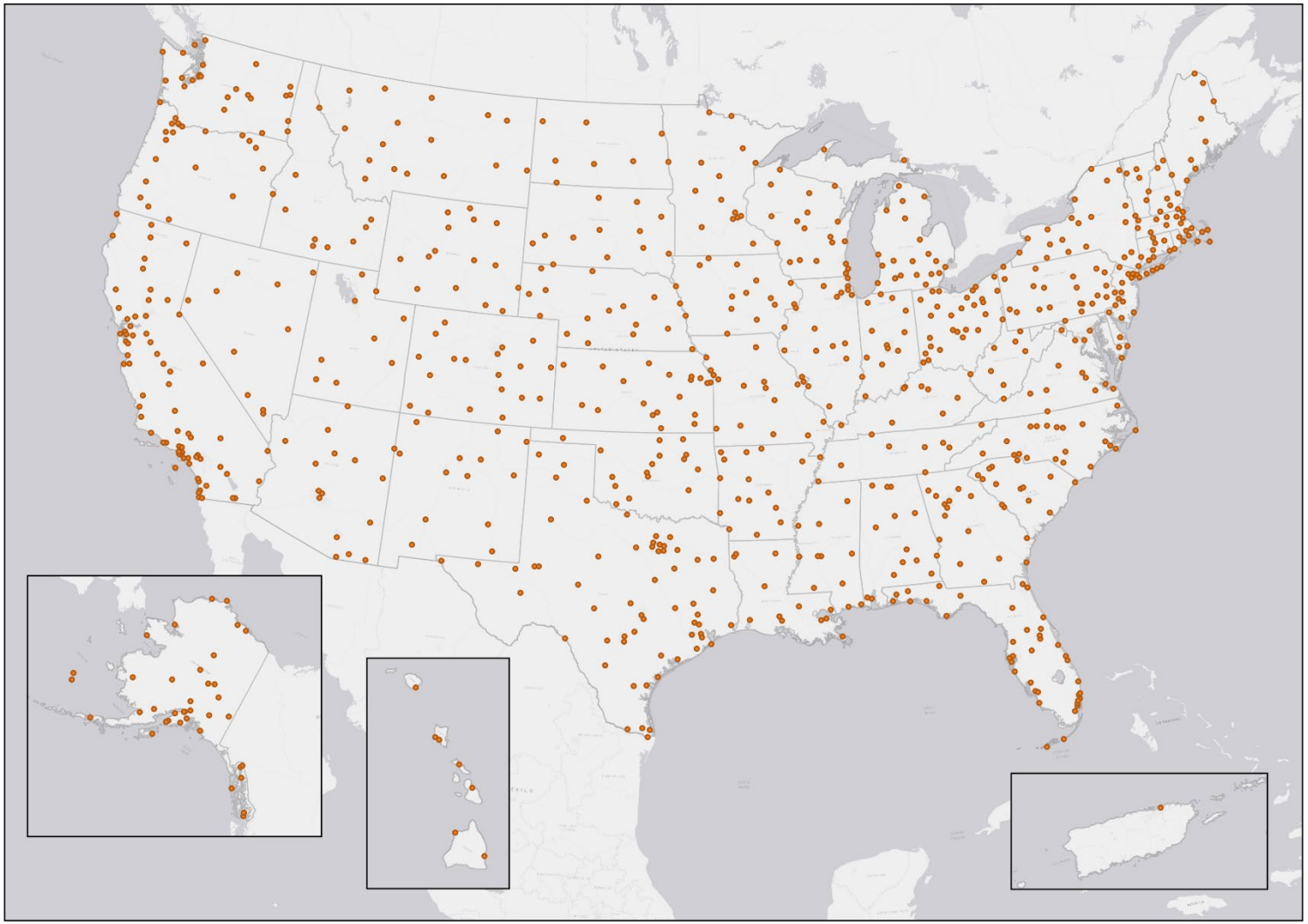


Figure 2. HEM4 Meteorological Stations

3. Preparing HEM4 Input Files

This section explains how to prepare the required and optional user-supplied input files for HEM4. In addition to the instructions provided in this section regarding how to set up your input files, especially for more advanced modeling options, it is important to review the AERMOD documentation for further guidance (EPA 2019a, EPA 2019b).

3.1 Overview and General Rules

HEM4 requires a series of Excel™ spreadsheet files to specify the emissions and configuration of the facilities (or facility) you are modeling. HEM4 accepts all recent Microsoft Excel™ versions using the xlsx spreadsheet format (e.g., Excel 2007 and later). It should be noted that Excel 2007/2010, 2013, 2016, and 2019 versions have a 1,048,576-row capacity (and 16,384-column capacity).

To use HEM4 to calculate ambient pollutant concentrations (using AERMOD), you will need the following three files at minimum:

- a facility list options file, which is the primary driver of the model run listing the facilities to be modeled and specifying the model run parameters and options;
- an emissions location file, which provides emission source locations and configurations for the facilities being modeled; and
- a HAP emissions file, which provides the names and amounts of the pollutants emitted from each emission source at the modeled facilities.

You may also need the following additional input files, depending on the options you choose to use in your modeling run.

- a polygon vertex file – this file is required if one or more of your sources is configured as a polygon; it specifies the location of the polygon(s) by providing coordinates of the vertices. (Note: this file is not needed for area sources.)
- a buoyant line parameter file – this file is required if one or more of your sources is a buoyant line; it defines the values for a single buoyant line source (or the average values for a group of parallel buoyant lines) including building length, building height, building width, line source width, building separation (between the individual lines when multiple lines are averaged) and buoyancy parameter.
- a building dimensions file – this file is required to model building downwash effects; it describes building dimensions or other obstructions near emission sources that would produce wake effects.
- An emission variations file – this file provides emission rate factors for individual sources for one or more of the facilities you specify and is required to model temporally-varying emissions (e.g., emissions reflecting diurnal, weekly, monthly, and seasonal variations) or emissions impacted by wind speed variations.

- a particle data file – this file is required to model particulate deposition; it specifies the particle size distribution for various size ranges.

- the gas parameter file (included in HEM4's resources folder) – this file is required to model gaseous deposition; it specifies the parameters needed for modeling dry and/or wet deposition of gaseous (vapor) pollutants including diffusion coefficients, cuticular resistance and Henry's Law coefficients. (Note: defaults are provided by the model automatically, but you should provide pollutant-specific parameters if available by editing the *Gas_param.xlsx* file as discussed in Section 3.5.4.)

- a land use and month-to-seasons files – these two files are required to model dry deposition of gaseous pollutants; they describe the land use and vegetative land cover surrounding emission source(s) for facilities listed in the files.

- a user-defined receptors file – this file specifies the locations of additional discrete receptors and is required if you want HEM4 to compute pollutant concentrations and risks at locations you specify (e.g., houses, schools, or other sites near a facility), in addition to U.S. census block receptors. (Note: your facility list options file must indicate the facilities to be modeled with user receptors.)

- an alternate receptor file – this file is required if you wish to use receptors other than U.S. Census block centroids in your modeling run and instead provide your own list of receptors for modeling within the U.S. or anywhere in the world; the file specifies the ID, location, elevation, hill height and population of the alternate receptors to be modeled.

These files are described in more detail below in Sections 3.2 through 3.5. In addition to the above list of input files, you can also optionally revise the census database (as described below in Section 3.5.9) and also revise the chemical health effect input files – the dose response values and target organ assumptions – used in the model (as described below in Section 3.5.10).

HEM4 will prompt you to provide the input files required for your model run by opening up Browse lines that allow you to search your computer for the location of each required input file. Directly inputting data from spreadsheets avoids having to retype the emission rates and other calculated parameters. However, this method of input has its drawbacks. Notably, HEM4 will not run successfully unless you have formatted the input files exactly as specified in the format guidelines. This section describes general rules you should follow to avoid common mistakes. To make formatting easier, specific formatting requirements are exemplified in template input files, which are provided in the default "HEM4\Inputs" folder. **Note**: **If this is your first time running HEM4, it is highly recommended that you first run the model with the template input files provided, as practice, and to confirm that HEM4 installed properly on your computer**.

General Rules for Input Files

- Use a separate Excel™ workbook for each input file. Ensure your Microsoft Office™ Trust Center settings allow Excel™ version 5 and higher to be fully opened and operational (i.e., not in protected view only).

- Use only one input file worksheet per workbook.

- Match columns with the format specified for the input file. You can use the template input files and substitute actual data for template data. Delete any extra lines of template data.

- Do not insert columns between data columns. HEM4 will read these, including any extra hidden columns, as data.

- Use the number of header rows indicated in the template input files (included with the HEM4 download) at the top of each spreadsheet file for all required and optional input files.

- Do not include text in numerical data fields (for instance "<0.001"). HEM4 may read these fields as 0s (zeroes) or may accept only a portion of the number.

- For location coordinates, HEM4 will accept latitudes and longitudes in decimal degrees as well as Universal Transverse Mercator (UTM) coordinates. **The maximum precision HEM4 uses for latitude and longitude decimal degrees is 5 places after the decimal**. (HEM4 will convert latitudes/longitudes to UTMs for use in AERMOD.) You must enter coordinates in the World Geodetic System of 1984 (WGS84) format.[1] The 1983 North American Datum (NAD83) and the WGS84 are identical for most applications, so no conversion is needed if using coordinates based on NAD83. However, if coordinates are based on the 1927 North American Datum (NAD27) geographic system format, they would need to be converted to WGS84 before being used in HEM4.

- **Match the units used for parameters**, such as emission rates and stack parameters, **with the units given in the file's format guidelines** provided in the following sections (for example: meters/second, meters, tons/year, etc.). The required units are also indicated in parentheses in the header rows of the template input files which are included with the model.

- Note that the length and decimal places indicated in the format guidelines for each field in the various input files is, in most cases, the suggested length based on HEM4's internal rounding conventions. For the Source ID field, however, it should be noted that AERMOD does not accept Source IDs longer than 8 characters.

3.2 Facility List Options File

The Facility List Options Excel™ file is the primary driver specifying the parameters and options of the modeling run and is required for any HEM4 run. This file is an enhanced version of the Facility List Options file used in Multi HEM-3, with several columns added allowing for additional features and several columns re-arranged for more intuitive grouping of fields. The Facility List Options file contains one row for every facility that will be run with the various modeling options

[1] WGS84, NAD83 and NAD27 are different world reference frames (a.k.a. geographic systems) that are used as the basis for projected coordinate systems like UTMs. HEM4 uses WGS84. For more information see https://www.nga.mil/ProductsServices/GeodesyandGeophysics/Pages/WorldGeodeticSystem.aspx and https://gisgeography.com/wgs84-world-geodetic-system/.

listed as columns for each facility row. **If you use all default modeling options, the only field requiring input is the Facility ID**. All other fields have defaults which are employed when the field in the Facility List Options file is left blank.

3.2.1 Fields in the Facility List Options File

Table 1 shows the fields included in the Facility List Options file. These fields are columns in the actual *Facility_List_Options.xlsx* input file that you must provide to HEM4, and each row is for a different facility as identified by the Facility ID. The rows in Table 1 are shown in the same column order required by HEM4 in the input file. (For a template, see *HEM4_ _Facility_List_Options.xlsx* in your HEM4 inputs folder.) The options listed in Table 1 are described in more detail following the table.

Table 1. Fields in the Facility List Options Input File (Required)

Field	Default Setting (if field left blank)	Description of Facility List Options Field
Facility ID (FacilityID)		You must enter an alphanumeric string identifying the facility being modeled. This field is mandatory; all other fields have default values when blank.
Met Station (met_station)	Met station selected by model as closest to the facility	The name of the meteorological surface station (e.g., NAME02.SFC) to be used by AERMOD when modeling each facility. The met station closest to facility is chosen unless you specify a name.
Rural/Urban (rural_urban)	HEM4 determines when using U.S. Census block receptors; HEM4 defaults to rural for alternate receptors	Used to set the type of dispersion environment for AERMOD. "R" indicates rural land use surrounding the facility; "U" indicates urban land use. If left blank when modeling using U.S. Census block receptors, HEM4 will determine whether the closest census block to the facility is located in an urbanized area, based on the 2010 Census. When using alternate receptors instead of U.S. Census block receptors, a blank in this column will cause HEM4 to default to a rural dispersion environment.
Urban Population **(urban_pop)**	Defaults to 50,000 people if left blank, but only used and needed if "U" specified in Rural/Urban field	If you indicate "U" for urban land use (in Rural/Urban field above), then you should provide the model with the urban population size, otherwise leave blank. Note: If you specify "U" in the Rural/Urban field but provide no urban population value in this field, HEM4 will use a default urban population of 50,000 people.
Max distance (max_dist)	50,000 meters	The outside max radius of the modeling domain in meters (must be ≥ the modeling distance and ≤ 50,000 meters).
Modeling distance (model_dist)	3,000 meters	The cutoff distance (in meters) for individual modeling of ambient impacts at census blocks; beyond this distance ambient impacts are interpolated rather than explicitly modeled. Note: For polygon source types, set the modeling distance > the largest distance across the polygon.
Radials (radials)	16	The number of radials in the polar receptor network emanating from the facility center (must be ≥ 4).

Field	Default Setting (if field left blank)	Description of Facility List Options Field
Circles (circles)	13	The number of concentric circles in the polar receptor network, centered on the facility center (must be ≥ 3).
Overlap distance (overlap_dist)	30 meters	The distance (in meters) between an emissions source and a census block or alternate receptor, within which you do not want the receptor to be considered as a point of maximum exposure/risk because it might be on facility property. Must be an integer value ≥ 1 meter and ≤ 500 meters.
First ring distance (ring1)	If left blank, calculated by HEM4 to be just outside the source locations, but not less than 100 m from facility center	The distance to the first ring (circle) of the polar network as measured from the facility center. You can override the default distance calculated by HEM4 to fit the size and shape of the facility properties to be modeled.
Facility Center	If left blank, calculated by HEM4 based on the source locations in the emissions locations input file	You can enter the facility center location in this field to override HEM4's (default) location. Enter as a comma separated list that should start with either "U" (if using UTM coordinates) or "L" (if using lat/lon coordinates). The list should contain two values if L for latitude followed by longitude (L, 35.91,-78.89) or three values if U for northing, easting and UTM zone number with hemisphere (U, 3975044, 690891, 17N). Hemisphere is S or N and defaults to N if omitted.
Ring Distances	HEM4 will automatically place 13 polar rings (circles) by default	You can override HEM4's placement of polar rings (circles) by specifying a list of distances in this field. Enter a comma separated list that contains at least 3 values representing the distance in meters for each polar ring from the facility center. The distances entered must be > 0 and <= 50,000 meters, and the values must be increasing (e.g., 100,500,1000,5000,10000,50000).
Acute (acute)	N	Entering “Y” directs HEM4 to calculate short-term (acute) concentrations for that facility. If left blank or “N” is entered, acute impacts are not estimated in the model run.
Hours (hours)	1-hour	The short-term (acute) averaging period that AERMOD will use for ambient concentrations, for that facility. The averaging period options are: 1, 2, 3, 4, 6, 8, 12 and 24-hours. The default is 1-hour.
Acute Multiplier (multiplier)	10	The acute multiplier applied to the average annual emission rate and used to approximate the short-term emission rate (e.g., 10 times the rate entered in the HAP Emissions file). Note: HEM4 also assumes that this short-term rate can occur at the same time as the worst-case meteorological conditions. Two-decimal precision is accommodated; minimum value is 1.00
High Value (high_value)	Maximum acute value is used as the high value when this field is left blank	This field indicates which acute concentration to report as the high acute value in the outputs, for each facility. If you wish to use a value other than the maximum (e.g., the 98th or 99th percentile), then enter the value in this field. The number you enter must be an integer and is calculated based on the

Field	Default Setting (if field left blank)	Description of Facility List Options Field
		number of hourly values in the modeled run. For example, if you want the 98th percentile acute value used from a data set of 8,760 hourly values (in one year), then enter 175 in this field, which is the truncated product of 0.02 x 8760. Similarly, if you want to use the 99th percentile acute value, then enter 87 in the text box, which is the truncated product of 0.01 x 8760. The default acute high value (if this field is left blank) is the maximum modeled acute concentration.
Deposition (dep)	N	Deposition is not modeled by default; entering "Y" directs the model to calculate deposition in the model run (particle, vapor, or both as designated below) and provide the deposition flux in the output files. You may model deposition with or without plume depletion (below). Note that you cannot model deposition/depletion for any facility that contains a buoyant line.
Depletion (depl)	N	Depletion is not modeled by default; entering "Y" directs the model to deplete the plume by the calculated deposition flux. Note: You may enter "Y" here even if you chose "N" for deposition; in that case the model will internally calculate deposition flux to deplete the plume but will not provide the deposition flux values in the output files. (This option saves space if you do not need the deposition flux.) Note that you cannot model deposition/depletion for any facility that contains a buoyant line.
Particle Deposition (pdep)	NO	The value "WD" directs the model to incorporate both wet and dry deposition for particles. Use "WO" for wet only particle deposition; use "DO" for dry only particle deposition; use "NO" (or leave blank) if not modeling deposition of particles. If you enter WD, WO or DO in this field for a given facility (or facilities), then HEM4 will prompt you to provide a particle size input file for that facility (or facilities), if you are using Method 1 for deposition. Note that you cannot model deposition/depletion for any facility that contains a buoyant line.
Particle Depletion (pdepl)	NO	The value "WD" directs the model to incorporate both wet and dry depletion of particles from the plume. Use "WO" for wet only particle depletion; use "DO" for dry only particle depletion; use "NO" (or leave blank) if not modeling depletion of particles from the plume. If you enter WD, WO or DO in this field for a given facility (or facilities), then HEM4 will prompt you to provide a particle size input file for that facility (or facilities), if you are using Method 1 for deposition. Note that you cannot model deposition/depletion for any facility that contains a buoyant line.
Vapor (gaseous) Deposition (vdep)	NO	The value "'WD" directs the model to incorporate both wet and dry vapor deposition of pollutants; use "WO" for wet only vapor deposition; use "DO" for dry only vapor deposition; use "NO" (or leave blank) if not modeling deposition of vapor pollutants. If you entered WD or DO in this field, HEM4 will prompt you to provide a land use input file and a month-to-

Field	Default Setting (if field left blank)	Description of Facility List Options Field
		seasons input file, which are needed for dry deposition/ depletion modeling. Note that you cannot model deposition/depletion for any facility that contains a buoyant line.
Vapor (gaseous) Depletion (vdepl)	NO	The value “WD” directs the model to incorporate both wet and dry depletion of vapor pollutants from the plume. Use “WO” for wet only vapor depletion; use “DO” for dry only vapor depletion; use “NO” (or leave blank) if not considering depletion of vapor pollutants from the plume. If you entered WD or DO in this field, HEM4 will prompt you to provide a land use input file and a month-to-seasons input file, which are needed for dry deposition/depletion modeling. Note that you cannot model deposition/depletion for any facility that contains a buoyant line.
Elevations (elev)	Y	Elevations of receptors are accounted for by default; entering an “N” excludes elevations from the model run.
User receptors (user_recpt)	N	Enter “Y” to include user receptors in the modeling run, for each facility. User receptors are not included by default. Note: if you are modeling using user receptors, HEM4 will prompt you for a separate user receptor input file.
Building Downwash (bldg_dw)	N	Enter “Y” in this field for each facility containing point sources for which you wish to model downwash over a nearby building. Building downwash is not included by default. If you are modeling building downwash, HEM4 will prompt you for a separate input file that must contain building dimension information, for (applicable point sources in) each facility marked with a "Y" in this column. Note that building downwash may only be modeled with vertical point (P), capped point (C), and horizontal point (H) source types.
FASTALL (fastall)	N	Entering “Y” directs HEM4 to use AERMOD’s control option FASTALL for modeling that facility, which conserves model run time by simplifying AERMOD’s dispersion algorithms. FASTALL is not used by default. Note that you cannot use FASTALL for any facility that contains a buoyant line.
Emissions Variation (emiss_var)	N	Entering “Y” indicates that you want to vary the emissions of one or more sources at this facility. This field allows the application of variations to the emission inputs from specific sources by different user-supplied time scales (e.g., by season, month, hour of day, day of week), or by different wind speeds (6 ranges). If you enter a “Y” for a given facility, then HEM4 will prompt you for a separate emissions variation input file for that facility, and that file must contain variation factors for at least one source at each facility marked with a "Y".
Annual (annual)	Y	Entering an "N" in the annual field indicates that you want the modeling run to be based on meteorological data from a period other than an annual period. If you enter an "N" in this annual field, then you must enter values in the "period_start" and "period_end" fields (below). Leaving this field blank or

Field	Default Setting (if field left blank)	Description of Facility List Options Field
		entering a "Y" will cause HEM4/AERMOD to calculate annual concentration averages using the entire met data file, which is the default.
Period Start (period_start)	[Entry required if an "N" is entered in Annual field above]	The period_start field indicates the start of the meteorological period during which AERMOD will run. You should enter a comma separated list of 3 or optionally 4 values here indicating the year, month, day and (optionally) hour of when the modeling period should begin. For example, if you enter 2016,02,11,12 then the model will use 2016 met data starting on February 11th at the 12th hour (noon) and end on the date and time indicated in the period_end field. Note that if you do not enter an hour here, then the model will use hour 1 as the default.
Period End (period_end)	[Entry required if an "N" is entered in Annual field above]	The period_end field indicates the end of the meteorological period during which AERMOD will run. You should enter a comma separated list of 3 or optionally 4 values here indicating the year, month, day and (optionally) hour of when the modeling period should end. For example, if you enter 2016,06,30,17 then the model will use the met data starting on the date and time indicated in the previous period_start field and ending in 2016 on June 30th at the 17th hour (5 pm). Note that if you do not enter an hour here, then the model will use hour 24 as the default.

Note: Take care when filling out the Facility List Options File, as this file drives and controls the modeling run. To avoid error, this file must be consistent with your other input files. For example, if you indicate 100% particles in the Percent Particulate column of your HAP Emissions input file and you wish to model deposition and/or depletion, then you cannot choose to model vapor deposition and/or depletion (by entering a "Y" in either the vdep or vdepl columns of your Facility List Options file). In addition, the modeling options you indicate in the Facility List Options file may require additional input files for modeling. For example, if you indicate in the Facility List Options file that you would like building downwash modeled for certain facilities (by entering a "Y" in this field), then one or more point sources at those facilities must be included in the separate building dimensions input file that HEM4 will prompt you for. You will also need to provide consistent input files if you marked a "Y" for any facilities in the user receptor or emissions variations fields. The various modeling options driven by the Facility List Options file are discussed more in the next sections.

3.2.2 Meteorological Station and Period Options

HEM4's library of meteorological (met) station data is described in Section 2.4.1. By default, HEM4 chooses the met station closest to the facility to be modeled (i.e., if this field is left blank). If you do not want HEM4 to choose the closest met station's data to use for your modeling run, in the meteorological station (met_station) column/field of the Facility List Options file, enter the name of the met surface station you want AERMOD to use when modeling each facility (e.g., NC13722.SFC). The names of all stations in the met library can be found in the

metlib_aermod.xlsx file in “HEM4\resources” folder, and the stations’ met data can be found in the “HEM4\aermod\MetData folder”. You can also add your own met station to the metlib_aermod.xlsx file in the HEM4’s resources subfolder and provide the new met station data as both SFC and PFL files in your “HEM4\aermod\MetData” folder, as explained in more detail in Section 2.4.

The other fields related to met data are at the end of the Facility List Options file, on the far-right side of the spreadsheet, and include “annual”, “period_start”, and “period_end”. These columns, as noted above in Table 1, allow you to choose to model with a period other than the default annual period of met data. And the period start and period end fields allow you to specify exactly what met period HEM4 should instruct AERMOD to use for your modeling run, down to the year, month, day and even hour. **The period start and end dates you specify must be included in the meteorological files being used. If the set of meteorological files you specify, or that HEM4 chooses, does not cover the dates you specify, AERMOD will generate an error and that facility will not be modeled.** These period options are useful if modeling, for example, facilities that come on and offline during different parts of a year. The options may also be helpful in performing analyses to determine what time periods in the year produce the highest local concentrations and impacts.

It should be noted that the selection of the met station and met period for your modeling run can have a significant effect on the air concentrations and therefore risk and HI estimates that HEM4 produces. See Table 1 for HEM4’s default settings used in the Facility List Options for the met station and period options.

3.2.3 Rural and Urban Dispersion Options

The Rural or Urban column/field is used by HEM4 to set the type of dispersion environment for AERMOD, for each facility. If you are modeling using U.S. Census blocks as receptors, then by default HEM4 will find the nearest U.S. Census block to the facility center and determine whether that census block is located in an urbanized area, as designated by the 2010 Census (FR 77:59). If the block is in an urbanized area, then the population of the designated urbanized area will be used to specify the population input for AERMOD's urban mode for that facility. If the block is not in an urbanized area, then AERMOD will use a rural dispersion environment for that facility.

If you are modeling using alternate receptors instead of census blocks (e.g., outside the U.S.), ideally you should determine which dispersion environment to use for each facility. If instead you leave the rural/urban field blank when using alternate receptors, then AERMOD will default to a rural dispersion environment, resulting typically in more conservative (higher) concentration predictions.

The EPA provides guidance on whether to select urban or rural dispersion in its Guideline on Air Quality Models (Appendix W). In general, use the urban option if (1) the land use is classified as urban for more than 50% of the land within a 3-kilometer radius of the emission source, or (2) the population density within a 3-kilometer radius is greater than 750 people per square kilometer. Of these two criteria, the land use criterion is more definitive. If you choose the urban dispersion environment for the model run, you should specify the population of the urban area surrounding the facility, if known, by entering it in the urban population column/field (urban_pop) of the Facility List Options file. This is true whether you are modeling with U.S. Census block receptors or with alternate receptors. If you choose to model using an urban dispersion

environment and do not provide a population, HEM4 will set your urban population column/field (urban_pop) to 50,000 people. As noted above, AERMOD uses the urban population value in its dispersion algorithms for urban areas.

3.2.4 Modeling Domain Options

You will provide HEM4 the parameters that define each facility's modeling domain in columns E through L of the Facility List Options file. The modeling domain is circular and centered on each facility, with a user-specified radius. HEM4 identifies all of the receptor locations in the modeling domain – census blocks for U.S. runs based on the census database, or alternate receptors for non-census modeling runs. The model then divides the blocks into two groups – inner and outer receptors – based on their distance from the facility. For the inner group of receptors (closest to the facility), each census block or alternate receptor location is modeled as a separate receptor in AERMOD.

Maximum Distance: In column E of the Facility List Options file, enter the maximum radius (in meters) to be modeled; this is the radius around each facility of the entire modeling domain. The maximum distance must be greater than or equal to the "modeling distance" (discussed next), but not greater than 50,000 meters because, as a Gaussian dispersion model, AERMOD is not recommended beyond 50 kilometers. If you leave this field blank, HEM4 will use a default maximum distance of 50,000 meters. The maximum distance is the radius of the circular study area for which HEM4 will model ambient impacts (at census block centroid receptors or alternate receptors, polar grid receptors, and user receptors, as explained below in this section). The center of this modeling domain is by default the geographical center of each facility (based on source locations for each facility) you are modeling, but you can change this center using the "facility center" column K, as discussed below.

Modeling Distance: In column F of the Facility List Options file, enter the distance (in meters) within which census blocks will be modeled individually. This is the cutoff distance around each facility for explicitly including census block or alternate receptors in the AERMOD run. Within this radial distance measured from the facility center, AERMOD will model each census block centroid or alternate receptor explicitly as a receptor. Outside of this radius, AERMOD will not model the census blocks or alternate receptors directly; ambient impacts at receptors beyond the modeling distance will be interpolated using dispersion modeling results for the polar receptor network, described below. If you leave this field blank, HEM4 will by default use a modeling distance of 3,000 meters. It should be noted that the Modeling Distance may not be greater than the Maximum Distance (above),

It should be noted that larger values for this cutoff modeling distance will require more time to model, because the number of receptors requiring explicit AERMOD modeling will be higher. However, you should set this cutoff value at a large enough distance so that the maximum risk receptor (discussed in Section 6.1.1) will be modeled individually. This distance will vary depending on the configuration of the sources but is generally between 1,500 and 2,000 meters. A typical modeling cutoff distance for larger facilities is 3,000 meters (or 3 km). When modeling large sources configured as polygons (e.g., U.S. Census tracts), set this modeling cutoff distance to be greater than the largest distance across the polygon, to ensure discrete modeling of all census blocks within the polygon.

Radials: In column G of the Facility List Options file, enter the number of radials in the area to be modeled. The polar grid receptors of the polar network are located at the intersection of a

radial and a polar ring (or "circle", described next). A typical run would include 13 concentric rings and 12 or 16 radial directions. HEM4 will distribute the radial directions evenly around the facility. For instance, if you select 16 directions, receptors will be modeled at compass bearings of 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5, 180, 202.5, 225, 247.5, 270, 292.5, 315, and 337.5 degrees. If you leave this field blank, by default HEM4 will use 16 radial directions. If you choose to enter a different number of radials, you must specify at least 4 radials in this field.

Circles: In column H of the Facility List Options file, enter the number of concentric circles (rings) in the polar receptor network around each facility, centered on the facility center. You must enter at least 3 rings. If you leave this field blank, by default HEM4 will use 13 rings. Also, by default, HEM4 will calculate the inner radius of the polar network, unless you choose to specify a distance to the first ring (or "Ring1", described below). This model-calculated first ring distance is based on the location of the emission sources and the facility center. HEM4 selects the distance that places the first modeling ring just beyond all emission sources, but not less than 100 meters from the facility center. HEM4 will place the concentric rings at a logarithmic progression of distances starting at the inner ring distance and ending at the outer radius of the modeling domain. However, you have the option to specify different ring distances (than HEM4's calculated distances) in the "ring_dists" column, described below. Although the polar grid receptors are used primarily for interpolating risks at census blocks outside of the modeling cutoff distance, it is important to include some rings close to the facility.

Overlap Distance: In column I of the Facility List Options file, enter the distance (in meters) where source and receptor are considered to be overlapping. This distance must be greater than or equal to 1 meter and less than or equal to 500 meters. If you leave this field blank, HEM4 by default will use an overlap distance of 30 meters, which is approximately equal to the width of a narrow buffer and a roadway. Within this distance, sources and receptors will be considered to be overlapping, as measured from each source at the facility (e.g., stack, edges of area and volume sources). This feature is provided to address situations, for example, wherein U.S. Census blocks are very close to a facility and have complex shapes. In such cases, the centroid of a census block may be much closer to the facility than the nearest actual dwelling. (In fact, if a census block surrounds a portion of the facility, the centroid of the block may be on facility property.) If a receptor falls within this distance, HEM4 will not calculate risks based on the location of that receptor but will instead assume that the risks associated with the receptor are the same as the highest predicted value for any receptor that does not overlap facility property (including polar receptors). An exception to this occurs when modeling polygon sources. Unlike other sources, when modeling polygons, overlapping of source and receptor is permitted. This allows the impacts, for example, of a U.S. Census tract modeled as a polygon source (e.g. mobile source emissions modeled uniformly across a census tract) to be calculated within the census tract being modeled.

Ring1 or First Ring: In column J of the Facility List Options file, enter the distance (in meters) to the first ring (circle) of the polar network for each facility, as measured from the facility center. As noted above (under "Circles"), if you leave this field blank then HEM4 will calculate the default value to the first ring to be just outside the source locations, but not less than 100 meters from the facility center. You can override the default distance calculated by the model to fit the size and shape of the facility properties to be modeled. For example, you should set the first receptor ring to less than 100 meters (or conversely greater than what HEM4 calculates), if appropriate to the size and shape of the facility property. Place the nearest polar receptor ring as close as possible to the facility boundary— this inner radius of the polar network should be the minimum distance from the facility center that is generally outside of facility property. For complex or irregularly shaped facilities however, you may find it useful to specify an inner ring

that encroaches on facility property in some directions. Furthermore, you may want to specify a set of boundary receptors by employing the user-defined receptors file (as described in Section 3.2.8). Note that **the first ring distance must be less than the modeling cutoff distance** (for explicit modeling of receptors).

Facility Center: In column K of the Facility List Options file, you may specify the facility center location to override HEM4's determination of where the facility center is located. If you leave this field blank, HEM4 will by default choose the facility center by determining the geographic center of the locations of all emission sources for that facility in your Emissions Location file (discussed in Section 3.4). If you wish to specify a different facility center location, then enter its location in this field as a comma separated list that should start with either "U" (if using UTM coordinates) or "L" (if using latitude/longitude coordinates). The list should contain two values if L for latitude followed by longitude (L, 35.91,-78.89) or three values if U for northing, easting and UTM zone number with hemisphere (U, 3975044, 690891, 17N). Hemisphere is S or N and defaults to N if omitted.

Ring distances: In column L of the Facility List Options file, you may override HEM4's placement of polar rings (circles) by specifying a list of distances in this field. To do so, enter a comma separated list that contains at least 3 values representing the distance in meters for each polar ring from the facility center. The distances entered must be greater than 0 and less than or equal to 50,000 meters, and the values must be increasing (e.g.,100,500,1000,5000,10000, 50000). If you leave this field blank, HEM4 will by default place 13 polar rings (circles), as noted above under “Circles”.

A note about the Polar Network: Columns G and H of the Facility List Options file, and optionally columns J, K and L, define HEM4’s polar network. In addition to ambient impacts at receptors (census block centroids or alternate receptors) within the modeling cutoff distance, HEM4 (using AERMOD) also explicitly models ambient impacts at polar grid receptors within the polar network. This polar network extends beyond the modeling cutoff distance to the maximum (outside) radius. The polar receptor network in HEM4 serves three functions:

(1) it is used to estimate default impacts if one or more U.S. Census block receptor or alternate receptor locations are inside the overlap cutoff distance;
(2) it is used to evaluate potential acute effects that may occur due to short-term exposures in unpopulated locations outside the facility boundary; and
(3) it is used to interpolate long- and short-term impacts at receptors (U.S. Census block locations or alternate receptors) that are outside the cutoff distance for modeling of individual receptors

Note that, if modeling with terrain effects, the elevation of each polar grid receptor is based on the elevation of nearby individually (explicitly) modeled or “discrete” receptors (including census blocks, alternate receptors and user receptors). **The maximum elevation of nearby discrete receptors is assigned to each polar receptor, to ensure terrain effects on receptor concentrations are conservatively estimated.** The importance of the polar network is discussed further in Section 5.

3.2.5 Acute Options

As introduced in Section 1.2, you can use HEM4 to estimate *chronic* health risks and, optionally, *acute* (short-term) health risks as well. Chronic health risks are estimated based on long-term

average concentrations, as predicted by AERMOD. The time frame of this average is determined by the number of years covered by the meteorological data file selected for the model run: the default is generally one year when running AERMOD, although periods other than one year can be chosen as discussed in Section 3.2.2 above regarding met station and period options. Acute health risks are based on short-term average exposures such as 1, 2, 3, 4, 6, 8, 12 and 24 hours.

You can choose to model acute health risks using columns M, N, O and P of the Facility List Options file. HEM4 uses what you input in these fields for each facility to direct AERMOD to model acute concentrations, and then HEM4 uses these acute concentration predictions by AERMOD to estimate acute health risks. Enter a Y (for "yes") in column M "acute" to indicate you want HEM4/AERMOD to model short-term (acute) concentrations for that facility. (If you leave this field blank then by default HEM4 will not model acute impacts, regardless of what you put in columns N, O and P.) Next, in column N "hours", enter the short-term (acute) averaging period that AERMOD will use for ambient concentrations, for each facility. The averaging period options are: 1, 2, 3, 4, 6, 8, 12 and 24 hours. (If you entered Y in column M and leave column N blank, then HEM4 will by default use an averaging period of 1 hour.)

In column O "multiplier", enter the acute multiplier for each facility. This multiplier is applied to the average annual emission rate (in tons/year from your HAP Emissions input file, which the model converts to grams/second) and used to approximate the short-term emission rate. If you entered a Y in column M, but leave this field blank, then by default HEM4 will use a multiplier of 10 for that facility (e.g., the default of 10 times the average annual emission rate entered in the HAP Emissions file might be used to approximate short-term emission spikes). Regarding short-term spikes, it is important to note that AERMOD applies this short-term rate over the course of the entire met period chosen (in Section 3.2.2) and **the peak acute value will occur at the same time as the worst-case meteorological conditions**. Therefore, the acute results produced with an appropriate multiplier can be viewed as conservative estimates. Two-decimal precision is accommodated in the multiplier column O, but the multiplier entered must be greater than or equal to 1.00.

The peak acute value reported by HEM4 is also impacted by what you enter in column P "high value". This field indicates which acute concentration to report as the high acute value in the outputs, for each facility. If you wish to use a value other than the maximum (e.g., the 98th or 99th percentile), then enter the associated value in this field. The number you enter must be an integer and is dependent on the number of hourly values in the modeled run. For example, if you want the 98th percentile acute value used from a dataset of 8,760 hourly values (in one year), then enter 175 in this text box, which is the truncated product of 0.02 x 8,760. Similarly, if you want to use the 99th percentile acute value, then enter 87 in the text box, which is the truncated product of 0.01 x 8,760. If instead you leave column P blank, then HEM4 will by default use the maximum modeled acute concentration as the "high value".

3.2.6 Deposition and Depletion Options

Deposition and Depletion: Deposition and depletion are not modeled by default by HEM4. However, depending on the deposition and depletion options you choose in the Facility List Options file in columns Q through V, HEM4 will (1) calculate and output a deposition flux and (2) deplete the plume (or not) based on the calculated deposition. Generally speaking, deposition modeled with plume depletion will reduce the ambient impacts from the emission sources by removing pollutants from the plume. Air concentrations will be depleted as pollutants are

deposited to the ground. Alternatively, you may choose to calculate the deposition flux, but not deplete the plume (to allow for non-depleted air concentrations that a standard run would produce). Deposition without plume depletion will not affect the air concentrations but will provide a deposition flux in the outputs. Whether you choose to deplete the plume or not, the modeled deposition flux may be then used as an input to a separate multipathway model such as the Total Risk Integrated Methodology (TRIM) (EPA 2018e).

Enter a Y (for "yes") in column Q of your Facility List Options file if you would like AERMOD to model deposition and HEM4 to output a deposition flux column (in $g/m^2/y$)[2] for all polar receptors and for the inner discretely modeled receptors. Enter a Y in column R if you would like AERMOD to model depletion (i.e., deplete the plume based on a calculated deposition flux). If you enter a Y in both columns Q and R, then HEM4 will output a deposition flux column AND deplete the plume. If you enter a Y in only column R (and leave column Q blank or enter an "N"), then no deposition flux will be provided, but the plume will be depleted (based on an internally calculated deposition flux). If you do not need the deposition flux output by the model, this option saves space.

HEM4 uses AERMOD to calculate deposition and depletion effects for particulate matter, vapor (gaseous) pollutants, or both. The make-up of your emissions – that is, the percentage particulate and gas – is dictated to HEM4 by your HAP Emissions input file. Specifically, column E in the HAP Emission input file ("Fraction emitted as particulate matter (%)") indicates to HEM4 whether your emissions are 100% particle (if column E is populated with 100 for all pollutants), 100% gas (if column E is left blank or populated with 0 for all pollutants), or a mixture of particles and gas. However, for each facility, you can choose to model deposition and/or depletion for merely the particulate portion of your emissions (if you have a particulate portion), the vapor portion of your emissions (if you have a gas portion), or both (if you have both particle and gas, as indicated in column E of your HAP Emissions input file).

Particle and Vapor Deposition and Depletion Types (Wet and Dry; Wet Only; Dry Only; None): If you entered "Y" in column Q and/or R regarding modeling deposition and/or depletion, you must also indicate what type of deposition and/or depletion you wish HEM4 to direct AERMOD to model: wet and dry (WD), dry only (DO), wet only (WO), or none (No or leave blank). Use columns S, T, U and V of your Facility List Options file to indicate what kinds of deposition and/or depletion you want modeled for particulates and vapor (gas). In column S "pdep" you should indicate the type of deposition of particles you want modeled, if any. In column T "pdepl", you should indicate the type of depletion of particles you want modeled, if any. Do likewise in columns U "vdep" and V "vdepl" for the types of deposition and depletion of your vapor pollutants, respectively. See the AERMOD User's Guide (EPA 2019a) and AERMOD Implementation Guide (EPA 2019b) for a more detailed discussion of these processes.

You can mix and match the type of deposition and depletion you tell HEM4 to model. For example, you can direct HEM4 to model wet and dry (WD) deposition, and then deplete the plume based on those wet and dry (WD) deposition processes. Alternatively, you can choose wet and dry deposition (WD), but then only deplete the plume based on the wet deposition process (WO). In addition, the "none" option (No or blank) allows you to model deposition for particles only, for example, even if your HAP Emissions file shows a mixture of particles and gas. To do this, you can indicate in column S "pdep" what type of deposition to model for your particle emissions (WD, WO or DO) and then leave column U "vdep" blank or enter "No". You

[2] If you specify a PERIOD average instead of an ANNUAL average, deposition results will be given in g/m^2.

may use these same options for depletion-only modeling. Table 2 below provides a partial list of some deposition/ depletion combinations and their modeling results.

Table 2. Sample Deposition and Depletion Options and Model Results

Entries in Columns Q - V of the Facility List Options File*						Model Results*
Q: dep	**R: depl**	**S: pdep**	**T: pdepl**	**U: vdep**	**V: vdepl**	
Y	Y	WD	WD	WD	WD	Deposition flux will be provided and the plume will be depleted, using wet and dry processes for both particles and vapor, for both deposition and depletion
Y		WO		DO		Deposition flux will be provided with no depletion of the plume, using wet-only processes for particles and dry-only processes for vapor
	Y		WD		WD	No deposition flux will be provided but the plume will be depleted using both wet and dry processes for particle and vapor
Y	Y	DO	WO			Deposition flux will be provided and the plume will be depleted, using dry only processes for particle-only deposition and wet-only processes for particle-only depletion
	Y				WO	No deposition flux will be provided but the plume will be depleted using wet-only processes for vapor only
Y		WD				Deposition flux will be provided with no depletion of the plume, using wet and dry processes for particle-only deposition
Y	Y	WD	WO	WD	DO	Deposition flux will be provided and the plume will be depleted, using wet and dry processes for particle and vapor deposition, but wet-only processes for particle depletion and dry-only processes for vapor depletion
[*The above is merely a partial list of some of the possible deposition/depletion combinations, for illustration purposes. Many more variations may be chosen that are not illustrated here*.]						

*Note: These Model Results will happen if your column entries are consistent with your emissions (e.g., you cannot model deposition and/or depletion of particulates if your emissions have no particulates in column E of your HAP Emissions file).

Concentration Outputs Broken Out into Particle and Vapor: Also, if your pollutants are a mixture of both particles and vapor and you would like the concentration outputs broken down by particle and vapor (instead of combined, as is the default in a standard run), you can also use the deposition/depletion fields in the Facility List Options file to do this. In other words, you can direct HEM4 merely to produce more detailed concentration outputs, showing the breakdown of particle and vapor concentration at each receptor location, without modeling either deposition or depletion. To do so, enter "Y" in column Q "dep" but leave all other deposition/depletion fields blank (indicating No or None). Neither deposition nor depletion will be modeled in this case.

However, the outputs will show distinct rows for particles ("P") and vapor ("V") at each location, rather than the standard combined ("C") row. Again, this is helpful only if your HAP Emissions file shows a mixture of particles and gas.

Additional Deposition/Depletion Input Files: Depending on the type of deposition and/or depletion you indicate in columns Q through V for each facility, and depending also on the method of particle deposition you indicate for each source at these facilities in your Emissions Location file (explained further in Section 3.4.2), HEM4 will prompt you to provide additional files. These files are introduced below and described in detail in Sections 3.5.3 and 3.5.4.

If you want to model deposition and/or depletion of particles in your emissions using Method 1 (described further in Section 3.4.2), HEM4 requires a particle data file. This additional input file will need to contain particle size (diameter) information, mass fraction percentages for each size, and particle density for each size, for emissions from each source (for which you wish to model particle deposition and/or depletion using Method 1). The particle data file is described further in Section 3.5.3.

If you want to model dry deposition and/or depletion of gaseous/vapor pollutants, HEM4 requires a land use input file and a month-to-seasons input file. These additional input files are needed to describe the land use and vegetation surrounding each facility at which you wish to model dry only (DO) or wet and dry (WD) deposition and/or depletion of gaseous pollutants, as discussed in Section 3.5.4. If you wish to model wet only (WO) deposition and/or depletion of gaseous pollutants, these additional input files are not needed by HEM4. (These files are also not needed for 100% particulate emissions.)

Finally, you should check to ensure that the gaseous pollutants in your HAP Emissions file are included in the Gas Parameter (Gas_Param) reference file, described further in Section 3.5.4. If these pollutants are not included – or if you wish to include different parameter values than the Gas Parameter file currently uses – you should edit the Gas Parameter file, as discussed in Section 3.5.4. Otherwise, generic default gas parameter values will be used.

It should be noted that HEM4 requires additional modeling time compared to a standard run (with no deposition and/or depletion modeling). Furthermore, HEM4 requires *significantly* more time to run if you opt to model deposition and/or depletion and you are also modeling acute impacts. The exact run time will depend on the particular source configuration and modeling domain, but the combination of acute calculations and deposition/depletion will generally increase run times from a few minutes to over an hour, or more, per facility.

Deposition and plume depletion have more of an effect on ambient concentrations farther from the facility than these processes do closer to the facility, where the maximum impact generally occurs. Therefore, if you select the deposition and/or depletion options for a model run, you may save time by performing two separate runs. For example, you can use the first HEM4 run to calculate chronic effects and include deposition and plume depletion. You can then use the second run to calculate acute effects without deposition and depletion.

It should also be noted that HEM4 does not model deposition and/or depletion at census block and alternate receptors beyond the modeling distance, except at the polar receptors. This means that deposition and/or depletion is modeled at only the "inner receptors" (discussed in Section 6.1.10) and the polar receptors. If you need deposition and/or depletion modeled for the entire modeling domain at all census block or alternate receptors, you should set the modeling distance equal to the maximum distance. HEM4 will require additional modeling time in this

scenario, compared to using a smaller modeling distance. As noted above, you may save modeling time by performing two separate runs, especially if you are also modeling acute impacts.

3.2.7 Elevation Option

HEM4 includes terrain elevations by default in your modeling run if you leave column W “elev” blank or enter a “Y” in this field in your Facility List Options file. To exclude terrain elevations in your modeling run (i.e., to model as flat terrain), enter an “N” in this field for a given facility.

Elevated terrain around the facility can cause local impacts to increase, though impacts will differ for each set of sources and elevations. It is especially important to include terrain elevations if the height of receptors around the facility may exceed the height of any stacks at the facility. Consult the EPA's *Guideline on Air Quality Models* (also published as Appendix W of 40 CFR Part 51) (EPA 2005) for more explicit directions on when the use of terrain elevations is recommended. If you choose to include elevations in the model run, you can specify elevations for each source in the Emissions Location file. If you do not provide elevations in the Emissions Location file, HEM4 will calculate source elevations from neighboring census block elevations. Note: You should provide elevations for every source or for no sources at each facility, as noted in Section 3.4 regarding the Emissions Location file.

3.2.8 User Receptors Option

If you would like to include additional “user receptors” in your model run for one or more facilities – in addition to the census block or alternate receptors, enter a “Y” in column X “user_rcpt” of your Facility List Options file. HEM4 does not include user receptors by default, so if this column is blank then user receptors will not be included for that facility. If you are modeling impacts at user receptor locations, HEM4 will prompt you for a separate input file containing the user receptor information, for each facility marked with a "Y". The user receptor input file is described in Section 3.5.6.

3.2.9 Building Downwash Option

If you would like to model building downwash over a building, which is under or near a point source, then enter “Y” in column Y “bldg_dw” of your Facility List Options file. HEM4 does not model building downwash by default and you should simply leave this field blank if you do not wish to model it as part of the plume dispersion. If you are modeling building downwash, HEM4 will prompt you for a separate input file that must contain building dimension information, for applicable point sources in each facility marked with a "Y" in this column. Note that building downwash may only be modeled with vertical point (P), capped point (C), and horizontal point (H) source types. The building dimension input file is described in more detail in Section 3.5.5.

Under AERMOD’s regulatory option, the effects of building downwash should be taken into account when a building is close enough to impact dispersion from an emission source. Building downwash will affect dispersion predictions when:

- the stack height is less than either 2.5 times the building height or the sum of the building height and 1.5 times the building width; and
- the distance between the stack and the nearest part of the building is less than or equal to five times the lesser of the height or the projected width of the building (EPA 1995, pg. 1–22 and 1–23).

AERMOD incorporates the Plume Rise Model Enhancements (PRIME) algorithms (Schulman 2000) for estimating enhanced plume growth and restricted plume rise for plumes affected by building wakes (EPA 2019d). A building may impact emissions from multiple sources. To model the impact of building downwash, HEM4 requires information on the configuration of the building when viewed from different wind directions, and this information is contained in the building dimensions input file, described further in Section 3.5.5.

3.2.10 FASTALL Option

To conserve model run time by simplifying the dispersion algorithms used to model a given facility's emissions, enter a "Y" in column Z "fastall" of your Facility List Options file. HEM4 does not employ FASTALL by default, so if you leave this field blank AERMOD will use the more rigorous (non-simplified) dispersion algorithms.

The FASTALL option conserves model runtime by simplifying the AERMOD algorithms used to represent meander of the pollutant plume. This simplification is achieved by eliminating the upwind component of dispersion for point and volume sources, and by reducing the requirement for uniformity of emissions over the extent of area sources (EPA 2019a). For faster runs, you may want to select the FASTALL option which includes these plume and source simplifications. (More information on AERMOD's FASTALL option is available for download at https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod.)

Note that if a facility listed in your Facility List Options file includes buoyant line sources in your accompanying Emissions Location file, you cannot use the FASTALL option for that facility. You may, however, use FASTALL for the other facilities in your Facility List Options file.

3.2.11 Emissions Variation Option

Enter a "Y" in column AA "emiss_var" of your Facility List Options to apply variations to the emissions from one or more sources at a given facility. You may vary emissions by different user-supplied time scales (e.g., by season, month, day of week, hour of day), or by different wind speeds (6 ranges). Note: HEM4 will prompt you for an emissions variation file if you entered "Y" for one or more facilities, and that file must contain variation factors for at least one source at each facility marked with a "Y". The emission variation input files are described in more detail in Section 3.5.7.

Finally, it should be noted that these emission variation factors will compound the effects of the acute multiplier (specified in column O "multiplier") on the short-term/acute emission rates used by AERMOD. For example, whatever factors you supply in an emission variations input file (described in Section 3.5.7) will be multiplied by an acute multiplier of 10 (if the default multiplier is used) to derive the short-term emission rate. Therefore, if applying hour-of-day emission

variation factors, you may want to set the acute multiplier to 1, unless it is reasonable to assume that the short-term rate may still exceed the hour-of-day factors by an additional multiple.

3.3 HAP Emissions File

The HAP Emissions Excel™ file, like the Facility List Options file, is required for any HEM4 modeling run. This file includes emissions in tons per year (tpy) for each HAP emitted from modeled sources, for all facilities listed in the Facility List Options file. Tables 3 and 4 give the format guidelines for the HAP Emissions file and a sample HAP emissions input file, respectively. A template input file is provided in the HEM4 Inputs folder named *HEM4_HAP_Emiss.xlsx*. The pollutants emitted per source at each facility are required in every HAP Emissions file and are discussed in Section 3.3.1. The percent particulate emitted from each source is generally only required if you are modeling deposition or depletion (see Section 3.2.6) and is discussed in Section 3.3.2.

Table 3. Format Guidelines for the HAP Emissions Input File (Required)

Field	Type	Description
Facility ID	Character	An alphanumeric string identifying the facility being modeled
Source ID	Character	An alphanumeric character string **up to 8 characters long**. It must contain at least one alphabetic character and all Source IDs must match a Source ID used in the Emissions Location file. Note: AERMOD allows a maximum of 8 characters for the Source ID; and all Source IDs will be converted to upper case by AERMOD.
Pollutant	Character	The pollutant name must correspond to one of the chemical names listed in the dose response library. (see *Dose_Response_Library.xlsx* in the resources folder)
Emission Amount	Numeric	The emitted amount of the pollutant in tons per year (tpy).
Percent Particulate	Numeric	The percent of pollutant emitted as particulate. Required if deposition and/or depletion will be modeled, or if a breakdown by particulate and vapor is desired in the concentration outputs. If left blank, defaults to 0% particulate when deposition is modeled. If deposition is not modeled, this field is ignored by HEM4.

Table 4. Sample HAP Emissions Input File

Facility ID	Source ID	Pollutant	Emissions (tons/year)	Fraction Emitted as Particulate Matter (%)
Fac2-IL	CT0001	Antimony compounds	1.2E-01	100.0
Fac2-IL	CT0001	Chromium (VI) compounds	3.2E-04	100.0
Fac2-IL	CT0001	Mercury (elemental)	4.2E-02	50.0
Fac2-IL	CV0001	Dibenzofuran	1.1E-01	90.0
Fac2-IL	CV0001	Xylenes (mixed)	1.3E+00	0.0
Fac1-NC	SR0001	Benz(a)anthracene	7.3E-06	11.9
Fac1-NC	SR0001	Benzo(a)pyrene	2.5E-08	23.9
Fac1-NC	SR0001	Benzo(b)fluoranthene	2.8E-06	17.8
Fac1-NC	MS0001	Chrysene	3.2E-05	52.3
Fac1-NC	MS0001	Dibenz(a,h)anthracene	3.6E-08	99.3
Fac1-NC	MS0001	Indeno(1,2,3-cd)pyrene	1.1E-07	98.9
Fac1-NC	RW0001	Chromium (VI) compounds	3.8E-05	100.0
Fac1-NC	RW0001	Mercury (elemental)	3.6E-04	50.0
Fac1-NC	RV0001	Nickel compounds	4.8E-03	100.0
Fac1-NC	RV0001	Selenium compounds	2.1E-04	100.0

3.3.1 Pollutant Emissions per Source

You should include one record (row) for each combination of facility (Facility ID), emission source (Source ID) and chemical (Pollutant) in your HAP Emissions file. The Source ID is a key parameter in the HAP Emissions file, because HEM4 uses the Source ID to link the emitted HAP at that source to other input files, such as the Emissions Location input file (discussed in Section 3.4) and other optional input files (discussed in Section 3.5). The Source ID should provide each source a distinct name, and different sources should have unique Source IDs even if they will be modeled at the same location. **AERMOD requires that the Source ID be restricted to eight (8) characters (or fewer)** and it must consist of all alphanumeric characters. Do not use spaces at the beginning or in the middle of the Source ID. In addition, AERMOD converts all letters in the Source ID string to upper case. Therefore, **upper and lowercase characters cannot be discriminated between**; so "ABC" and "abc" would be treated as the same Source ID. While each source should have a unique Source ID, it is advantageous to group certain types of sources within part of the Source ID. For example, “ST” could be used in the Source ID to indicate a storage tank and each distinct storage tank could be given a number (e.g., ST01, ST02). Such grouping is important for certain summary programs, as discussed in Section 4.5.

Each chemical you name in the HAP Emissions file (under “Pollutant” in the sample shown in Table 4) must match one of the chemical names listed in the dose response table located in the HEM4 resources folder. The dose response values are part of HEM4’s Chemical Health Effects Library, described in Section 2.2. If necessary, you can add pollutants to the two Excel™ spreadsheets comprising HEM4’s Chemical Health Effects Library: the dose response table and

the target organ endpoints table. Section 3.5.10 explains how to make changes to the Chemical Health Effects Library. Finally, **emission amounts for each HAP emitted from each Source ID must be expressed in tons/year. Be sure your input files use the correct units.**

3.3.2 Percent Particulate for Deposition and Depletion

If you are modeling deposition or depletion, or if you want separate records for particle phase and vapor phase at each receptor location in the concentration outputs, then you must provide HEM4 with the breakdown between vapor and particulate matter in the emission inputs. Provide this breakdown in column E of the HAP Emissions file, expressed as the fraction emitted as particulate for each emission record (each combination of source and pollutant). For a given facility, if you are not modeling deposition or depletion, then HEM4 will ignore the field. If you are modeling deposition or depletion and have left this field blank, then HEM4 assigns the blank a default value of 0% particulate. Note that if you are modeling deposition or depletion, you will need additional input files depending on the type of deposition to be modeled, as described in Section 3.2.6 and Sections 3.5.3 and 3.5.4. (Note: You do not need any additional input files if you merely want a breakdown of particle and vapor in your outputs.)

3.4 Emissions Location File

The Emissions Location Excel™ file, like the HAP Emissions file and the Facility List Options file, is required for any HEM4 run. The file includes emission source locations and types (e.g., the latitude and longitude of a stack) for all Source IDs listed in the HAP Emissions file, for all facilities listed in the Facility List Options file. Tables 5 and 6 display the format guidelines for the fields in the Emissions Location file and a sample file, respectively. A template input file is provided in the HEM4 Inputs folder named *HEM4_Emiss_Loc.xlsx*. For each Source ID at every facility, the Emissions Location file includes the location, source type and required parameters, as discussed in Section 3.4.1. Additionally, the Emissions Location file includes the particle deposition method you will identify, for any sources for which you wish to model particle deposition or depletion, as discussed in Section 3.4.2.

Table 5. Fields in the Emissions Location Input File (Required)

Field	Type	Source type(s)*	Description
Facility ID	Character	all	An alphanumeric string identifying the facility being modeled
Source ID**	Character	all	Source ID is a unique alphanumeric character string **up to 8 characters long**, with no spaces. It must match exactly the Source ID in other input files (*e.g.*, the HAP Emissions file). Note: AERMOD allows a maximum of 8 characters for the Source ID; and all Source IDs will be converted to upper case by AERMOD.

Field	Type	Source type(s)*	Description
Coordinate system	Character	all	Type of coordinates: L = latitude, longitude; U = UTM. Base all coordinates on the WGS84 geographic system. Note: NAD83 and WGS84 are identical for most applications, but coordinates based on NAD27 need to be converted to WGS84 before being used in HEM4.
X-coordinate	Numeric	all	UTM east coordinate, in meters (if coordinate system = U) or decimal longitude (if system = L) of the center of point or volume sources, the southwest corner of area sources, the first vertex of polygon sources, or the starting point of line and buoyant line sources.*** For longitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
Y-coordinate	Numeric	all	UTM north coordinate, in meters (if coordinate system = U) or decimal latitude (if system = L) of the center of point or volume sources, the southwest corner of area sources, the first vertex of polygon sources, or the starting point of line and buoyant line sources. *** For latitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
UTM zone	Character	all	UTM zone where the source is located if the coordinate system = U; leave this field blank if the coordinate system = L. If using the UTM coordinate system, enter the UTM Zone from 1 to 60 followed by the hemisphere (S or N). For example, 17N. If you do not include a hemisphere, HEM4/AERMOD will default to N.
Source type	Character	all	Type of source*: P = vertical point, C = capped point, H = horizontal point, A = area, V = volume, I = polygon, N = line, B = buoyant line
Length - x	Numeric	A, N	Length in meters in x-dimension direction for area and line sources. For area source types, the x direction refers to the direction before the source is rotated (if it is rotated). For line source types, enter the width (m), which must be >= 1 meter.
Length - y	Numeric	A	Length in meters in y-dimension direction for area sources. This is the length in the y direction before the source is rotated (if it is rotated).
Angle	Numeric	A	Angle of rotation: blank except for area sources. For area source types, enter the angle of rotation (from North) between 0 and 90 degrees. (HEM4 defaults to 0 if left blank).
Lateral	Numeric	V	Initial lateral/horizontal dimension (in meters) for volume sources.
Vertical	Numeric	V, A, I, N	Initial vertical dimension (in meters) for volume sources. Optional for area, polygon & line sources.

Field	Type	Source type(s)*	Description
Release height	Numeric	V, A, I, N, B	Height of release (in meters) for area, volume, polygon, line and buoyant line sources. Use the height (top) of the source for area and polygon sources and the vertical center for volume sources. Note: that for buoyant line sources, AERMOD requires a minimum release height of 2 meters.
Stack height	Numeric	P, C, H	Release height above ground (in meters) for all point source types.
Diameter	Numeric	P, C, H	Diameter of stack (in meters) for all point source types.
Velocity	Numeric	P, C, H	Velocity at which emissions are released from the stack (in meters/second) for all point source types.
Temperature	Numeric	P, C, H	Temperature (in Kelvin) at which emissions exit the stack for all point source types.
Elevation	Numeric	all	Elevation above sea level in meters at the source location. Use when modeling terrain effects and user-specified elevations are desired. This field is optional; HEM4 will calculate if all source elevations are left blank. Note: if an elevation value is provided by the user for one or more sources, any blanks (i.e., non-entries for other source elevations) will be interpreted by the model as an elevation of 0 meters; therefore, either enter elevations for every source or leave all blank.
X-coordinate2	Numeric	N, B	Second X (end) coordinate for line and buoyant line source types. UTM east coordinate, in meters (if coordinate system = U) or decimal longitude (if system = L) of the ending point of line and buoyant line sources.*** For longitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
Y-coordinate2	Numeric	N, B	Second Y (end) coordinate for line and buoyant line source types. UTM north coordinate, in meters (if coordinate system = U) or decimal latitude (if system = L) of the ending point of line and buoyant line sources.*** For latitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
Method	Numeric	Any but B	The Method field indicates the type of particle deposition AERMOD should use. Enter 1 or leave blank for Method 1 (which is the default); enter 2 for Method 2. Use Method 1 when greater than 10 percent of the total particulate mass has a diameter of 10 µm or larger, or when the particle size distribution is known. For Method 1, these source-specific particle size distributions must be provided in a separate particle data file (described in Section 3.5.3). Method 2 may be used when the particle size distribution is not well-known and when a small fraction (less than 10 percent of the mass) is in particles with a diameter of 10 µm or larger. The

Field	Type	Source type(s)*	Description
			particle data required for Method 2 is less specific than Method 1 but requires that you enter the mass fraction of fine particles and the mass-mean particle diameter for the given source in the next two fields.
Mass Fraction	Numeric	All, except B	The Mass Fraction field refers to the fraction of the particle mass emitted from this source in the fine particle category (less than 2.5 microns). Leave this field blank if you are using Method 1. For Method 2, you should enter a number between 0 and 1 that is the fraction of particles emitted in the fine category (a blank will be interpreted as a 1, the default, meaning that all are emitted as fine particles). For example, if one-half of the emissions from this source are fine particles (< 2.5 microns), enter a mass fraction in this field of 0.50.
Particle Diameter	Numeric	All, except B	The Particle Diameter field is the representative mass-mean aerodynamic particle diameter in microns emitted from this source when using Method 2 for particle deposition (a blank is interpreted as 1 micron, the default). Leave this field blank for Method 1. For Method 2, enter the mass-mean particle diameter in microns.

Table Notes:

* Source types for which the parameter is used: all = needed for every source type, A = area, P = vertical point, C = capped point, H = horizontal point, V = volume, I (capital "i") = polygon, N = line, B = Buoyant line. Note that currently AERMOD cannot model deposition/depletion for buoyant lines (B), nor can the FASTALL option be used with buoyant lines. For additional information on these source types, including what additional fields are needed, see the AERMOD User's Guide at https://www3.epa.gov/ttn/scram/models/aermod/aermod_userguide.pdf

** If you are modeling deposition or depletion and pollutant properties are known to vary, use a separate record for each pollutant and source. Thus, if you are modeling vapor deposition/depletion, use a unique Source ID for each pollutant emitted from a given source (e.g., SAMPLE3A for benzene, SAMPLE3B for 1,3-butadiene). The same is true for particulate deposition/depletion if the particulate properties (size and density distributions) are known and vary by pollutant, not just source. If you are not modeling vapor deposition/depletion and the same properties are assumed for all particulates emitted from a source, one Source ID per emission source is sufficient (e.g., SAMPLE3 for all modeled pollutants from the same source).

*** Start/end coordinates for buoyant line sources generally should be entered in order from West to East, and from South to North. However, in the case where the buoyant lines are parallel to the Y axis, the order that the lines should be entered is dependent on which endpoint is entered first, the southern or northern endpoint of the lines. If the southern endpoint is entered first, the lines should be entered in the order of the eastern most line to the western most line. If the northern endpoint is entered first, lines should be ordered west to east. Incorrect ordering of these parameters will result in an AERMOD error stating "Input buoyant line sources not in correct order"

Table 6. Sample Emissions Location Input File

	Source Locations & Types						Dimensions & Release Height (non-point sources)						
Facility ID	**Source ID**	**Coordinate system (U = UTM, L= latitude/ longitude) (All source types)**	**X-coordinate Longitude (decimal) or UTM East (m) (All source types)**	**Y-coordinate Latitude (decimal) or UTM North (m) (All source types)**	**UTM zone**	**Source type (P, C, H = point, A = area V= volume I = polygon N = line B = buoyant line)**	**Length in x-direction (m) A & N sources (width for N sources)**	**Length in y-direction (m) A sources**	**Angle (degrees) A sources**	**Lateral Dim. (m) V sources**	**Vertical Dim. (m) V sources or optionally A, I and N sources**	**Release height (m) A, V, I, N and B sources**	*continued*
Fac2-IL	CT0001	L	-88.257293	41.480164		P [or C or H]							...
Fac2-IL	CV0001	L	-88.256715	41.481944		A	130	120	45			2	...
Fac1-NC	SR0001	L	-78.883686	35.900628		V				20	3	10	...
Fac1-NC	MS0001	L	-78.888792	35.905920		I						5	...
Fac1-NC	RW0001	L	-78.888430	35.901810		N	20					50	...
Fac1-NC	RV0001	U	690891	3975044	17	B						40	...

	Point Source Parameters					Buoyant & Line Endpoints		Particle Deposition Method		
…continued from above (Source type indicated for reference)	**Stack height (m) P, C, or H sources**	**Stack Diameter (m) P, C, or H sources**	**Exit Velocity (m/s) P, C, or H sources**	**Exit Temperature (K) P, C, or H sources**	**Elevation (m) HEM4 will calculate if blank for every source**	**X-coord.2 Longitude (decimal) or UTM East (m) B & N sources**	**Y-coord.2 Latitude (decimal) or UTM North (m) B & N sources**	**Method (1 or 2; defaults to 1) All sources, except B**	**Mass Fraction (decimal > 0 and < 1 for Method 2 only) All sources, except B**	**Particle Diameter (microns, for Method 2 only) All sources, except B**
…(P, C or H)	50	2.8	21.83	322				2	0.04	0.0006
…(A)										
…(V)										
…(I)										
…(N)						-78.886303	35.902183			
…(B)						691291	3975044			

3.4.1 Source Types and Parameter Requirements

Generally, the Emissions Location file should include one record for each individual source (e.g., stack/point source, area source, line source, buoyant line source) to be modeled, at each facility. For certain modeling situations, more than one record per source is recommended.[3] This record provides information on the location, size, height, and configuration for each source. You must enter every Facility ID to be modeled in column A of the Emissions Location file. Enter each Source ID in column B, taking care to match each named Source ID with a corresponding Source ID in the HAP Emissions file, described in Section 3.3.

Source Locations: In column C "Coordinate system", you can enter source locations as UTM coordinates, or as latitude and longitude (which HEM4 will convert to UTM coordinates for use in AERMOD). Complete the coordinate system field for each source record and specify which coordinates you are entering. Enter "U" for UTM or "L" for latitude and longitude. If using UTM coordinates, specify the UTM zone (in each emission source record). Enter the location coordinates for each source in column D "X coordinate, Longitude (decimal) or UTM East (m)" and in column E "Y coordinate, Latitude (decimal) or UTM North (m)". (The endpoints for line and buoyant line source types, discussed further below, will be entered is columns S and T.) If you are using longitudes and latitudes, 5-decimal places are recommended which corresponds to an accuracy of roughly 1 meter. See Table 5 above for further specifications for these fields. You must base all coordinates on the WGS84 geographic system. As noted in Section 3.1, NAD83 and WGS84 are identical for most applications, so no conversion is needed if using coordinates based on NAD83. However, if coordinates are based on NAD27, they would need to be converted to WGS84 before being used in HEM4. There are various commercial computer programs available that can perform this conversion.

Source Types: Use the source type field in column G to indicate whether the emission source is a vertical non-capped point source (P), a capped point source (C), a horizontal point source (H), an area source (A), a volume source (V), a polygon source (I, for upper case "i"), a line source (N), or a buoyant line source (B)[4]. For additional information on these source types, including assumptions used by AERMOD to model their emissions as well as the additional parameters needed for each, you should consult the AERMOD User's Guide at https://www3.epa.gov/ttn/scram/models/aermod/aermod_userguide.pdf.

Point Sources - Vertical stack, Horizontal stack, and Capped stack: Point source types include vertical stacks (P), horizontal stacks (H) and capped stacks (C) source types. These point sources require you to specify the stack height (in meters in column N), the stack diameter (in meters in column O), the exit velocity (in meters/second in column P), and the exit/release temperature (in Kelvin in column Q) for the pollutant plume. Although capped and horizontal

[3] If modeling deposition or depletion (described in Section 3.2.6) at a facility, and pollutant properties are known to vary, we recommend you include a separate Source ID record for each pollutant and source—that is, a unique Source ID—for each pollutant being emitted from the same source. This is generally recommended for modeling of vapor deposition/depletion and for modeling of particulate deposition/ depletion if the size or density distributions are known for each pollutant (HAP*)* and vary for each pollutant. If you are not modeling deposition/depletion of vapor phase pollutants, and the same particulate properties are assumed for all pollutants being emitted from a given source, one record per source in the emissions location input file is sufficient.

[4] Note that the current AERMOD version 19191 cannot model deposition or depletion for buoyant lines (B), nor can the FASTALL option in the Facility List Options file be used with buoyant lines.

stacks (C and H, respectively) require the same user-specified parameters as vertical stacks (P), AERMOD models these point sources differently than vertical stacks (EPA 2019a, EPA 2019b).

Non-Point Sources: Columns H through N in the Emissions Location file pertain to area (A) sources, volume (V) sources, polygon (I for capital "i) sources, line (N) sources, and buoyant line (B) sources. Table 5 above provides guidance on what you should provide in each of these fields. Fugitive emissions are often modeled as rectangular area (A) sources. A conveyor belt, in which release temperature is assumed to be ambient and release velocity zero or negligible, may be simulated as volume (V) sources. A polygon (I) can be used to represent a complex (non-rectangular) area source with many vertices. A polygon (I) may also be used to represent an entire U.S. Census tract from which a source is modeled as a uniform emission (e.g., for mobile sources). Polygon source types require a Polygon Vertex file as an additional input, as discussed in Section 3.5.1. Line source (N) types can be used to represent roadways and airport runways and may be used instead of similarly shaped area sources.

Unlike point source types (P, C, or H), area (A), volume (V), polygon (I) and line (N) source types in AERMOD all assume ambient pollutant release temperatures and zero or negligible pollutant release/exit velocities. Buoyant line sources (B), on the other hand, are useful in simulating continuous vents along a roofline where the emissions, similar to point sources (P, C or H), are released at elevated (non-ambient) temperature and with a non-zero release velocity. However, unlike tall stack sources where the plume can move in all directions without impediment, buoyant line source types simulate pollutants emitted close to a building's roof where vertical wind shear and building downwash effects become important. Buoyant line (B) source types require a Buoyant Line Parameters file as an additional input, as discussed in Section 3.5.2.These non-point source types are discussed in more detail below.

Area Sources: An area source (A) type represents a rectangular area from which emissions are released at ambient temperature and with zero or negligible velocity (e.g., fugitive emissions from a building or tank farm). In AERMOD, area sources can be at ground level, or at a height above ground level. Specifying a release height (in column M) is optional and defaults to 0. The default orientation for area sources is with one axis in the north-south direction, but you can rotate these sources using the "angle" parameter (in column J), which specifies the rotation of the source from north (in the clockwise direction), to better fit the orientation of the source you are modeling. The X and Y coordinates you choose (in columns D and E) should reflect the southwest corner of the area source. The length in the X direction you enter (in column H) should reflect the length of the area source in the easterly direction, or in the southeasterly direction if the source is rotated. The length in the Y direction you enter (in column I) should reflect the length of the area source in the northerly direction, or the northeasterly direction if the source is rotated. Unlike AERMOD, where 360-degree rotation is allowed, the angle parameter for HEM4 area sources must be between 0 and 90 degrees. You can use this angle to represent any possible orientation by switching the X and Y lengths (shown in Figure 3). You can also optionally enter an initial vertical dimension of the area source (in column L).

Volume Sources: Volume source (V) types – such as multiple vents and conveyor belts – are specified by a lateral /horizontal dimension (you enter in column K), a vertical dimension (you enter in column L), and a release height (you enter in column M). Emissions from a volume source are assumed to be released at ambient temperature and with zero or negligible velocity. Both the release height (in column M) and the source location coordinates (in columns D and E) should reflect the center of the source.

Polygon Sources: You can create a polygon source (I, for capital "i") type to represent a polygon with 3 sides or many more (up to 20 sides). This source type provides considerable flexibility in specifying the shape of an area source. You can use a polygon source type to reflect U.S. Census tract boundaries, for example, when modeling mobile source emissions provided at the tract level. An associated polygon vertex input file is required when modeling polygon source types. Section 3.5.1 discusses this in more detail. The shape of the polygon source, as defined in the Polygon Vertex Input file, is determined by a list of X and Y coordinates representing the vertices of the polygon. You can order these X and Y coordinates in either a clockwise or counterclockwise direction. However, the first coordinates entered in the Polygon Vertex Input file must match the coordinates entered in the emissions location file (in columns D and E) as the location of the first vertex of the polygon. You can also optionally enter an initial vertical dimension of the polygon (in column L). Emissions from polygon source types are assumed to be released at ambient temperature and zero or negligible velocity.

Line Sources: The line source (N) type allows you to specify long, narrow sources, such as roadways or airport runways. You must enter a start-point (in columns D and E) and end-point of the line (in columns S and T), as well as the width of the line (a value equal to or greater than 1 meter that you enter in column H). Optionally, you can also specify an initial vertical dimension (in column L). In this way, the line source can be used as an alternative to a rectangular area source (A). [Note: According to the AERMOD User's Guide (EPA 2019a, p.3-100) the line source type utilizes the same routines as the area source type and will give identical results, given the same inputs.] Like area, volume and polygon source types, emissions from line source types are assumed to be released at ambient temperature and zero or negligible velocity.

Buoyant Line Sources: Like the line source, for the buoyant line source (B), you must enter the starting coordinates (in columns D and E) and the end coordinates (in columns S and T).[5] The buoyant line source (B) type was first developed to simulate the transport and diffusion of emissions from aluminum reduction plants in which some emissions from the reduction process escape through continuous (rooftop) ridge ventilators (ERT 1980). In general, the buoyant line source can be used to characterize emissions from a continuous roof vent that spans a portion or the entire building. Emissions from such buoyant line sources result in enhanced plume rise (especially from multiple rows of closely spaced emission lines) and the plume is subject to vertical wind shear and building downwash effects. This source type incorporates an average buoyancy parameter (in meters^4/seconds^3) as well as the average building dimensions (in meters) of the building(s) on which the buoyant line source is located. You must provide HEM4 with these inputs for your buoyant line source type in a Buoyant Line Parameters Input file, as discussed in Section 3.5.2. It should be noted that AERMOD 19191 requires a minimum release height (in your Emissions Location file) of 2 meters and a minimum wind speed (determined from your met station data) of 1 meter-per-second for buoyant line sources. (If you enter a release height less than 2 meters, AERMOD will change it to 2 meters.) Also, as noted previously, AERMOD 19191 cannot model deposition or depletion for buoyant lines, nor can the FASTALL option in the Facility List Options file be used with buoyant lines. For more detailed information regarding the necessary inputs for the buoyant line source type, see the AERMOD

[5] You may wish to use a series of buoyant lines to represent multiple roof vent lines. AERMOD requires a strict ordering of these lines in order to run properly. The start/end coordinates for buoyant line sources generally should be entered in order from West to East, and from South to North. However, in the case where the buoyant lines are parallel to the Y axis, the order that the lines should be entered is dependent on which endpoint is entered first, the southern or northern endpoint of the lines. If the southern endpoint is entered first, the lines should be entered in the order of the eastern most line to the western most line. If the northern endpoint is entered first, lines should be ordered west to east.

User's Guide (EPA 2019a), as well as documentation for the buoyant line and point source (BLP) dispersion model (ERT 1980).

Elevation: If you wish to consider terrain impacts in your modeling, you can specify the elevation above sea level in meters for each emission source. Enter elevations (in column R) for every source or for no sources; do not enter a partial list, because in that case blanks/non-entries will be interpreted by the model as a zero (0) elevation if a value is entered for one or more other sources. If you leave the elevation field blank for all sources, and if you chose to model elevations in the Facility List Options file, then HEM4 will estimate an elevation for the emission sources based on the elevations of nearby U.S. Census blocks or alternate receptors. Note that if you chose to not model elevations in your Facility List Options file, then no elevations will be considered in the model run including for sources in the Emissions Location file.

It should be noted that HEM4 will model area, volume, polygon, line, and buoyant line sources as flat surfaces, which can result in strangely located (underground) impacts if the source is located, for example, on a hillside with varying elevations. To avoid this, either opt to model with no elevations in the Facility List Options file, or break-up the source into smaller pieces with uniform elevations.

It should also be noted that "release height" (in column M) is different than elevation and indicates the height above the ground elevation where emissions are released (in which the ground is set to an elevation above sea level, or not, as reported in the preceding paragraphs discussing the elevation field). For point sources, fill in the "stack height" field (in column N) to designate the release height (for vertical stack, horizontal stack and capped stack source types). For all other source types (area, volume, polygon, line and buoyant line), you should fill in the "release height" (in column M) with the source's height above the ground (in meters). If you leave this field blank, HEM4 will assume the release height is zero (0), meaning at ground level.

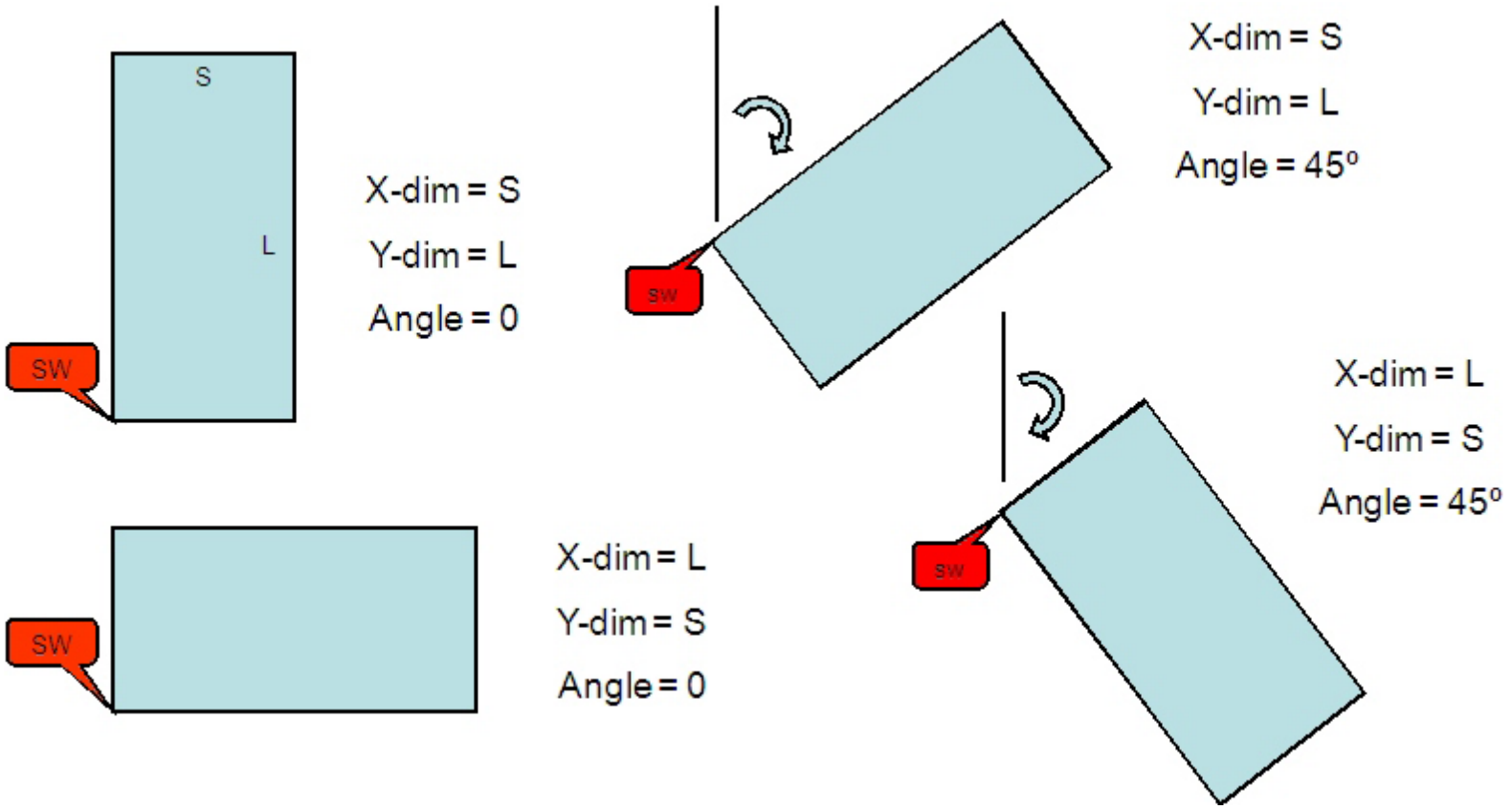


Figure 3. Example Orientations of Area Emission Sources for the HEM4 Model

3.4.2 Particle Deposition Method

Columns U (Method), V (Massfrac), and W (Partdiam) of the Emissions Location file should only be filled in if you wish to model particle deposition or depletion using Method 2. If you do not wish to model particle deposition/depletion or if you wish to use AERMOD's Method 1 to model particle deposition/ depletion, then leave these fields blank for those sources.

Particle Deposition/Depletion Method: The Method field (in column U) indicates to HEM4 the type of particle deposition AERMOD should use. As noted above, you should enter 1 or leave this field blank for Method 1 (which is the default). Method 1 should be used when a significant fraction (greater than about 10 percent) of the total particulate mass has a diameter of 10 µm or larger, or when the particle size distribution is known. The particle size distribution must be known reasonably well in order to use Method 1 and these source-specific particle size distributions must be provided in a separate Particle Data file, as discussed in Section 3.5.3. You should also leave this field (column U) blank if you are not modeling particle deposition/ depletion at all. Enter 2 in this field if you wish to model particle deposition or depletion for the given source using AERMOD's Method 2. Method 2 may be used when the particle size distribution is not well known and when a small fraction (less than 10 percent of the mass) is in particles with a diameter of 10 µm or larger. The particle data required for Method 2 is less detailed than Method 1 but does require that you enter the mass fraction of fine particles and the mass-mean particle diameter for the given source in the next two fields.

Mass Fraction for Method 2: The Mass Fraction field (in column V) refers to the fraction of the particle mass emitted from this source in the fine particle category (less than 2.5 microns). Leave this field blank if you are using Method 1, or if you are not modeling particle deposition/ depletion at all. For Method 2, you should enter a number between 0 and 1 that is the fraction of particles emitted in the fine category (a blank will be interpreted by the model as a 1, the default, meaning that all are emitted as fine particles). For example, if one-half of the emissions from this source are fine particles (< 2.5 microns), enter a mass fraction in this field of 0.50.

Particle Diameter for Method 2: The Particle Diameter field (in column W) is the representative mass-mean aerodynamic particle diameter in microns emitted from this source when using Method 2 for particle deposition (a blank is interpreted by the model as 1 micron, the default). Leave this field blank for Method 1, or if you are not modeling particle deposition/depletion at all. For Method 2, enter the mass-mean particle diameter in microns.

3.5 Additional Input Files

In addition to the three required input files (Facility List Option, HAP Emissions, and Emissions Location) discussed in Sections 3.2, 3.3 and 3.4, other files may be required for your modeling run depending on (a) what modeling options you chose in the Facility List Options file, (b) what source types you are modeling in your Emissions Location file, (c) what kinds of receptors you are modeling with, and/or (d) what changes you may wish to make to HEM4's underlying databases and resource files. These additional input files are discussed in the next sections.

3.5.1 Polygon Vertex Input File for Modeling Polygon Emission Sources

If your Emissions Location input file contains one or more polygons (source type "I"), then HEM4 will prompt you for a Polygon Vertex file. This file provides HEM4 with the locations of the polygon vertices. Polygons are useful for complex source configurations at a facility, and for modeling U.S. Census tracts as sources (e.g., for mobile source emissions modeled uniformly across a tract).

Include a separate record for each vertex of the polygon in the Polygon Vertex file. A polygon may have any number of vertices (≥ 3 and ≤ 20). Each record must include information for one vertex of the polygon. As noted in Section 3.4.1, you can order the X and Y vertex coordinates in either a clockwise or counterclockwise direction. The first and last vertex must have identical coordinates, and these coordinates must match the coordinates listed as the location of the first vertex of the polygon source in your Emissions Location file. The first record for each polygon source must also include the number of vertices for the polygon and the total area of the polygon, in meters squared. You can enter coordinates as UTM coordinates, or as longitudes and latitudes. If using UTM coordinates, you must specify the UTM zone. Base all coordinates on the WGS84 reference system.

Optionally, you can assign an ID (name) to the polygon. This may be useful, for example, if you are using the polygon to model a U.S. Census tract. In this case, you may wish to use the U.S. Census tract ID as the polygon ID and enter it in the last column of the Polygon Vertex file.

Tables 7 and 8 give the format guidelines for the Polygon Vertex file, and a sample Polygon Vertex file, respectively. A template input file is provided in the HEM4 Inputs folder named *HEM4_polygon_vertex.xlsx*.

Table 7. Format Guidelines for the Polygon Vertex File

Field	Type	Description
Facility ID	Character	An alphanumeric character identifying the facility being modeled
Source ID	Character	An alphanumeric character string up to 8 characters long, with no spaces. The Source ID must be listed as polygon (Type = I) source types in the Emissions Location file. Note: AERMOD allows a maximum of 8 characters for the Source ID; and all Source IDs will be converted to upper case by AERMOD.
Coordinate system	Character	Type coordinates: L = longitude, latitude; U = UTM [WGS84].
X-coordinate	Numeric	UTM east coordinate, in meters (if Coordinate System = U) or decimal longitude (if System = L). For longitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
Y-coordinate	Numeric	UTM north coordinate, in meters (if Coordinate System = U) or decimal latitude (if System = L). For latitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.

Field	Type	Description
UTM zone	Numeric	If using the UTM coordinate system (U), enter the UTM Zone from 1 to 60 followed by the hemisphere (S or N). For example, 17N (default hemisphere is N if not specified). If using longitudes/latitudes, leave this cell blank.
Num of Vertices	Numeric	Number of vertices in the polygon. This number must be 3 or greater. The upper limit is 20.
Area	Numeric	Size of area within polygon, in meters squared.
Polygon ID	Character	Optional ID to indicate the name of the polygon (e.g., a U.S. Census tract is sometimes modeled as a polygon and the polygon ID may be the U.S. Census tract ID).

Table 8. Sample Polygon Vertex File

Facility ID	Source ID	Coordinate system (U = UTM, L = latitude, longitude)	Longitude (decimal) or UTM East (m)	Latitude (decimal) or UTM North (m)	UTM zone	Num of Vertices (≥ 3 and ≤20)	Area (m^2)	Polygon ID (optional)
Fac1-TX	SAMPLE4	L	-95.3586	29.7674		9	402939.4	
Fac1-TX	SAMPLE4	L	-95.3524	29.7685			0	
Fac1-TX	SAMPLE4	L	-95.3515	29.7663			0	
Fac1-TX	SAMPLE4	L	-95.3533	29.7654			0	
Fac1-TX	SAMPLE4	L	-95.3533	29.7622			0	
Fac1-TX	SAMPLE4	L	-95.3574	29.7634			0	
Fac1-TX	SAMPLE4	L	-95.3582	29.7651			0	
Fac1-TX	SAMPLE4	L	-95.3575	29.7661			0	
Fac1-TX	SAMPLE4	L	-95.3586	29.7674			0	
Fac1-TX	SAMPLE5	L	-95.3512	29.7688		11	710176.8	
Fac1-TX	SAMPLE5	L	-95.3524	29.7685			0	
Fac1-TX	SAMPLE5	L	-95.3515	29.7663			0	
Fac1-TX	SAMPLE5	L	-95.3509	29.7653			0	
Fac1-TX	SAMPLE5	L	-95.3533	29.7654			0	
Fac1-TX	SAMPLE5	L	-95.3533	29.7622			0	
Fac1-TX	SAMPLE5	L	-95.3574	29.7634			0	
Fac1-TX	SAMPLE5	L	-95.3582	29.7651			0	
Fac1-TX	SAMPLE5	L	-95.3575	29.7661			0	
Fac1-TX	SAMPLE5	L	-95.3586	29.7674			0	
Fac1-TX	SAMPLE5	L	-95.3512	29.7688			0	

3.5.2 Buoyant Line Parameter Input File for Modeling Buoyant Line Sources

If your Emissions Location input file contains one or more buoyant line sources (source type "B"), then HEM4 will prompt you for a Buoyant Line Parameter file. Buoyant line source types are useful in simulating continuous rooftop vents in which emissions are released at non-ambient (elevated) temperature and non-negligible velocity, as discussed in Section 3.4.1. Because building downwash effects are especially important with buoyant line source types, the Buoyant Line Parameter file must provide HEM4 with the length, width, and height of the building(s) on which the buoyant line source type (e.g., rooftop vent) sits. In addition, the file must contain the width of the buoyant line source(s), the distance between the buildings (zero for a solitary buoyant line), and the buoyancy parameter for the buoyant line source(s).

The buoyancy parameter of a line source is calculated from an equation based on the line source length (m) and width (m), the exit/release velocity (m/s), the exit/release temperature (K), the ambient temperature (K) and the acceleration due to gravity (9.81 m/s^2), as presented in Equation 2-47 on page 2-37 of the Buoyant Line and Point Source Dispersion Model User's Guide (ERT 1980).[6] **These parameters should be average values for the array of buoyant line sources, if multiple parallel buoyant line sources are present** (EPA 2019a). You must provide the following parameters in the Buoyant Line Parameter File:

- Average Building Length (in meters);
- Average Building Height (in meters);
- Average Building Width (in meters);
- Average Line Source Width, of the individual lines (in meters);
- Average Building Separation, between the individual lines (in meters); and
- Average Buoyancy Parameter (in $meters^4/seconds^3$)

Note: The current AERMOD version 19191 allows modeling only a single buoyant line source (comprised of one or multiple lines) per modeling run, so HEM4 allows a single buoyant line source per facility. Multiple model runs are recommended to adequately model the emissions from multiple non-parallel buoyant line sources at a given facility. (See the AERMOD User's Guide page 3-85 for further information; EPA 2019a.)

Tables 9 and 10 provide the format guidelines for the Buoyant Line Parameter input file and a sample input file, respectively. A template input file is provided in the HEM4 Inputs folder named *HEM4_buoyant_line_param.xlsx*. See also the resources shown in footnote 6 below for helpful guidance in setting up a buoyant line source.

[6] In addition, diagrams detailing buoyant line equation parameters and sample calculations are available in: *Source Characterizations: Buoyant Line Sources, Missouri Department of Natural Resources Air Pollution Control Program.* http://dnr.mo.gov/env/apcp/docs/buoyantlinesources10-24-12.pdf on website http://dnr.mo.gov/env/apcp/permitmodeling/sourcecharacterizations.htm. November 12, 2013.

Table 9. Format Guidelines for the Buoyant Line Parameter Input File

Field	Type	Description
Facility ID	Character	An alphanumeric character string identifying the facility being modeled
Average Building Length	Numeric	The average length of the building or buildings on which the parallel buoyant line source types are located (in meters)
Average Building Height	Numeric	The average height of the building or buildings on which the parallel buoyant line source types are located (in meters)
Average Building Width	Numeric	The average width of the building or buildings on which the parallel buoyant line source types are located (in meters)
Average Line Source Width	Numeric	The average width of the individual buoyant line source types (in meters)
Average Building Separation Distance	Numeric	The average building separation distance between the (parallel) individual buoyant lines (in meters)
Average Buoyancy Parameter	Numeric	The average buoyancy parameter for the buoyant line emission plumes (in meters^4/seconds^3); See BLP Dispersion Model documentation (ERT 1980).

Table 10. Sample Buoyant Line Parameter Input File

Facility ID	Avg Building Length (m)	Avg Building Height (m)	Avg Building Width (m)	Avg Line Source Width (m)	Avg Building Separation (m)	Avg Buoyancy (m^4/s^3)
Fac1-NC	454.3	16.76	40	5.73	40.95	3335.49

3.5.3 Particle Data Input File for Modeling Particulate Deposition and Depletion

AERMOD can implement dry and wet deposition and plume depletion of both particulate and vapor emissions (EPA 2019a). This section describes the input file needed for modeling particulate deposition and/or particulate depletion.

If you indicated in your Facility List Options file that your run will model deposition or depletion of particulate emissions AND you chose (in your Emissions Location file) to use Method 1 for particle deposition for one or more sources, then you must provide HEM4 with a separate Particle Data input file describing the particle size distribution. In this file, include a separate record for each particle size range emitted by each emission source, for which HEM4/AERMOD will model particle deposition/depletion using Method 1. Each record must include an average particle diameter for the size range, the percentage that the size range represents in terms of the total mass of particulate matter from the given emission source, and the average density of particles in the size range. The mass percentages must total to 100 for each emission source (for which you are modeling particle deposition/depletion using Method 1). Tables 11 and 12 provide format guidelines for the Particle Data input file and a sample input file, respectively. A template input file is provided in the HEM4 Inputs folder named *HEM4_particle_data.xlsx*.

Table 11. Format Guidelines for the Particle Data Input File

Field	Type	Description
Facility ID	Character	An alphanumeric character string identifying the facility being modeled
Source ID	Character	The Source ID is a unique alphanumeric character string up to 8 characters long with no spaces. It must match a Source ID in the HAP Emissions and Emissions Location file. Note: AERMOD allows a maximum of 8 characters for the Source ID; and all Source IDs will be converted to upper case by AERMOD.
Particle diameter	Numeric	The average diameter (in μm) for the particle size range covered by this record.
Mass fraction	Numeric	The percentage (by mass) of particulate matter in this size range. Must add up to 100% for each Source ID.
Particle density	Numeric	The average density of the particles in this size range (in g/cm^3).

Table 12. Sample Particle Data Input File

Facility ID	Source ID	Particle diameter (μm)	Mass fraction (%)	Particle density (g/cm^3)
Fac1-TX	SAMPLE1	0.50	72.0	1.00
Fac1-TX	SAMPLE1	1.50	8.0	0.75
Fac1-TX	SAMPLE1	2.50	4.0	0.50
Fac1-TX	SAMPLE1	4.00	4.0	1.00
Fac1-TX	SAMPLE1	10.00	12.0	0.35
Fac1-TX	SAMPLE2	0.50	60.0	1.00
Fac1-TX	SAMPLE2	1.50	8.0	0.80
Fac1-TX	SAMPLE2	2.50	4.0	0.15
Fac1-TX	SAMPLE2	4.00	4.0	0.90
Fac1-TX	SAMPLE2	10.00	24.0	1.00

3.5.4 Input Files Required for Modeling Vapor Deposition and Depletion

As described in Section 3.2.6, AERMOD can model dry and wet deposition of both particulate and vapor (gaseous) emissions and the resulting plume depletion (EPA 2019a). This section describes the inputs required for modeling vapor deposition and vapor depletion.

Gas Parameter File for Modeling Deposition/Depletion of Vapor Pollutants: To model wet and/or dry deposition or depletion of vapor pollutants, you must provide HEM4 with the necessary information to evaluate the scavenging of these pollutants in precipitation and deposition on vegetation and other surfaces. When modeling any type of vapor deposition or depletion (wet, dry, or both wet and dry), HEM4 accesses a gas parameter file containing pollutant properties related to gaseous deposition. Note: The Gas Parameter file is included in HEM4's resources folder, which is included in the model's installation files; therefore, HEM4 will NOT prompt you for this file. (The default file pathway is *"HEM4\resources\Gas_Param.xlsx"*.) This file includes the following four parameters for each pollutant:

- diffusivity in air (D_a, in cm^2/sec);
- diffusivity in water (D_w, in cm^2/sec);
- cuticular resistance to uptake by lipids for individual leaves (r_{cl}, in sec/cm); and
- Henry's Law coefficient (H, in Pascal-m^3/mol).

Values for these parameters are provided in the Gas Parameter file for 129 pollutants, based on a study by Argonne National Laboratories (Wesely 2002) and a more recent paper which compiles Henry's Law coefficients from numerous other sources (Sander 2015). When modeling a vapor/gaseous pollutant that is not listed in the Gas_Param file, HEM4 uses the following default parameters:

D_a = 0.07 cm^2/sec, D_w = 0.7 cm^2/sec, r_{cl} = 2,000 sec/cm, H = 5.0 Pascal-m^3/mol.

These defaults are based on the logarithmic average of parameters for the 129 pollutant species currently contained in the Gas Parameter file, using one significant figure accuracy. It should be emphasized that these defaults are averages taken over ranges sometimes in excess of ten orders of magnitude and may not be appropriate for the pollutants of interest to you.

You can calculate parameters for additional pollutants and add these to the *Gas_Param.xlsx* file or revise the values in the Gas_Param file, as appropriate. For example, you may wish to estimate parameters for pollutants of interest to you by calculating averages based on the values in the Gas Parameter file for smaller groups of pollutants in the same chemical family and of similar molecular weight to your pollutant of interest (e.g., polycyclic aromatic hydrocarbons, PAHs).

Parameter values for additional pollutant species are available in the literature cited here (Wesely 2002 and Sander 2015), as well as in EPA's Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities Final Report (dated September 2005 and available at https://epa-prgs.ornl.gov/radionuclides/2005_HHRAP.pdf). Wesely 2002 also describes a methodology for estimating cuticular resistance, which is less commonly cited in the literature.

It should be noted that the Gas Parameter Input File is needed only when modeling deposition (wet, dry, or both wet and dry) of vapor/gaseous pollutants. It is not required to model deposition (of any type) of particulate emissions.

Land Use and Month-to-Seasons Input Files for Modeling Dry Deposition of Vapor Pollutants

If you chose to model dry (or wet and dry) vapor deposition or dry (or wet and dry) vapor depletion in your Facility List Options file, then HEM4 will prompt you to provide two additional input files described in this section. To quantify dry deposition of vapor (gaseous) pollutants to vegetation, AERMOD requires information on the land use and vegetation surrounding the emission source. You must provide this information in Excel™ spreadsheets called the land use and month-to-seasons input files.

Land Use Input File: In the land use input file, you must enter a code characterizing the average land use for 36 directions from the emission sources (which emit vapor pollutants at a facility you chose to model dry deposition or dry depletion at), at increments of 10 degrees compass bearing. Table 13 gives the format guidelines for the land use input file, and Table 14 shows a sample land use input file. A template input file is provided in the HEM4 Inputs folder named *HEM4_landuse.xlsx*.

Month-to-Seasons Input File: You must also provide HEM4 the month-to-seasons input file containing further information on the typical stage of vegetation in the modeled region during each month of the year. As the format guidelines in Table 15 show, this file associates each month with a season code, describing the stage of vegetation ranging from lush midsummer vegetation to winter snow coverage. Table 16 shows a sample input table for the month-to-seasons input file. A template input file is provided in the HEM4 Inputs folder named *HEM4_month-to-seasons.xlsx*.

Again, **it should be noted that the Land Use and Month-to-Seasons input files are required only if you choose to model dry (or wet and dry) vapor deposition or dry (or wet and dry) vapor depletion** in your Facility List Options file. These files are not required for modeling wet deposition or depletion of vapor emissions, nor are they required for modeling any kind of (wet or dry) deposition/depletion of particulate emissions.

Table 13. Format Guidelines for Land Use Input File

Field	Type	Description
Facility ID	Character	An alphanumeric character string identifying the facility being modeled
Direction Sector 1	Numeric	Land use code (value = 1-9) for the modeling domain at a compass bearing of 10 degrees from the emission release point: 1 Urban land, no vegetation 2 Agricultural land 3 Rangeland 4 Forest 5 Suburban areas, grassy 6 Suburban areas, forested 7 Bodies of water 8 Barren land, mostly desert 9 Non-forested wetlands
Direction Sector n (n = 2 thru 35)	Numeric	Land use code at a bearing of n × 10
Direction Sector 36	Numeric	Land use code at a bearing of 360 degrees

Table 14. Sample Input File for Land Use

Facility ID	D01 (10°)	D02 (20°)	D03 (30°)	D04 (40°)	D05 (50°)	...	D36 (360°)
Fac1-NC	1	9	5	5	6	...	1

Table 15. Format Guidelines for Month-to-Seasons Input File

Field	Type	Description
Facility ID	Character	An alphanumeric character string identifying the facility being modeled
January	Numeric	Seasonal category (value = 1-5) for month 1 (January): 1 Midsummer with lush vegetation 2 Autumn with unharvested crop land 3 Late autumn after frost and harvest, or with no snow 4 Winter with snow on ground 5 Transitional spring with partial green coverage or short annuals
November	Numeric	Seasonal category (value = 1-5) for month 11
December	Numeric	Seasonal category (value = 1-5) for month 12

Table 16. Sample Month-to-Seasons Input File

Facility ID	M01	M02	M03	M04	M05	…	M12
Fac1-NC	4	4	5	5	1	...	4

3.5.5 Building Dimensions Input File for Modeling Building Downwash

If you chose to model building downwash in your Facilities List Options file for one or more facilities, then HEM4 will prompt you for a Building Dimensions input file, which is required by AERMOD to model building downwash effects. The following parameters are required in the building dimensions input file:

- building height (keyword=BUILDHGT);
- projected building width perpendicular to the direction of flow (keyword=BUILDWID);
- building length in the direction of flow (keyword=BUILDLEN);
- distance from the stack to the center of the upwind face of the building parallel to the direction of flow (keyword=XBADJ); and
- distance from the stack to the center of the upwind face of the building perpendicular to the direction of flow (keyword=YBADJ).

You must provide these parameters for 36 wind directions, at increments of 10 degrees (compass bearing). Calculate these parameters using the EPA's Building Profile Input Program for PRIME (BPIPPRM). You can download the BPIPPRM model code and documentation from the EPA's Support Center for Regulatory Atmospheric Modeling (SCRAM) website at https://www.epa.gov/scram/air-quality-dispersion-modeling-related-model-support-programs#bpipprm.

Table 17 gives the format guidelines for the Excel™ Building Dimensions input file, and Table 18 shows a sample Excel™ Building Dimensions file. A template input file is provided in the HEM4 Inputs folder named *HEM4_bldg_dimensions.xlsx*.

Table 17. Format Guidelines for the Building Dimensions File

Field	(notes)	Type	Description
Facility ID	--	Character	An alphanumeric character string identifying the facility being modeled
Pathway	--	Character	"SO" should always be entered in this field because it represents a source pathway record, which corresponds to the code used in the AERMOD input file.
Keyword	--	Character	Specifies which values are given in this record (row), as follows: BUILDHGT = building height BUILDWID = projected building width perpendicular to the direction of flow BUILDLEN = building length in the direction of flow XBADJ = along-flow distance from the stack to the upwind face of the building YBADJ = across-flow distance from the stack to the upwind face of the building

Field	(notes)	Type	Description
Source ID	--	Character	The Source ID is a unique alphanumeric character string up to 8 characters long with no spaces. It must match a Source ID in the HAP Emissions and Emissions Location file. Note: AERMOD allows a maximum of 8 characters for the Source ID; and all Source IDs will be converted to upper case by AERMOD.
Value 1	(n = 1)	Numeric	Dimension or distance (depending on the Keyword parameter) viewed from a compass bearing of 10 degrees from north (clockwise direction) of the emission release point.
Value 2	(n = 2)	Numeric	Dimension or distance of the building at a bearing of 20 degrees.
Value n	(n = 3 to 35)	Numeric	Dimension or distance of the building at a bearing of [n × 10] degrees.
Value 36	(n = 36)	Numeric	Dimension or distance of the building at a bearing of 360 degrees.

Table 18. Sample Building Dimensions Input File

Facility ID	Pathway	Keyword	Source ID	Value 1 (10°)	Value 2 (20°)	Value 3 (30°)	...	Value 36 (360°)
Fac1-NC	SO	BUILDHGT	SAMPLE1	26.00	26.00	26.00	...	26.00
Fac1-NC	SO	BUILDWID	SAMPLE1	111.07	107.16	100.00	...	111.60
Fac1-NC	SO	BUILDLEN	SAMPLE1	128.17	115.85	100.00	...	136.60
Fac1-NC	SO	XBADJ	SAMPLE1	-93.97	-98.48	-100.00	...	-86.60
Fac1-NC	SO	YBADJ	SAMPLE1	55.54	53.58	50.00	...	55.80

3.5.6 User-Defined Receptors File

If you opted to include user receptors in your Facility List Options file for one or more facilities, then HEM4 will prompt you for a User Receptors file. HEM4 will automatically calculate ambient concentrations and resultant cancer risks and noncancer hazard indices for all U.S. Census blocks or for all alternate receptors within the defined modeling domain. You can also specify additional receptor sites to model, such as schools, ambient monitors, residential areas other than the census block's centroid, or facility boundaries.

Specify the locations of these sites in the User Receptors input file, using a separate record to indicate the location of each user receptor. You must enter locations of each user receptor using UTM coordinates, or in longitude and latitude. If using UTM coordinates, you must specify the UTM zone. Base all coordinates on the WGS84 reference system.

If you chose in your Facility List Options file to include elevations in your model run, you can enter the elevation above sea level for each user receptor. If you leave this field blank in the User Receptors input file (but did choose to include elevations in your model run in your Facility List Options file), then HEM4 will assume an elevation for each user receptor based on the surrounding U.S. Census block elevations or alternate receptor elevations. Specifically, if you leave the elevation field empty in the User Receptor file for every receptor, then HEM4 will use the elevation of the closest U.S. Census block or alternate receptor (if not using U.S. Census blocks in your modeling run). Note: You should enter an elevation for every user receptor, or leave the elevation field blank for all, to allow HEM4 to provide the elevations. (Otherwise, if you enter an elevation for some but not all user receptors, HEM4 will assign a 0 value to the receptors you left blank.)

In addition, you may provide hill heights in the User Receptor file, or you may leave the hill height field blank for HEM4 to calculate these values. AERMOD uses the controlling hill height for flow calculations. Controlling hill height is defined as the highest elevation that is above a 10% grade from the receptor. [For more information on the use and calculation of controlling hill heights using an algorithm in AERMAP, the AERMOD terrain processor (EPA 2018c), see Section 2.3.1.] If you leave the hill height field blank in the User Receptors file (but did choose to include elevations in your model run in your Facility List Options file), then HEM4 will assign the hill height of that user receptor to be the maximum of: 1) the hill height of the closest U.S. Census block or alternate receptor (if not using U.S. Census blocks in your modeling run), 2) the elevation of the closest U.S. Census block or alternate receptor, or 3) the user receptor elevation that you provide. Note: As cautioned above for user receptor elevation, you should enter a hill height for every user receptor, or leave the hill height blank for all, to allow HEM4 to provide the hill heights. (Otherwise, if you enter a hill height for some but not all user receptors, HEM4 will assign a 0 value to the receptors you left blank.)

In the User Receptor file, you should specify a "receptor type code" indicating the type of receptor. A code of "P" represents populated sites like houses/residences, "B" represents facility boundary sites, and "M" represents ambient monitors. **You may name your user receptors with up to 9 characters** and HEM4 will display these names in the output files for ease of reference. **Each user receptor name must be unique**.

Tables 19 and 20 give format guidelines for the User Receptors file and a sample input file, respectively. In addition, a template input file is provided in the HEM4 Inputs folder named *HEM4_user_receptors.xlsx*.

Table 19. Format Guidelines for the User–Defined Receptors File

Field	Type	Description
Facility ID	Character	An alphanumeric character string identifying the facility being modeled
Coordinate system	Character	Type of coordinates: L = longitude, latitude; U = UTM [WGS84]
X-coordinate	Numeric	UTM east coordinate, in meters (if Coordinate System = U) or decimal longitude (if System = L). For longitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
Y-coordinate	Numeric	UTM north coordinate, in meters (if Coordinate System = U) or decimal latitude (if System = L). For latitudes, 5 decimal place accuracy is recommended, corresponding to 1-meter accuracy.
UTM zone	Numeric	If using the UTM coordinate system (U), enter the UTM Zone from 1 to 60 followed by the hemisphere (S or N). For example, 17N (default hemisphere is N if not specified). If using longitudes/latitudes, leave this cell blank.
Elevation	Numeric	Elevation of the receptor above sea level, in meters. Optional: HEM4 will calculate if left blank and you are modeling terrain effects.*
Receptor type	Character	Type of receptor: P = populated site (e.g., house or school); B = facility boundary; M = monitor.
Receptor ID	Alpha-numeric	Name of receptor provided by user, containing letters and numbers, no symbols or spaces. **The name you provide must be 9 characters or less.** This name will be displayed in the outputs.
Hill Height	Numeric	Hill height scale, in meters. Optional: HEM4 will calculate if left blank and you are modeling terrain effects.* (You may leave all hill heights blank, even if you enter elevations for your user receptors in the elevation field.)

*Note: Fill-in for every receptor or for none. If you enter one or more values, then HEM4 will assign a zero (0) to any blank values.

Table 20. Sample Input File for User–Defined Receptors

Facility ID	Location type (U – UTM, L = latitude/ longitude)	X-coordinate (decimal) or UTM East (m)	Y-coordinate (decimal) or UTM North (m)	UTM zone	Elevation (m)	Receptor type (P = populated site, B = facility boundary, M = monitor)	Receptor ID	Hill Height (m)
Fac1	L	-78.88875	35.90016		100	P	UHouse12	
Fac2	U	560005	441000	16	244	M	UMonitor3	

3.5.7 Emissions Variation Input Files

If you chose to model emissions variations for one or more facilities in your Facility List Options file, then HEM4 will prompt you for a separate Emissions Variation input file. AERMOD computes hourly concentration data based on user-supplied emission inputs. AERMOD also gives you the option of specifying variable emission rate factors for individual sources. You can base these source-specific factors on different temporal scales—such as season, month, day of the week, and hour of day—or on wind speed.

For HEM4 to calculate temporal or wind speed emissions variations, AERMOD requires information on the type of variation and the factors to use for each variation. These variation types and factors will be applied to one or more sources at each of the facilities you indicated in your Facility List Options file. You must supply this information in an Emissions Variation input file in the form of an Excel™ spreadsheet. The types of variations AERMOD can apply include the following (with the HEM4 template file provided in parentheses, as well as the "n" number of factors):

- **SEASON** (*HEM4_emisvar_season.xlsx*): emission rates vary seasonally (n=4);
- **MONTH** (*HEM4_emisvar_month.xlsx*): emission rates vary monthly (n=12);
- **HROFDY** (*HEM4_emisvar_hrofdy.xlsx*): emission rates vary by hour-of-day (n=24);
- **HRDOW** (*HEM4_emisvar_hrdow.xlsx*): emission rates vary by hour-of-day, and day-of-week [M-F, Sat, Sun] (n=72);
- **SEASHR** (*HEM4_emisvar_seashr.xlsx*): emission rates vary by season and hour-of-day (n=96);
- **HRDOW7** (*HEM4_emisvar_hrdow7.xlsx*): emission rates vary by hour-of-day, and the seven days of the week [M, Tu, W, Th, F, Sat, Sun] (n=168);
- **SHRDOW** (*HEM4_emisvar_shrdow.xlsx*): emission rates vary by season, hour-of-day, and day-of-week [M-F, Sat, Sun] (n=288);
- **SHRDOW7** (*HEM4_emisvar_shrdow7.xlsx*): emission rates vary by season, hour-of-day, and the seven days of the week [M, Tu, W, Th, F, Sat, Sun] (n=672);
- **MHRDOW** (*HEM4_emisvar_mhrdow.xlsx*): emission rates vary by month, hour-of-day, and day-of-week [M-F, Sat, Sun] (n=864);
- **MHRDOW7** (*HEM4_emisvar_mhrdow7.xlsx*): - emission rates vary by month, hour-of-day, and the seven days of the week [M, Tu, W, Th, F, Sat, Sun] (n=2,016); and
- **WSPEED** (*HEM4_emisvar_wspeed.xlsx*): emission rates vary by wind speed (n=6) (Note: the 6 factors are applied to the wind speed categories used by AERMOD that have the following default upper bound speeds in m/s of 1.54, 3.09, 5.14, 8.23, 10.8 and no upper bound).

Table 21 provides the format guidelines for the Emissions Variation input files. Tables 22, 23, 24, and 25 provide sample Emissions Variation input files for a sample of the variations AERMOD can accommodate including: seasonal emission variations (4 factors), hour of day emission variations (24 factors), monthly emission variations (12 factors), and both season and hour of day emission variations (96 factors), respectively. Table 26 provides a sample input file for varying source-specific emissions by wind speed. It should be noted that HEM4 expects a maximum of 12 factor columns across these Emissions Variation input spreadsheets (for a total of 15 columns, including the Facility ID, Source ID and Variation keyword).

It should also be noted that although the types of emission variations described above and the samples provided below are for a single type of emissions variation, you can also choose to use different variation types for different sources and/or facilities, within the same input file. The only limitation is that each source can only have a single type of variation applied in a model run. A template input file containing multiple emissions variations in one file is also provided in the HEM4 Inputs folder and is named *HEM4_emisvar_multiple_variations.xlsx*. See the AERMOD User's Guide (EPA 2019a) for more detailed information regarding the temporal and wind speed factors available for varying source-specific emissions.

Table 21. Format Guidelines for the Emissions Variation Input Files

Field	Type	Description
Facility ID	Character	An alphanumeric character string identifying the facility being modeled
Source ID	Character	The Source ID is a unique alphanumeric character string up to 8 characters long with no spaces. It must match a Source ID in the HAP Emissions and Emissions Location file. Note: AERMOD allows a maximum of 8 characters for the Source ID; and all Source IDs will be converted to upper case by AERMOD.
Variation	Character	Type of variable emission rates being used (SEASON, MONTH, HROFDY, HRDOW, SEASHR, HRDOW7, SHRDOW, SHRDOW7, MHRDOW, MHRDOW7 or WSPEED).*
Factor 1	Character	First factor to be applied to emission rate.
Factor 2	Character	Second factor to be applied to emission rate.
Factor 3	Character	Third factor to be applied to emission rate.
…	…	…
Factor n	Character	n^{th} factor to be applied to emission rate.

* Each emission variation type has a set number of "n" factors. The number of factors are as follows: SEASON=4, MONTH=12, HROFDY=24, HRDOW=72, SEASHR=96, HRDOW7=168, SHRDOW=288, SHRDOW7=672, MHRDOW=864, MHRDOW7=2,016, WSPEED=6. See HEM4's template input files for examples and consult the AERMOD User's Guide for additional information.

Table 22. Sample Emissions Variation File based on Seasons (4 factors)

Facility ID	Source ID	Variation	Winter	Spring	Summer	Fall
Fac1	SAMPLE1	SEASON	0.50	0.75	1.00	1.00

Table 23. Sample Emissions Variation File based on Hour of Day (24 factors)

Facility ID	Source ID	Variation	Hour factor (1)	Hour factor (2)	Hour factor (3)	Hour factor (4)	Hour factor (5)	Hour factor (6)	…	Hour factor (12)
Fac1	SAMPLE1	HROFDY	0.2138	0.1433	1.2928	0.098	0.1342	0.3301	…	1.4356
			(13)	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**	**…**	**(24)**
Fac1	SAMPLE1	HROFDY	1.3959	1.2728	0.1079	1.5255	1.5255	1.5519	…	1.799

Table 24. Sample Emissions Variation File based on Month (12 factors)

Facility ID	Source ID	Variation	JAN	FEB	MAR	APR	MAY	JUN	…	DEC
Fac1	SAMPLE1	MONTH	0.2138	0.1433	1.2928	0.098	0.1342	0.3301	…	1.4356

Table 25. Sample Emissions Variation File based on Season and Hour of Day (96 factors)

Facility ID	Source ID	Variation	Season-hour Factor	Season-hour Factor	Season-hour Factor	Season-hour Factor	Season-hour Factor	Season-hour Factor	Season-hour Factor	Season-hour Factor
			Winter 1	**Winter 2**	**Winter 3**	**Winter 4**	**Winter 5**	**Winter 6**	**…**	**Winter 12**
Fac1	SAMPLE1	SEASHR	0.2138	0.1433	1.2928	0.098	0.1342	0.3301	…	1.4356
			Winter 13	**Winter 14**	**Winter 15**	**Winter 16**	**Winter 17**	**Winter 18**	**…**	**Winter 24**
Fac1	SAMPLE1	SEASHR	1.3959	1.2728	0.1079	1.5255	1.5255	1.5519	…	1.799
			Spring 1	**Spring 2**	**Spring 3**	**Spring 4**	**Spring 5**	**Spring 6**	**…**	**Spring 12**
Fac1	SAMPLE1	SEASHR	1.9045	1.9475	1.4684	1.0435	0.8305	0.6952	…	0.3979
			Spring 13	**Spring 14**	**Spring 15**	**Spring 16**	**Spring 17**	**Spring 18**	**…**	**Spring 24**
Fac1	SAMPLE1	SEASHR	0.2138	0.1433	1.2928	0.098	0.1342	0.3301	…	1.4356
			Summer 1	**Summer 2**	**Summer 3**	**Summer 4**	**Summer 5**	**Summer 6**	**…**	**Summer 12**
Fac1	SAMPLE1	SEASHR	1.3959	1.2728	0.1079	1.5255	1.5255	1.5519	…	1.799
			Summer 13	**Summer 14**	**Summer 15**	**Summer 16**	**Summer 17**	**Summer 18**	**…**	**Summer 24**
Fac1	SAMPLE1	SEASHR	1.9045	1.9475	1.4684	1.0435	0.8305	0.6952	…	0.3979
			Fall 1	**Fall 2**	**Fall 3**	**Fall 4**	**Fall 5**	**Fall 6**	**…**	**Fall 12**
Fac1	SAMPLE1	SEASHR	0.2138	0.1433	1.2928	0.098	0.1342	0.3301		1.4356
			Fall 13	**Fall 14**	**Fall 15**	**Fall 16**	**Fall 17**	**Fall 18**	**…**	**Fall 24**
Fac1	SAMPLE1	SEASHR	0.2138	0.1433	1.2928	0.098	0.1342	0.3301	…	1.4356

Table 26. Sample Emissions Variation File based on Wind Speed (6 factors)

Facility ID	Source ID	Variation	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Cat. 6
Fac1	SAMPLE1	WSPEED	0.2138	0.1433	1.2928	0.098	0.1342	0.3301

3.5.8 Alternate Receptors file

As noted previously, HEM4 can model based on U.S. Census blocks or based on alternate receptors you provide. If you check "Use alternate receptors" on the required inputs user interface (discussed below in Section 4.1), then HEM4 will prompt you for an Alternate Receptor file, in lieu of using U.S. Census blocks for the model run. This allows you to model with HEM4 anywhere in the world, both within the U.S and outside the U.S.

The Alternate Receptor file must be a CSV file and provide HEM4 with a list of receptor locations, the type of each receptor (populated "P" or various types of non-populated receptors, such as boundary "B" and monitor "M" receptors), and the populations represented by each receptor. It is important to note that only populated "P" receptors are chosen by HEM4 to be the sites of maximum risk or hazard index; and only "P" receptors are used by HEM4 in cancer incidence calculations. This is discussed further below in Sections 5 and 6. **Note: For HEM4 to run using alternate receptors, you must provide population values for every Alternate Receptor of type "P". The population you provide may be any integer value, 0 or greater**. Even if only one populated Alternate Receptor is missing a value in its population field, HEM4 will not commence the modeling run.

In addition, if you chose in your Facility List Options file to include elevations in your model run, then you must also provide HEM4 the elevation above sea level for each alternate receptor, as well as the hill height of each receptor. To model terrain effects, the alternate receptor file must be filled-in completely for every elevation and hill height. **Any blanks in the elevation fields or hill height fields of the Alternate Receptors file will cause AERMOD to be run in the FLAT mode with no terrain effects**.

AERMOD uses the controlling hill height for flow calculations. Controlling hill height is defined as the highest elevation that is above a 10% grade from the receptor. For more information on the use and suggested calculation of controlling hill heights using an algorithm in AERMAP, the AERMOD terrain processor (EPA 2018c), see Section 2.3.1. It is important to again note that if you leave any hill height field blank in the Alternate Receptors file, then AERMOD will be run in the FLAT mode with no terrain effects (even if you opt to include elevations in your model run in your Facility List Options file and also provide elevations for your alternate receptors).

Alternatively, you can choose to model with the elevation option turned off in your Facility List Options file. In such a modeling run, you do not need to provide any elevations or hill heights in the Alternate Receptor file, as HEM4 will model everything on a flat plane.

Tables 27 and 28 give format guidelines for the Alternate Receptors file and a sample input file, respectively. In addition, a template input file is provided in the HEM4 Inputs folder named *HEM4_alternate_receptors.csv*.

Table 27. Format Guidelines for Alternate Receptors File (CSV)

Field	Type	Sample Value	Description
Receptor ID	Numeric	1	A unique number identifying the Receptor
Type of receptor	Character	P	Type of receptor: P = populated (e.g., house), B = boundary, M = monitor
Coordinate system	Character	L	Type of coordinates: L = longitude, latitude; U = UTM [WGS84]
X-coordinate	Numeric	-52.74629	UTM east coordinate, in meters (if Coordinate System = U) or decimal longitude (if System = L). 5 decimal place precision is recommended for longitude, corresponding to 1 meter
Y-coordinate	Numeric	47.53796	UTM north coordinate, in meters (if Coordinate System = U) or decimal latitude (if System = L). 5 decimal place precision is recommended for latitude, corresponding to 1 meter
UTM zone with hemisphere	Character	17N	UTM zone where the receptor is located if Coordinate System = U
Elevation	Numeric	219.7	Elevation of the receptor above sea level, in meters. Required if you are modeling terrain effects (i.e. choose to model elevations in the Facility List Options file)
Hill Height	Numeric	219.7	Hill height scale, in meters. Required if you are modeling terrain effects (i.e. choose to model elevations in the Facility List Options file)
Population	Numeric	45	Population represented by the alternate receptor; required by HEM4 for every “P” type alternate receptor for incidence calculations.

Table 28. Sample Input File for Alternate Receptor Input File

Receptor ID	Type of Receptor (P, B, M)	Coordinate System (U = UTM L = latitude, longitude)	X-coordinate: Longitude (decimal) or UTM East (m)	Y-coordinate: Latitude (decimal) or UTM North (m)	UTM zone with hemisphere	Elevation (m)	Hill Height (m)	Population
1	B	L	-52.746286	47.53880		219.7	219.7	0
2	P	L	-52.74685	47.54225		219.3	219.3	5
3	P	L	-52.74817	47.53796		220.6	220.6	25
4	P	L	-52.74760	47.53683		262.7	262.7	7
5	M	L	-52.75023	47.53795		263.4	263.4	0
6	P	L	-52.74708	47.53599		292.1	292.1	45
n	…	…	…	…	…	…	…	…

3.5.9 Census Update file

HEM4 provides you the option to change the census file, as discussed below in Section 4.7. Before you use this option, it should be noted that these changes are permanent to your census files. For this reason, it is recommended that you save your original census files to a separate location before using this file to change the official census database provided on EPA's HEM4 webpage.

With the Census Update file, you can:

(1) Zero-out the population of a specific U.S. Census block;
(2) Move a block to a new latitude and longitude location; and/or
(3) Delete a U.S. Census block.

You may wish to **Zero-out** the population of the block if it is clear no residences are present in the block. This change will keep the block in the dataset, so concentrations and risks are modeled, but this receptor will not be considered for maximum risk purposes.

You may wish to **Move** a block to different coordinates that better represent the population.

You may wish to **Delete** or remove a block from the dataset; for example, because there are no people living in the block. However, it should be noted that once removed, the block cannot be added back.

Tables 29 and 30 give format guidelines for the Census Update file and a sample update file, respectively. In addition, a template input file is provided in the HEM4 Inputs folder named *HEM4_Census_block_update_template.xlsx*.

Table 29. Format Guidelines for the Census Update File
(used to permanently change your U.S. Census files)

Field	Type	Sample Value	Description
Facility ID	Character	Fac2	The Facility ID field in the Census Update file is optional and may be left blank. You may wish to use it outside of HEM4 to track the source of changes.
Run Group	Character	Landfills	The Run Group field in the Census Update file is optional and may be left blank. You may wish to use it outside of HEM4 to track the source of changes.
Block ID	Character (not numeric)	170010001001003	In this field, enter the 15-digit U.S. Census block ID. Enter the block ID as text characters rather than numerals, because some block IDs have leading zeroes.
Latitude	Numeric	39.96789	If the Change is a "Move", enter the Latitude (decimal) of where the block should be moved. 5 decimal places are recommended, corresponding to 1-meter accuracy. You may leave this field blank for "Zero" and "Delete" changes.
Longitude	Numeric	-91.37989	If the Change is a "Move", enter the Longitude (decimal) of where the block should be moved. 5 decimal places are recommended, corresponding to 1-meter accuracy. You may leave this field blank for "Zero" and "Delete" changes.
Change	Character	Move	The potential changes include: Zero, Move, and Delete

Table 30. Sample Census Update File

Facility ID	Run Group	Block ID	Latitude (decimal)	Longitude (decimal)	Change
Fac1-TX	Landfills	170010001001003			Zero
Fac1-TX	Landfills	170010001001009	39.96789	-91.37989	Move
Fac1-TX	Landfills	170010001001010			Delete
Fac1-TX	Landfills	370010201001001			Zero
Fac1-TX	Landfills	370010201001002	36.34567	-79.45678	Move
Fac1-TX	Landfills	370010201001003			Delete

3.5.10 Updating the Chemical Unit Risk Estimates and Health Benchmarks Input Files

As discussed in Section 2.2.1, the Chemical Health Effects Library contains chemical health effects data, including dose response toxicity values. You can make changes to the Chemical Health Effects Library by editing the Excel™ spreadsheet files that comprise the library—entitled *Dose_Response_Library.xlsx* and *Target_Organ_Endpoints.xlsx*. These files are located in HEM4's resources folder. You can add new pollutants to these files or edit the values for the chemicals already in the files. If you want to keep your files consistent with the data EPA uses in their HAP risk assessments, check for updated toxicity values on EPA's Dose Response Assessment webpage (EPA 2018a).

When adding new chemical names to the Dose Response Library file, use the same spelling as used in the HAP emissions input file. The Chemical Abstracts Service (CAS) number field in the Chemical Health Effects Library is optional. If you do not specify a cancer URE for a new pollutant, then the URE will be assumed to be 0 (zero) and cancer risks will not be evaluated for that pollutant. Similarly, if you do not specify a noncancer chronic RfC or acute benchmark for a new pollutant, HEM4 will not calculate adverse noncancer chronic or acute health effects, respectively**. If a noncancer chronic RfC is indicated in the Dose Response Library file for a pollutant you add, you must also enter the pollutant in the Target Organ Endpoints file and indicate what organs or organ systems may be impacted**.

For future model runs, to ensure you have the most recent file versions, you should again check EPA's HEM download webpage (https://www.epa.gov/fera/download-human-exposure-model-hem) for the date listed next to the "Toxicity Value Files" link. EPA regularly updates these files. If EPA's update is more recent than the dates shown for the files in HEM4's resources folder, then download the newer files from EPA's HEM download webpage (from link above) and replace your outdated Dose Response Library and/or Target Organ Endpoints files. You may also manually modify the files in your HEM4's resources folder based on updated values from EPA's HEM download page, or from EPA's Dose Response Assessment webpage (EPA 2018a).

4. Step-by-Step Instructions for Running HEM4

Before you initiate a HEM4 modeling run[7], you should ensure you have the necessary input files prepared for your specific modeling needs. Section 3 provides detailed descriptions of all HEM4 input files, and template input files for each are provided in the HEM4 Inputs folder. Table 31 provides a summary of the template files provided in your HEM4 Inputs folder and for what kind of run each file is needed. In addition to the files listed in Table 31, a HEM4 run requires the U.S. Census (if not using alternate receptors) and meteorological databases, and the files located in HEM4's resources folder. These include the *Dose_Response_Library.xlsx* file, the *Target_ Organ_Endpoints.xlsx* file, and, for vapor deposition/depletion, the *Gas_Param.xlsx* file.

Table 31. Summary of HEM4 Template Input Files

Template Input File Name	Description	When Needed
HEM4_Fac_List_Options.xlsx	Facility List Options file	Every run
HEM4_HAP_Emiss.xlsx	HAP [Pollutant] Emissions file	Every run
HEM4_Emiss_Loc.xlsx	Emissions Location file	Every run
HEM4_alternate_receptors.csv	Alternate Receptor file	Required if modeling with alternate receptors (whether outside or inside the U.S.) instead of census block receptors
HEM4_user_receptors.xlsx	User Receptor file	Required if the user receptor column in the Faclist has a "Y" for one or more facilities
HEM4_buoyant_line_param.xlsx	Buoyant Line Source Parameter file	Required if a source in the Emissions Location file is a buoyant line
HEM4_polygon_vertex.xlsx	Polygon Vertex file	Required if a source in the Emissions Location file is a polygon
HEM4_bldg_dimensions.xlsx	Building Dimensions file	Required if the building downwash column in the FacList has a "Y" for one or more facilities
HEM4_particle_data.xlsx	File containing particle size distribution of emissions per source	Required if the deposition OR depletion column AND Pdep OR Pdepl column in FacList has a "Y", AND if Method 1 (the default) is indicated in EmissLoc. (HAP Emiss must also contain particulates)
HEM4_landuse.xlsx	File describing land use surrounding emissions source	Required if the deposition OR depletion column AND Vdep OR Vdepl column in FacList has a "Y". (HAP Emiss must also contain gases/vapor)
HEM4_month-to-seasons.xlsx	File describing monthly stage of vegetation surrounding emissions source	Required if the deposition OR depletion column AND Vdep OR Vdepl column in FacList has a "Y". (HAP Emiss must also contain gases/vapor)
HEM4_emisvar_season.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and seasonal variations are desired (4 factors)
HEM4_emisvar_month.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and monthly variations are desired (12 factors)
HEM4_emisvar_hrofdy.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and hour-of-day variations are desired (24 factors)

[7] Note: It is advisable to close and re-start HEM4 between modeling runs, which clears memory for each new run and avoids potential issues by ensuring a full reset.

Template Input File Name	Description	When Needed
HEM4_emisvar_hrdow.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and hour-of-day + type-of-day (M-F, Sat, Sun) variations are desired (72 factors)
HEM4_emisvar_seashr.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and season + hour-of-day variations are desired (96 factors)
HEM4_emisvar_hrdow7.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and hour-of-day + day-of-week (7) variations are desired (n=168);
HEM4_emisvar_shrdow.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and season + hour of day + type-of-day (weekday, Sat, Sun) variations are desired (288 factors)
HEM4_emisvar_shrdow7.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and season + hour-of-day + day-of-week (7) variations are desired (672 factors)
HEM4_emisvar_mhrdow.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and month + hour-of-day + type-of-day (weekday, Sat, Sun) variations are desired (864 factors)
HEM4_emisvar_mhrdow7.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and month + hour-of-day + day-of-week (7) variations are desired (2,016 factors)
HEM4_emisvar_wspeed.xlsx	Emissions Variation file	Required if the Emissions Variation column in Faclist has a "Y" and wind speed (m/s) variations are desired (6 factors)

Finally, to ensure you have the most recent model version, as well as the most recent chemical health effect (toxicity) values, U.S. Census data, and meteorological data, you should check EPA's HEM download webpage for updates (https://www.epa.gov/fera/download-human-exposure-model-hem). EPA updates these files periodically. If EPA's update is more recent than the version of HEM4 on your computer, then download the newer model version from EPA's HEM download webpage (from link above) and start the newer model. If the chemical health effect files (e.g., Dose Response Library file, Target Organ Endpoints file) on EPA's website are more recent than the ones currently in HEM4's resources folder, then replace the files in your subfolder with the ones you download from EPA's website. Likewise, check the timestamp and update your U.S. Census data (in HEM4's "census" subfolder) and the meteorological data (in HEM4's "aermod" subfolder), as necessary.

After you have ensured the HEM4 model and integrated databases are up-to-date and after you have prepared the input files for the modeling application, start HEM4 by using Windows File Explorer™ to navigate to the folder where HEM4 was unzipped and double click on the HEM4 executable file. The HEM4 title screen will be displayed, as shown below in Figure 4. Note that the buttons near the bottom of the menu bar on the left – the ***HEM4 USER GUIDE*** and the ***AERMOD USER GUIDE*** buttons – link to this HEM4 guide (at https://www.epa.gov/fera/risk-assessment-and-modeling-human-exposure-model-hem) and to AERMOD's user guide (at https://www3.epa.gov/ttn/scram/models/aermod/aermod_userguide.pdf), respectively, and you

should access them whenever you need further instruction and understanding regarding the inputs or outputs of HEM4, or when troubleshooting a modeling run issue.

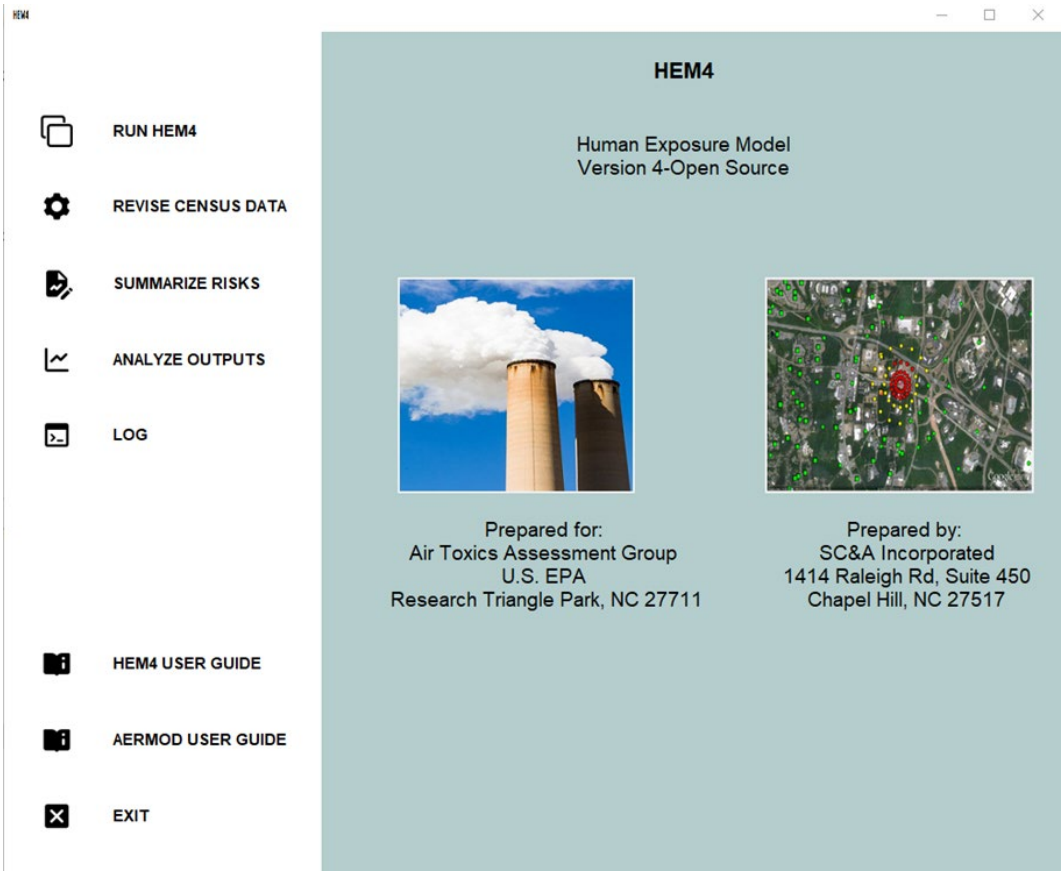


Figure 4. HEM4 Title Screen

The ***RUN HEM4*** button at the top of the menu bar on the left will take you to the next screen, from which you can initiate a model run. To view this HEM4 User's Guide or the AERMOD User's Guide, on this screen or any subsequent screen, click on the buttons on the bottom of the menu bar.

4.1 Provide Standard Input Files and Indicate Receptors

On the initial input screen (***RUN HEM4)*** shown below in Figure 5, you must first indicate whether you will use U.S. Census receptors or alternate receptors for your model run. Within the U.S., you can use either U.S. Census receptors or alternate receptors that you provide. For modeling runs outside the U.S., you must use alternate receptors. Figure 5 shows the input selection buttons for the three required input files: the Facility List Options file, the HAP Emissions file, and the Emissions Location file. Clicking on each of these buttons will allow you to browse your computer to select the appropriate file. The Facility List Options file, HAP Emissions file, and Emissions Location file are described in detail in Sections 3.2, 3.3 and 3.4, respectively.

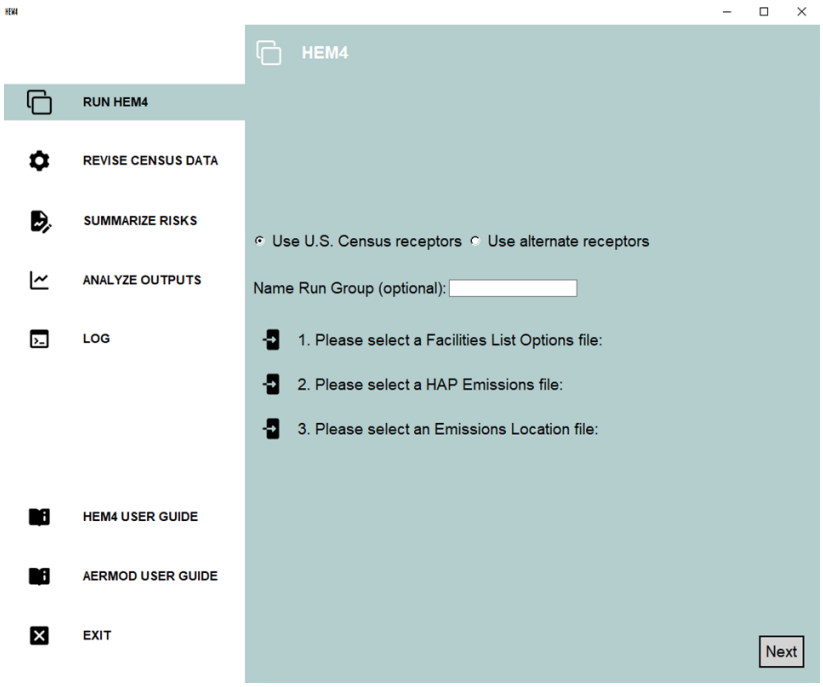


Figure 5. Run HEM4 with U.S. Census Receptors

If you choose to use alternate receptors, then an additional input selection button will appear near the bottom middle of the screen, as shown in Figure 6, that requires you to browse for and select an alternate receptor CSV file. (**Note: It may take several minutes for your Alternate Receptor file to upload for modeling**. **Do not click *Next* until it has uploaded**.) The Alternate Receptors file is described in Section 3.5.8. As with all modeling runs, for a run using alternate receptors, you must also browse for and select the Facility List Options, HAP Emissions, and Emissions Location input files.

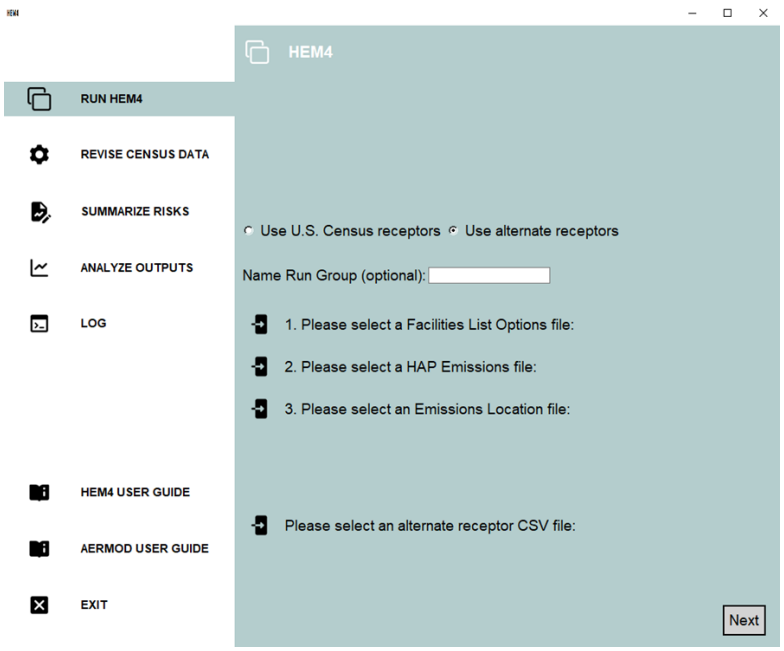


Figure 6. Run HEM4 with Alternate Receptors

For either type of run, you can (optionally) enter a run group name in the ***Name Run Group*** box provided. This is recommended because the name will be used to identify the subfolder containing the results of your run, located within the "output" folder, and will be helpful in identifying which folder the post-modeling tools for summarizing, viewing and analysis should be pointed towards. The name you enter in the "Name Run Group" box will also be prepended to the output files containing the results for the run as a whole.

After you have indicated what type of receptors should be used for the modeling run and entered the three required input files on this initial screen, click ***Next*** at the bottom right corner of the screen to continue. If no additional input files are needed beyond the Facility List Options, Emissions Location and HAP Emissions files already entered, then a pop-up box will appear asking you to confirm the start of the HEM4 run, as shown below in Figure 7.

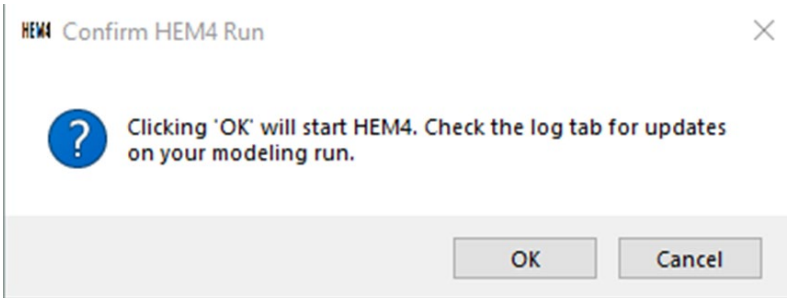


Figure 7. Confirm HEM4 Run Pop-Up Start Box

Clicking *'OK'* in this box will initiate the modeling, and a log of the modeling progress will appear as shown and described in Section 4.4. Click *Cancel* if you need to change any input files already entered. If additional input files are required, one or two additional screens will appear after you click ***Next***, which are discussed in Sections 4.2 and 4.3

4.2 Provide Additional Input Files

If additional inputs are required, one of two screens will appear next, depending on the nature of your sources in the Emissions Location file and the modeling options you indicated in your Facility List Options file. One screen that may appear is shown below in Figure 8. The other input screen which may appear is shown and discussed in Section 4.3.

This screen will prompt you for one or more of the following additional input files: a user receptors file; an emissions variation file; a buoyant line parameters file; a polygon vertex file; and/or a building dimensions file. For example, if you indicated in your Facility List Options file that you'd like to include emissions variations for one or more facilities to be modeled, then a button will appear on this screen asking for the location of your Emissions Variation file (as shown in Figure 8). Likewise, if one of the sources in your Emissions Location file is a buoyant line source, then a button will appear prompting you to browse your computer and select a buoyant line parameter file. If other input files are needed based on your Facility List Options file and Emissions Location file, additional buttons will appear and request that you browse for and select the required file. When you hover over each of these input file buttons, instructions will be displayed on the top of the screen describing each file type.

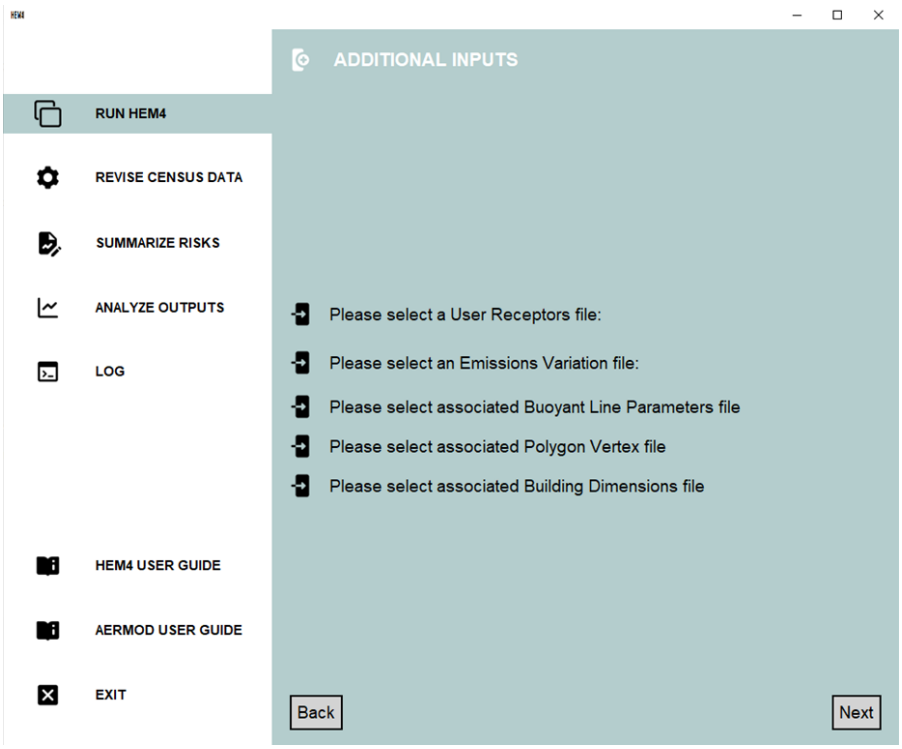


Figure 8. Provide Additional Input Files

After you have entered these additional input files, click ***Next*** at the bottom right corner of the screen to continue. If no other inputs are needed, HEM4 will display the pop-up box, shown above in Figure 7, stating "*Clicking 'OK' will start HEM4. Check the log tab for updates on your modeling run*." Click *Cancel* if you need to change any input files. If you are ready for HEM4 to start your modeling run, click *OK*, and a log of the modeling progress will appear as shown and described in Section 4.4. If additional inputs are needed for deposition and depletion modeling, another input screen will open next, as shown and discussed in Section 4.3.

4.3 Provide Deposition and Depletion Input Files

When modeling deposition/depletion, HEM4 can direct AERMOD to (1) calculate a deposition flux and (2) deplete the plume based on the calculated deposition. You can direct HEM4 to provide the deposition flux in the outputs, or not (to save space). Generally speaking, deposition modeled with plume depletion will reduce the ambient impacts from the emission source by removing pollutants from the plume. Air concentrations will be depleted as pollutants are deposited to the ground. Deposition and plume depletion have more of an effect on ambient concentrations farther from the facility than it does closer to the facility where the maximum impact generally occurs. Alternatively, you may choose to calculate the deposition flux, but not deplete the plume (to allow for higher, more conservative air concentrations). Either way, the modeled deposition flux may be used as an input to a separate multipathway model such as the Total Risk Integrated Methodology (TRIM) (EPA 2018e).

In most cases, if you chose to model deposition and/or depletion in the Facility List Option file, HEM4 will require additional input files [8]. HEM4 uses AERMOD to calculate deposition and depletion effects for particulate matter, vapor (gaseous) pollutants, or both. The make-up of your emissions – that is, the percentage particulate and gas – is dictated to HEM4 by your HAP Emissions input file. Specifically, the fifth column in the HAP Emission input file ("Fraction emitted as particulate matter") indicates to HEM4 whether your emissions are 100% particle (if this column is populated with 100 for all pollutants), 100% vapor (if this column is left blank or populated with 0 for all pollutants), or a mixture of particles and gas. You will need to browse your computer and select the additional files needed for modeling of deposition and/or depletion on the screen depicted in Figure 9. You will be prompted to provide between 1 and 3 deposition/ depletion related input files, depending on your modeling options and the nature of the emissions to-be-modeled.

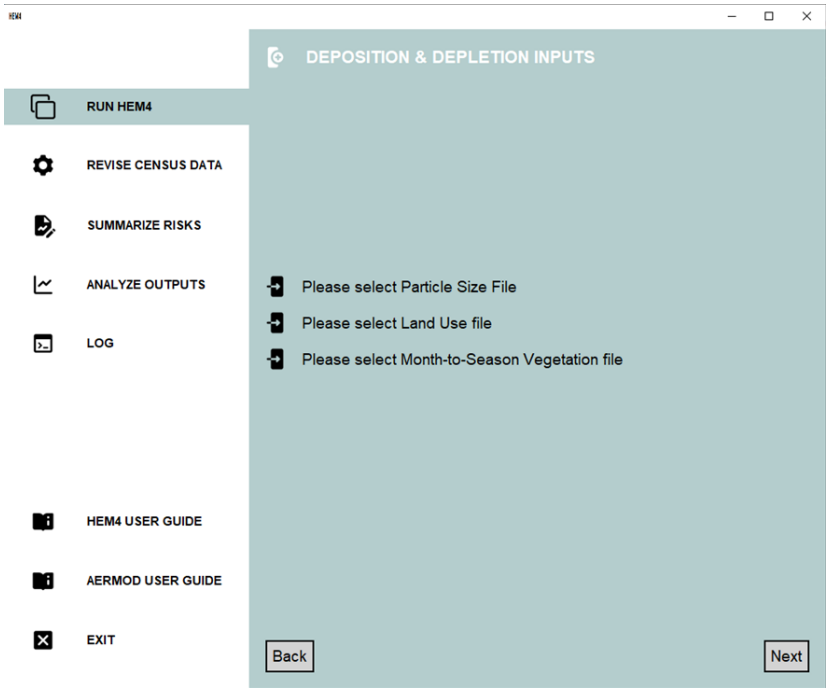


Figure 9. Provide Deposition and Depletion Input Files

If your Facility List Options file indicates that you chose to model particle deposition and/or particle depletion using AERMOD's Method 1 (as discussed in Section 3.4.2) AND your HAP Emissions file indicates that some of the emissions are in particle form, then a particle data file is required by HEM4/AERMOD. Upload the particle data input file containing the particle size information, mass fraction and particle size density for each pollutant (HAP) by browsing your computer for it at the first Browse button on this screen, as shown in Figure 9.

[8] Note: The one deposition and/or depletion modeling case, which requires no additional inputs and therefore no deposition/depletion input screen, is if you are modeling only particle deposition and/or depletion AND chose in your Emissions Location input file to use Method 2 for the Deposition Method. It should also be noted that AERMOD does not model deposition or depletion of emissions from buoyant line sources. Therefore, if you indicate in your Facility List Options file that deposition or depletion should be modeled for a facility with buoyant line sources in your Emissions Location file, AERMOD will not run successfully. In this case, remove the buoyant line source IDs from your input files and model that source separately, without deposition or depletion.

If your Facility List Options file indicates that you chose to model vapor (gaseous) deposition and/or vapor depletion AND your HAP Emissions file indicates that some of the emissions are in vapor form, then HEM4 will instruct AERMOD to model vapor deposition and/or depletion. Depending on the type of vapor deposition/depletion you indicated in your Facilities List Option file, two additional inputs may be required by HEM4/AERMOD: a land use input file and a month-to-seasons input file. These additional input files are needed only to quantify dry (or "wet and dry") deposition and/or depletion of vapor emissions, as discussed in Section 3.5.4. If you wish to model "wet only" deposition and/or depletion of gaseous pollutants, these additional input files are not needed by HEM4. (These files are also not needed to model particle-only deposition and/or depletion.) Upload these files by browsing your computer for them at the second and third buttons on this screen shown in Figure 9.

As noted in Section 3.5.4, you should also check to ensure that the vapor (gaseous) pollutants in your HAP Emissions file are included in the Gas Parameter reference file. If these pollutants are not included – or if you wish to include different parameter values than the Gas Parameter file currently uses – you should edit the Gas Parameter file located in HEM4's resources folder, as discussed in Section 3.5.4. Otherwise, generic default gas parameter values will be used. (The default file pathway is "HEM4\resources\Gas_Param.xlsx".)

It should be noted that HEM4 requires significantly more time to run if you opt to model deposition and/or depletion. The exact run time will depend on the particular source configuration and modeling domain but can be over an hour or more per facility. You can utilize the FASTALL option in the Facility List Options file to expedite the run. As noted in Section 3.2.10, FASTALL conserves model runtime by simplifying the AERMOD algorithms used to represent the meander of the pollutant plume (EPA 2019a).

After you enter the required files on the deposition/depletion input screen, click ***Next*** on the bottom right and HEM4 will display the pop-up box (shown above in Figure 7) stating "*Clicking 'OK' will start HEM4. Check the log tab for updates on your modeling run*." Click *Cancel* if you need to change any file locations on this screen, and the ***Back*** button to change any input files on the previous screen. If you are ready for HEM4 to start your modeling run, click *OK* and a log of the modeling progress will appear as shown and described in Section 4.4.

4.4 Check HEM4 Log

After HEM4 starts modeling your facilities (or facility), the ***LOG*** screen will appear to show you HEM4's progress in real-time including any errors in processing, if there are any. The Log screen is shown below in Figure 10. (Note: The cursor is visually disabled on the log screen, but it is recommended that you not place your cursor on the log tab screen itself, because doing so may reset where the log displays the next line of progress and result in seemingly non-sequential progress messages; rather use the scroll bar on the right to show more of the log screen, as needed.) Once the modeling run is complete, HEM4 also produces a log text file as a permanent record of the modeling.

The Log screen and text file will provide you with the following modeling run information:

- the meteorological period used, whether annual (the default) or a different period you selected;
- the full list of input files uploaded for the modeling run;

- any mismatch between input files prior to you correcting the mismatched files (e.g., mismatched Source IDs between the HAP Emissions and Emissions Location files);
- the default values used for any parameters with out-of-range (unacceptable) values specified in your input files;
- the run group name;
- the Facility IDs modeled and the location of each facility's center;
- the start and end time for the AERMOD portion of the modeling run;
- the full list of outputs produced; and
- the number of minutes required for HEM4 to model each facility and produce the facility-specific outputs.

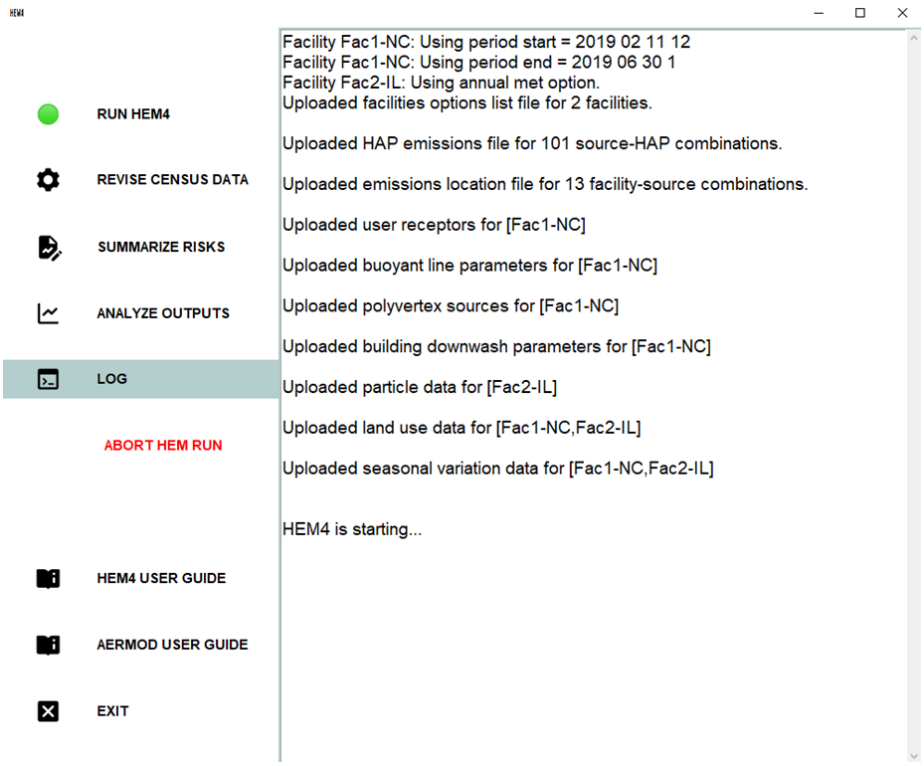


Figure 10. Log Screen

After the modeling is complete, the log text file, named HEM4.log, will be located in the run group folder you name (as discussed in Section 4.1) and will contain information about the facilities modeled in your run. The log file will also indicate what default values HEM4 used (listed in Sections 3.2, 3.3, and 3.4) for the three required input files, in lieu of erroneous out-of-range values you may have included in your input files, as discussed further in Section 4.8. Finally, the log file will also indicate what facilities failed to run successfully, including what errors caused the failure, which is also discussed further in Section 4.8.

The Appendix includes a sample HEM4 log file produced for a two-facility modeling run. The log file will also list any risk summary program outputs you opted to produce. The next section discusses how to run the risk summary programs.

4.5 Summarize Risks

The ***SUMMARIZE RISKS*** button on the menu bar on the left allows you to summarize HEM4 results using one or more summary programs to produce the following risk summary reports, which are based on all facilities modeled in the run group:

- Max Risk Report;
- Cancer Drivers;
- Hazard Index Drivers;
- Risk Histogram;
- Hazard Index Histogram;
- Incidence Drivers;
- Acute Impacts;
- Multipathway; and
- Source Type Risk Histogram.

The Summarize Risks screen is shown in Figure 11. Note: Before you choose to summarize your risk results via these reports, you may wish to perform certain QA checks on the modeled facility-specific results, as described in Section 9.

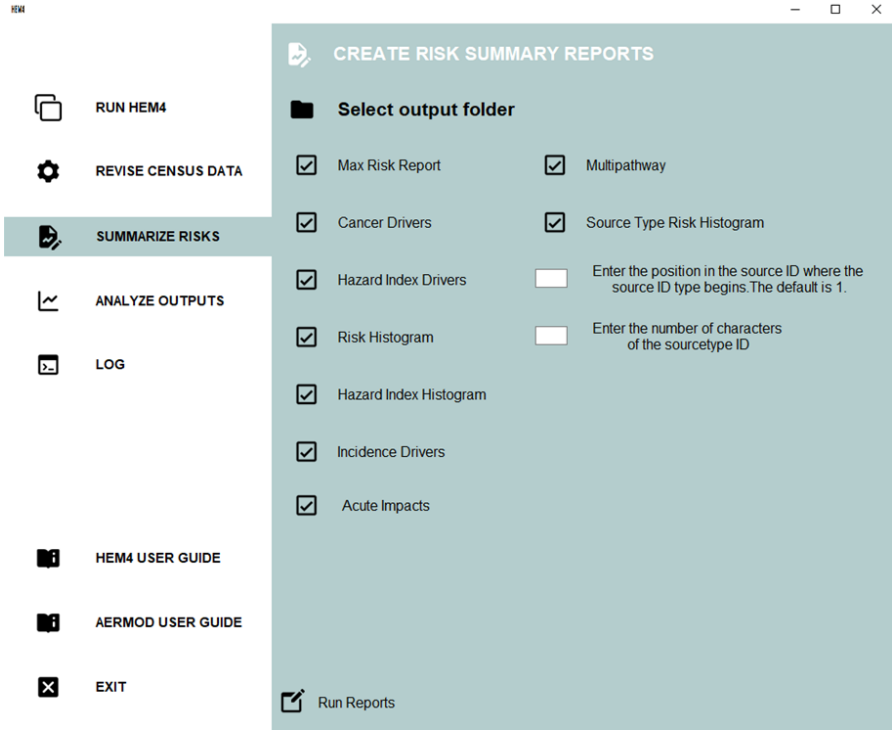


Figure 11. Run the Risk Summary Programs

First, click on the ***Select output folder*** button to browse for the folder where the HEM4 outputs you want summarized are located. Next, select which summaries you would like to run by checking the box before each, and then click on the "Run Reports" button to initiate the selected summaries. The outputs produced by these risk summary programs are report summaries of all facilities modeled in your run as group, rather than facility-specific outputs, and are described in Section 8.

The Source Type Risk Histogram summary requires you to indicate where in your Source IDs the source type begins and ends. As discussed in Section 3.3.1, it's helpful to create your Source IDs so that the type of source is identified always in the same location in the Source ID string. For example, if you are modeling a series of storage tanks and wastewater vessels, you could identify them with IDs such as ST01, ST02, ST03, WW01, WW02, and so on. In this example, the source type starts in location 1 of the Source ID string and is 2 characters long (i.e., ST and WW). Therefore, in this case, after you check the Source Type Risk Histogram box (shown above in Figure 11), you would enter a 1 next to "Enter the position in the Source ID where the source type begins." You would then enter a 2 next to "Enter the number of characters in the source type."

After you have selected the summaries you want run, check the Log screen for progress. The *HEM4.log* text file will also report any errors. The Risk Summary Reports you choose to run will be placed in the same output folder where you indicated the HEM4 results are located (which were summarized using these programs).

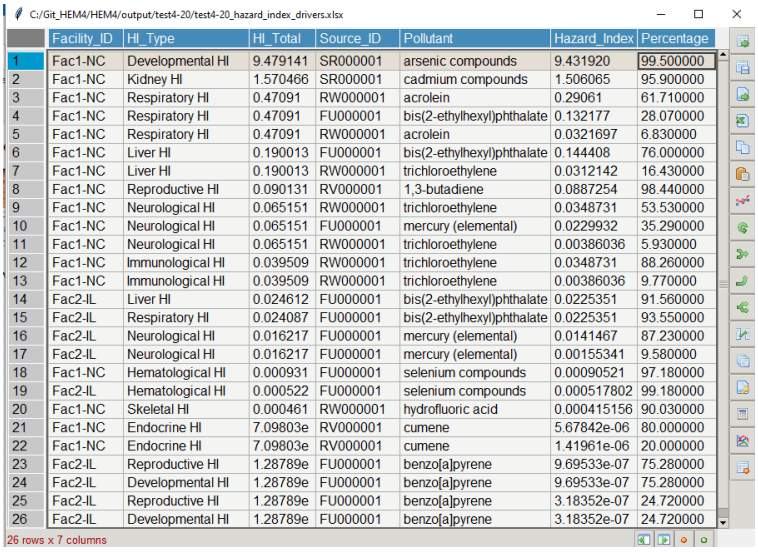
4.6 Analyze Outputs

The ***ANALYZE OUTPUTS*** button on the menu bar on the left allows you to view and analyze the HEM4 facility-specific modeling results as well as the run group-wide Risk Summary outputs. The View and Analyze Outputs screen is show below in Figure 12.

Figure 12. View and Analyze Outputs

This screen consists of three buttons that allow you to (1) open a facility or summary output table via a spreadsheet app for further analysis and graphing; (2) open a chronic or acute risk map; and (3) view summary graphical outputs in web browser. After you click on these buttons, HEM4 will prompt you to identify the location of the output files you wish to view and analyze further.

If you choose to open a facility or summary Excel or CSV output table using the first button (shown in Figure 12), HEM4 will open the file within a spreadsheet app with numerous widgets available for further analysis and graphing. This widget is provided by a pandastable library as an interactive way to review and analyze HEM4's tabular output data (see https://pandastable.readthedocs.io/en/latest/description.html.) An example of a Hazard Index Drivers output (spreadsheet) opened via this first button is shown in Figure 13. The spreadsheet and graphing widgets along the right-hand side include: Load table; Save; Import CSV; Load Excel file; Copy table to clipboard; Paste table; Select data to plot; Transpose; Aggregate; Pivot; Melt; Merge, concatenate or join; Prepare a sub-table; Filter table; Calculate; Model fitting; Clear table; Contract columns; Expand columns; Zoom out; and Zoom in.



	Facility_ID	HI_Type	HI_Total	Source_ID	Pollutant	Hazard_Index	Percentage
1	Fac1-NC	Developmental HI	9.479141	SR000001	arsenic compounds	9.431920	99.500000
2	Fac1-NC	Kidney HI	1.570466	SR000001	cadmium compounds	1.506065	95.900000
3	Fac1-NC	Respiratory HI	0.47091	RW000001	acrolein	0.29061	61.710000
4	Fac1-NC	Respiratory HI	0.47091	FU000001	bis(2-ethylhexyl)phthalate	0.132177	28.070000
5	Fac1-NC	Respiratory HI	0.47091	RW000001	acrolein	0.0321697	6.830000
6	Fac1-NC	Liver HI	0.190013	FU000001	bis(2-ethylhexyl)phthalate	0.144408	76.000000
7	Fac1-NC	Liver HI	0.190013	RW000001	trichloroethylene	0.0312142	16.430000
8	Fac1-NC	Reproductive HI	0.090131	RV000001	1,3-butadiene	0.0887254	98.440000
9	Fac1-NC	Neurological HI	0.065151	RW000001	trichloroethylene	0.0348731	53.530000
10	Fac1-NC	Neurological HI	0.065151	FU000001	mercury (elemental)	0.0229932	35.290000
11	Fac1-NC	Neurological HI	0.065151	RW000001	trichloroethylene	0.00386036	5.930000
12	Fac1-NC	Immunological HI	0.039509	RW000001	trichloroethylene	0.0348731	88.260000
13	Fac1-NC	Immunological HI	0.039509	RW000001	trichloroethylene	0.00386036	9.770000
14	Fac2-IL	Liver HI	0.024612	FU000001	bis(2-ethylhexyl)phthalate	0.0225351	91.560000
15	Fac2-IL	Respiratory HI	0.024087	FU000001	bis(2-ethylhexyl)phthalate	0.0225351	93.550000
16	Fac2-IL	Neurological HI	0.016217	FU000001	mercury (elemental)	0.0141467	87.230000
17	Fac2-IL	Neurological HI	0.016217	FU000001	mercury (elemental)	0.00155341	9.580000
18	Fac1-NC	Hematological HI	0.000931	FU000001	selenium compounds	0.00090521	97.180000
19	Fac2-IL	Hematological HI	0.000522	FU000001	selenium compounds	0.000517802	99.180000
20	Fac1-NC	Skeletal HI	0.000461	RW000001	hydrofluoric acid	0.000415156	90.030000
21	Fac1-NC	Endocrine HI	7.09803e	RV000001	cumene	5.67842e-06	80.000000
22	Fac1-NC	Endocrine HI	7.09803e	RV000001	cumene	1.41961e-06	20.000000
23	Fac2-IL	Reproductive HI	1.28789e	FU000001	benzo[a]pyrene	9.69533e-07	75.280000
24	Fac2-IL	Developmental HI	1.28789e	FU000001	benzo[a]pyrene	9.69533e-07	75.280000
25	Fac2-IL	Reproductive HI	1.28789e	FU000001	benzo[a]pyrene	3.18352e-07	24.720000
26	Fac2-IL	Developmental HI	1.28789e	FU000001	benzo[a]pyrene	3.18352e-07	24.720000

Figure 13. Hazard Index Drivers File Opened via Spreadsheet App

As a further example of this tool, if you click on the “Select-data-to-plot” widget on the right-hand side of the spreadsheet, a data plot automatically pops-up with numerous formatting options for graphing. A depiction of one plot is shown in Figure 14.

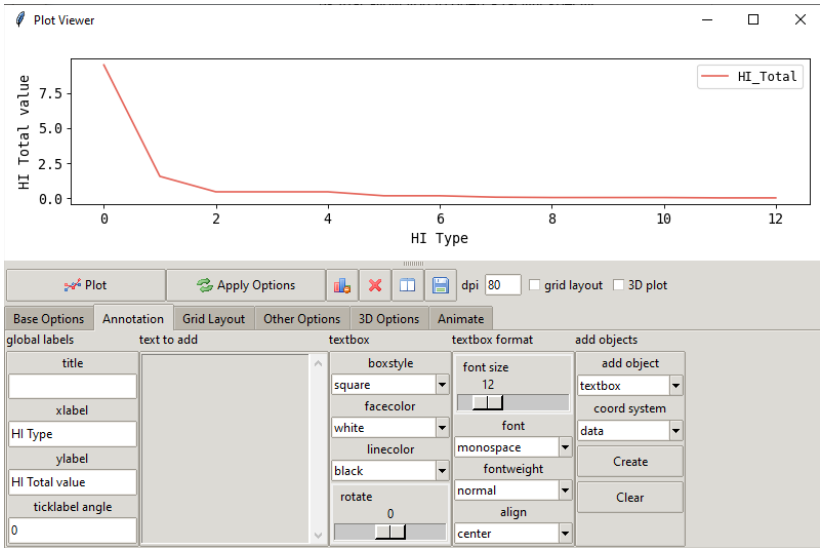


Figure 14. Select Data to Plot Widget

If you choose to open a chronic or acute risk map with the second button (shown in Figure 12), you will be asked to select a chronic kmz file from your modeled outputs, which HEM4 will launch in Google Earth™. Or you can select an acute map html file to view on a satellite street map. An example of a chronic kmz file is shown below in Figure 15 displayed via Google Earth™, with the cancer and noncancer chronic results overlaid on the map. These results are discussed further in Section 6. Note: The first time you run HEM4, your computer may take several minutes to open Google Earth™; but the application will open quickly after subsequent runs.

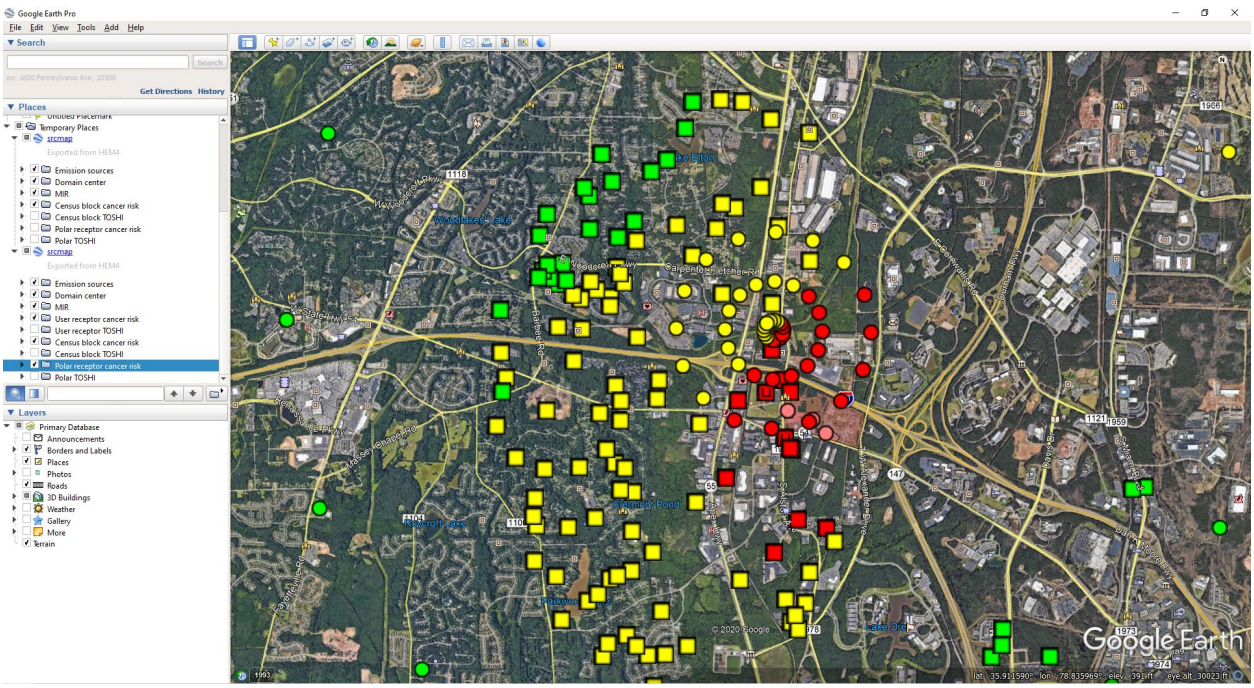


Figure 15. Chronic Risk Map shown in Google Earth™

To open an acute map, you must first run the Acute Impacts summary from the Summarize Risks ("Create Risk Summary Reports") screen, shown in Figure 11. After you run the Acute Impacts summary program, HEM4 will produce an output subfolder called "Acute Maps", which will be located in the same place where the other facility-specific and summary outputs from your run are located. Click on the "Open a chronic or acute map" button on the View and Analyze Outputs screen (shown in Figure 12) and then HEM4 will ask you to select the html file you wish to view. Choose an html file from any of the html files located in the "Acute Maps" subfolder and HEM4 will display your map in your default browser window. An example html acute map is shown in Figure 16, for one of the acute benchmarks (REL) based on modeled acrolein results. The acute output files underlying these mapped results are explained in Sections 6 and 7.

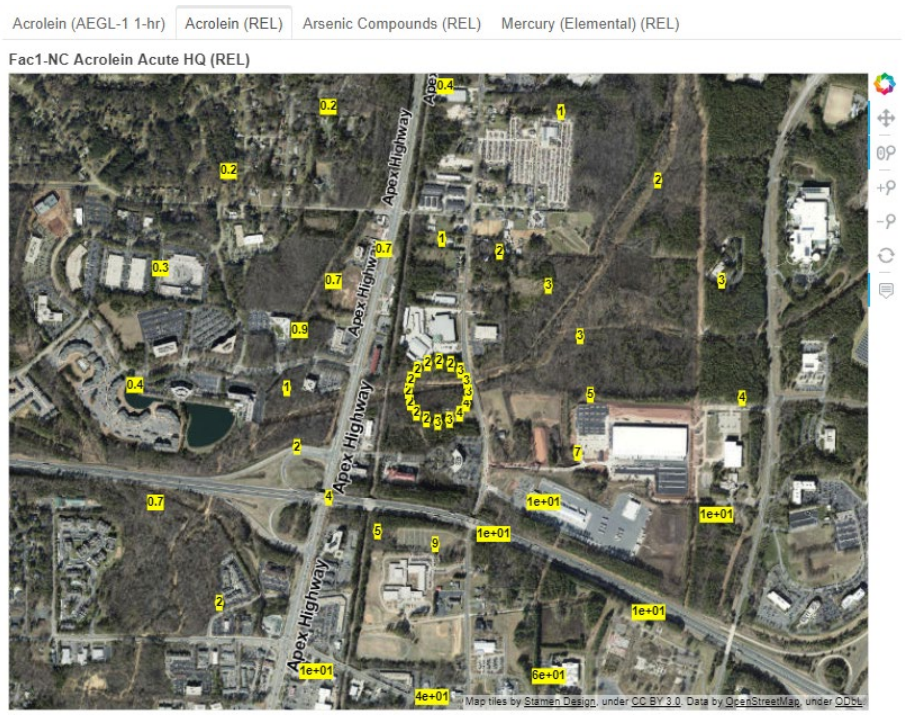


Figure 16. Acute Map View of HTML File

Finally, you can choose to view summary graphical outputs in your default web browser by clicking on the third button (shown in Figure 12). **To use these statistical and graphical visualization tools, you must choose a folder containing Risk Summary reports** run from the Summarize Risk screen (shown in Figure 11). Note that all risk summary reports must be present in your selected folder to use these statistical and graphing tools, except the Max Risk report, Multipathway report and Acute Impact report: these three reports may be present in your selected folder but are not required. After you select your desired output folder, the graphical visualizations of your results that appear in your default web browser are constructed via the Dash app, which is a Python framework for building interactive web applications. The graphical displays of your results offered by this application include:

- a map of your modeled facilities;
- pie charts based on the cancer incidence percentages by pollutant and source type;
- bar charts showing the number of people at increasing levels of cancer risk (e.g., less than 1-in-1 million risk, greater than or equal to 1-in-1 million risk, greater than or equal to 10-in-1 million risk, greater than or equal to 100-in-1 million risk);
- bar charts showing the number of people at increasing noncancer hazard index levels for each of the 14 modeled target organ specific hazard indices (e.g., less than or equal to 1, greater than 1, greater than 10, greater than 100, greater than 1000);
- bar charts showing the source and pollutant risk drivers of your modeling run for both cancer and noncancer;
- bar charts showing the acute screening hazard quotients by benchmark and pollutant for each facility with modeled acute impacts; and
- an interactive and exportable spreadsheet displaying the maximum cancer risk and noncancer hazard index values for each modeled facility.

An example of one of the several graphical visualizations of your results offered by this application is shown in Figure 17, which displays pie charts based on the cancer incidence percentages by pollutant and source type, for a modeling run based on 5 different pollutants and 8 different source types.

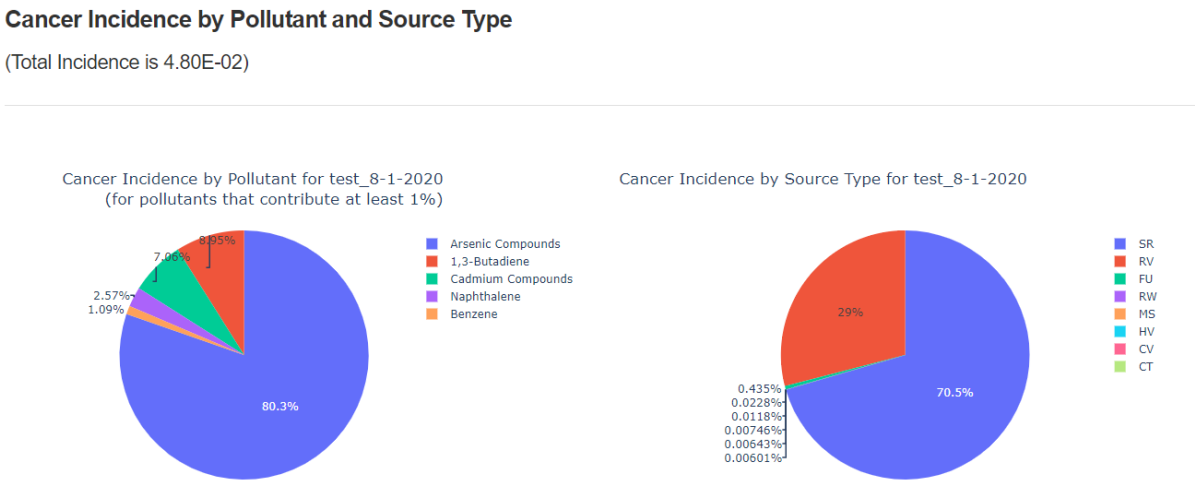


Figure 17. Example Graphical Visualization of Incidence by Pollutant and Source Type

The output files underlying these results are explained in Sections 6 and 7.

4.7 Revise Census Data Option

The ***REVISE CENSUS DATA*** button on the menu bar on the left allows you to change your U.S. Census file using the census update file described in Section 3.5.9. On this screen, shown in Figure 18, click on the "Please select a census update file" button to select an update file from your computer. Once your census update file is selected, click on the "Revise" button on this screen, which will change the census files that HEM4 uses to model any facilities after the change. (Note: this revision is permanent to your census files unless you change your census files back to their original. For this reason, it is recommended that you save your original census files to a separate location before clicking on "Revise" using this screen.)

You can use the census update file described in Section 3.5.9 to (1) zero-out the population of a specific U.S. Census block, (2) move a block to a new latitude and longitude location, and/or (3) delete or remove a census block. The reasons for making such revisions to your census dataset are also discussed in Section 3.5.9.

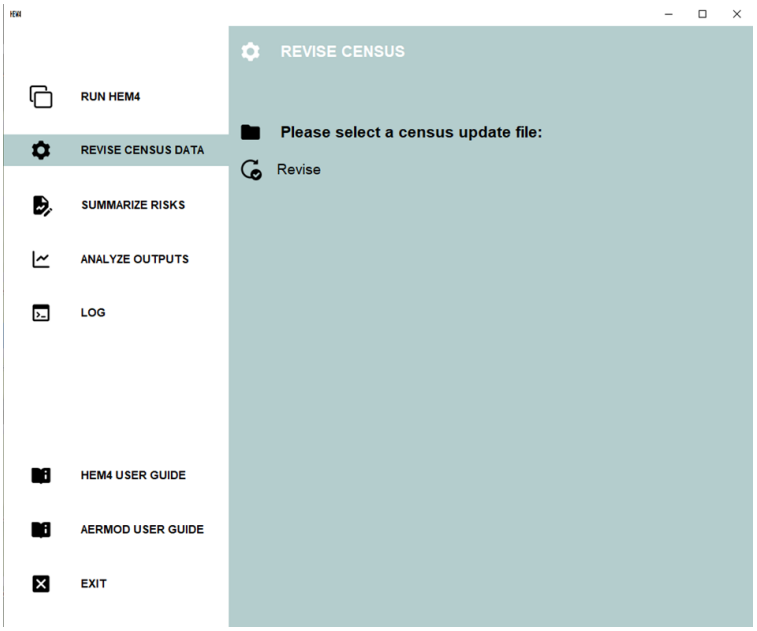


Figure 18. Revise Census Data Screen

4.8 Error Messages and Failed Runs

When initiating a model run, HEM4 will perform a series of checks on your inputs to identify obvious errors that would cause the model (including AERMOD) to fail. Identifying these input errors prior to HEM4 attempting to model the erroneous values avoids most unsuccessful model runs and provides you with instructions to rectify the problem. Reviewing the AERMOD documentation is also important and helpful if you receive an error from HEM4 or from AERMOD (in the aermod.out file, described in Section 6.1.13) when running your inputs and the resolution of the error is not clear (EPA 2019a, EPA 2019b).

For example, on the user interfaces that instruct you to select input files (discussed above in Section 4), if you attempt to upload an input file with the wrong number of columns (a.k.a. fields), then an error message will pop-up indicating that the file you uploaded had “x” columns, but should have “y” columns. HEM4 will also compare the Source IDs in your input files to ensure they match. If the Source IDs in your Emissions Location file do not match the Source IDs in your HAP Emissions file, then an error message will pop-up indicating that “Your Emissions Location and HAP Emissions files have mismatched Source IDs. Please correct one or both files with matching sources and upload again.” A sample of the kinds of pop-up error messages and their meanings are listed in Table 32.

Additionally, if you entered a value for an input parameter that is out-of-range of the acceptable values for that parameter, then HEM4 will replace your problematic value with the default value, and indicate the replacement in the log file, as noted above in Section 4.4. The values HEM4 defaults to are listed for applicable parameters within each standard input file starting in Section 3.2.

Table 32. Sample List of Error Messages and Causes in HEM4

Pop-Up Error Message	Meaning / Cause
"One or more facility IDs are missing in the <file> List."	The uploaded file contains records without a valid Facility ID.
"One or more met stations referenced in the Facility List are invalid."	The uploaded Facility List Options file contains facilities with met station references that are not present in the master list of met stations.
"One or more source IDs are missing in the <file> List."	The uploaded file contains records without a valid Source ID.
"One or more pollutants are missing in the <file> List."	The uploaded file contains records without a valid pollutant (HAP).
"One or more locations are missing a coordinate system in the <file> List."	The uploaded file contains records without valid coordinate system values.
"One or more source types are missing a valid value in the Emissions Locations List."	The uploaded Emissions Location file contains records without a valid source type value for one or more fields.
"The following pollutants were not found in HEM4's Dose Response Library: [list of HAP names not found]. Would you like to amend your HAP Emissions file? (They will be removed otherwise.)"	One or more HAP listed in the HAP Emissions file is not included in the Dose Response Library. Note: If you do not revise your HAP Emissions file to include only HAP listed in your Dose Response library, then HEM4 will drop those HAP for the current run. Alternatively, you may exit the run and amend the Dose Response Library before starting a new run.
"Facility <fac>: [lat/lon] value out of range in the Emissions Locations List."	The uploaded Emissions Location file contains an out-of-range latitude or longitude value for one or more sources.
"Facility <fac>: UTM zone value malformed or invalid in the Emissions Locations List."	The uploaded Emissions Location file contains an invalid UTM zone value.
"Error: Some non-numeric values were found in numeric columns in this data set."	The uploaded file contains non-numeric values in a field that should have only numbers.
"Length Mismatch: Input file has x columns but should have y columns."	The uploaded file contains the wrong number of columns.
"<file> parameters are specified in the Facilities List Options file. Please upload a <file> File."	The Facility List Options file specifies modeling options requiring additional input files that have not been uploaded.
"AERMOD models building downwash from point sources only (i.e., vertical P, horizontal H, or capped C point sources). Your building dimensions file includes non-point sources. Please edit your building dimensions file to remove all non-point sources."	AERMOD models building downwash of emissions from vertical point (P), capped point (C), and horizontal point (H) source types only. The uploaded Facility List Options file indicates building downwash for one or more facilities and the Source IDs for those facilities in the uploaded building dimensions input file include sources other than P, C, or H types.

Pop-Up Error Message	Meaning / Cause
“AERMOD cannot currently model deposition or depletion of emissions from buoyant line sources, and the Emissions Location file includes a buoyant line source for one or more facilities. Please disable deposition and depletion for each of these facilities or remove the buoyant line source(s)."	AERMOD version 19191 can model deposition and/or depletion from all source types except buoyant lines. The uploaded Facility List Options file indicates deposition and/or depletion for one or more facilities and one or more Source IDs for those facilities in the uploaded Emissions Location file are buoyant lines.
“AERMOD’s FASTALL option cannot be used with buoyant line sources, and the Emission Location file includes a buoyant line source for one or more facilities. Please disable FASTALL for each of these facilities or remove the buoyant line source(s)."	AERMOD version 19191 does not allow the FASTALL option with buoyant line sources. The uploaded Facility List Options file indicates FASTALL for one or more facilities and one or more Source IDs for those facilities in the uploaded Emissions Location file are buoyant lines.
"AERMOD ran unsuccessfully. Please check the error Section of the aermod.out file in the <fac> output folder."	AERMOD didn't run successfully, for a reason specified in the aermod.out file.
"Cannot generate summaries because there is no Facility_Max_Risk_and_HI Excel file in the folder you selected."	The Risk Summary reports could not be run because the Facility_Max_Risk_and_HI output file is needed, but is missing.

If HEM4 is unable to model a facility or facilities due to errors in the inputs, HEM4 will not only note the errors in the log file but will also produce an Excel file entitled “Skipped Facilities” in the run group’s output subfolder. You can use the list of skipped facilities in column A of this output file to create a new Facility List Options file, after you fix the errors, to model these facilities. This is discussed further in Section 9.

Finally, **in the event of a failed modeling run, you should close down HEM4 and then re-start before your next modeling run**. A full shutdown and re-start of HEM4 ensures the memory has been cleared, which will reset values in the underlying model code and avoid a variety of potential issues in the next run.

5. HEM4 Modeling Calculations for each Facility

Section 3 describes the HEM4 input files and Section 4 describes the step-by-step instructions for the user to initiate a HEM4 modeling run. This section describes the internal modeling algorithms and simplifying assumptions employed by HEM4, once initiated, during a modeling run. We list the AERMOD options used to model emission dispersion from each facility and describe the method HEM4 implements to transform AERMOD's single pollutant concentration modeling into multiple pollutant concentration estimations. This section also discusses HEM4's post-dispersion computation of health impacts at modeled receptors, including cancer risk and noncancer health hazards, as well as HEM4's calculations to estimate the contributions of individual pollutants and emission sources to the estimated concentrations and health impacts at the modeled receptors.

5.1 Dispersion Modeling

As noted previously in this guide, HEM4 carries out dispersion modeling by running the AERMOD dispersion model. Section 3 describes a number of input options you can specify for running AERMOD—for example, incorporating deposition and depletion, emissions variations, and using urban or rural dispersion parameters. This section discusses the options that HEM4 implements by default. In addition, this section describes the dilution factor methodology used in HEM4 for modeling multiple pollutants based on AERMOD's single pollutant modeling.

5.1.1 Regulatory Default, ALPHA and BETA Options

HEM4 uses primarily the regulatory default options when running AERMOD. These options include the following:

- Uses stack-tip downwash (except for Schulman-Scire downwash);
- Uses buoyancy-induced dispersion (except for Schulman-Scire downwash);
- Does not use gradual plume rise (except for building downwash);
- Uses the "calms processing" routines;
- Uses upper-bound concentration estimates for sources influenced by building downwash; from super-squat buildings;
- Uses default wind profile exponents;
- Uses low wind speed threshold;
- Uses default vertical potential temperature gradients; and
- Uses missing-data processing routines.

However, it should also be noted that AERMOD (version 19191) includes model option keywords ALPHA and BETA for certain modeling options. The ALPHA keyword indicates one or more options are being used that are scientific/formulation updates considered to be in the research phase and have not been fully evaluated and peer reviewed by the scientific community; and/or non-scientific model options in development that still need rigorous testing and for which EPA is seeking feedback from the user community. The BETA keyword indicates one or more options are being used that have been fully vetted through the scientific community with appropriate evaluation and peer review. BETA options are planned for future promulgation as regulatory options in AERMOD. See the AERMOD users guide for more information (EPA 2019a).

For the current version of HEM4, the only ALPHA options available are Method 2 particle deposition and gaseous (vapor) deposition. The only current BETA option in AERMOD, RLINE (a source type intended mainly for roadway modeling), is not currently an option in HEM4. To keep HEM4 general, the ALPHA and BETA keywords will always be included in the AERMOD runstream file prepared by HEM4, even when no ALPHA or BETA options are being used.

5.1.2 Dilution Factors

HEM4 uses AERMOD to compute a series of dilution factors, specific to each emission source and receptor. This approach more quickly analyzes the impacts of multiple pollutants than if separately modeling each pollutant. The dilution factor for a particular emission source and receptor is defined as the predicted ambient impact from the given source and at the given receptor, divided by the emission rate from the given source.

If you choose not to analyze deposition or depletion, then the dilution factor does not vary from pollutant to pollutant. If you do select deposition or depletion, HEM4 will compute separate dilution factors for gaseous and particulate pollutants. In addition, you can specify different particle sizes and densities for each particulate matter emission source. To use pollutant-specific parameters for particulates and/or gases, requires a separate Source ID for each pollutant at a given source. As noted in Section 3.4, you can create multiple Source IDs using the same locations and source parameters to accommodate different pollutants when modeling deposition or depletion.

5.2 Estimating Risks and Hazard Indices

HEM4 estimates the total cancer risk, noncancer hazard index (HI) and optionally acute hazard quotient (HQ) for all U.S. Census block locations or alternate receptor locations in the modeling domain, all user receptors, and all receptors in the polar network. Receptors in the HEM4 domain fall into two categories: those with impacts explicitly modeled by HEM4/AERMOD, and those with impacts estimated via interpolation rather than explicit modeling. Section 5.2.1 describes methods used to calculate cancer risks and noncancer health hazards for receptors that HEM4/AERMOD explicitly models. Section 5.2.2 describes the interpolation approach used to estimate cancer risks and noncancer health hazards at receptors not explicitly modeled.

Based on the results for U.S. Census blocks or alternate receptors, and other receptors, HEM4 estimates the maximum individual risk (MIR), maximum HI, and optionally high acute value for populated receptors (Section 5.2.3); as well as the maximum impacts for all offsite receptors, including unpopulated locations (Section 5.2.4). For these locations, the model calculates the contributions of individual pollutants and emission sources to cancer risks, chronic HI, and optionally acute HQ (Section 5.2.5).

5.2.1 Explicit Modeling of Inner Receptors, User Receptors and Polar Receptors

HEM4 calculates cancer risks, target-organ-specific HI, and optionally acute HQ for three types of discrete receptors that are explicitly modeled by AERMOD. These are (1) U.S. Census blocks or alternate receptors within the user-defined modeling “cutoff” distance for explicit modeling of individual receptors, (2) all user receptors, and (3) the user-defined polar receptor network.

As noted above in Section 5.1.2, Dilution Factors, HEM4 combines pollutants into two categories — particulates and gases (vapor) — for the purposes of dispersion modeling. The model retains these categories to calculate cancer risks, noncancer HI and optionally acute HQ. HEM4 uses the following algorithms:

For cancer risk:

$$CR_T = \Sigma_{i,j}\, CR_{i,j}$$

$$CR_{i,j} = DF_{i,j} \times CF \times \Sigma_k \left[E_{i,k} \times URE_k\right]$$

For noncancer hazard indices:

$$HI_T = \Sigma_{i,j}\, HQ_{i,j}$$

$$HQ_{i,j} = DF_{i,j} \times CF \times \Sigma_k \left[E_{i,k} / (RfC_k \times 1000\ \mu g/mg)\right]$$

where:

CR_T = total cancer risk at a given receptor (probability for one person)
$\Sigma_{i,j}$ = the sum over all sources i and pollutant types j (particulate or gas)
$CR_{i,j}$ = cancer risk at the given receptor for source i and pollutant type j
$DF_{i,j}$ = dilution factor [($\mu g/m^3$) / (g/sec)] at the given receptor for source i and pollutant type j
CF = conversion factor, 0.02877 [(g/sec) / (tons/year)]
Σ_k = sum over all pollutants k within pollutant group j (particulate or gas)
$E_{i,k}$ = emissions (tons/year) of pollutant k from source i
URE_k = cancer unit risk estimate [1/($\mu g/m^3$)] for pollutant k (cancer risk for an individual exposed to 1 $\mu g/m^3$ over a lifetime)
HI_T = TOSHI at a given receptor and for a given organ
$HQ_{i,j}$ = organ-specific hazard quotient at the given receptor for source i and pollutant type j
RfC_k = noncancer health effect reference concentration (mg/m^3) for pollutant k (concentration at and below which no adverse health effect is expected)

The above equations are equivalent to the following simpler equations:

$$CR_T = \Sigma_{i,k}\, AC_{i,k} \times URE_k$$

$$HI_T = \Sigma_{i,k}\, AC_{i,k} / (RfC_k \times 1000\ \mu g/mg)$$

where:

$AC_{i,k}$ = ambient concentration ($\mu g/m^3$) for pollutant k at the given receptor. This is the same as $[E_{i,k} \times DF_{i,j} \times CF]$

However, use of these simpler equations would require modeling all pollutants individually in AERMOD, and performing separate risk calculations for each pollutant.

If the cancer unit risk estimate (URE) is not available for a given pollutant, then that pollutant is not included in the calculation of cancer risk. Likewise, if the noncancer reference concentration (RfC) is not available for a given pollutant, that pollutant is not included in the calculation of HI.

Note that separate reference concentrations are used for acute HQ and chronic HQ. As discussed in Section 2.2.1, for acute impacts, instead of the chronic RfC, the short term concentration is compared with various threshold or benchmark levels for acute health effects (e.g., the California EPA reference exposure level [REL] for no adverse effects).

5.2.2 Interpolated Modeling of Outer Receptors using the Polar Receptor Network

For U.S. Census blocks and alternate receptors outside of the user-defined modeling "cutoff" distance for individual block modeling, HEM4 estimates cancer risks, noncancer HI and optionally acute HQ by interpolation from the polar receptor network. HEM4 estimates impacts at the polar grid receptors using AERMOD modeling results and the algorithms described in Section 5.2.1. If you choose to model terrain effects with the elevation option in your Facility List Options file, then HEM4 estimates an elevation for each polar receptor. HEM4 estimates elevations and controlling hill heights for the polar grid receptors based on values from the U.S. Census library for modeling runs using the U.S. Census, or from the alternate receptor file for runs not based on the U.S. Census. HEM4 divides the modeling domain into sectors based on the polar grid receptor network, with each census block assigned to the sector corresponding to the closest polar grid receptor.

HEM4 then assigns each polar grid receptor an elevation based on the **highest elevation** for any U.S. Census block receptor, user receptor, or alternate receptor in its sector. The controlling hill height is also set to the maximum hill height within the sector. If a sector does not contain any census blocks or alternate receptors, the model defaults to the elevation and controlling hill height of the nearest block or nearest alternate receptor outside the sector, or defaults to the elevation of the nearest source (if the polar grid receptor is closer to a source than to a block or alternate receptor outside its sector).

HEM4 interpolates the impacts at each outer U.S. Census block receptor or alternate receptor from the four nearest polar grid receptors. The interpolation is linear in the angular direction, and logarithmic in the radial direction, as summarized in the following equations:

$$I_{a,\,r} = I_{A1,\,r} + (I_{A2,\,r} - I_{A1,\,r}) \times (a - A1) \,/\, (A2 - A1)$$

$$I_{A1,\,r} = \exp\{\ln(I_{A1,R1}) + [\ln(I_{A1,R2}) - \ln(I_{A1,R1})] \times [(\ln r) - \ln(R1)] \,/\, [\ln(R2) - \ln(R1)]\}$$

$$I_{A2,\,r} = \exp\{\ln(I_{A2,R1}) + [\ln(I_{A2,R2}) - \ln(I_{A2,R1})] \times [(\ln r) - \ln(R1)] \,/\, [\ln(R2) - \ln(R1)]\}$$

where:

- $I_{a,r}$ = the impact (cancer risk, chronic HI or acute HQ) at an angle, a, from north, and radius, r, from the center of the modeling domain
- a = the angle of the target receptor, from north
- r = the radius of the target receptor, from the center of the modeling domain
- A1 = the angle of the polar network receptors immediately counterclockwise from the target receptor
- A2 = the angle of the polar network receptors immediately clockwise from the target receptor
- R1 = the radius of the polar network receptors immediately inside the target receptor
- R2 = the radius of the polar network receptors immediately outside the target receptor

5.2.3 Maximum Individual Risks, Hazard Indices, and Hazard Quotients

HEM4 evaluates the predicted chronic impacts for all populated receptors to identify the locations of the MIR and the highest HI for various target organs (maximum TOSHIs). For these calculations, populated receptors include all U.S. Census block locations or alternate receptors and any user receptors you included in the run designated as type P (for populated). In general, type P receptors should include houses near the facility boundary, as well as other residences not represented well by the location of the U.S. Census blocks or alternate receptors.

The maximum cancer risk may occur at a location other than the maximum HI for a given organ. Likewise, the location of the maximum HI for one organ will not necessarily be the same as the location for a different organ. HEM4 performs a separate evaluation of the maximum impact location for each health impact.

The model also tests for instances where U.S. Census blocks, alternate receptors or type P user receptors appear to be located on plant property. To do so, HEM4 calculates the distance between each receptor and each emission source. These distances are compared with the overlap distance that you specified in the Facility List Options file. If a populated-type receptor is located within the overlap distance, then HEM4 does not use these calculated results for this receptor to estimate the maximum individual cancer risk or maximum HI for populated areas. Instead, the model assumes the impacts at the overlapping receptor to be equal to the maximum impacts for any receptors that do not overlap plant property. This could include both populated and unpopulated receptors (e.g. polar receptors), as long as they do not overlap plant property.

If you chose to model acute (short-term) impacts in the Facility List Options file, HEM4 will also evaluate predicted acute impacts for all receptors to identify the locations of the highest acute HQs. For the acute calculations, all receptors are evaluated – both populated and unpopulated receptors – including U.S. Census blocks or alternate receptors, all user receptors you may have specified and all polar receptors. As described in the preceding paragraph, HEM4 also checks to ensure that the maximum populated acute receptor is not overlapped. In the case of an overlapped populated receptor, then the next highest non-overlapped populated receptor is chosen.

5.2.4 Maximum Offsite Impacts

In addition to evaluating the maximum cancer risks, chronic HI, and acute HQ (if modeled) for populated receptors, HEM4 evaluates maximum offsite impacts for all receptors. All U.S. Census blocks or alternate receptors, all user receptors (populated and unpopulated), and all points (receptors) on the polar receptor network are included in the evaluation of maximum offsite impacts, except for those receptors that are found to be overlapping emission sources.

5.2.5 Contributions of Different Pollutants and Emission Sources

HEM4 calculates the contributions of different pollutants and emission sources to cancer risks. chronic HI, and acute HQ (if modeled) at the receptors where impacts are highest, both for populated receptors and for all offsite receptors. As noted in Section 5.2.1, HEM4 groups pollutants together when calculating total risks, HI and HQ (if modeled) for the large number of receptors that are typically included in an overall modeling domain. Thus, the model does not

compute the contributions of individual pollutants and emission sources for all receptors. However, HEM4 retains the information needed to determine the contributions of individual pollutants and emission sources at the receptors where impacts are highest. HEM4 calculates these contributions using the following equations:

$$AC_{i,k,m} = E_{i,k} \times DF_{i,j,m} \times CF$$

$$CR_{i,k,m} = AC_{i,k,m} \times URE_k$$

$$HQ_{i,k,m} = AC_{i,k,m} / (RfC_k \times 1000\ \mu g/mg)$$

where:

$AC_{i,k,m}$ = the predicted ambient concentration ($\mu g/m^3$) for pollutant k, from source i, at receptor m

$E_{i,k}$ = emissions (tons/year) of pollutant k from source i

$DF_{i,j,m}$ = the dilution factor [($\mu g/m^3$) / (g/sec)] for source i, receptor m, and pollutant group j, which includes pollutant k

CF = conversion factor, 0.02877 [(g/sec) / (ton/year)]

$CR_{i,k,m}$ = the estimated cancer risk from source i, and pollutant k, at receptor m

URE_k = cancer unit risk estimate [1/($\mu g/m^3$)] for pollutant k (cancer risk for an individual exposed to 1 $\mu g/m^3$ over a lifetime)

$HQ_{i,k,m}$ = the organ-specific hazard quotient as a result of emissions of pollutant k, from source i, at receptor m

RfC_k = noncancer health effect reference concentration (mg/m^3) for pollutant k (concentration at and below which no adverse health effect is expected)

Note that the methodology outlined above for cancer and chronic noncancer impacts is similar for acute impacts, although acute emissions are used (including any acute factor/multiplier you may have indicated in your Facility List Options files) as well as acute benchmarks discussed in Section 2.2.1.

5.3 Population Exposures and Incidence

Using the predicted impacts for U.S. Census blocks or alternate receptors, HEM4 estimates the populations exposed to various cancer risk levels and noncancer HI levels. To do so, the model adds up the populations for receptors that have predicted cancer risks or noncancer HI above a given threshold. For cancer risk, around each facility HEM4 predicts the number of people exposed to a risk greater than or equal to the following thresholds:

- 1 in 1,000 (or 1,000-in-1 million) risk;
- 1 in 10,000 (or 100-in-1 million) risk;
- 1 in 20,000 risk;
- 1 in 100,000 (or 10-in-1 million) risk;
- 1 in 1,000,000 (or 1-in-1 million) risk; and
- 1 in 10,000,000 (or 0.1-in-1 million) risk.

For noncancer HI, around each facility HEM predicts the number of people exposed to each of the 14 TOSHIs above the following thresholds:

- Greater than 100;

- Greater than 50;
- Greater than 10;
- Greater than 1.0;
- Greater than 0.5; and
- Greater than 0.2.

If you opt to model acute impacts, HEM4 will provide the acute concentration for every pollutant at every receptor, including every populated receptor, and will also include the population of those receptors (whether U.S. Census blocks or alternate receptors). Because of the transitory nature of acute exposures, acute health impacts are modeled not only where people reside but at all receptors in the modeling domain. Therefore, the highest acute health impacts often occur at unpopulated polar receptor locations. It is important to note that the maximum acute impacts will occur at different times for different spatial locations (receptors) and are therefore not additive. For these reasons, population exposures are not tallied by HEM4 for acute health impacts, only for cancer and chronic noncancer TOSHI.

HEM4 also estimates the contributions of different pollutants and emission sources to total annual cancer incidence for the overall modeling domain using the following equations:

$$CI_{i,k,m} = CR_{i,k,m} \times P_m / LT$$

$$CI_m = \Sigma_{i,k} \left[CI_{i,k,m}\right]$$

$$TCI = \Sigma_m \left[CI_m\right]$$

where:

$CI_{i,k,m}$ = the estimated annual cancer incidence (excess cancer cases/year) for populated receptor m due to emissions from pollutant k and emission source i

$CR_{i,k,m}$ = the estimated cancer risk from source i, and pollutant k, at populated receptor m

P_m = the population of populated receptor m

LT = the average lifetime used to develop the cancer unit risk estimate, 70 years

$\Sigma_{i,k}$ = the sum over all modeled pollutants k and emission sources i

CI_m = the estimated total cancer incidence for populated receptor m due to emissions from all modeled pollutants and emission sources

Σ_m= the sum over all populated receptors m in the modeling domain

TCI = the estimated total annual cancer incidence (excess cancer cases/year) for the population living within the modeling domain from all modeled pollutants and emission sources

It should be noted that the above incidence calculations are made for the pollutant types “j” being modeled (whether particulate, gas, or combined).

For each facility, HEM4 provides the estimated total annual cancer incidence (excess cancer cases/year) predicted to be caused by all modeled pollutants emitted from all modeled sources. Increasing in specificity, HEM4 also provides the annual cancer incidence predicted to be caused by each emission source at a facility for all pollutants emitted from that source, as well as by each pollutant from all sources emitting that pollutant at a facility. At the greatest level of specificity, HEM4 provides the estimated cancer incidence broken down by both pollutant and emission source – that is, for every pollutant individually from each source separately.

5.4 Summarizing Human Health Impacts

Section 5.1 above discusses how HEM4 uses AERMOD for dispersion modeling of your inputs to produce multi-pollutant concentration predictions at the receptors in your modeling domain, around a given facility. Sections 5.2 and 5.3 above discuss the methodology and algorithms used by HEM4 to transform predicted concentrations into human health impacts around each modeled facility. The following sections describe the outputs produced by HEM4 for each facility and for your run group as a whole, which allow you to summarize the risk and health impacts per facility and across all facilities you choose to group together in a modeling run.

6. HEM4 Output Files

After running the AERMOD dispersion model to determine receptor-specific concentrations, HEM4 completes the post-AERMOD risk and exposure calculations (explained in Section 5) and then produces a variety of facility-specific concentration, cancer risk, noncancer hazard quotients (HQ) and hazard indices (HI), incidence and population exposure output files. These facility-specific outputs are discussed in Section 6.1. HEM4 also produces three summary output files, based on the results for the entire RUN group (e.g., source category/sector) of modeled facilities. These multi-facility outputs are updated after the output files for the individual facilities have been created and essentially concatenate the individual facility results into group-wide summary files. These run group summary files are discussed in Section 6.2. The Risk Summary Reports are discussed in Section 7.

6.1 Facility-Specific Outputs

A standard HEM4 run produces the following facility-specific output files:

- 6 risk and HI files (maximum individual risk [MIR], maximum offsite impacts, risk breakdown, block summary chronic, ring summary chronic, and source risk KMZ);
- 3 incidence and population exposure files (incidence, cancer risk exposure, noncancer risk exposure);
- 3 concentration files (all inner receptors, all outer receptors, all polar receptors);
- dispersion model output file(s) from AERMOD (the number depends on the type run);
- 1 file cataloging modeling options used (input selection options); and
- 1 quality assurance (QA) file showing receptors discarded (overlapping source receptors).

In addition, depending on the modeling options chosen, a HEM4 run may produce 3 other non-standard/optional files, including the following 3 acute files:

- acute breakdown,
- acute chem populated, and
- acute chem max.

These facility-specific standard and optional files are described below in this section.

6.1.1 Maximum Individual Risk

The Maximum Individual Risk output file provides the MIR value for cancer and the max TOSHI value for noncancer chronic health effects predicted for any populated receptor that does not overlap facility property, such as census blocks, alternate receptors, and user-defined receptors that are designated as “populated”. (Note: user-defined receptors are considered populated receptors but are assigned a population of zero.) This file also indicates the population and exact location of the receptors where these maxima occur. Note that the MIR and max TOSHIs may or may not occur at the same receptors/locations, depending on what pollutants are being emitted from one source versus another source (indicated in the HAP Emissions input file) and the locations and parameters of the sources (indicated in the Emissions Location input file).

Table 33 below describes the fields of information provided in the Maximum Individual Risk file. A sample Maximum Individual Risk output file is provided in Appendix A.

Table 33. Fields Included in the Maximum Individual Risk & Maximum Offsite Impacts Files

Field	Description
Parameter	Maximum individual cancer risk (MIR) or maximum TOSHI including maximum respiratory HI, maximum liver HI, maximum neurological HI, etc. for 14 TOSHIs
Value of MIR or TOSHI	MIR value or maximum TOSHI value, including a rounded value and a value in scientific notation
Population	Population at the location of the MIR or maximum HI, if it is a census block or alternate receptor
Distance	Distance from the center of the modeling domain, in meters
Angle	Angle from north
Elevation	Elevation in meters above sea level
Hill Height	Controlling hill height of receptor, in meters above sea level, as described in Section 2.3.1.
FIPS code	Five-digit Federal Information Processing Standard (FIPS) code which uniquely identifies the county of the receptor, if the receptor is a census block. (Note: For alternate receptor run, there is a field called “Receptor ID”)
Block ID	10-digit census block ID for linking to census demographic data, if the receptor is a census block. (Note: For alternate receptor run, there is a field called “Receptor ID”)
UTM east coordinate	In meters
UTM north coordinate	In meters
Latitude	Decimal
Longitude	Decimal
Receptor type	Census block receptor, polar grid receptor, alternate receptor, user-defined receptor, boundary receptor, monitor location
Notes	This field indicates whether the receptor was modeled discretely or interpolated and also indicates if the original maximum receptor was overlapped (and therefore not used). In the case of interpolation or an overlap, you may wish to re-model the facility.

Relevant to the Maximum Individual Risk file, it should be noted that if any populated receptor is located within the minimum overlap distance, then it is assumed that either the source location or the receptor location is inappropriate. (A block centroid may be inappropriate as a receptor location if the block partially encompasses an emission source, such as at a corner of the facility.) When an overlap condition occurs, this is indicated in the Notes field/column and the calculated results for the overlapping receptor are not used. Instead, the maximum cancer risk and TOSHIs are assumed equal to the maximum (next highest) impacts for any receptor that does not overlap facility property. This could include both populated (census, alternate, populated user-defined) receptors and unpopulated (polar, unpopulated user-defined such as boundary and monitor) receptors, as long as they do not overlap facility property. In this

situation, check the source coordinates in the emissions location input file, and define a set of facility boundary receptors in the user-defined receptors file.

6.1.2 Maximum Offsite Impacts

The Maximum Offsite Impacts output file provides similar information to the Maximum Individual Risk output file, but the receptors of maximum impact in this file include any receptors, not only populated receptors. This file lists the highest cancer risks and TOSHI predicted at any receptor that does not overlap with the emission sources, whether the receptor is populated or unpopulated. The receptors included in this calculation include all discretely modeled census blocks (aka “inner receptors”), all user-defined receptors (including populated user receptors, boundary sites and ambient monitor sites), and all points in the polar receptor network, except for those receptors overlapping emission sources. Table 33 above describes the fields of information provided in the Maximum Offsite Impacts file. A sample Maximum Offsite Impacts output file is provided in Appendix A.

6.1.3 Risk Breakdown

The Risk Breakdown output file provides the breakdown of risk and TOSHI by pollutant and source, including a listing of pollutant concentrations and unit risk estimates (URE) and reference concentration (RfC) values. This file includes information about the MIR and HI (for populated census block, user, and alternate receptors), as well as the maximum offsite impacts (for any receptor, including non-populated receptors such as polar grid receptors, boundary receptors, and monitors), as discussed in Section 5.2.

This file also shows the contributions of gaseous and particulate emissions for any pollutants that are emitted in both forms, if you opted to model deposition/depletion or if you merely elected to show the particulate/gaseous breakdown, as explained in Section 3.2.6. Table 34 below describes the fields of information provided in the Risk Breakdown file. A sample Risk Breakdown output file is provided in Appendix A.

As previously noted, HEM4 computes cancer risks using the EPA’s recommended UREs for HAP and other toxic air pollutants. The resulting estimates reflect the risk of developing cancer for an individual breathing the ambient air at a given receptor site over a 70-year lifetime. Noncancer health effects are quantified using HQ and HI for various target organs. The HQ for a given pollutant and receptor site is the ratio of the ambient concentration of the pollutant to the RfC level at which no adverse effects are expected. The HI for a given organ is the sum of HQs for substances that affect that organ.

Table 34. Fields Included in the Risk Breakdown File

Field	Description
Site type	MIR (for max populated receptor) or maximum offsite impact (for max of any receptor, populated or not)
Parameter	Cancer risk, all 14 TOSHIs (e.g., respiratory HI, liver HI, neurological HI)
Source ID	Individual source identification code, "Total by pollutant all sources", or "Total" for all pollutants and all sources combined
Pollutant	Pollutant name, "all modeled pollutants" for all pollutants combined for each source, or "all pollutants all sources" for all pollutants and all sources combined
Emission (Pollutant) type	P = particulate, V = vapor (gas), C = combined, NA = not applicable
Value	Cancer risk or noncancer HQ
Value_rnd	Cancer risk or noncancer HQ rounded to one significant figure
Conc_ugm3	Pollutant concentration ($\mu g/m^3$)
Conc_rnd	Pollutant concentration ($\mu g/m^3$) rounded to two significant figures
Emissions_tpy	Modeled tons per year (tpy) emitted of pollutant
URE	Unit risk estimate used to compute cancer risks for the pollutant [1 / ($\mu g/m^3$)]
RfC	Reference concentration used to compute HQs for the pollutant (mg/m^3); Note that HEM4 converts this to $\mu g/m^3$ to compute TOSHIs

6.1.4 Block Summary Chronic

The Block Summary Chronic file provides the total cancer risk and all 14 TOSHIs for every populated census block receptor, populated alternate receptor, and all user receptors, and also indicates whether the receptor is an overlap location. As noted above, if any populated receptor is located within the minimum overlap distance, then it is assumed that either the source location or the receptor location is inappropriate. (For example, a block centroid may be inappropriate as a receptor location if the block partially encompasses an emission source, such as at a corner of the facility.) When an overlap condition occurs, the calculated results for the overlapping receptor are not used. Instead, the maximum cancer risk and HI are assumed equal to the maximum impacts for any receptor that does not overlap facility property. This could include both populated (census block, populated user-defined, or alternate) receptors and unpopulated (polar, boundary, or monitor) receptors, as long as they do not overlap facility property. In the case of an overlap, you may wish to check the coordinates in your Emissions Location input file, and define a set of facility boundary receptors in the user-defined receptors file.

To facilitate detailed geographic information system (GIS) analyses of HEM4 results, the file gives the latitude and longitude, and the UTM coordinates of each receptor, in addition to cancer risk estimates and HI. This output file also gives the county FIPS code and block identification number for U.S. Census-based runs or alternate Receptor ID for non-census runs,

as well as the population of each receptor. This information is intended to facilitate studies linking HEM4 results with census information, such as demographic or economic data. Table 35 below describes the fields of information provided in the Block Summary Chronic file. A sample Block Summary Chronic output file is provided in Appendix A.

6.1.5 Ring Summary Chronic

The Ring Summary Chronic file provides the same information provided by the Block Summary Chronic File, but for points in the polar receptor network. However, because these are polar receptors, the FIPS, Block, and population fields are not included in the Ring Summary Chronic File, while three additional fields are provided: distance from center of polar network, angle from north, and sector number. Table 35 describes the fields of information in the Ring Summary Chronic file, and a sample file is provided in Appendix A.

Note: For both the Block Summary Chronic and Ring Summary Chronic files, in the case of an overlapped receptor, the risk and TOSHI values for that receptor displayed in these files will not be the originally modeled values. Instead, the maximum cancer risk and TOSHIs are assumed equal to the maximum (next highest) impacts for any receptor that does not overlap facility property. This could include both populated (census, alternate, populated user-defined) receptors and unpopulated (polar, unpopulated user-defined such as boundary and monitor) receptors, as long as they do not overlap facility property. The originally modeled values that occurred in the location of the overlap are available in the All Inner Receptor, All Outer Receptor, and/or All Polar Receptor files described in Sections 6.1.10, 6.1.11, and 6.1.12, respectively.

Table 35. Fields Included in the Block Summary and Ring Summary Chronic Files

Field	Description
Latitude	Decimal
Longitude	Decimal
Overlap	N for No, Y for Yes. If Yes, the values shown for the receptor in that row are the next highest receptor (whether populated or non-populated), not overlapped. See also the Overlapping Source Receptors file.
Elevation	Elevation in meters above sea level
FIPS code	Five-digit Federal Information Processing Standard (FIPS) code which uniquely identifies the county of the receptor, if the receptor is a census block. (Not part of Ring Summary Chronic File) Note: For alternate receptor run, there is a field called "Receptor ID".
Block ID	10-digit census block ID for linking to census demographic data, if the receptor is a census block. (Not part of Ring Summary Chronic File) Note: For an alternate receptor run, there is a field called "Receptor ID".
X	UTM Easting Coordinate
Y	UTM Northing Coordinate
Hill Height	Controlling hill height of receptor, in meters above sea level, as described in Section 2.3.1
Population	Population at the location of the MIR or maximum HI, if it is a census block, or has user-provided population in the case of an alternate receptor. (Not part of Ring Summary Chronic File)
Parameter	Cancer risk, all 14 TOSHIs (e.g., respiratory HI, liver HI, neurological HI)
Discrete/ Interpolated	D for Discretely modeled receptor (within the modeling distance, aka "inner receptors"), I for Interpolated receptor (outside the modeling distance, aka "outer receptors") (Not part of Ring Summary Chronic File)
Distance	Distance in meters from the center of the polar network of the polar receptor's location on polar ring (Not part of Block Summary Chronic File)
Angle (from north)	Angle from north of the polar radial on which the polar receptor is located (0 to 360 degrees) (Not part of Block Summary Chronic File)
Sector	Sector number within the polar network (the number depends on number of radials indicated in your Facility List Options file; default is 1-16) (Not part of Block Summary Chronic File)

6.1.6 Source Risk KMZ Image

The Source Risk KMZ file is a Google Earth™ map centered on the facility, as shown in Figure 19. The map displays the emission sources in the center as red circles for point/stack sources, red rectangles for area sources, red polygons for polygon-shaped sources, and red lines for line and buoyant line sources. The map also displays all receptors within the modeled area,

including both census block centroid receptors or alternate receptors (displayed as squares) and polar grid receptors (displayed as circles). The MIR receptor is marked with a red “X”.

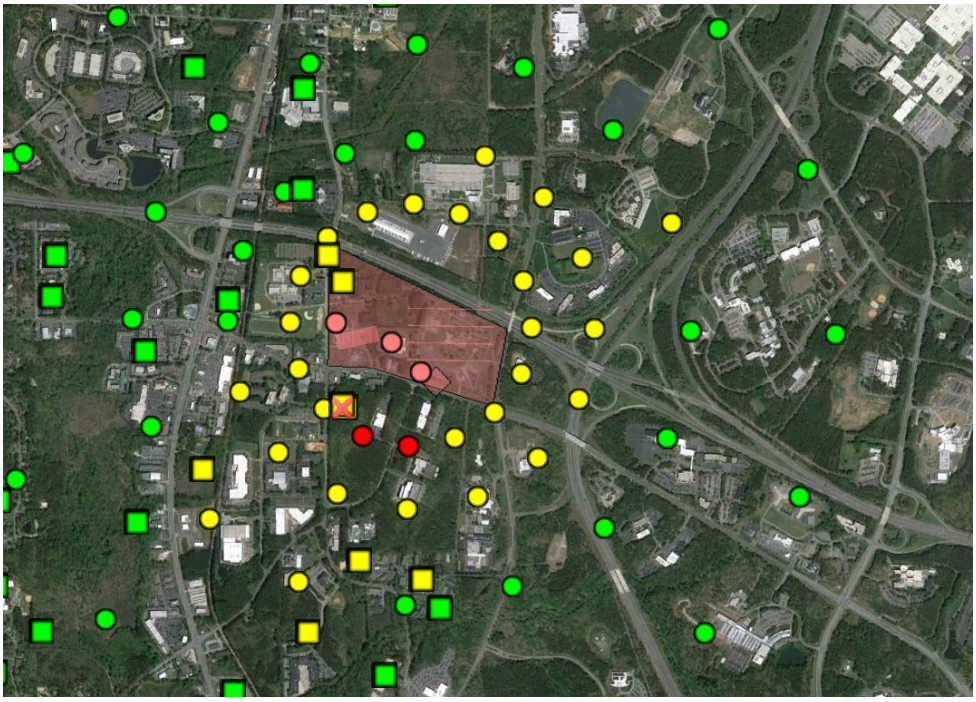


Figure 19. Sample Google Earth™ Map of Results

Click on the square census block receptors to see the total cancer risk and maximum TOSHI for that receptor, the FIPS and block ID of the receptor (for census blocks), as well as a listing of the top pollutants contributing to that block’s total cancer risk and maximum TOSHI. Click on the circular polar receptors to view similar information for each polar receptor. The cancer risk at the census block and polar receptors are color coded on the Google Earth™ map. Red indicates a receptor with a modeled total cancer risk greater than 100 in a million. Yellow indicates a risk level between 20 and 100 in a million. Green indicates a risk less than 20 in 1 million.

Figure 19 shows an example in which only two non-populated polar grid receptors have a risk greater than 100 in a million (shown as dark red circles). All populated census block receptors have modeled risks between 20 and 100 in a million (shown as yellow squares) or less than 20 in a million (shown as green squares).

6.1.7 Incidence

The facility-specific Incidence file provides the overall total incidence for all modeled pollutants from all sources in the given facility, the pollutant-specific total incidence for all sources combined, and the individual incidence per source for each pollutant. As explained in Section 5.3, the incidence is calculated as the cancer risk of each populated receptor (e.g., census block or alternate receptor) times the receptor population, divided by a 70-year average lifespan. This individual populated receptor incidence is then summed over all populated receptors in the modeling domain of the facility. Table 36 below describes the fields of information provided in the facility-specific Incidence file. A sample Incidence output file is provided in Appendix A.

Table 36. Fields Included in the Incidence File

Field	Description
Source ID	Individual source identification code, or "Total" for all sources combined
Pollutant	Pollutant name, or "All modeled pollutants" for all pollutants combined for each source and for the Total
Emission (Pollutant) type	P = particulate, V = vapor (gas), C = combined
Incidence	Cancer risk or noncancer HQ
Incidence, rounded	Cancer risk or noncancer HQ rounded to one significant figure

6.1.8 Cancer Risk Exposure

The Cancer Risk Exposure file is a simple two column (two field) file that provides the population numbers exposed to various cancer risk levels in the modeling domain surrounding the facility. Population numbers are provided for the following cancer risk levels:

- Greater than or equal to 1 in 1,000 (≥1,000-in-a-million risk);
- Greater than or equal to 1 in 10,000 (≥100-in-a-million risk);
- Greater than or equal to 1 in 20,000 (≥50-in-a-million risk);
- Greater than or equal to 1 in 100,000 (≥10-in-a-million risk);
- Greater than or equal to 1 in 1,000,000 (≥1-in-a-million risk); and
- Greater than or equal to 1 in 10,000,000 (≥0.1-in-a-million risk).

A sample Cancer Risk Exposure output file is provided in Appendix A.

6.1.9 Noncancer Risk Exposure

The Noncancer Risk Exposure file, like the Cancer Risk Exposure file described above, is a simple file that provides the population numbers exposed to various HI levels for all 14 TOSHIs, in the modeling domain surrounding the facility. Population numbers are provided for the following noncancer HI levels:

- Greater than 100;
- Greater than 50;
- Greater than 10;
- Greater than 1.0;
- Greater than 0.5; and
- Greater than 0.2.

Population numbers at each of the above noncancer HI levels are provided for the following TOSHIs:

- Respiratory HI;
- Liver HI;

- Neurological HI;
- Developmental HI;
- Reproductive HI;
- Kidney HI;
- Ocular HI;
- Endocrine HI;
- Hematological HI;
- Immunological HI;
- Skeletal HI;
- Spleen HI;
- Thyroid HI; and
- Whole Body HI.

A sample Noncancer Risk Exposure output file is provided in Appendix A.

6.1.10 All Inner Receptors

The All Inner Receptors file provides the chronic concentration (in $\mu g/m^3$) and (if optionally modeled) the acute concentration of every populated (census block or alternate) receptor inside the modeling distance, as well as every user-defined receptor. **Note**: All concentrations in this file are discretely (explicitly) modeled, not interpolated. This file will also contain the deposition flux (in $g/m^2/y$) if you opted to calculate deposition with or without depletion. Columns for both dry and wet deposition flux results are provided and will be populated with non-zero results depending on the type of deposition modeling (wet, dry or both) you selected in the Facility List Option fields. Table 37 below describes the fields of information provided in the All Inner Receptors file. A sample All Inner Receptors file output file is provided in Appendix A.

6.1.11 All Outer Receptors

The All Outer Receptors file includes nearly the same information provided in the All Inner Receptor file (described above) for every receptor located between the modeling distance (often specified as 3 km) and the outer edge of the modeling domain (the "maximum distance" often specified as 50 km). The dry and wet deposition fluxes provided in the All Inner Receptors file, however, are not provided in this file, for the outer receptors. **Note**: All concentrations in this file are interpolated using the polar grid receptors, not discretely (explicitly) modeled. Table 37 below describes the fields of information provided in the All Outer Receptors file. A sample All Outer Receptors file output file is provided in Appendix A.

Table 37. Fields Included in the All Inner and All Outer Receptor Files

Field	Description
FIPS code	Five-digit Federal Information Processing Standard (FIPS) code which uniquely identifies the county of the receptor if the receptor is a census block. (Note: For alternate receptor run, there is a field called "Receptor ID")
Block ID	10-digit census block ID for linking to census demographic data, if the receptor is a census block. (Note: For alternate receptor run, there is a field called "Receptor ID")
Latitude	Decimal
Longitude	Decimal
Source ID	Individual source identification code affiliated with given concentrations
Emission (Pollutant) type	P = particulate, V = vapor (gas), C = combined
Pollutant	Pollutant name affiliated with given concentrations
Conc	Chronic air concentration in $\mu g/m^3$
Acute Conc	Acute (short-term) air concentration in $\mu g/m^3$, if modeled
Elevation	Elevation in meters above sea level
Dry deposition	Dry deposition flux in g/m^2/year, if modeled (not included in All Outer Receptor file)
Wet deposition	Wet deposition flux in g/m^2/year, if modeled (not included in All Outer Receptor file)
Population	Population of receptor
Overlap	N for No, Y for Yes. Note: the value shown is the originally modeled value, even if overlapped (and therefore not used in other files such as the Maximum Individual Risk, Risk Breakdown, and Block Summary Chronic files)

6.1.12 All Polar Receptors

The All Polar Receptors file provides similar information to the All Inner Receptors and All Outer Receptors for the nodes of the polar receptor grid, including the chronic concentration (in $\mu g/m^3$) and (if optionally modeled) the acute concentration of every polar receptor. **Note**: Like the All Inner Receptors file, all concentrations in the All Polar Receptors file are discretely (explicitly) modeled, not interpolated. Likewise, this file will also contain the deposition flux (in $g/m^2/y$) if you opted to calculate deposition with or without depletion. Columns for both dry and wet deposition flux results are provided and will be populated with non-zero results depending on the type of deposition modeling (wet, dry or both) you selected in the Facility List Option fields. In addition, this file will contain the distance from the center of the polar network, the angle, sector, and ring number that describes the location of each polar receptor. Table 38 below describes the fields of information provided in the All Polar Receptors file. A sample All Polar Receptors file output file is provided in Appendix A.

Table 38. Fields included in the All Polar Receptors File

Field	Description
Source ID	Individual source identification code
Emission (Pollutant) type	P = particulate, V = vapor (gas), C = combined
Pollutant	Pollutant name affiliated with given concentrations
Conc	Chronic air concentration in µg/m^3
Acute Conc	Acute air concentration in µg/m^3
Distance	Distance in meters from the center of the polar network of the polar receptor's location on polar ring
Angle (from north)	Angle from north of the polar radial on which the polar receptor is located (0 to 360 degrees)
Sector	Sector number within the polar network (the number depends on number of radials indicated in your Facility List Options file; default is 1-16)
Ring number	The number of the ring ("circle") in the polar network on which the receptor is located, beginning with number 1 closest to facility center
Elevation	Elevation in meters above sea level
Latitude	Decimal
Longitude	Decimal
Overlap	N for No, Y for Yes. Note: the value shown is the originally modeled value, even if overlapped (and therefore not used in other files such as the Maximum Individual Risk, Risk Breakdown, and Ring Summary Chronic files).
Wet deposition	Wet deposition flux in g/m^2/year, if modeled (not included in All Outer Receptor files)
Dry deposition	Dry deposition flux in g/m^2/year, if modeled (not included in All Outer Receptor files)

6.1.13 AERMOD Outputs

With each run, HEM4 automatically provides a set of AERMOD text files that track the inputs and keywords (modeling commands) passed to AERMOD, including the receptor network and meteorological files, as well as the AERMOD outputs. The outputs produced by AERMOD are then passed back to HEM4 and used to produce the other outputs described in this guide. You should review these AERMOD text files (especially the aermod.out file described below) to confirm that AERMOD completed its modeling without error. These text files are described below:

- **aermod.inp** – a text file for combined particle and vapor phase emissions listing the inputs passed to AERMOD for modeling, including modeling control options (see AERMOD User's Guide), rural or urban dispersion environment, averaging time, specific input file parameters (e.g., from the Emissions Location file), the network of discrete receptor coordinates (block or alternate receptors in UTM), elevations and hill heights, meteorological data, and designated text formatted output files. Note: If particle and vapor phase emissions are modeled separately, then the above information will be provided for particle phase emissions in an **aermod_P.inp** file and for vapor phase emissions in an **aermod_V.inp** file.

- **aermod.out** – a text file for combined particle and vapor phase emissions listing the inputs received by AERMOD in the aermod.inp file (noted above), any fatal error messages, warning messages, informational messages, indication of successful AERMOD set-up or not, AERMOD version number used for modeling, type of deposition and depletion modeled if any, modeling options employed, whether short-term (acute) concentrations were modeled along with their period, number and type of sources, number of receptors, vintage of meteorological data used, emission rates modeled for each source (in grams per second), elevations and hill heights of every discrete (census block or alternate) receptor and every polar grid receptor, UTM coordinates and unit HAP chronic concentration at every receptor for each source, UTM coordinates and unit HAP short-term/acute concentration (if modeled) based on the acute high value selected, the number of hours processed, the number of calm (very low wind) hours identified, the number of missing hours in the meteorological data used for modeling, and an indication whether AERMOD finished the modeling run successfully or not. Note: If particle and vapor phase emissions are modeled separately, then the above information will be provided based on particle phase emissions in an **aermod_P.out** file and for vapor phase emissions in an **aermod_V.out** file. Deposition fluxes (wet/dry) will be provided with depletion applied to concentrations, if modeled.

- **plotfile.plt** – a text file for combined particle and vapor phase emissions listing the average modeled chronic concentration at every UTM receptor location and each modeled source. Note: If particle and vapor phase emissions are modeled separately, then these concentrations will be provided based on particle phase emissions in a **plotfile_p.plt** file and in a **plotfile_v.plt** file for vapor phase emissions. Deposition fluxes (wet/dry) will be provided with depletion applied to concentrations, if modeled.

- **maxhour.plt** – a text file for combined particle and vapor phase emissions listing the modeled short-term/acute concentration (based on the acute high value indicated in your Facility List Options file) at every UTM receptor location and each modeled source. Note: If particle and vapor phase emissions are modeled separately, then these acute concentrations will be provided based on particle phase emissions in a **maxhour_p.plt** file and for vapor phase emissions in an **maxhour_v.plt** file.

Note: Concentration results provided by AERMOD in the above files should not be interpreted as predicted concentrations of any pollutant listed in the HEM4 input files. Rather, these AERMOD results reflect concentrations attributable to a unit-emission rate (1 kg/s), which HEM4 converts to specific modeled pollutant emissions, as explained in Section 5 above. To fully understand the AERMOD processing and output files, refer to the AERMOD documentation for further guidance (EPA 2019a, EPA 2019b).

6.1.14 Input Selection Options

The Input Selection Options output file is a useful QA file to refer to because it provides a record of the modeling options you chose for the run, as well as the names and location of the input files you indicated. The following information is provided in this file:

- Facility ID;
- AERMOD control options used;
- Phase of emissions;
- Dispersion environment (rural or urban or blank for default);
- Whether deposition was modeled;
- Whether depletion was modeled;
- Type of deposition modeled for particle and vapor;
- Type of depletion modeled for particle and vapor;
- Whether elevations were modeled (or flat terrain used);
- Acute averaging period (e.g., 1 hour);
- Acute multiplier (factor applied to annual average emissions, if any);
- Whether building downwash was modeled;
- Whether user receptors were modeled;
- Maximum domain distance used (in meters);
- Modeling distance used (in meters);
- Overlap distance used (in meters);
- Number of polar rings used;
- Number of polar radials used;
- Whether acute was modeled;
- Distance to first ring (meter);
- Whether FASTALL was used;
- Run group name;
- Facility List Options file – name/location;
- Emissions Location file – name/location;
- HAP Emissions file – name/location;
- User Receptor file – name/location (if used);
- Particle Size file – name/location (if used);
- Building downwash file – name/location (if used);
- Buoyant line file – name/location (if used);
- Landuse file – name/location (if used);
- Month-to-Seasons file – name/location (if used);
- Polygon vertex file – name/location (if used);
- Whether Alternate Receptors were used; and
- Whether any of the Alternate Receptors were missing population values. Note: To compute incidence, population values are needed at every populated alternate receptor. Even if only one Alternate Receptor is missing a value in its population field, incidence is not computed by HEM4.

6.1.15 Acute Maximum Concentrations (Optional)

If you optionally chose to model acute impacts for a given facility, HEM4 will produce an Acute Chem Max output file. The Acute Chem Max output provides the maximum acute (short-term) pollutant concentration at any receptor for all sources combined. The "maximum" reported in this file refers to the acute high value you identified (e.g., the absolute maximum, the 99th percentile, the 98th percentile) and is based on the acute multiplier you provided (e.g., 10 times the average annual emission rate), as well as the acute averaging period (generally 1-hour) you indicated in the respective acute fields of your Facility List Options file. The maxima provided in the Acute Chem Max output may occur at any receptor—populated or unpopulated—including census blocks, alternate receptors, polar grid receptors, and user-defined receptors. This file also provides the specific location of the receptor with highest modeled concentration for each pollutant – including UTM and latitude/longitude coordinates, FIPS, Block, distance from facility center, and angle from north – as well as the elevation and hill height of the receptor. It should be noted that each pollutant may cause a different receptor to be the maximum (based on emissions of that specific pollutant). Finally, this output file also lists the acute reference concentrations for 11 different acute benchmarks, above which adverse short-term health impacts can be expected. For example, the file provides:

- the California Acute Reference Exposure Level (REL) benchmark;
- the Acute Exposure Guideline Level (AEGL1) for transient, reversible effects and AEGL2 for long-lasting, irreversible effects, based on one and eight hours of exposure;
- the Emergency Response Planning Guideline (ERPG-1) for mild or transient effects and the ERPG-2 for irreversible or serious effects, based on one hour of exposure; and
- several other acute benchmark concentrations, as described in Table 41.

The EPA's Air Toxics Risk Assessment Library (EPA 2017) provides a more detailed description of these acute benchmarks (available for download at http://www.epa.gov/fera/air-toxics-risk-assessment-reference-library-volumes-1-3). Table 39 below describes the fields of information provided in the Acute Chem Max file, and a sample file output file is provided in Appendix A. **Note**: the concentrations reported in Table 39 are in $\mu g/m^3$, while the acute benchmark values (reference concentrations) are in mg/m^3, and should therefore be multiplied by 1,000 for comparison to the modeled concentrations.

6.1.16 Acute Populated Concentrations (Optional)

If you optionally chose to model acute impacts for a given facility, HEM4 will also produce an Acute Chem Pop output file. The Acute Chem Pop file provides the same information described above in the Acute Chem Max file, but for only populated receptors (census blocks, alternate receptors and user-defined receptors), not unpopulated receptors. Therefore, the concentrations shown in this file may or may not be the acute maxima/high values for all receptors; but they are the acute high values for the populated receptors. See discussion in Section 6.1.16. Table 39 below describes the fields of information provided in the Acute Chem Max file, and a sample file output file is provided in Appendix A. **Note**: the concentrations reported in Table 39 are in $\mu g/m^3$, while the acute benchmark values (reference concentrations) are in mg/m^3, and should therefore be multiplied by 1,000 for comparison to the modeled concentrations.

Table 39. Fields included in the Acute Chem Max and Acute Chem Pop Files

Field	Description
Pollutant	Pollutant name
Conc	High value maximum Acute Concentration in μg/m^3
Conc sci	High value maximum Acute Concentration, scientific notation, in μg/m^3
AEGL-1, 1-hour	Acute Exposure Guideline Level 1 (AEGL-1) for a 1-hour exposure: the concentration above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects (mg/m^3)
AEGL-1, 8-hour	See AEGL-1 above, but for an 8-hour exposure
AEGL-2, 1-hour	Concentration above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape for a 1-hour exposure (mg/m^3)
AEGL-2, 8-hour	See AEGL-2 above, but for an 8-hour exposure
ERPG-1	Emergency Response Planning Guideline 1 (ERPG-1): concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor (mg/m^3)
ERPG-2	Concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action (mg/m^3)
IDLH/10	Immediately Dangerous to Life or Health: concentration believed likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment, divided by a factor of 10 (mg/m^3)
MRL	Acute Minimal Risk Level: daily human exposure that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure (mg/m^3)
REL	Reference Exposure Level: concentration below which no adverse health effects are anticipated, based on the most sensitive adverse health effect reported (mg/m^3)
TEEL_0	Temporary Emergency Exposure Limit 0 (TEEL) defined by the U.S. Department of Energy: the threshold concentration below which most people will experience no adverse health effects
TEEL_1	Maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or perceiving a clearly defined objectionable odor
Population	If the receptor is a census block or alternate receptor
Distance	From the center of the modeling domain (in meters)
Angle	From north
Elevation	In meters above sea level
Hill	Controlling hill height in meters above sea level, as described in Section 2.3.1
County FIPS	If the receptor is a census block. (Note: For alternate receptor run, there is a field called “Receptor ID”)
Census block ID	For linking to demographic data (if the receptor is a census block). (Note: For an alternate receptor run, there is a field called “Receptor ID”)
UTM east coordinate	In meters
UTM north coordinate	In meters
Latitude	Decimal
Longitude	Decimal
Receptor type	C = census block or alternate receptor, P = populated receptor user-defined receptor, PG = polar grid receptor, B = boundary receptor, M = monitor
Notes	Indicates whether the receptor was discretely (explicitly) modeled or interpolated

6.1.17 Acute Breakdown (Optional)

If you chose to optionally model acute impacts for a given facility, HEM4 also produces a third acute output file entitled Acute Bkdn, which provides the contribution ("breakdown") of each emission source to the receptor of maximum acute impact for each pollutant (i.e., the acute concentration of pollutant at the maximum receptor for that pollutant, caused by each source). This information is provided for both the maximum/high value receptor (whether populated or nonpopulated) and for the highest populated receptor.

The acute breakdown file includes the following fields:

- pollutant;
- Source ID;
- emission type (P for particle, V for vapor, C for combined);
- the maximum pollutant concentration ($\mu g/m^3$) at a populated receptor;
- the maximum pollutant concentration ($\mu g/m^3$) at all receptors (both populated and unpopulated); and
- columns indicating whether the pollutant's concentration at each receptor was interpolated or not.

Note: Concentration values are interpolated outside the modeling distance (e.g., between 3 km and 50 km).

6.2 Run Group Outputs

In addition to the facility-specific outputs listed in Section 6.1, HEM4 produces three summary output files, based on the results for the entire run group of modeled facilities. These multi-facility outputs are updated after the output files for the individual facilities have been created and essentially concatenate the individual facility results into group-wide summary files. In each of these three xlsx files, HEM4 writes one row of information for each facility upon completion of that facility's individual modeling run. The three group-wide output files created by HEM4 in the following sections and sample files are provided in Appendix A. Note: These files will be produced even if you are modeling only one facility.

6.2.1 Facility Max Risk and HI

The Facility Max Risk and HI output file provides the maximum modeled risk and hazard index results for every facility as well as additional facility-specific modeling results, including:

- a listing of all Facility IDs modeled;
- the cancer risk at the receptor that experiences the highest risk in the modeled radius around each facility (i.e., facility-specific MIR);
- whether or not the MIR (max cancer risk) is interpolated from nearby receptors[9];
- the type of receptor where the MIR (max cancer risk) occurs (e.g., census block, alternate receptor, polar grid, user-defined receptor);
- the latitude and longitude of the MIR (cancer) receptor;
- the census block ID, alternate receptor ID or user receptor ID of the MIR receptor;
- the 14 TOSHIs at the receptors that experience the maximum TOSHI for each facility including: whether or not the TOSHI value is interpolated, the receptor type(s) where the max TOSHIs occur, the latitude and longitude for certain max TOSHI receptors (e.g., respiratory, neurological), and the census block ID, alternate receptor ID or user receptor ID of each max TOSHI receptor;
- the population, if any, excluded from the modeling run because of any census block centroid(s) located within the overlap distance around each emission source (and therefore considered on facility property)[10];
- the cancer incidence (predicted excess cancers per year due to modeled emissions) at each facility;
- the file name of the meteorological station used in the modeling of each facility;
- the distance (in kilometers) from the facility center to the meteorological station used in the modeling run;
- the latitude and longitude location of the facility center; and
- the dispersion environment used by HEM4 for modeling each facility – rural or urban.

The TOSHIs modeled by HEM4 can impact the following organs and organ systems: respiratory; liver; neurological; developmental; reproductive; kidney; ocular; endocrine; hematological; immunological; skeletal; spleen; thyroid; and whole body. In the sample abbreviated Facility Max Risk and HI provided in Appendix A, only respiratory HI is shown,

[9] An interpolated MIR generally suggests that the modeling distance should be increased and the facility remodeled.

[10] A value in the population overlap field generally indicates that the facility should be remodeled (e.g., with a smaller overlap distance specified) to ensure that the population associated with the census block centroid(s) is accounted for.

which is commonly the highest TOSHI level based on the dispersion and inhalation modeling performed by AERMOD and HEM4.

6.2.2 Facility Cancer Risk Exposure

The Facility Cancer Risk Exposure output file lists the facilities by ID, their corresponding latitudes and longitudes (of the calculated facility centers), and the population exposed to different cancer risk levels surrounding each facility, including:

- the number of people from each facility exposed to a cancer risk level greater than or equal to 1 in 1,000 (or 1,000 in a million);
- the number of people from each facility exposed to a cancer risk level greater than or equal to 1 in 10,000 (or 100 in a million);
- the number of people from each facility exposed to a cancer risk level greater than or equal to 1 in 100,000 (or 10 in a million);
- the number of people from each facility exposed to a cancer risk level greater than or equal to 1 in 1,000,000 (or 1 in a million); and
- the number of people from each facility exposed to a cancer risk level greater than or equal to 1 in 10,000,000 (or 0.1 in a million).

Note that each row of this output file is facility-specific and does not reflect the impacts of multiple facilities with overlapping modeling domains (which may impact the same receptor and increase population numbers at various risk levels beyond what each single facility causes). A sample Cancer Risk Exposure file is provided in Appendix A.

6.2.3 Facility TOSHI Exposure

The Facility TOSHI Exposure output file lists the facilities by ID and the number of people with a TOSHI greater than 1 for each facility and for each of the 14 TOSHIs currently modeled by HEM4. Note: Because the convention of one significant figure is employed, an HI greater than 1 equates mathematically to an HI greater than or equal to 1.5. A Facility TOSHI Exposure file is provided in Appendix A.

6.2.4 Additional Run Group Outputs

HEM4 will also produce several other group output files with each run, including:

- An **Inputs folder** containing every input file used by HEM4 (that you provided) for your modeling run - a useful QA feature to ensure the inputs you intended to be modeled were indeed the ones modeled
- A Google Earth™ map showing the source locations at every facility in your modeling run - named **AllFacility_source_locations.kmz**

- A **hem4.log** text file, as described in Section 4.4, which provides a permanent record of your model run – includes the files uploaded, the output files produced, whether the run was successful and/or any errors that occurred

- If HEM4 could not model all facilities listed in your inputs, a **Skipped Facilities** file (*Skipped_Facilities.xlsx*) will be produced which simply lists the IDs of those skipped facilities. You may use this to remodel those facilities, after correcting or amending the issues that caused the facilities to be skipped. This is discussed further in Section 9.

Note: **Do not change the names of the facility-level or HEM4 output files** (discussed above), as several of these files are referenced by their specific names in the code of the Risk Summary Report programs, described next in Section 7.

7. Risk Summary Reports

You may choose to run nine different Risk Summary Reports, as described in the step-by-step HEM4 instructions in Section 4.5. These reports, like the Run Group outputs described in Section 6.2, are based on risk results from all facilities modeled in your run group. However, the Risk Summary Reports have the added benefit of taking into account multiple impacts on the same receptor from nearby facilities. The nine Risk Summary Reports are described in this section.

7.1 Max Risk Summary

The Max Risk Summary output (*max_risk.xlsx*) provides the maximum cancer risk and maximum noncancer risk for all 14 TOSHI's at any populated receptor in the run group, accounting for multiple impacts on receptors from neighboring facilities. This summary also provides the FIPS and block ID for census blocks, the alternate receptor ID, or the user receptor ID of each of the maxima, as well as the receptor's population. The Max Risk Summary also lists the Facility ID(s) of the facility or facilities that impact these max receptors (i.e., contribute to the max risk and max TOSHIs at these receptors). Note: The maxima reported in this summary will equal the highest facility-specific risk and HI listed in the Facility Max Risk and HI output (discussed in Section 6.2.1), except when more than one facility's impacts on the same receptor cause the max risk and HI to be greater than the highest facility-specific risk and HI. A sample Max Risk Summary file is shown in Figure 20.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	RISK_TYPE	FIPS	BLOCK	POPULATION	RISK										
2	mir	36045	0613001004	126	4.8218E-07										
3	respiratory	36045	0613001004	126	0.003784775										
4	liver	36045	0613001004	126	0.00016653										
5	neurological	37165	0104001092	16	0.115473556										
6	developmental	36045	0613001004	126	2.37305E-05										
7	reproductive			0	0										
8	kidney			0	0										
9	ocular			0	0										
10	endocrine			0	0										
11	hematological			0	0										
12	immunological			0	0										
13	skeletal			0	0										
14	spleen			0	0										
15	thyroid			0	0										
16	whole body			0	0										
17	Facilities Impacting mir Block	Facilities Impacting respiratory Block	Facilities Impacting liver Block	Facilities Impacting neurological Block	Facilities Impacting developmental Block	Facilities Impacting reproductive Block	Facilities Impacting kidney Block	Facilities Impacting ocular Block	Facilities Impacting endocrine Block	Facilities Impacting hematological Block	Facilities Impacting immunological Block	Facilities Impacting skeletal Block	Facilities Impacting spleen Block	Facilities Impacting thyroid Block	Facilities Impacting whole body Block
18	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259	3604511259
19															

Figure 20. Sample Max Risk Summary Output

7.2 Cancer Drivers Summary

The Cancer Drivers output (*cancer_drivers.xlsx*) provides the pollutants and sources that are driving the maximum risk at each modeled facility (i.e., those pollutant-source combinations driving the risk at the receptor with the highest risk, for each facility). This file lists the facilities by ID; the MIR modeled at each facility from all pollutants and emission sources acting on the receptor; the predominant pollutant(s) and emission source(s) contributing to at least 90% of that facility's MIR; the cancer risk associated with each of those pollutant-source combinations; and the percentage risk contribution to the MIR for each. Figure 21 shows a sample output. **Note**: The Risk Contribution column for each facility will not sum to 100%, because only the pollutant-source combinations that add to at least 90% are displayed.

	A	B	C	D	E	F
1	Facility ID	MIR	Pollutant	Cancer Risk	Risk Contribution	Source ID
2	270536222111	1.13E-06	Arsenic compounds	8.90885E-07	78.84	CEPM0005
3	270536222111	1.13E-06	Nickel compounds	2.35101E-07	20.81	CEPM0005
4	3605517127011	1.02585E-06	Arsenic compounds	9.7294E-07	94.84	CEPM0002
5	484535678711	3.45674E-07	Arsenic compounds	4.61526E-08	13.35	CEPM0006
6	484535678711	3.45674E-07	Arsenic compounds	4.25802E-08	12.32	CEPM0026
7	484535678711	3.45674E-07	Arsenic compounds	3.81743E-08	11.04	CEPM0024
8	484535678711	3.45674E-07	Arsenic compounds	3.30016E-08	9.55	CEPM0007
9	484535678711	3.45674E-07	Arsenic compounds	3.27424E-08	9.47	CEPM0001
10	484535678711	3.45674E-07	Arsenic compounds	3.24023E-08	9.37	CEPM0004
11	484535678711	3.45674E-07	Arsenic compounds	2.62015E-08	7.58	CEPM0029
12	484535678711	3.45674E-07	Arsenic compounds	2.52855E-08	7.31	CEPM0005
13	484535678711	3.45674E-07	Arsenic compounds	2.46037E-08	7.12	CEPM0003
14	484535678711	3.45674E-07	Arsenic compounds	2.29875E-08	6.65	CEPM0002
15	480292859911	2.67013E-07	Arsenic compounds	3.40035E-08	12.73	CEIT0017
16	480292859911	2.67013E-07	Arsenic compounds	3.35951E-08	12.58	CEIT0024
17	480292859911	2.67013E-07	Arsenic compounds	3.35095E-08	12.55	CEIT0019
18	480292859911	2.67013E-07	Arsenic compounds	3.3506E-08	12.55	CEIT0018
19	480292859911	2.67013E-07	Arsenic compounds	3.34516E-08	12.53	CEIT0023
20	480292859911	2.67013E-07	Arsenic compounds	3.31681E-08	12.42	CEIT0020
21	480292859911	2.67013E-07	Arsenic compounds	3.29414E-08	12.34	CEIT0022
22	480292859911	2.67013E-07	Arsenic compounds	3.28125E-08	12.29	CEIT0021

Figure 21. Sample Cancer Drivers Summary Output

7.3 Hazard Index Drivers Summary

The Hazard Index Drivers output (*hazard_index_drivers.xlsx*) provides the sources and pollutants that are driving the maximum TOSHI at each modeled facility (i.e., those source-pollutant combinations driving the HI at each receptor with the highest TOSHI, for each facility). This file lists the facilities by ID; the "HI type" (respiratory, neurological, liver, etc., for all non-zero TOSHI values); the maximum TOSHI ("HI Total") modeled at each facility from all pollutants and emission sources acting on the receptor, the predominant sources and pollutants contributing to at least 90% of each maximum TOSHI; the TOSHI ("Hazard Index") value associated with each of these source-pollutant combinations; and the percentage each source-pollutant combination contributes to each maximum TOSHI (for all nonzero TOSHIs at each

facility). Figure 22 shows a sample output. **Note**: The Percentage column for each facility will not sum to 100%, because only the source-pollutant combinations that add to at least 90% are displayed.

	A	B	C	D	E	F	G
1	**Facility ID**	**HI Type**	**HI Total**	**Source ID**	**Pollutant**	**Hazard Index**	**Percentage**
2	Fac1-NC	Developmental HI	8.9969812	SR000001	arsenic compounds	8.964020301	99.63
3	Fac1-NC	Kidney HI	1.4796741	SR000001	cadmium compounds	1.445809726	97.71
4	Fac1-NC	Respiratory HI	0.6770494	RW000001	acrolein	0.557883699	82.4
5	Fac1-NC	Respiratory HI	0.6770494	FU000001	bis(2-ethylhexyl)phthalate	0.113999602	16.84
6	Fac1-NC	Liver HI	0.1816668	FU000001	bis(2-ethylhexyl)phthalate	0.113999602	62.75
7	Fac1-NC	Liver HI	0.1816668	RW000001	trichloroethylene	0.066946044	36.85
8	Fac1-NC	Neurological HI	0.0882496	RW000001	trichloroethylene	0.066946044	75.86
9	Fac1-NC	Neurological HI	0.0882496	FU000001	mercury (elemental)	0.020602338	23.35
10	Fac1-NC	Reproductive HI	0.0746997	RW000001	trichloroethylene	0.066946044	89.62
11	Fac1-NC	Reproductive HI	0.0746997	RV000001	1,3-butadiene	0.007751977	10.38
12	Fac1-NC	Immunological HI	0.0671872	RW000001	trichloroethylene	0.066946044	99.64
13	Fac2-IL	Liver HI	0.0405107	FU000001	bis(2-ethylhexyl)phthalate	0.037081163	91.53
14	Fac2-IL	Respiratory HI	0.039644	FU000001	bis(2-ethylhexyl)phthalate	0.037081163	93.54
15	Fac2-IL	Neurological HI	0.0266972	FU000001	mercury (elemental)	0.023278107	87.19
16	Fac2-IL	Neurological HI	0.0266972	FU000001	mercury (elemental)	0.00256432	9.61
17	Fac1-NC	Hematological HI	0.0009175	FU000001	selenium compounds	0.000910023	99.18
18	Fac2-IL	Hematological HI	0.0008619	FU000001	selenium compounds	0.000854773	99.18
19	Fac1-NC	Skeletal HI	0.000797	RW000001	hydrofluoric acid	0.000796977	100
20	Fac1-NC	Endocrine HI	2.296E-06	RV000001	cumene	2.29579E-06	100
21	Fac2-IL	Reproductive HI	2.124E-06	FU000001	benzo[a]pyrene	1.60048E-06	75.34
22	Fac2-IL	Developmental HI	2.124E-06	FU000001	benzo[a]pyrene	1.60048E-06	75.34
23	Fac2-IL	Reproductive HI	2.124E-06	FU000001	benzo[a]pyrene	5.23844E-07	24.66
24	Fac2-IL	Developmental HI	2.124E-06	FU000001	benzo[a]pyrene	5.23844E-07	24.66

Figure 22. Sample Hazard Index Drivers Summary Output

7.4 Risk Histogram Summary

The Risk Histogram output (*histogram_risk.xlsx*) provides the population and facility counts at various risk levels. This file lists the number of people and facilities in the modeled run group in the following risk bins:

- less than 1 in 1 million risk (displayed as “<1e-6”);
- greater than or equal to 1 in 1 million risk (displayed as “>= 1e-6”);
- greater than or equal to 10 in 1 million risk (displayed at “>=1e-5”);
- greater than or equal to 100 in 1 million risk (displayed as “>=1e-4”); and
- greater than or equal to 1,000 in 1 million risk (displayed as “>=1e-3”).

Note: This program assigns populations and facilities to cancer risk bins based on their risk level after rounding to one significant figure, per EPA convention. Also, note that the Risk Histogram Summary takes into account multiple impacts on the same receptor (from facilities located close to one another). This may cause the population numbers from this file to differ from the population numbers provided by the Facility Cancer Risk Exposure file. Figure 23 shows a sample output. Finally, it should also be noted that the total population modeled in the

run group can be determined by summing cells B2 and B3; and the total number of facilities modeled can be determined by summing cells C2 and C3.

	A	B	C
1	**Risk level**	**Population**	**Facility count**
2	<1e-6	3088984	0
3	>=1e-6	835305	2
4	>=1e-5	45866	1
5	>=1e-4	435	1
6	>=1e-3	0	0

Figure 23. Sample Risk Histogram Summary Output

7.5 Hazard Index Histogram Summary

The Hazard Index Histogram output (hi_histogram.xlsx) provides the population and facility counts at various noncancer HI levels, for all 14 TOSHIs. This file lists the number of people and facilities in the modeled run group in the following noncancer HI bins:

- > 1,000;
- > 100;
- > 10;
- > 1; and
- <= 1.

Note: This program assigns populations and facilities to noncancer HI bins based on their HI level after rounding to one significant figure, per EPA convention. Also, note that the Hazard Index Histogram Summary takes into account multiple impacts on the same receptor (from facilities located close to one another). This may cause the population numbers from this file to differ from the population numbers provided by the Facility TOSHI Exposure file. Figure 24 shows an abbreviated sample output for 3 TOSHIs; the actual file shows results for 14 TOSHIs.

	A	B	C	D	E	F	G
1	**HI Level**	**Respiratory Pop**	**Respiratory Facilities**	**Liver Pop**	**Liver Facilities**	**Neurological Pop**	**Neurological Facilities**
2	> 1000	0	0	0	0	0	0
3	> 100	0	0	0	0	0	0
4	> 10	0	0	0	0	0	0
5	> 1	167	1	0	0	22	1
6	<= 1	3924289	1	3924289	2	3924434	1

Figure 24. Sample Hazard Index Histogram Summary Output (Partial)

7.6 Incidence Drivers Summary

The Incidence Drivers output (*incidence_drivers.xlsx*) provides the pollutants driving the incidence across the entire run group of modeled facilities. (As noted in previous sections, the incidence is equal to the cancer risk of each block times the population of that block, divided by a 70-year lifetime, and summed over all blocks in the modeling domain.) In this file, the total incidence and individual incidence attributable to each pollutant are provided, as well as the percentage that pollutant-specific incidence is of total incidence. The pollutants are listed in descending order of contribution to the total incidence. Figure 25 shows a sample output.

	A	B	C
1	**Pollutant**	**Incidence**	**% of Total Incidence**
2	arsenic compounds	0.039060199	81.83%
3	1,3-butadiene	0.003666767	7.68%
4	cadmium compounds	0.003205572	6.72%
5	naphthalene	0.00105277	2.21%
6	benzene	0.000444901	0.93%
7	bis(2-ethylhexyl)phthalate	0.000219206	0.46%
8	chromium (vi) compounds	5.6644E-05	0.12%
9	trichloroethylene	1.01883E-05	0.02%
10	Total incidence	0.04773414	100%

Figure 25. Sample Incidence Drivers Summary Output

7.7 Acute Impacts Summary

The Acute Impacts output (*acute_impacts.xlsx*) provides the maximum acute concentration for every modeled pollutant, six acute benchmark values (REL, AEGL1, AEGL2, ERPG1, ERPG2 and IDLH, as defined above in Table 41), and the hazard quotient (HQ) based on the ratio of the pollutant's max acute concentration to the dose-response values for those six benchmarks. It should be noted that the max acute concentration is based on the acute high value you chose in your Facility List Options file. The file also provides the receptor ID at which this max acute concentration occurs, including the FIPS and block ID for a census block receptor, the alternate receptor ID, the user receptor ID, or the distance and angle for a polar receptor.

The Acute Impacts Summary is available only if you entered Y in the acute column of the Facility List Options input file prior to modeling, for one or more facilities in your run group. Note: The pollutant concentration is provided in mg/m^3 in this output (not $\mu g/m^3$ as provided by HEM4 at receptor locations in other output files) because the benchmark values are based on mg not µg). Figure 26 shows an abbreviated sample screenshot of the Acute Impacts Summary file.

7.8 Multipathway Summary

The Multipathway Summary output (*multi_pathway.xlsx*) provides arsenic, polycyclic aromatic hydrocarbon (PAH) and dioxin/furan (D/F) concentrations and risk at MIR receptors and within directional octants around each facility, which are useful for a post-HEM4 multipathway analysis.

This file lists the following information:

- the Run Group's label;
- the Facility ID;
- whether the facility was modeled using an urban or rural dispersion environment;
- whether the receptor in a given output row is an MIR or the closest receptor to the facility center in a specific octant direction (E, N, NE, NW, S, SE, SW, W);
- the pollutants the MIR is attributable to (All HAP, As for Arsenic, PAH, or D/F for Dioxins/Furans);
- whether the closest octant receptor is at a census block centroid, alternate receptor, or a discrete user receptor;
- the FIPS plus Block ID of the census receptor, or the ID of alternate and user receptor;
- the latitude and longitude location of the receptor;
- the population of the receptor;
- the total inhalation risk of that receptor (for all HAP);
- the total inhalation risk of that receptor attributable to Arsenic compounds;
- the total inhalation risk of that receptor attributable to PAHs; and
- the total inhalation risk of that receptor attributable to Dioxins/Furans.

Figure 27 shows a screenshot of a sample Multipathway Summary file. Note that blank cells indicate that emissions from this sample facility do not include arsenic, PAH, or D/F.

Facility ID	Pollutant	CONC_MG/M3	REL	AEGL_1_1H	[4 other benchmark columns]	HQ_REL	HQ_AEGL1	[4 other HQ columns based on 4 other benchmarks]	[4 columns indicating Receptor ID or distance and angle for polar receptor]
Fac1-NC	acetaldehyde	0.014339116	0.47	81	...	0.03050876	0.00017703	...	...
Fac1-NC	acrolein	0.100373815	0.0025	0.069	...	40.149526	1.45469297	...	...
Fac1-NC	arsenic compounds	0.069242032	0.0002	0	...	346.210161	0	...	...
Fac1-NC	benz[a]anthracene	1.61754E-06	0	0	...	0	0	...	...
Fac1-NC	benzene	0.029947323	0	170	...	0	0.00017616	...	...

Figure 26. Sample Acute Impacts Summary Output (abbreviated)

Run Group	Facility ID	Rural/ Urban	Octant or MIR	Chem, Centroid, or Discrete	Fips + Block	Lat	Lon	Population	Total Inhalation Cancer Risk	Total Inhalation As Cancer Risk	Total Inhalation PAH Cancer Risk	Total Inhalation D/F Cancer Risk
test_8-8-2020	Fac1-NC	U	MIR	All HAP	370639801001074	35.89908	-78.888	3	0.000610761	0	0	0
test_8-8-2020	Fac1-NC	U	MIR	As						0	0	0
test_8-8-2020	Fac1-NC	U	MIR	PAH						0	0	0
test_8-8-2020	Fac1-NC	U	MIR	DF						0	0	0
test_8-8-2020	Fac1-NC	U	E	Centroid	370630020283011	35.89548	-78.8494	1	1.28285E-05	0	0	0
test_8-8-2020	Fac1-NC	U	N	Centroid	370630020271050	35.91643	-78.8859	55	7.45249E-05	0	0	0
test_8-8-2020	Fac1-NC	U	NE	Centroid	370630020281025	35.92024	-78.8455	3	2.99575E-05	0	0	0
test_8-8-2020	Fac1-NC	U	NW	Centroid	370630020272047	35.90438	-78.8882	7	0.000248176	0	0	0
test_8-8-2020	Fac1-NC	U	S	Centroid	370630020272057	35.89265	-78.8873	219	0.00017255	0	0	0
test_8-8-2020	Fac1-NC	U	SE	Centroid	370630020283042	35.88258	-78.864	41	1.48092E-05	0	0	0
test_8-8-2020	Fac1-NC	U	SW	Discrete	U00000000URCPT1	35.90016	-78.8888	0	0.000518777	0	0	0
test_8-8-2020	Fac1-NC	U	W	Discrete	U00000000URCPT2	35.90434	-78.8909	0	0.00018499	0	0	0

Figure 27. Sample Multipathway Summary Output

7.9 Source Type Risk Histogram Summary

The Source Type Risk Histogram Summary (*source_type_risk.xlsx*) output provides a table showing the maximum cancer risk overall for the run group, as well as individually by emission source type. For the maximum overall risk and for the source type-specific risk, the file also provides the number of people estimated at three risk levels: >= 1 in 1 million, >= 10 in 1 million, and >= 100 in 1 million. The overall incidence and the incidence attributable to each emission source type is also provided. Figure 28 shows a screenshot of a sample Source Type Risk Histogram Summary file.

	Maximum Overall	SR	RV	FU	MS	RW	CV	HV	CT
Cancer Risk									
Maximum (in 1 million)	600	600	5	4	0.5	0.4	0.009	0.007	0.002
Number of people									
>= 100 in 1 million	435	435	0	0	0	0	0	0	0
>= 10 in 1 million	48,998	37,478	0	0	0	0	0	0	0
>= 1 in 1 million	800,229	528,652	214,494	239	0	0	0	0	0
Incidence	0.047	0.035	0.012	0.00022	5.9E-06	0.000011	3.3E-06	3.8E-06	2.1E-06
Run Group MIR (in a million) = 600.0									

Figure 28. Sample Sourcetype_Histogram_Sorted RTR Summary Output

Note: The Maximum Overall column lists the population at various risk levels attributable to all source types/emission process groups combined, while the other columns list the population at various risk levels attributable to each individual source type in isolation. The sum of the population tallies across the individual source types may not necessarily equal the corresponding value in the maximum overall column, at a given risk level, because: (a) two or more source types' impact in combination may be required to cause a census block population to exceed a given risk level; or conversely (b) an individual source type's impact in isolation may be enough to cause a census block population to exceed a given risk level, while other source types may similarly impact the same census block population and also (in isolation) cause that population to exceed the given risk level.

8. Understanding the Risk Results

This section contains an overview on using some of the HEM4 outputs and Risk Summary Reports to ascertain the cancer risks, noncancer hazards and acute impacts posed by a group of modeled facilities.

Step 1: Open the ***Max_Risk.xlsx*** summary report output to obtain the highest cancer risk and noncancer TOSHIs for all the modeled facilities in your run group, as well as the max receptor IDs and population at each max receptor. You can also view the number of facilities impacting each maximum receptor (in the case of nearby facilities impacting the same receptor).

Step 2: Open the ***Facility_max_risk_and_HI.xlsx*** output to obtain the facility-specific MIR in column B (mx_can_rsk), as well as the facility-specific maximum TOSHI values in each of their respective columns. Note: the highest facility-specific maximum is not necessarily the run group maximum based on concurrent emissions from the entire group of modeled facilities. Multi-facility impacts on the same receptor (from facilities located close to one another) are not accounted for in the ***Facility_max_risk_and_HI.xlsx*** output file, because each row of this output file is specific to each individual facility. Therefore, the run group maximum reported in the ***Max_Risk.xlsx*** summary report (which, as mentioned in Step 1, accounts for multiple impacts on the same receptor from more than one facility) will either be equal to or greater than the highest facility-specific MIR in the ***Facility_max_risk_and_HI.xlsx*** output.

Step 3: Open the ***Cancer_drivers.xlsx*** output to obtain the pollutant and emission source type driving the modeled risk. To report the top cancer drivers for a run group, use the Pollutant from column C and the Source ID from column F for all rows associated with the facility showing the highest risk. The MIR value from this highest facility will equal that listed in the ***Facilty_max_risk_and_HI.xlsx*** file from Step 2. Note: This output does not account for 100% of the modeled risk, but rather provides those pollutant-emission source combinations that contribute at least 90% to the facility's MIR (from one or more pollutant-emission source combinations, depending on how many combinations are needed to describe 90% of the modeled risk at each facility).

Step 4: Open the ***Histogram_risk.xlsx*** output to obtain the number of people and facilities at various risk levels. The total population within the modeling domain (by default a 50-kilometer radius around each facility or your user-specified radius) equals the sum of cells B2 + B3. This histogram output counts facilities based on modeled risk at populated census blocks, alternate receptors, and user receptors. Consequently, this file's facility count numbers will be in accord with the manual counting of facilities at each risk level from the ***Facility_max_risk_and_HI.xlsx*** file. Note: What risk bin a facility falls into in this output is based on the one significant figure rounding convention adopted by the EPA.

Step 5: Open the ***Hazard_Index_Drivers.xlsx*** output to obtain the pollutant and emission source driving all (non-zero) TOSHIs at each modeled facility. To report the top HI drivers for a run group, use the Pollutant from column E and the Source ID from column D for all rows associated with the facility showing the highest total TOSHI in column C ("HI Total"). The TOSHI value from this highest facility should equal the TOSHI value listed in the ***Facilty_max_risk_and_HI.xlsx*** file from Step 2. Note: This output

does not account for 100% of the modeled TOSHI, but rather provides those pollutant-emission source combinations that contribute at least 90% to the facility's total TOSHI.

Step 6: Open the ***Hi_histogram.xlsx*** output to obtain the number of people and facilities at various HI levels for each of the 14 TOSHIs. These numbers are based on the one significant figure rounding convention (e.g., an HI of 1.4 rounds to 1 and so is considered <= 1).

Step 7: Open the ***Incidence_drivers.xlsx*** output to obtain the run group-wide incidence attributable to each pollutant. This file is sorted in descending order of incidence and column C provides the percentage each pollutant drives the total incidence for all of your modeled facilities.

Step 8: Open the ***Source_type_risk.xlsx*** output to obtain the number of people at various risk levels caused by each emission source type, and the incidence attributable to each source type. This output also shows the run group MIR and the number of people at various risk levels attributable to all source types combined ("Maximum Overall" which accounts for impacts on the same receptor by different source types), as well as the overall incidence.

Step 9: Open the ***Acute_impacts.xlsx*** output, if you modeled acute impacts, to obtain the hazard quotients (HQs) based on various benchmarks for each pollutant of interest, as well as the highest acute concentration for each HAP. You can perform a manual count using this output file to determine the number of facilities with an HQ >= 1.5 for any benchmark. (Note: An HQ >=1.5 is the mathematical definition of "greater than 1" when using EPA's one significant figure rounding convention.) This output file also provides (in the far-right columns) the Receptor ID experiencing the maximum acute concentration for each pollutant at every modeled facility.

Step 10: Open the ***AllFacility_source_locations.kmz*** output to see all modeled sources at each facility in your run group on a Google Earth™ map. This map provides a ready view of the distance between your modeled facilities, and it allows you to perform QA to determine whether the modeled locations of your sources are reasonable.

For additional details regarding the modeling results for each of the facilities in the run group, open the individual facility subfolders in the output folder. Section 6 discusses these facility-specific output files. Each facility folder also contains a ***source_risk.kmz*** output file which displays the detailed modeled risk results for that facility on a Google Earth™ map.

Finally, HEM4 provides numerous graphical ways to review and understand your outputs, as discussed further in Section 4.6 regarding the *Analyze Outputs* buttons on the HEM4 interface.

9. Quality Assurance Remodeling

There are several quality assurance (QA) checks that you should perform after HEM4 has completed modeling each of your facilities. These QA checks should be made before you run the Risk Summary Reports (described in Section 4.5), to determine if any of the facilities need to be revised and remodeled.

Ensuring the Maximum Individual Risk (MIR) and Max Target Organ-Specific Hazard Index (TOSHIs) are Located at Populated Receptors

First, open and review the ***Facility_max_risk_and_HI.xlsx*** file to ensure that:

- the number of facilities modeled in column A equals the number of facilities in the input files (e.g., ***Facility_List_Options.xlsx***);
- the maximum cancer risk values in column B occur at census blocks, alternate receptors, or populated user-defined receptors rather than at unpopulated polar grid (or boundary or monitor) receptors, as noted in column D; and
- the TOSHI values in the various HI columns occur at census blocks, alternate receptors, or populated user-defined receptors rather than at unpopulated polar grid (or boundary or monitor) receptors.

The cancer risk and noncancer TOSHI QA checks described above are especially important for facilities of interest, such as those facilities with relatively high cancer risk or TOSHI values in the modeled set. Remodel those facilities (as described below) that failed one or more of the QA checks before running the Risk Summary Reports. Rerunning HEM4 for such facilities will ensure that all facilities in the run group are modeled and that the modeled maximum risk and TOSHI values occur at populated receptors.

Follow these steps to rerun a facility when the MIR or the maximum TOSHIs occur at an unpopulated receptor (such as a polar grid receptor)[11]. First, review the ***Source_risk.kmz*** file located in the individual facility subfolder. Opening this file will start Google Earth™ if it is installed on your computer. Figure 29 shows a sample Google Earth™ kmz output file.

Zoom in on the facility center and turn on the polar grid (by checking the box next to “Polar receptor cancer risk” in the Places key) to make visible the polar grid receptor at which the MIR or TOSHI value occurs. Next, find the census block centroid closest to the MIR polar receptor. Use the ‘ruler’ tool to measure the distance (in meters) from the census block centroid to the approximate facility center. Increase this distance enough to ensure that a census block centroid near the current polar MIR receptor will be closer to the facility center than this revised first polar ring when the facility is rerun, as explained further below. Follow these steps for all facilities of interest requiring remodeling due to an overlapped populated receptor.

[11] The MIR or maximum TOSHIs can occur at a polar grid receptor if there is a census block or alternate receptor located within the overlap distance of the facility boundary. In this case, HEM4 will select the closest receptor to the facility boundary (i.e., census block, alternate, user-defined, or polar) to estimate the MIR at a location nearest to the population inside the overlap distance that has been excluded.

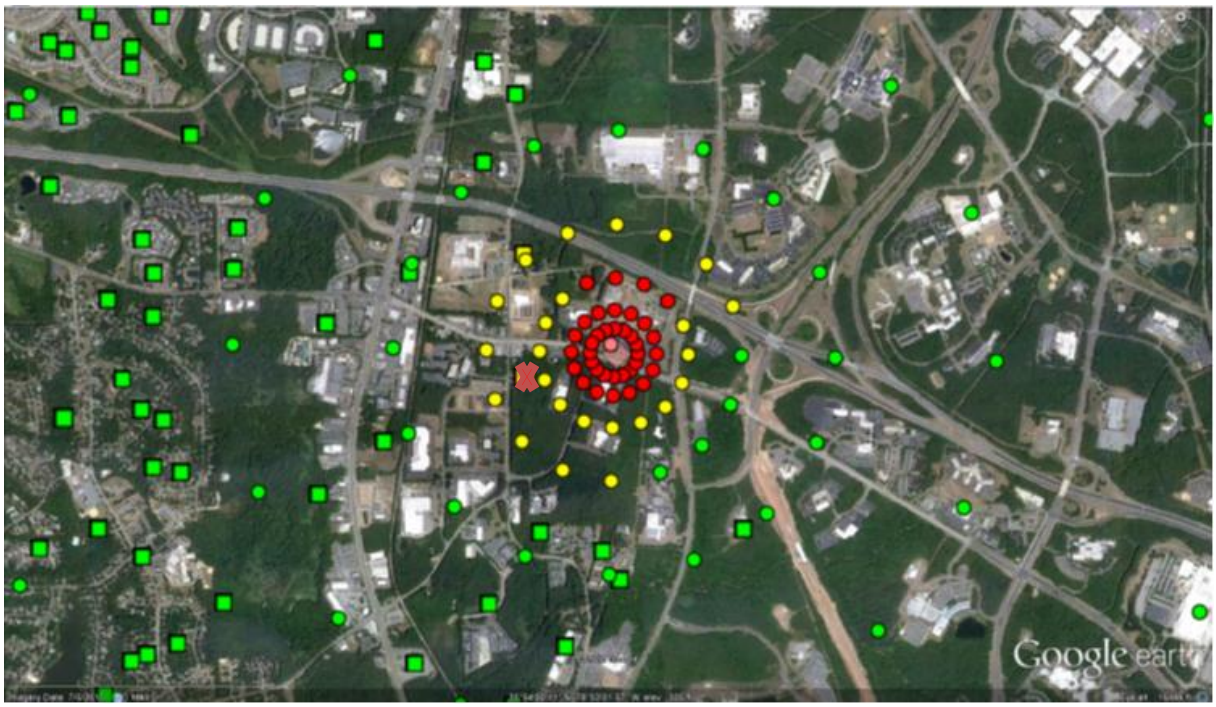


Figure 29. Sample Source_risk.kmz HEM4 Output

To rerun the facility or facilities, create a copy of the input file ***Facility_List_Options.xlsx***. Be careful to name the new file so that it is obvious it is not the original ***Facility_List_Options.xlsx*** file (e.g., ***QA1_Facility_list_options.xlsx*** to indicate it is the first QA run). Delete the rows for the facilities that do NOT have to be rerun.

Next, under the column heading 'ring1', enter the value determined from the above instructions (i.e., the distance in meters between the approximate facility center and the census block centroid closest to the MIR polar receptor, rounded up). Save these changes and close the file.

Re-start HEM4 using the new ***QA1_Facility_list_ options.xlsx*** file as an input. (Note: There may be extra facilities in the *HAP Emissions* and *Emissions Location* files from your original run, because HEM4 will only use data for the facilities listed in the Facility List Options file you specify for the QA run.) HEM4 will then remodel the facilities with revised first ring distances. This "bumping out" of the first polar ring will allow HEM4 to choose a populated census block or alternate receptor as the MIR or TOSHI receptor, because the first polar ring of polar receptors will be more distant from the facility center than the closest populated receptor. When re-running HEM4, it is advisable to name the 'output' folder using "QA1" in case additional QA runs are necessary.

Once you have rerun the facility or facilities, check the outputs to determine if the relevant MIR or TOSHI is now at a populated receptor by opening the ***QA1_Facility_max_risk_and_HI.xlsx*** file. If the MIR or TOSHI is still at a polar grid receptor, repeat the above steps (starting with opening the ***Source_risk.kmz*** file) using the identifier *QA2* for the naming convention. Make the first ring of the polar grid more distant from the facility center than in the first adjustment.

After you have successfully adjusted the distance so that the MIR and maximum TOSHIs occur at populated receptors, copy the most recent facility rows from all ***QA_Facility_max_risk_ and_HI.xlsx*** files (e.g., *QA1, QA2*, *QA3*) into the original ***Facility_max_risk_and_HI.xlsx*** file.

Perform this row replacement for each remodeled facility, using the most recent QA run applicable to that facility. In addition, replace the original subfolder for each remodeled facility by copying the most recent facility output subfolder (including all its revised contents) from the QA run to the location of the original facility output. Move or delete the original subfolder.

Ensuring Maxima are Discretely Modeled, not Interpolated:

A facility may require remodeling (using the steps described above) if the MIR and/or max TOSHI values of that facility are interpolated, rather than explicitly modeled. The ***Facility_max_risk_and_HI.xlsx*** output indicates interpolated maximum risk values in column C and maximum TOSHI values in the columns to the right of each TOSHI value (e.g., column I for the respiratory HI). If these fields are blank, then the values are not interpolated. Generally, a value is interpolated if the maximum receptor is located outside the modeling distance within which receptors are explicitly modeled (e.g., at a default value of 3,000 m or 3 km). This can occur if a modeled facility is located in a sparsely populated area, where there are no census block centroids or alternate receptors within the modeling distance (e.g., 3 km) of the facility center.

Open the ***Source_risk.kmz*** file located in the individual facility subfolder to determine if a facility with an interpolated MIR and/or TOSHI should be remodeled with an increased modeling distance. This Google Earth™ kmz file will show where the closest populated receptors are located. The modeling distance should be increased to include the populated receptor(s). Use Google Earth's™ ruler tool to determine the new modeling distance. Remember to increase this distance slightly before remodeling the facility in a QA run, as discussed above. Note: If the risk and all TOSHIs are considered low—and if the reason for the low values is that the facility is located in a sparsely populated area—you may decide that revising the modeling distance and remodeling is not necessary.

An interpolated MIR or TOSHI value may also occur if one or more of the emission sources is mislocated – for example, with an incorrect latitude or longitude that places a source too far from the actual facility location and other modeled sources. This interpolated situation requires remodeling to correct the location inaccuracy. If one or more source is mislocated (as determined by reviewing the facility specific ***Source_risk.kmz*** or the run group-wide ***AllFacility_source_locations.kmz*** file), perform a QA rerun for that facility using a corrected *Emissions Location* file (and a corrected *polygon vertex* file and/or *buoyant line parameters* file, if the misplaced source is configured as a polygon or buoyant line source).

In general, the image of each facility's emission sources and receptors on a Google Earth™ satellite map (i.e., the ***Source_risk.kmz*** file) is a powerful tool for QA checks of the inputs and modeling parameters that HEM4 uses (see Figure 29 above as an example). It is best practice to review each ***Source_risk.kmz*** file, even if all MIR and TOSHI values listed in the ***Facility_max_risk_and_HI.xlsx*** output occur at populated receptors and no values are interpolated. Reviewing these map images allows you to determine if sources are mislocated and require remodeling and if the surrounding populations are represented well enough by the populated receptors. (If surrounding populations are not represented sufficiently by the receptors, you can remodel with the addition of user-defined receptors placed near residences.)

This QA check of each ***Source_risk.kmz*** image is highly recommended. Even a QA check of a kmz image that shows nothing amiss may prove useful. For example, if nothing looks amiss in the ***Source_risk.kmz*** image, but the MIR and/or TOSHI values seem too high to be reasonable, this may indicate an error in the emission amounts or pollutant names provided in the HAP Emissions input file.

Once you have performed all QA checks and remodeled any facilities, you are ready to run the Risk Summary Reports, as described in Section 4.5. The Risk Summary Report programs need as inputs the final *Facility_max_risk_and_HI.xlsx* and several facility-specific outputs (depending on the HEM4 options you selected and which Risk Summary Reports you run). **Therefore, do not rename the HEM4 output files**.

Modeling Skipped Facilities:

As noted in Section 4.8, if HEM4 is unable to model a facility or facilities due to errors in the inputs, HEM4 will produce an Excel file entitled "Skipped Facilities" *(Skipped_facilities.xslx*) in the run group's output subfolder. After you fix the errors in the inputs, you can use the list of skipped facilities in column A of this output file to create a new Facility List Options file. Use the new Facility List Options file to model the facilities as a group. Then copy the resulting skipped facility output folders back into the directory/folder containing the original group's modeled outputs. Next, append the resulting Facility Mask Risk and HI rows into the original Facility Max Risk and HI file (described in Section 6.2.1). Do the same appending for the Facility Cancer Risk Exposure file (described in Section 6.2.2) and the Facility TOSHI Exposure file (described in Section 6.2.3). Finally, run the Risk Summary Reports on the full set of HEM4 outputs (as described in Section 4.5 and Section 7).

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11. Appendix A: Sample HEM4 Output Files

This appendix contains examples (some abbreviated to fit) of the facility-specific and run group HEM4 output files. Sample Risk Summary Reports are provided in Section 7.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Parameter	Value	Value rounded	Value scientific notation	Population	Distance (m)	Angle (from north)	Elevation (m)	Hill height (m)	FIPs	Block	UTM easting	UTM northing	Latitude	Longitude	Receptor type	Notes
Cancer risk	0.00061	0.0006	6.1e-04	3	491.8557	217.7	89.7	89.7	37063	9801001074	690605	3974816	35.89908	-78.888	Census block	Discrete
Respiratory HI	0.67705	0.7	6.8e-01	0	459.4366	233.9	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor	Discrete
Liver HI	0.18167	0.2	1.8e-01	0	459.4366	233.9	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor	Discrete
Neurological HI	0.08825	0.09	8.8e-02	0	459.4366	233.9	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor	Discrete
Developmental HI	8.99698	9	9.0e+00	3	491.8557	217.7	89.7	89.7	37063	9801001074	690605	3974816	35.89908	-78.888	Census block	Discrete
Reproductive HI	0.0747	0.07	7.5e-02	0	459.4366	233.9	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor	Discrete
Kidney HI	1.47967	1	1.5e+00	3	491.8557	217.7	89.7	89.7	37063	9801001074	690605	3974816	35.89908	-78.888	Census block	Discrete
Ocular HI	0	0	0	0	0	0	0	0			0	0	0	0		
Endocrine HI	2.3E-06	2E-06	2.3e-06	219	1124.139	191.4	85.8	85.8	37063	0020272057	690684	3974103	35.89265	-78.8873	Census block	Discrete
Hematological HI	0.00092	0.0009	9.2e-04	3	491.8557	217.7	89.7	89.7	37063	9801001074	690605	3974816	35.89908	-78.888	Census block	Discrete
Immunological HI	0.06719	0.07	6.7e-02	0	459.4366	233.9	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor	Discrete
Skeletal HI	0.0008	0.0008	8.0e-04	0	459.4366	233.9	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor	Discrete
Spleen HI	0	0	0	0	0	0	0	0			0	0	0	0		
Thyroid HI	0	0	0	0	0	0	0	0			0	0	0	0		
Whole body HI	0	0	0	0	0	0	0	0			0	0	0	0		

Figure 30. Sample Maximum Individual Risk HEM4 Output (facility-specific)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Parameter	Value	Value_ rnd	Value_ sci	Population	Distance (in meters)	Angle (from north)	Elevation (in meters)	Hill Height (in meters)	Fips	Block	Utm_east	Utm_north	Latitude	Longitude	Rec_type
Cancer risk	0.000783	0.0008	7.8e-04	0	565	67.5	92	92			691428	3975421	35.90438	-78.878745	Polar grid
Respiratory HI	0.677049	0.7	6.8e-01	0	459.436612	233.85	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor
Liver HI	0.277505	0.3	2.8e-01	0	565	90	92	92			691471	3975205	35.90242	-78.878321	Polar grid
Neurological HI	0.08825	0.09	8.8e-02	0	459.436612	233.85	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor
Developmental HI	11.47101	10	1.1e+01	0	565	67.5	92	92			691428	3975421	35.90438	-78.878745	Polar grid
Reproductive HI	0.0747	0.07	7.5e-02	0	459.436612	233.85	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor
Kidney HI	1.974576	2	2.0e+00	0	565	67.5	92	92			691428	3975421	35.90438	-78.878745	Polar grid
Ocular HI	0	0	0	0	0	0	0	0			0	0	0	0	
Endocrine HI	4.2E-06	4E-06	4.2e-06	0	565	90	92	92			691471	3975205	35.90242	-78.878321	Polar grid
Hematological HI	0.001641	0.002	1.6e-03	0	565	90	92	92			691471	3975205	35.90242	-78.878321	Polar grid
Immunological HI	0.067187	0.07	6.7e-02	0	459.436612	233.85	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor
Skeletal HI	0.000797	0.0008	8.0e-04	0	459.436612	233.85	90.5	90.5	U0000	0000URCPT1	690535	3974934	35.90016	-78.88875	User receptor
Spleen HI	0	0	0	0	0	0	0	0			0	0	0	0	
Thyroid HI	0	0	0	0	0	0	0	0			0	0	0	0	
Whole body HI	0	0	0	0	0	0	0	0			0	0	0	0	

Figure 31. Sample Maximum Offsite Risk HEM4 Output (facility-specific)

A	B	C	D	E	F	G	H	I	J	K	L
Site type	Parameter	Source ID	Pollutant	Emission type	Value	Value rounded	Conc (ug/m3)	Conc rounded (ug/m3)	Emissions (tpy)	URE 1/(ug/m3)	RFc (mg/m3)
Max indiv risk	Cancer risk	CT000001	All modeled pollutants	NA	1.88E-09	2E-09	6.95E-10	7E-10	2.456E-07	0	0
Max indiv risk	Cancer risk	CT000001	2,3,4,7,8-pentachlorodibenzofuran	C	1.04E-09	1E-09	1.05E-10	1E-10	3.7E-08	9.9	1.3E-07
Max indiv risk	Cancer risk	CT000001	1,2,3,7,8-pentachlorodibenzo-p-dioxin	C	2.25E-10	2E-10	6.82E-12	7E-12	2.41E-09	33	4E-08
…	…	…	…	…	…	…	…	…	…	…	…
Max indiv risk	Cancer risk	Total	All pollutants all sources	NA	0.000611	0.0006	1.964495	2	39.355593	0	0
Max indiv risk	Cancer risk	Total by pollutant all sources	arsenic compounds	NA	0.000579	0.0006	0.134549	0.1	1.06	0	0
Max indiv risk	Cancer risk	Total by pollutant all sources	cadmium compounds	NA	2.61E-05	0.00003	0.014526	0.01	0.2	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Max offsite impact	Cancer risk	CT000001	All modeled pollutants	NA	6.26E-09	6E-09	2.31E-09	2E-09	2.456E-07	0	0
Max offsite impact	Cancer risk	CT000001	2,3,4,7,8-pentachlorodibenzofuran	C	3.44E-09	3E-09	3.48E-10	3E-10	3.7E-08	9.9	1.3E-07
…	…	…	…	…	…	…	…	…	…	…	…
Max offsite impact	Cancer risk	Total	All pollutants all sources	NA	0.000783	0.0008	2.157177	2	39.355593	0	0
Max offsite impact	Cancer risk	Total by pollutant all sources	arsenic compounds	NA	0.000739	0.0007	0.171925	0.2	1.06	0	0
Max offsite impact	Cancer risk	Total by pollutant all sources	cadmium compounds	NA	3.54E-05	0.00004	0.019652	0.02	0.2	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Max indiv risk	Developmental HI	CT000001	2,3,4,7,8-pentachlorodibenzofuran	C	0	0	1.05E-10	1E-10	3.7E-08	9.9	1.3E-07
Max indiv risk	Developmental HI	CT000001	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	C	0	0	5.15E-12	5E-12	1.82E-09	3.3	4E-07
…	…	…	…	…	…	…	…	…	…	…	…
Max indiv risk	Developmental HI	CT000001	All modeled pollutants	NA	0	0	6.95E-10	7E-10	2.456E-07	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Max indiv risk	Developmental HI	Total	All pollutants all sources	NA	8.996981	9	1.964495	2	39.355593	0	0
Max indiv risk	Developmental HI	Total by pollutant all sources	arsenic compounds	NA	8.969901	9	0.134549	0.1	1.06	0	0
Max indiv risk	Developmental HI	Total by pollutant all sources	trichloroethylene	NA	0.027078	0.03	0.054157	0.05	0.24	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Max offsite impact	Developmental HI	CT000001	2,3,4,7,8-pentachlorodibenzofuran	C	0	0	3.48E-10	3E-10	3.7E-08	9.9	1.3E-07
Max offsite impact	Developmental HI	CT000001	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	C	0	0	1.71E-11	2E-11	1.82E-09	3.3	4E-07
…	…	…	…	…	…	…	…	…	…	…	…
Max offsite impact	Developmental HI	CT000001	All modeled pollutants	NA	0	0	2.31E-09	2E-09	2.456E-07	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Max offsite impact	Developmental HI	Total	All pollutants all sources	NA	11.47101	10	2.157177	2	39.355593	0	0
Max offsite impact	Developmental HI	Total by pollutant all sources	arsenic compounds	NA	11.46165	10	0.171925	0.2	1.06	0	0
Max offsite impact	Developmental HI	Total by pollutant all sources	trichloroethylene	NA	0.009358	0.009	0.018716	0.02	0.24	0	0
…	…	…	…	…	…	…	…	…	…	…	…

Figure 32. Sample Risk Breakdown HEM4 Output (facility-specific, abbreviated)

Note: To capture the full extent of the kind of information provided in this output, the above sample Risk Breakdown file includes missing rows as indicated by the ellipses (…) for risk by individual source and pollutant, for risk by individual source and all pollutants combined, and for risk by individual pollutant and all sources combined. The above sample file also depicts only one of the 14 TOSHIs (Developmental HI) included in the actual file. The file includes the above breakdown for cancer risk and for all 14 (noncancer) TOSHIs, for both populated receptors (“Max indiv risk”) and for any receptor whether populated or unpopulated (“Max offsite impact”).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Latitude	Longitude	Overlap	Elevation	FIPs	Block	X	Y	Hill	Population	MIR	Respiratory HI	Liver HI	Neurological HI	...
36.09438	-79.38606	N	181.3	37001	203004018	645293	3995623	181.3	66	3.86E-07	0.000246666	3.85E-05	1.43E-05	...
36.09624	-79.37883	N	173.5	37001	203005002	645941	3995840	173.5	3	3.89E-07	0.000248244	3.87E-05	1.43E-05	...
36.09475	-79.38259	N	178.3	37001	203005005	645605	3995669	178.3	3	3.88E-07	0.000247772	3.86E-05	1.43E-05	...
36.09726	-79.38345	N	173.7	37001	203005007	645523	3995946	173.7	55	3.85E-07	0.000245794	3.83E-05	1.42E-05	...
36.09843	-79.3833	N	171.2	37001	203005008	645534	3996075	171.2	35	3.84E-07	0.00024509	3.82E-05	1.42E-05	...
36.08863	-79.3819	N	174.5	37001	203005010	645678	3994991	174.5	57	3.94E-07	0.0002521	3.93E-05	1.46E-05	...
36.092	-79.38435	N	185.3	37001	203005011	645452	3995361	185.3	2	3.89E-07	0.000248895	3.88E-05	1.44E-05	...
36.09427	-79.38459	N	179.3	37001	203005012	645426	3995613	179.3	13	3.87E-07	0.000247309	3.86E-05	1.43E-05	...
36.09397	-79.38536	N	183.4	37001	203005013	645357	3995577	183.4	2	3.87E-07	0.000247214	3.86E-05	1.43E-05	...
36.09193	-79.38555	N	185.4	37001	203005014	645343	3995351	185.4	13	3.88E-07	0.000248466	3.88E-05	1.44E-05	...
36.09238	-79.38517	N	184.4	37001	203005015	645377	3995402	184.4	10	3.88E-07	0.000248321	3.87E-05	1.44E-05	...
36.09002	-79.38582	N	181	37001	203005017	645323	3995140	181	14	3.90E-07	0.000249604	3.90E-05	1.44E-05	...
36.08975	-79.38621	N	178	37001	203005018	645288	3995109	178	11	3.90E-07	0.000249626	3.90E-05	1.44E-05	...
36.08996	-79.3878	N	183.5	37001	203005019	645144	3995129	183.5	19	3.89E-07	0.000248859	3.89E-05	1.44E-05	...
36.0873	-79.38689	N	183.1	37001	203005039	645232	3994836	183.1	36	3.91E-07	0.000250958	3.92E-05	1.45E-05	...
36.08769	-79.3852	N	181.4	37001	203005040	645383	3994881	181.4	37	3.92E-07	0.00025139	3.93E-05	1.46E-05	...
36.08671	-79.3833	N	174.7	37001	203005042	645556	3994776	174.7	24	3.94E-07	0.000252807	3.95E-05	1.46E-05	...
36.08729	-79.38956	N	189.6	37001	203005046	644991	3994831	189.6	82	3.90E-07	0.000249883	3.90E-05	1.45E-05	...
36.08615	-79.38586	N	181.1	37001	203005048	645326	3994709	181.1	26	3.93E-07	0.000252133	3.94E-05	1.46E-05	...
36.08476	-79.38295	N	171.2	37001	203005050	645591	3994560	171.2	12	3.96E-07	0.000254249	3.97E-05	1.47E-05	...
36.08756	-79.37782	N	169.4	37001	203005052	646047	3994878	169.4	24	3.97E-07	0.000254489	3.97E-05	1.47E-05	...
36.0909	-79.37605	N	166.8	37001	203005053	646200	3995251	166.8	99	3.95E-07	0.000252943	3.94E-05	1.46E-05	...
36.0907	-79.37304	N	156.3	37001	203005054	646472	3995234	156.3	19	3.98E-07	0.000254301	3.96E-05	1.47E-05	...
36.09164	-79.37145	N	157.3	37001	203005056	646614	3995340	157.3	8	3.98E-07	0.000254305	3.96E-05	1.47E-05	...
36.09327	-79.37612	N	166	37001	203005057	646190	3995514	166	24	3.93E-07	0.000251308	3.92E-05	1.45E-05	...
36.0889	-79.37362	N	154.5	37001	203005061	646424	3995033	154.5	46	3.99E-07	0.00025531	3.98E-05	1.48E-05	...
36.08887	-79.371	N	157	37001	203005062	646659	3995034	157	16	4.01E-07	0.000256407	4.00E-05	1.48E-05	...
36.08803	-79.37061	N	159.1	37001	203005063	646696	3994941	159.1	17	4.02E-07	0.000257159	4.01E-05	1.49E-05	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 33. Sample Block Summary Chronic HEM4 Output (facility-specific, abbreviated)

Note: The Block Summary Chronic file is large because it includes the cancer risk ("MIR") and all 14 TOSHIs for every modeled block or alternate receptor. The above sample file includes ellipses (…) because it shows only a partial list of rows and only 3 of the 14 TOSHI's (Respiratory HI, Liver HI and Neurological HI). In addition, the actual file includes a final column indicating whether the concentration (and therefore risk and TOSHIs) at each receptor were discretely modeled or interpolated.

Latitude	Longitude	Overlap	Elevation (m)	X	Y	Hill	MIR	Respiratory HI	Liver HI	Neurological HI	Developmental HI	...	Distance (m)	Angle (from north)	Sector
35.90762	-78.88444	N	92	690906	3975770	92	0.000276	0.16267133	0.06719334	0.022959781	4.061680358	...	565	0	1
35.91028	-78.88437	N	85	690906	3976065	85	0.000163	0.08834714	0.03991907	0.012732447	2.405209191	...	860	0	1
35.91433	-78.88426	N	86	690906	3976515	86	9.86E-05	0.05006334	0.02351642	0.007284751	1.449323028	...	1310	0	1
35.92046	-78.8841	N	86	690906	3977195	86	5.67E-05	0.02748919	0.01321489	0.004022705	0.830353561	...	1990	0	1
35.92956	-78.88386	N	98	690906	3978205	98	3.29E-05	0.01497071	0.00728229	0.002192643	0.476986257	...	3000	0	1
35.94127	-78.88355	N	108	690906	3979505	108	1.98E-05	0.00851103	0.00414235	0.001235919	0.283698446	...	4300	0	1
35.95749	-78.88311	N	128	690906	3981305	128	1.19E-05	0.00487219	0.00221982	0.000669144	0.164677271	...	6100	0	1
35.98092	-78.88249	N	128	690906	3983905	128	7.18E-06	0.00297086	0.00127924	0.000389865	0.098200187	...	8700	0	1
36.01425	-78.88159	N	126	690906	3987605	126	4.30E-06	0.00182397	0.00072968	0.000225519	0.057813435	...	12400	0	1
36.0611	-78.88034	N	134	690906	3992805	134	2.61E-06	0.0011715	0.00040331	0.000128775	0.03383493	...	17600	0	1
36.12777	-78.87855	N	174	690906	4000205	174	1.60E-06	0.00087183	0.00020231	7.08E-05	0.018804954	...	25000	0	1
36.22237	-78.87599	N	234	690906	4010705	234	9.40E-07	0.00061899	9.59E-05	3.64E-05	0.00985544	...	35500	0	1
36.35301	-78.87245	N	207	690906	4025205	207	6.14E-07	0.00039616	6.43E-05	2.42E-05	0.00651898	...	50000	0	1
35.90719	-78.88206	N	92	691122	3975727	92	0.000317	0.20423035	0.08411586	0.028758088	4.672317905	...	565	22.5	2
35.90963	-78.88074	N	92	691235	3976000	92	0.000192	0.10610333	0.04725769	0.015216162	2.82876806	...	860	22.5	2
35.91334	-78.87874	N	86	691407	3976415	86	0.000106	0.05416447	0.02491204	0.007832226	1.5593033	...	1310	22.5	2
35.91895	-78.8757	N	86	691668	3977044	86	5.91E-05	0.02814812	0.01306979	0.004078483	0.86713832	...	1990	22.5	2
35.92728	-78.8712	N	98	692054	3977977	98	3.20E-05	0.01471825	0.00679289	0.002115014	0.466186678	...	3000	22.5	2
35.938	-78.86539	N	115	692552	3979178	115	1.81E-05	0.00825512	0.00360303	0.001123976	0.256202648	...	4300	22.5	2
35.95285	-78.85736	N	126	693240	3980841	126	1.10E-05	0.00516917	0.00198365	0.000625377	0.149211565	...	6100	22.5	2
35.9743	-78.84575	N	126	694235	3983243	126	6.79E-06	0.00327005	0.00114822	0.000363808	0.089533991	...	8700	22.5	2
36.00481	-78.82921	N	122	695651	3986661	122	4.11E-06	0.00201365	0.00066383	0.000211097	0.053338866	...	12400	22.5	2
36.04769	-78.80594	N	119	697641	3991465	119	2.48E-06	0.00123679	0.00037985	0.000121813	0.031601403	...	17600	22.5	2
36.1087	-78.77279	N	128	700473	3998302	128	1.51E-06	0.00079302	0.00020903	6.91E-05	0.018536631	...	25000	22.5	2
36.19526	-78.72566	N	185	704491	4008003	185	9.14E-07	0.00055697	0.00010008	3.60E-05	0.010134297	...	35500	22.5	2
36.31474	-78.66039	N	161	710040	4021399	161	5.74E-07	0.0003369	6.18E-05	2.22E-05	0.006426578	...	50000	22.5	2
35.90606	-78.88005	N	92	691306	3975605	92	0.000421	0.26615504	0.10388434	0.036941868	6.177728359	...	565	45	3
35.90789	-78.8777	N	92	691514	3975813	92	0.000272	0.16583271	0.06683816	0.023219576	3.998420365	...	860	45	3
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 34. Sample Ring Summary Chronic HEM4 Output (facility-specific, abbreviated)

Note: The Ring Summary Chronic file includes the cancer risk ("MIR") and all 14 TOSHIs for every modeled polar receptor. The above sample file includes ellipses (…) because it shows only a partial list of rows and only 4 of the 14 TOSHI's (Respiratory HI, Liver HI, Neurological HI, and Developmental HI). The final 3 columns shown (above) cycle through polar receptor ring distances over each angle from north (or sector) for a total of 16 angles/sectors by default, unless you indicate a different number of radials in your Facility List Options file.

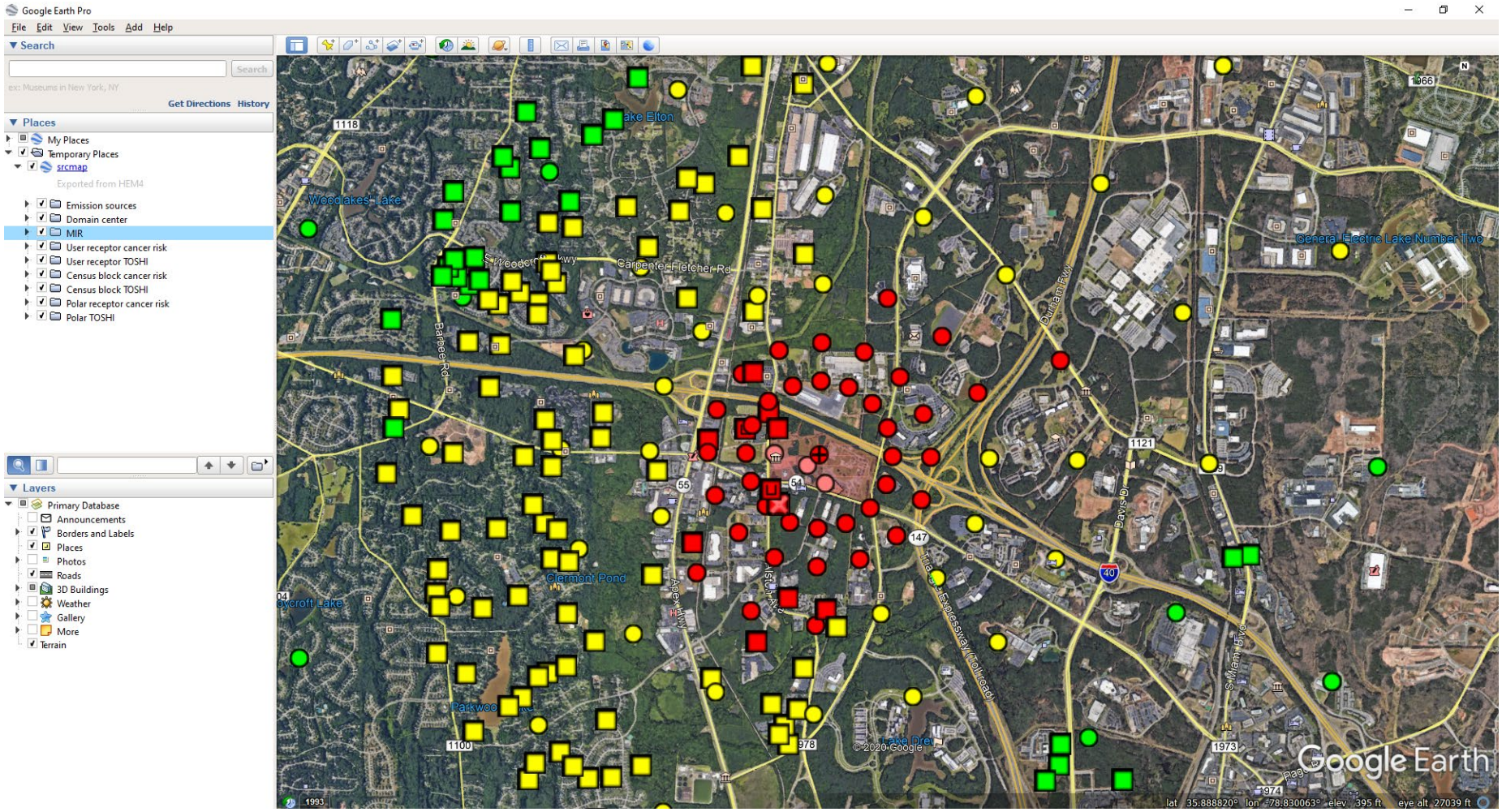


Figure 35. Sample Source Risk KMZ Google Earth™ Image (facility-specific)

A	B	C	D	E
Source ID	**Pollutant**	**Emission type**	**Incidence**	**Incidence rounded**
Total	All modeled pollutants	C	0.047682	0.048
CT000001	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	C	1.513E-09	1.5E-09
CT000001	1,2,3,4,6,7,8-heptachlorodibenzofuran	C	6.008E-09	6E-09
CT000001	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	C	1.238E-08	1.2E-08
CT000001	1,2,3,4,7,8-hexachlorodibenzofuran	C	1.44E-07	1.4E-07
CT000001	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	C	1.317E-08	1.3E-08
CT000001	1,2,3,6,7,8-hexachlorodibenzofuran	C	1.296E-07	1.3E-07
CT000001	1,2,3,7,8,9-hexachlorodibenzofuran	C	2.316E-08	2.3E-08
CT000001	1,2,3,7,8-pentachlorodibenzo-p-dioxin	C	1.744E-07	1.7E-07
…	…	…	…	…
Total	1,2,3,4,6,7,8,9-octachlorodibenzo-p-dioxin	C	5.041E-10	5E-10
Total	1,2,3,4,6,7,8,9-octachlorodibenzofuran	C	5.209E-11	5.2E-11
Total	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	C	8.953E-09	9E-09
Total	1,2,3,4,6,7,8-heptachlorodibenzofuran	C	3.556E-08	3.6E-08
CT000001	All modeled pollutants	C	1.462E-06	0.0000015
CV000001	All modeled pollutants	C	3.309E-06	0.0000033
FU000001	All modeled pollutants	C	0.0001703	0.00017
HV000001	All modeled pollutants	C	3.88E-06	0.0000039
MS000001	All modeled pollutants	C	5.983E-06	0.000006
RV000001	All modeled pollutants	C	0.0051644	0.0052
RV000002	All modeled pollutants	C	3.079E-06	0.0000031
RV000003	All modeled pollutants	C	1.772E-06	0.0000018
RV000004	All modeled pollutants	C	0.0069082	0.0069
RW000001	All modeled pollutants	C	1.116E-05	0.000011
SR000001	All modeled pollutants	C	0.0354084	0.035

Figure 36. Sample Incidence HEM4 Output (facility-specific, abbreviated)

Note: The sample Incidence file above includes ellipses (…) for some rows because the file is too long to depict fully. The above rows indicate the kinds of information provided in this file.

	A	B
1	**Level**	**Population**
2	Greater than or equal to 1 in 1,000	0
3	Greater than or equal to 1 in 10,000	435
4	Greater than or equal to 1 in 20,000	2119
5	Greater than or equal to 1 in 100,000	48998
6	Greater than or equal to 1 in 1,000,000	800221
7	Greater than or equal to 1 in 10,000,000	1545731

Figure 37. Sample Cancer Risk Exposure HEM4 Output (facility-specific)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Level	**Respiratory HI**	**Liver HI**	**Neurological HI**	**Developmental HI**	**Reproductive HI**	**Kidney HI**	**Ocular HI**	**Endocrine HI**	**Hematological HI**	**Immunological HI**	**Skeletal HI**	**Spleen HI**	**Thyroid HI**	**Whole body HI**
Greater than 100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greater than 50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greater than 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greater than 1.0	0	0	0	435	0	0	0	0	0	0	0	0	0	0
Greater than 0.5	0	0	0	3065	0	12	0	0	0	0	0	0	0	0
Greater than 0.2	12	0	0	19289	0	432	0	0	0	0	0	0	0	0

Figure 38. Sample Noncancer Risk Exposure HEM4 Output (facility-specific)

A	B	C	D	E	F	G	H	I	J	K	L	M
FIPs	Block	Latitude	Longitude	Source ID	Emission type	Pollutant	Conc (ug/m3)	Elevation (m)	Dry deposition (g/m2/yr)	Wet deposition (g/m2/yr)	Population	Overlap
17063	1022007	41.459428	-88.264967	CT000001	P	2,3,4,7,8-pentachlorodibenzofuran	1.00E-11	189.2	2.15E-12	2.46E-12	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	6.50E-13	189.2	1.40E-13	1.60E-13	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,7,8-pentachlorodibenzo-p-dioxin	6.93E-13	189.2	1.49E-13	1.70E-13	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,6,7,8-hexachlorodibenzofuran	6.25E-12	189.2	1.34E-12	1.53E-12	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,4,7,8-hexachlorodibenzofuran	6.97E-12	189.2	1.49E-12	1.71E-12	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,7,8,9-hexachlorodibenzofuran	1.11E-12	189.2	2.38E-13	2.72E-13	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	2,3,4,6,7,8-hexachlorodibenzofuran	4.56E-12	189.2	9.78E-13	1.12E-12	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzofuran	2.95E-12	189.2	6.32E-13	7.24E-13	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	5.92E-13	189.2	1.27E-13	1.45E-13	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,7,8-pentachlorodibenzofuran	6.37E-12	189.2	1.37E-12	1.56E-12	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	indeno[1,2,3-c,d]pyrene	4.06E-11	189.2	8.70E-12	9.96E-12	11	N
17063	1022007	41.459428	-88.264967	CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	7.57E-13	189.2	1.62E-13	1.86E-13	11	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	2,3,4,7,8-pentachlorodibenzofuran	9.21E-12	189.1	2.00E-12	2.27E-12	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	5.97E-13	189.1	1.29E-13	1.47E-13	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,7,8-pentachlorodibenzo-p-dioxin	6.36E-13	189.1	1.38E-13	1.57E-13	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,6,7,8-hexachlorodibenzofuran	5.73E-12	189.1	1.24E-12	1.41E-12	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,4,7,8-hexachlorodibenzofuran	6.39E-12	189.1	1.39E-12	1.58E-12	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,7,8,9-hexachlorodibenzofuran	1.02E-12	189.1	2.21E-13	2.51E-13	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	2,3,4,6,7,8-hexachlorodibenzofuran	4.18E-12	189.1	9.07E-13	1.03E-12	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzofuran	2.71E-12	189.1	5.87E-13	6.68E-13	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	5.43E-13	189.1	1.18E-13	1.34E-13	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	1,2,3,7,8-pentachlorodibenzofuran	5.84E-12	189.1	1.27E-12	1.44E-12	16	N
17063	1022008	41.4587614	-88.2642443	CT000001	P	indeno[1,2,3-c,d]pyrene	3.72E-11	189.1	8.08E-12	9.19E-12	16	N
…	…	…	…	…	…	…	…	…	…	…	…	…

Figure 39. Sample All Inner Receptors HEM4 Output (facility-specific, abbreviated)

Note: The Dry deposition and Wet deposition flux columns will be blank if you did not choose to model deposition in your Facility List Options file.

A	B	C	D	E	F	G	H	I	J	K
FIPs	Block	Latitude	Longitude	Source ID	Emission type	Pollutant	Conc (µg/m3)	Elevation (m)	Population	Overlap
17093	8907002213	41.5097585	-88.271948	CT000001	P	2,3,4,7,8-pentachlorodibenzofuran	8.50E-12	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	5.51E-13	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,7,8-pentachlorodibenzo-p-dioxin	5.87E-13	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,6,7,8-hexachlorodibenzofuran	5.29E-12	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,4,7,8-hexachlorodibenzofuran	5.90E-12	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,7,8,9-hexachlorodibenzofuran	9.40E-13	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	2,3,4,6,7,8-hexachlorodibenzofuran	3.86E-12	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzofuran	2.50E-12	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	5.01E-13	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,7,8-pentachlorodibenzofuran	5.39E-12	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	indeno[1,2,3-c,d]pyrene	3.44E-11	177.7	5	N
17093	8907002213	41.5097585	-88.271948	CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	6.41E-13	177.7	5	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	2,3,4,7,8-pentachlorodibenzofuran	5.56E-12	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	3.61E-13	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,7,8-pentachlorodibenzo-p-dioxin	3.84E-13	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,6,7,8-hexachlorodibenzofuran	3.46E-12	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,4,7,8-hexachlorodibenzofuran	3.86E-12	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,7,8,9-hexachlorodibenzofuran	6.15E-13	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	2,3,4,6,7,8-hexachlorodibenzofuran	2.53E-12	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzofuran	1.63E-12	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	3.28E-13	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	1,2,3,7,8-pentachlorodibenzofuran	3.53E-12	173.3	11	N
17093	8907002186	41.4973643	-88.294909	CT000001	P	indeno[1,2,3-c,d]pyrene	2.25E-11	173.3	11	N
…	…	…	…	…	…	…	…	…	…	…

Figure 40. Sample All Outer Receptors HEM4 Output file (facility-specific, abbreviated)

Note: The All Outer Receptor file tends to be a very large file, especially if you chose to model with the default maximum distance for your modeling domain of 50 kilometers and a default (discrete / inner) modeling distance of 3 kilometers. Deposition flux is not calculated for the outer modeling domain represented by the All Outer Receptor file, so these columns will not appear in this file even if you chose to model deposition.

A	B	C	D	E	F	G	H	I	J	K	L	M	N
Source ID	Emission type	Pollutant	Conc (ug/m3)	Distance (m)	Angle (from north)	Sector	Ring number	Elevation (m)	Latitude	Longitude	Overlap	Wet deposition (g/m2/yr)	Dry deposition (g/m2/yr)
CT000001	P	2,3,4,7,8-pentachlorodibenzofuran	1.61E-11	100	0	1	1	196	41.49089612	-88.27001629	N	2.21E-12	3.69E-12
CT000001	P	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	1.04E-12	100	0	1	1	196	41.49089612	-88.27001629	N	1.43E-13	2.39E-13
CT000001	P	1,2,3,7,8-pentachlorodibenzo-p-dioxin	1.11E-12	100	0	1	1	196	41.49089612	-88.27001629	N	1.52E-13	2.55E-13
CT000001	P	1,2,3,6,7,8-hexachlorodibenzofuran	1.00E-11	100	0	1	1	196	41.49089612	-88.27001629	N	1.37E-12	2.30E-12
CT000001	P	1,2,3,4,7,8-hexachlorodibenzofuran	1.12E-11	100	0	1	1	196	41.49089612	-88.27001629	N	1.53E-12	2.56E-12
CT000001	P	1,2,3,7,8,9-hexachlorodibenzofuran	1.78E-12	100	0	1	1	196	41.49089612	-88.27001629	N	2.44E-13	4.08E-13
CT000001	P	2,3,4,6,7,8-hexachlorodibenzofuran	7.31E-12	100	0	1	1	196	41.49089612	-88.27001629	N	1.00E-12	1.68E-12
CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzofuran	4.73E-12	100	0	1	1	196	41.49089612	-88.27001629	N	6.48E-13	1.08E-12
CT000001	P	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	9.49E-13	100	0	1	1	196	41.49089612	-88.27001629	N	1.30E-13	2.18E-13
CT000001	P	1,2,3,7,8-pentachlorodibenzofuran	1.02E-11	100	0	1	1	196	41.49089612	-88.27001629	N	1.40E-12	2.34E-12
CT000001	P	indeno[1,2,3-c,d]pyrene	6.51E-11	100	0	1	1	196	41.49089612	-88.27001629	N	8.91E-12	1.49E-11
CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	1.21E-12	100	0	1	1	196	41.49089612	-88.27001629	N	1.66E-13	2.79E-13
CT000001	P	2,3,4,7,8-pentachlorodibenzofuran	1.41E-11	500	0	1	2	196	41.49449822	-88.27008666	N	4.31E-12	3.08E-12
CT000001	P	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	9.17E-13	500	0	1	2	196	41.49449822	-88.27008666	N	2.79E-13	2.00E-13
CT000001	P	1,2,3,7,8-pentachlorodibenzo-p-dioxin	9.76E-13	500	0	1	2	196	41.49449822	-88.27008666	N	2.97E-13	2.13E-13
CT000001	P	1,2,3,6,7,8-hexachlorodibenzofuran	8.80E-12	500	0	1	2	196	41.49449822	-88.27008666	N	2.68E-12	1.92E-12
CT000001	P	1,2,3,4,7,8-hexachlorodibenzofuran	9.81E-12	500	0	1	2	196	41.49449822	-88.27008666	N	2.99E-12	2.14E-12
CT000001	P	1,2,3,7,8,9-hexachlorodibenzofuran	1.56E-12	500	0	1	2	196	41.49449822	-88.27008666	N	4.76E-13	3.41E-13
CT000001	P	2,3,4,6,7,8-hexachlorodibenzofuran	6.42E-12	500	0	1	2	196	41.49449822	-88.27008666	N	1.96E-12	1.40E-12
CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzofuran	4.15E-12	500	0	1	2	196	41.49449822	-88.27008666	N	1.27E-12	9.06E-13
CT000001	P	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	8.34E-13	500	0	1	2	196	41.49449822	-88.27008666	N	2.54E-13	1.82E-13
CT000001	P	1,2,3,7,8-pentachlorodibenzofuran	8.97E-12	500	0	1	2	196	41.49449822	-88.27008666	N	2.73E-12	1.96E-12
CT000001	P	indeno[1,2,3-c,d]pyrene	5.72E-11	500	0	1	2	196	41.49449822	-88.27008666	N	1.74E-11	1.25E-11
CT000001	P	1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	1.07E-12	500	0	1	2	196	41.49449822	-88.27008666	N	3.25E-13	2.33E-13
...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 41. Sample All Polar Receptors HEM4 Output file (facility-specific, abbreviated)

Note: The Dry deposition and Wet deposition flux columns will be blank if you did not choose to model deposition in your Facility List Options file.

Figure 42. Sample AERMOD.inp file (facility-specific, abbreviated)

Note: If particle and vapor phase emissions are modeled separately (e.g., when modeling deposition/depletion), then two aermod.inp files will be provided in the facility folder: an aermod_P.inp file for particle phase emissions and an aermod_V.inp file for vapor phase emissions.

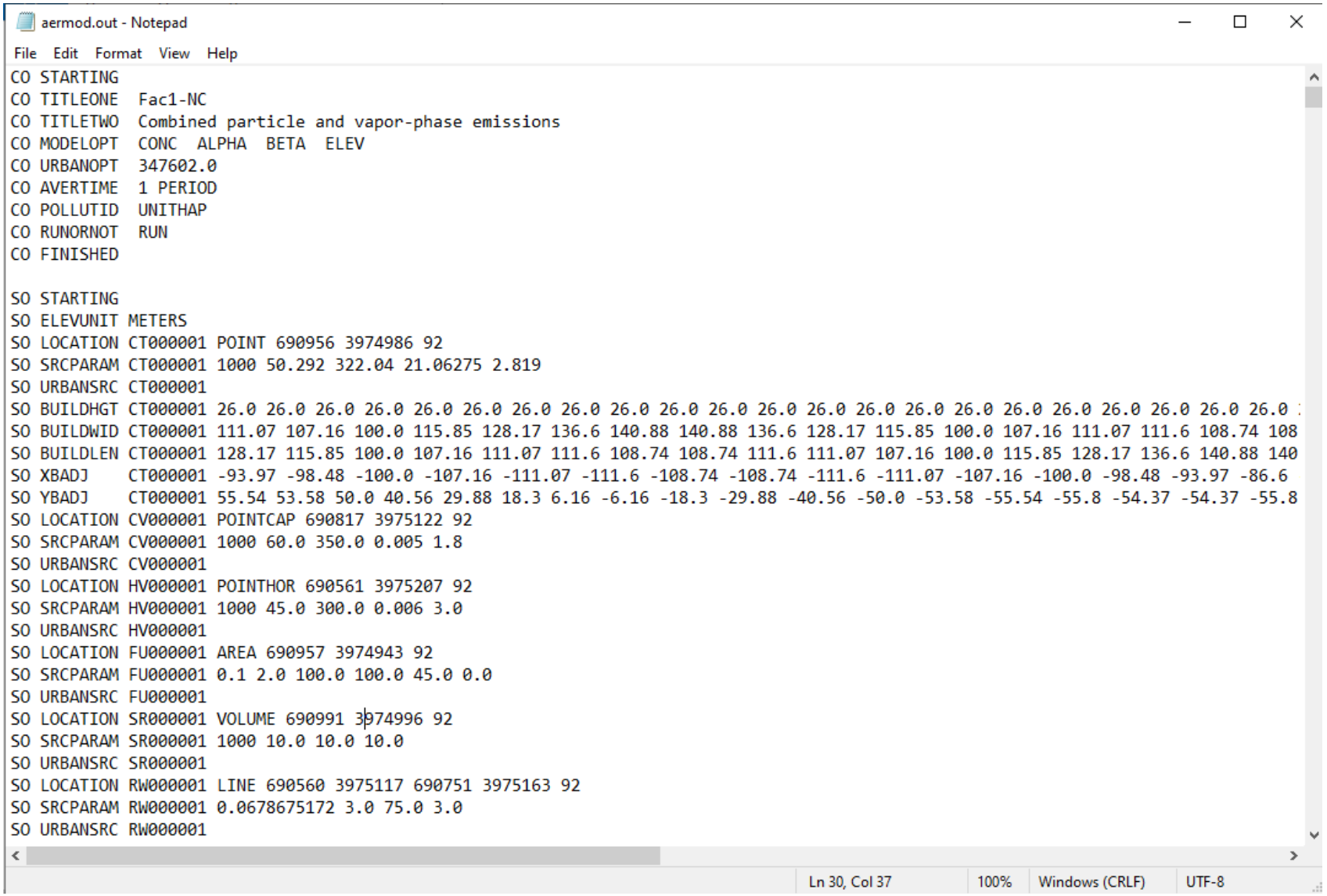
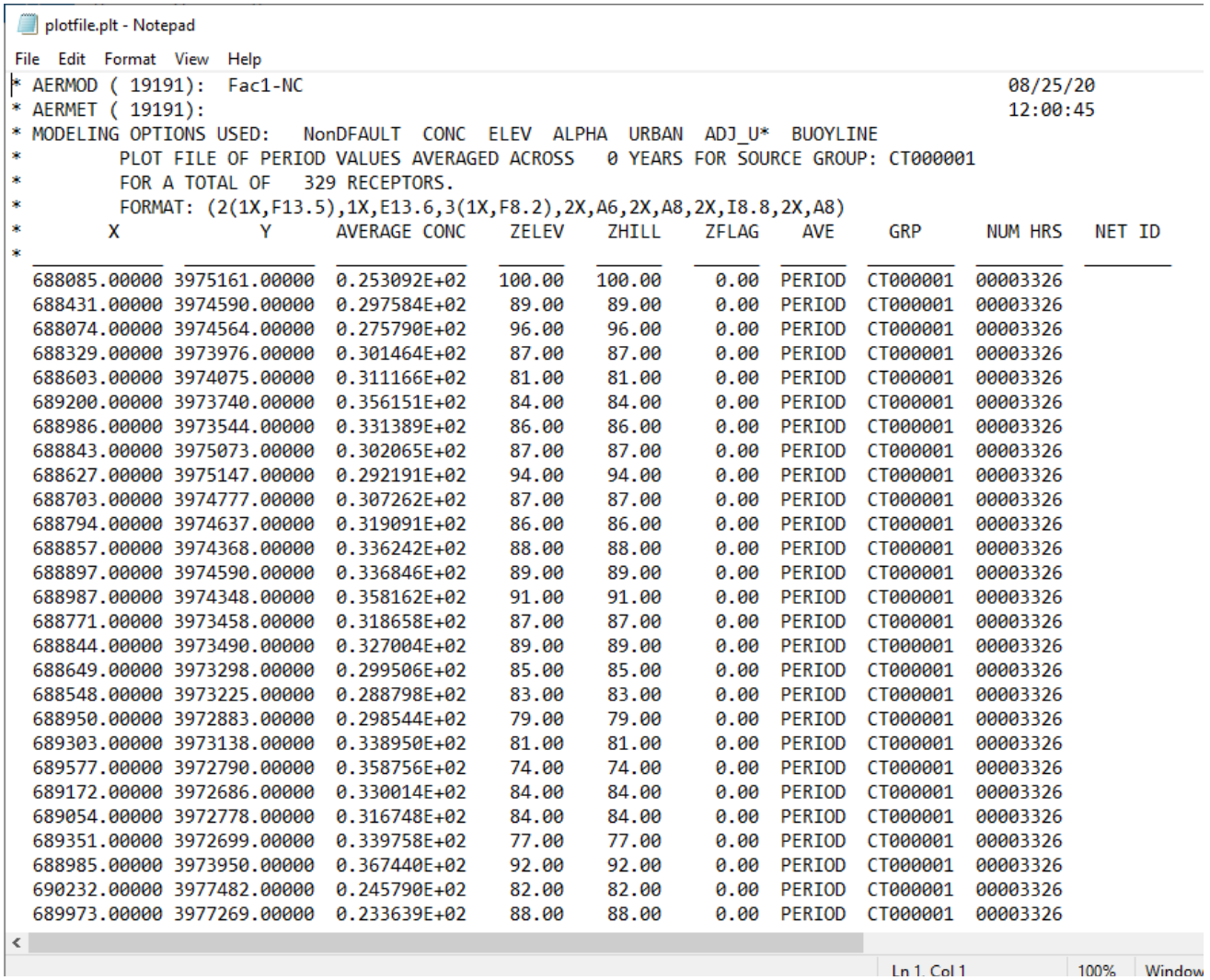


Figure 43. Sample AERMOD.out file (facility-specific, abbreviated)

Note: If particle and vapor phase emissions are modeled separately (e.g., when modeling deposition/depletion), then two aermod.out files will be provided in the facility folder: an aermod_P.out file for particle phase emissions and an aermod_V.out file for vapor phase emissions. Deposition fluxes (Dry Depo and Wet Depo) will be provided with depletion applied to concentrations, if modeled.



plotfile.plt - Notepad

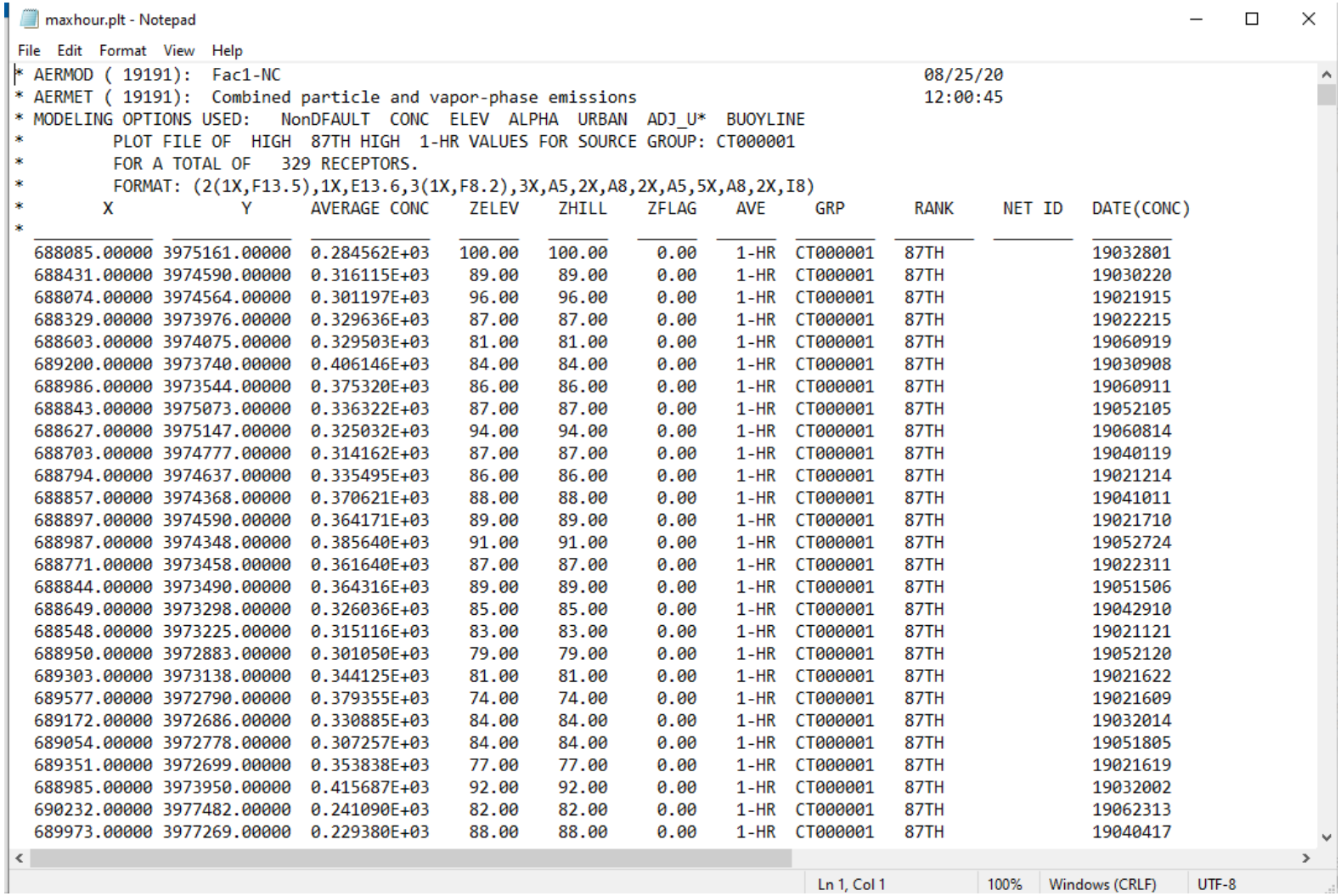
File Edit Format View Help

```
* AERMOD ( 19191):  Fac1-NC                                                    08/25/20
* AERMET ( 19191):                                                            12:00:45
* MODELING OPTIONS USED:   NonDFAULT  CONC  ELEV  ALPHA  URBAN  ADJ_U*  BUOYLINE
*         PLOT FILE OF PERIOD VALUES AVERAGED ACROSS   0 YEARS FOR SOURCE GROUP: CT000001
*         FOR A TOTAL OF   329 RECEPTORS.
*         FORMAT: (2(1X,F13.5),1X,E13.6,3(1X,F8.2),2X,A6,2X,A8,2X,I8.8,2X,A8)
*        X             Y      AVERAGE CONC    ZELEV    ZHILL    ZFLAG    AVE     GRP      NUM HRS   NET ID
* ____________  ____________  ____________  ______  ______  ______  ______  ________  ________  ________
  688085.00000 3975161.00000  0.253092E+02  100.00  100.00    0.00  PERIOD  CT000001  00003326
  688431.00000 3974590.00000  0.297584E+02   89.00   89.00    0.00  PERIOD  CT000001  00003326
  688074.00000 3974564.00000  0.275790E+02   96.00   96.00    0.00  PERIOD  CT000001  00003326
  688329.00000 3973976.00000  0.301464E+02   87.00   87.00    0.00  PERIOD  CT000001  00003326
  688603.00000 3974075.00000  0.311166E+02   81.00   81.00    0.00  PERIOD  CT000001  00003326
  689200.00000 3973740.00000  0.356151E+02   84.00   84.00    0.00  PERIOD  CT000001  00003326
  688986.00000 3973544.00000  0.331389E+02   86.00   86.00    0.00  PERIOD  CT000001  00003326
  688843.00000 3975073.00000  0.302065E+02   87.00   87.00    0.00  PERIOD  CT000001  00003326
  688627.00000 3975147.00000  0.292191E+02   94.00   94.00    0.00  PERIOD  CT000001  00003326
  688703.00000 3974777.00000  0.307262E+02   87.00   87.00    0.00  PERIOD  CT000001  00003326
  688794.00000 3974637.00000  0.319091E+02   86.00   86.00    0.00  PERIOD  CT000001  00003326
  688857.00000 3974368.00000  0.336242E+02   88.00   88.00    0.00  PERIOD  CT000001  00003326
  688897.00000 3974590.00000  0.336846E+02   89.00   89.00    0.00  PERIOD  CT000001  00003326
  688987.00000 3974348.00000  0.358162E+02   91.00   91.00    0.00  PERIOD  CT000001  00003326
  688771.00000 3973458.00000  0.318658E+02   87.00   87.00    0.00  PERIOD  CT000001  00003326
  688844.00000 3973490.00000  0.327004E+02   89.00   89.00    0.00  PERIOD  CT000001  00003326
  688649.00000 3973298.00000  0.299506E+02   85.00   85.00    0.00  PERIOD  CT000001  00003326
  688548.00000 3973225.00000  0.288798E+02   83.00   83.00    0.00  PERIOD  CT000001  00003326
  688950.00000 3972883.00000  0.298544E+02   79.00   79.00    0.00  PERIOD  CT000001  00003326
  689303.00000 3973138.00000  0.338950E+02   81.00   81.00    0.00  PERIOD  CT000001  00003326
  689577.00000 3972790.00000  0.358756E+02   74.00   74.00    0.00  PERIOD  CT000001  00003326
  689172.00000 3972686.00000  0.330014E+02   84.00   84.00    0.00  PERIOD  CT000001  00003326
  689054.00000 3972778.00000  0.316748E+02   84.00   84.00    0.00  PERIOD  CT000001  00003326
  689351.00000 3972699.00000  0.339758E+02   77.00   77.00    0.00  PERIOD  CT000001  00003326
  688985.00000 3973950.00000  0.367440E+02   92.00   92.00    0.00  PERIOD  CT000001  00003326
  690232.00000 3977482.00000  0.245790E+02   82.00   82.00    0.00  PERIOD  CT000001  00003326
  689973.00000 3977269.00000  0.233639E+02   88.00   88.00    0.00  PERIOD  CT000001  00003326
```

Ln 1, Col 1 100% Window

Figure 44. Sample plotfile.plt output file (facility-specific, abbreviated)

Note: If particle and vapor phase emissions are modeled separately (e.g., when modeling deposition/depletion), then these concentrations will be provided based on particle phase emissions in a plotfile_p.plt file and in a plotfile_v.plt file for vapor phase emissions. Deposition fluxes (Dry Depo and Wet Depo) will be provided with depletion applied to concentrations, if modeled.



maxhour.plt - Notepad

File Edit Format View Help

```
* AERMOD ( 19191):  Fac1-NC                                                    08/25/20
* AERMET ( 19191):  Combined particle and vapor-phase emissions                12:00:45
* MODELING OPTIONS USED:   NonDFAULT  CONC  ELEV  ALPHA  URBAN  ADJ_U*  BUOYLINE
*         PLOT FILE OF  HIGH  87TH HIGH  1-HR VALUES FOR SOURCE GROUP: CT000001
*         FOR A TOTAL OF   329 RECEPTORS.
*         FORMAT: (2(1X,F13.5),1X,E13.6,3(1X,F8.2),3X,A5,2X,A8,2X,A5,5X,A8,2X,I8)
*        X             Y      AVERAGE CONC    ZELEV    ZHILL    ZFLAG    AVE     GRP       RANK     NET ID   DATE(CONC)
* ____________  ____________  ____________  ______  ______  ______  ______  ________  ________  ________  ________
  688085.00000 3975161.00000  0.284562E+03  100.00  100.00    0.00    1-HR  CT000001  87TH                19032801
  688431.00000 3974590.00000  0.316115E+03   89.00   89.00    0.00    1-HR  CT000001  87TH                19030220
  688074.00000 3974564.00000  0.301197E+03   96.00   96.00    0.00    1-HR  CT000001  87TH                19021915
  688329.00000 3973976.00000  0.329636E+03   87.00   87.00    0.00    1-HR  CT000001  87TH                19022215
  688603.00000 3974075.00000  0.329503E+03   81.00   81.00    0.00    1-HR  CT000001  87TH                19060919
  689200.00000 3973740.00000  0.406146E+03   84.00   84.00    0.00    1-HR  CT000001  87TH                19030908
  688986.00000 3973544.00000  0.375320E+03   86.00   86.00    0.00    1-HR  CT000001  87TH                19060911
  688843.00000 3975073.00000  0.336322E+03   87.00   87.00    0.00    1-HR  CT000001  87TH                19052105
  688627.00000 3975147.00000  0.325032E+03   94.00   94.00    0.00    1-HR  CT000001  87TH                19060814
  688703.00000 3974777.00000  0.314162E+03   87.00   87.00    0.00    1-HR  CT000001  87TH                19040119
  688794.00000 3974637.00000  0.335495E+03   86.00   86.00    0.00    1-HR  CT000001  87TH                19021214
  688857.00000 3974368.00000  0.370621E+03   88.00   88.00    0.00    1-HR  CT000001  87TH                19041011
  688897.00000 3974590.00000  0.364171E+03   89.00   89.00    0.00    1-HR  CT000001  87TH                19021710
  688987.00000 3974348.00000  0.385640E+03   91.00   91.00    0.00    1-HR  CT000001  87TH                19052724
  688771.00000 3973458.00000  0.361640E+03   87.00   87.00    0.00    1-HR  CT000001  87TH                19022311
  688844.00000 3973490.00000  0.364316E+03   89.00   89.00    0.00    1-HR  CT000001  87TH                19051506
  688649.00000 3973298.00000  0.326036E+03   85.00   85.00    0.00    1-HR  CT000001  87TH                19042910
  688548.00000 3973225.00000  0.315116E+03   83.00   83.00    0.00    1-HR  CT000001  87TH                19021121
  688950.00000 3972883.00000  0.301050E+03   79.00   79.00    0.00    1-HR  CT000001  87TH                19052120
  689303.00000 3973138.00000  0.344125E+03   81.00   81.00    0.00    1-HR  CT000001  87TH                19021622
  689577.00000 3972790.00000  0.379355E+03   74.00   74.00    0.00    1-HR  CT000001  87TH                19021609
  689172.00000 3972686.00000  0.330885E+03   84.00   84.00    0.00    1-HR  CT000001  87TH                19032014
  689054.00000 3972778.00000  0.307257E+03   84.00   84.00    0.00    1-HR  CT000001  87TH                19051805
  689351.00000 3972699.00000  0.353838E+03   77.00   77.00    0.00    1-HR  CT000001  87TH                19021619
  688985.00000 3973950.00000  0.415687E+03   92.00   92.00    0.00    1-HR  CT000001  87TH                19032002
  690232.00000 3977482.00000  0.241090E+03   82.00   82.00    0.00    1-HR  CT000001  87TH                19062313
  689973.00000 3977269.00000  0.229380E+03   88.00   88.00    0.00    1-HR  CT000001  87TH                19040417
```

Ln 1, Col 1 100% Windows (CRLF) UTF-8

Figure 45. Sample maxhour.plt output file (optional facility-specific, abbreviated)

Note: The Maxhour plot file will be produced if you opted to model acute concentrations in your Facility List Options file. If particle and vapor phase emissions are modeled separately (e.g., when modeling deposition/depletion), then these acute concentrations will be provided based on particle phase emissions in a maxhour_p.plt file and for vapor phase emissions in an maxhour_v.plt file.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Facility ID	Aermod Title2	Emissions Phase	Rural/ Urban	Deposition (YN)	Depletion (YN)	Deposition Type (particle/ vapor)	Depletion Type (particle/ vapor)	Elevation (YN)	Acute Hours	Acute Multiplier	Building Downwash (YN)	User Receptors (YN)	Max Modeling Distance	Discrete Modeling Distance	Overlap Distance	Number of Polar Rings	Number of Polar Radials	Acute (YN)	First Ring Distance	...
Fac1-NC	CO TITLETWO Combined particle and vapor-phase emissions			N	N	NO/NO	NO/NO	Y	1	50	Y	Y	50000	3000	30	13	16	Y	565	...

Figure 46. Sample Input Selection Options HEM4 Output file (facility-specific, abbreviated)

Note: The above Input Selection Options files does not show all information provided; the actual file contains 34 fields / columns providing chosen modeling run options.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Pollutant	Conc (ug/m3)	Conc sci (ug/m3)	Aegl_1 1hr (mg/m3)	...	Rel (mg/m3)	...	Population	Distance (in meters)	Angle (from north)	Elevation (in meters)	Hill Height (in meters)	Fips	Block	Utm easting	Utm northing	Latitude	Longitude	Receptor type	Notes
1,3-butadiene	64.17283562	6.4e+01	1500	...	0	...	0	565	90	92	92	na	na	691471	3975205	35.90242	-78.87832	PG	Polar
acetaldehyde	14.33911644	1.4e+01	81	...	0.47	...	0	459	233	90	90	U0000	0000URCPT1	35	3974934	35.90016	-78.88875	P	Discrete
acrolein	100.3738151	1.0e+02	0.069	...	0.0025	...	0	459	233	90	90	U0000	0000URCPT1	35	3974934	35.90016	-78.88875	P	Discrete
arsenic compounds	69.24203227	6.9e+01	0	...	0.0002	...	0	565	180	92	92	na	na	690906	3974640	35.89744	-78.88471	PG	Polar
benzene	29.94732329	3.0e+01	170	...	0	...	0	565	90	92	92	na	na	691471	3975205	35.90242	-78.87832	PG	Polar
bis(2-ethylhexyl)phthalate	1839.115705	1.8e+03	0	...	0	...	0	565	180	92	92	na	na	690906	3974640	35.89744	-78.88471	PG	Polar
cadmium compounds	7.45282988	7.5e+00	0.1	...	0	...	0	565	180	92	92	na	na	690906	3974640	35.89744	-78.88471	PG	Polar
chloroform	0.409275616	4.1e-01	0	...	0.15	...	0	565	67	92	92	na	na	691428	3975421	35.90438	-78.87874	PG	Polar
chromium (iii) compounds	39.58179966	4.0e+01	0	...	0	...	0	565	180	92	92	na	na	690906	3974640	35.89744	-78.88471	PG	Polar
chromium (vi) compounds	0.0395818	4.0e-02	0	...	0	...	0	565	180	92	92	na	na	690906	3974640	35.89744	-78.88471	PG	Polar
cumene	1.02676537	1.0e+00	250	...	0	...	0	565	90	92	92	na	na	691471	3975205	35.90242	-78.87832	PG	Polar
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 47. Sample Acute Maximum Concentrations HEM4 Output file (optional facility specific, abbreviated)

Note: The Acute Maximum Concentrations (acute_chem_max) file will be produced if you opted to model acute concentrations in your Facility List Options file. The above sample file is abbreviated; the actual file contains 11 acute benchmark columns, not only the Aegl_1hr and Rel columns shown.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Pollutant	Conc (ug/m3)	Conc sci (ug/m3)	Aegl_1 1hr (mg/m3)	...	Rel (mg/m3)	...	Population	Distance (in meters)	Angle (from north)	Elevation (in meters)	Hill Height (in meters)	Fips	Block	Utm easting	Utm northing	Latitude	Longitude	Receptor type	Notes
1,3-butadiene	10.2245116	1.0e+01	1500	...	0	...	219	1124	191	85	85	37063	0020272057	690684	3974103	35.89265	-78.8873	C	Discrete
acetaldehyde	9.996	1.0e+01	81	...	0.47	...	7	383	301	97	97	37063	0020272047	690578	3975403	35.90438	-78.88816	C	Discrete
acrolein	69.972	7.0e+01	0.069	...	0.0025	...	7	383	301	97	97	37063	0020272047	690578	3975403	35.90438	-78.88816	C	Discrete
arsenic compounds	60.7940659	6.1e+01	0	...	0.0002	...	2	492	220	90	90	37063	0020272056	690588	3974829	35.89921	-78.88819	C	Discrete
benzene	4.77143877	4.8e+00	170	...	0	...	219	1124	191	85	85	37063	0020272057	690684	3974103	35.89265	-78.8873	C	Discrete
bis(2-ethylhexyl)phthalate	942.976132	9.4e+02	0	...	0	...	2	492	220	90	90	37063	0020272056	690588	3974829	35.89921	-78.88819	C	Discrete
cadmium compounds	6.54636892	6.5e+00	0.1	...	0	...	2	492	220	90	90	37063	0020272056	690588	3974829	35.89921	-78.88819	C	Discrete
chloroform	0.05841962	5.8e-02	0	...	0.15	...	2	4329	48	117	117	37063	0018091060	694160	3978061	35.92762	-78.84785	C	Interpolated
chromium (iii) compounds	35.8686185	3.6e+01	0	...	0	...	2	492	220	90	90	37063	0020272056	690588	3974829	35.89921	-78.88819	C	Discrete
chromium (vi) compounds	0.03586862	3.6e-02	0	...	0	...	2	492	220	90	90	37063	0020272056	690588	3974829	35.89921	-78.88819	C	Discrete
cumene	0.16359219	1.6e-01	250	...	0	...	219	1124	191	85	85	37063	0020272057	690684	3974103	35.89265	-78.8873	C	Discrete
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 48. Sample Acute Populated Concentrations HEM4 Output file (optional facility-specific, abbreviated)

Note: The Acute Populated Concentrations (acute_chem_pop) file will be produced if you opted to model acute concentrations in your Facility List Options file. The above sample file is abbreviated; the actual file contains 11 acute benchmark columns, not only the Aegl_1hr and Rel columns shown.

A	B	C	D	E	F	G
Pollutant	Source ID	Emission type	Max conc at populated receptor (ug/m3)	Is max populated receptor interpolated? (Y/N)	Max conc at any receptor (ug/m3)	Is max conc at any receptor interpolated? (Y/N)
1,2,3,4,6,7,8,9-octachlorodibenzo-p-dioxin	FU000001	C	6.81669E-07	N	1.3295E-06	N
1,2,3,4,6,7,8,9-octachlorodibenzofuran	FU000001	C	7.04392E-08	N	1.3738E-07	N
1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	CT000001	C	3.11291E-09	N	2.0383E-09	N
1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	CV000001	C	1.87004E-08	N	1.1675E-08	N
1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	HV000001	C	8.13071E-09	N	2.569E-08	N
1,2,3,4,6,7,8-heptachlorodibenzofuran	CT000001	C	1.23623E-08	N	8.0945E-09	N
1,2,3,4,6,7,8-heptachlorodibenzofuran	CV000001	C	7.42649E-08	N	4.6364E-08	N
1,2,3,4,6,7,8-heptachlorodibenzofuran	HV000001	C	3.22894E-08	N	1.0202E-07	N
1,2,3,4,7,8,9-heptachlorodibenzofuran	FU000001	C	9.42976E-08	N	1.8391E-07	N
1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	CT000001	C	2.54693E-09	N	1.6677E-09	N
1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	CV000001	C	1.53004E-08	N	9.552E-09	N
1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	HV000001	C	6.6524E-09	N	2.1019E-08	N
1,2,3,4,7,8-hexachlorodibenzofuran	CT000001	C	2.96397E-08	N	1.9407E-08	N
1,2,3,4,7,8-hexachlorodibenzofuran	CV000001	C	1.78057E-07	N	1.1116E-07	N
1,2,3,4,7,8-hexachlorodibenzofuran	HV000001	C	7.74168E-08	N	2.446E-07	N
1,2,3,4,7,8-hexachlorodibenzofuran	RV000003	C	3.94583E-09	N	1.2858E-09	N
1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	CT000001	C	2.71077E-09	N	1.7749E-09	N
1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	CV000001	C	1.62846E-08	N	1.0166E-08	N
1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	HV000001	C	7.08033E-09	N	2.2371E-08	N
1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	RV000002	C	5.67075E-10	N	5.9953E-11	N
1,2,3,6,7,8-hexachlorodibenzofuran	CT000001	C	2.66608E-08	N	1.7457E-08	N
1,2,3,6,7,8-hexachlorodibenzofuran	CV000001	C	1.60162E-07	N	9.9989E-08	N
1,2,3,6,7,8-hexachlorodibenzofuran	HV000001	C	6.96362E-08	N	2.2002E-07	N
1,2,3,6,7,8-hexachlorodibenzofuran	RV000003	C	3.54927E-09	N	1.1565E-09	N
...	...	...	...	...	...	...

Figure 49. Sample Acute Breakdown HEM4 Output file (optional facility-specific)

Note: The Acute Breakdown file will be produced if you opted to model acute concentrations in your Facility List Options file.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Facil_id	mx_can_rsk	can_rsk_interpltd	can_rcpt_type	can_latitude	can_longitude	can_blk	respiratory_hi	[59 TOSHI columns]	pop_overlp	incidence	metname	km_to_metstation	fac_center_latitude	fac_center_longitude	rural_urban
Fac1-NC	0.000610761	N	Census block	35.8990848	-78.8880045	9801001074	0.6770494	...	0	0.047682	NC13722_2019.SFC	9.2712	35.9025311	-78.884577	U
Fac2-IL	9.00146E-07	N	Census block	41.4797356	-88.2618629	8907002218	0.03653	...	0	4.581E-06	IL04808_2019.SFC	35.6838	41.49	-88.27	R

Figure 50. Sample Facility Max Risk and HI HEM4 Output file (for run group, abbreviated)

Note: The Facility Max Risk and HI file covers the entire run group with one row of output per facility. The above sample file is abbreviated; there are 59 additional columns not shown pertaining to all 14 TOSHI values and locations.

A	B	C	D	E	F	G	H
Facil_id	latitude	longitude	Number people exposed to >= 1 in 1,000 risk	Number people exposed to >= 1 in 10,000 risk	Number people exposed to >= 1 in 100,000 risk	Number people exposed to >= 1 in 1,000,000 risk	Number people exposed to >= 1 in 10,000,000 risk
Fac1-NC	35.90253	-78.884577	0	435	48998	800221	1545731
Fac2-IL	41.49	-88.27	0	0	0	0	296

Figure 51. Sample Facility Cancer Risk Exposure HEM4 Output file (for run group)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Facility ID	Number people exposed to > 1 Respiratory HI	Number people exposed to > 1 Liver HI	Number people exposed to > 1 Neurological HI	Number people exposed to > 1 Developmental HI	Number people exposed to > 1 Reproductive HI	Number people exposed to > 1 Kidney HI	Number people exposed to > 1 Ocular HI	Number people exposed to > 1 Endocrinological HI	Number people exposed to > 1 Hematological HI	Number people exposed to > 1 Immunological HI	Number people exposed to > 1 Skeletal HI	Number people exposed to > 1 Spleen HI	Number people exposed to > 1 Thyroid HI	Number people exposed to > 1 Whole Body HI
Fac1-NC	0	0	0	435	0	0	0	0	0	0	0	0	0	0
Fac2-IL	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 52. Sample Facility TOSHI Exposure HEM4 Output file (for run group)

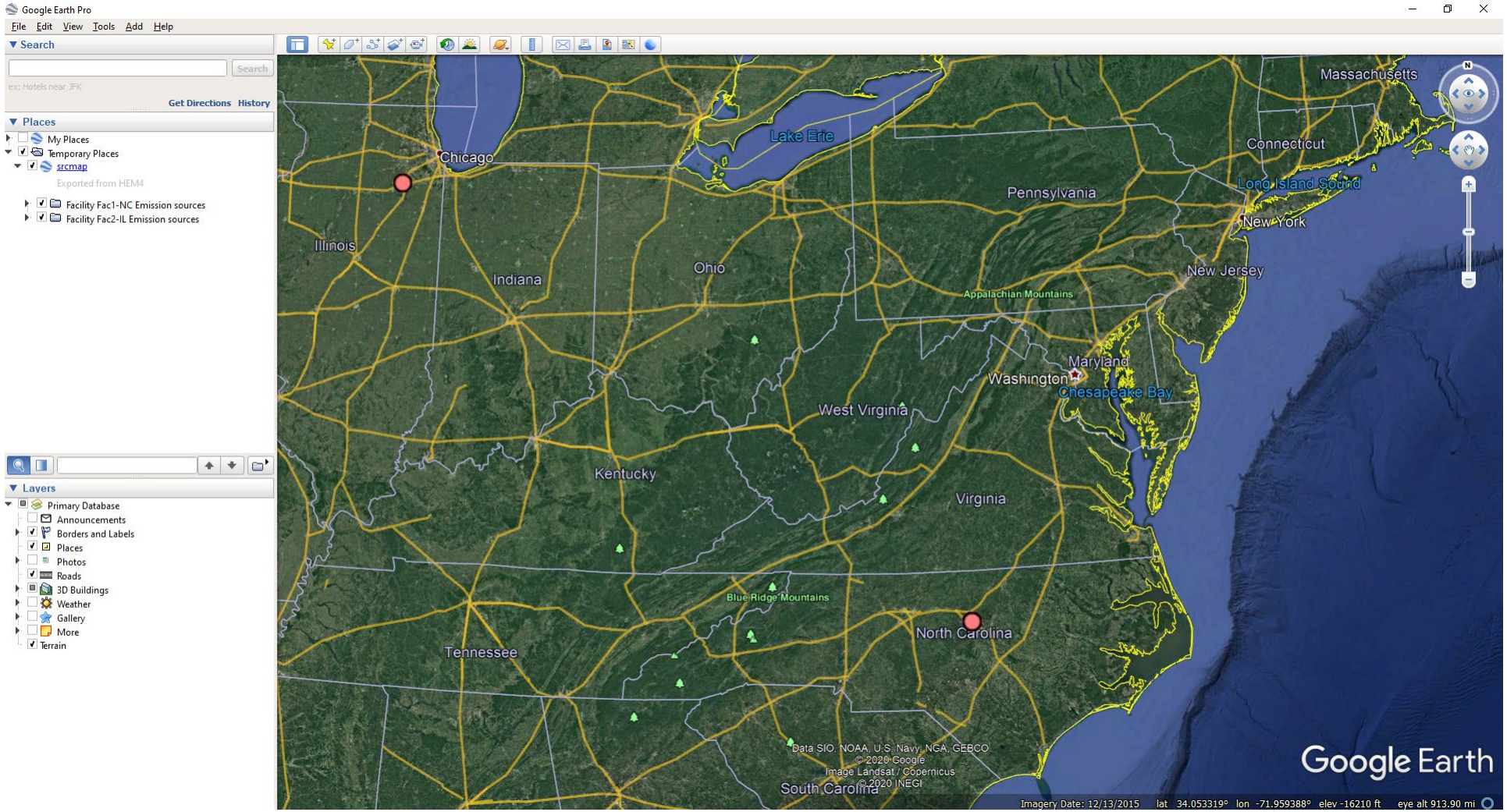


Figure 53. Sample All Facility Source Locations Google Earth™ Image (for run group)

Note: The All Facility Source Locations Google Earth™ image depicts the two sample facilities modeled in this run group – located in Illinois and North Carolina – on a map. On the actual map image, you can zoom in to see the individual sources at each facility in more detail.

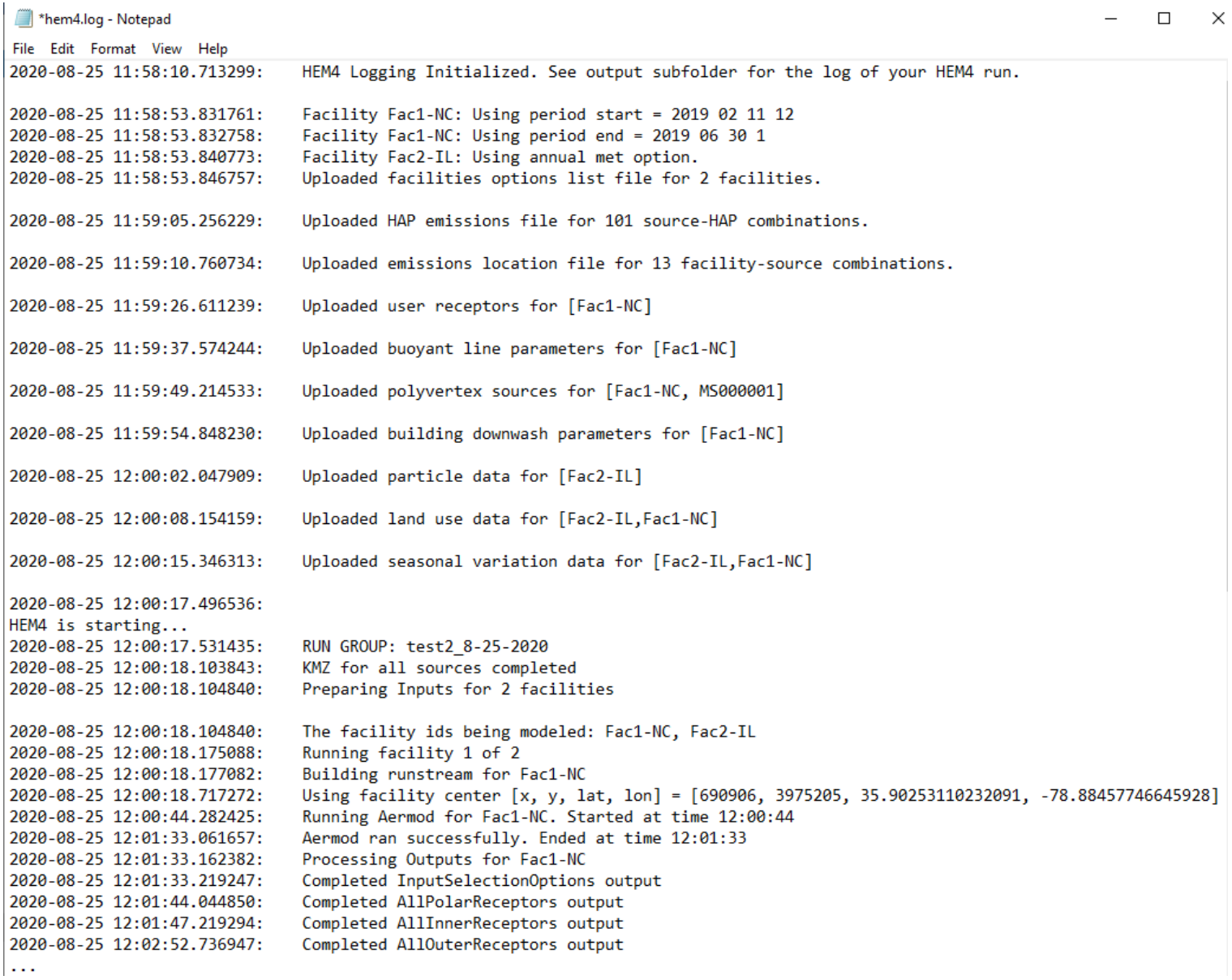


Figure 54. **Sample HEM4 Log Output file (for run group, abbreviated)**

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Appendix 3
Meteorological Data for HEM Modeling

METEOROLOGICAL DATA PROCESSING
USING AERMET
FOR HEM

US EPA
Air Toxic Assessment Group
RTP, NC 27711

February, 2021

BACKGROUND

The AERMOD meteorological processor, AERMET, and its supporting modeling system (AERSURFACE and AERMINUTE) were used to process one year of meteorological data for over 800 observation stations across the continental United States, Alaska, Hawaii, and Puerto Rico.

METEOROLOGICAL DATA

To estimate the boundary layer parameters required by AERMOD, AERMET requires hourly surface weather observations (which may include hourly values calculated from 1-minute data) and the full (i.e., meteorological variables reported at all levels) twice-daily upper air soundings. The surface and upper air stations are paired to produce the required input data for AERMOD.

USEPA meteorologists obtained calendar years 2016-2019 Integrated Surface Hourly Data (ISHD) for over 800 Automated Surface Observation System (ASOS) stations spanning the entire US, as well as Puerto Rico and the US Virgin Islands, from the National Climatic Data Center (NCDC). To support AERMET, ASOS 1-minute data for each surface station were also obtained from NCDC in a DSI 6405 format.

Further, upper air sounding data for the same time period for over 80 observation sites were obtained from the "NOAA/ESRL" online Radiosonde Database. These datasets were produced by ESRL in Forecast Systems Laboratory (FSL) format. Attachment 1 lists the surface and upper air stations, as well as the coordinates, ground elevation, and anemometer height for each station.

AERMET PROCESSING

Utilizing the AERMET meteorological data preprocessor, and the ASOS surface and FSL upper air stations, surface and profile files for input into AERMOD were generated nationwide. The surface stations were paired with representative upper air stations by taking the upper air station closest to each surface station. The AERSURFACE tool was used to estimate the surface characteristics for input into AERMET utilizing land cover data surrounding the surface station. In addition, the AERMINUTE preprocessor was used to process 1-minute ASOS wind data for input into AERMET. Table 1 and Attachment 1 outline the approach and site specific inputs each of the data preprocessors and tools used to generate the AERMOD meteorological data.

Table 1. AERMET Processing Options

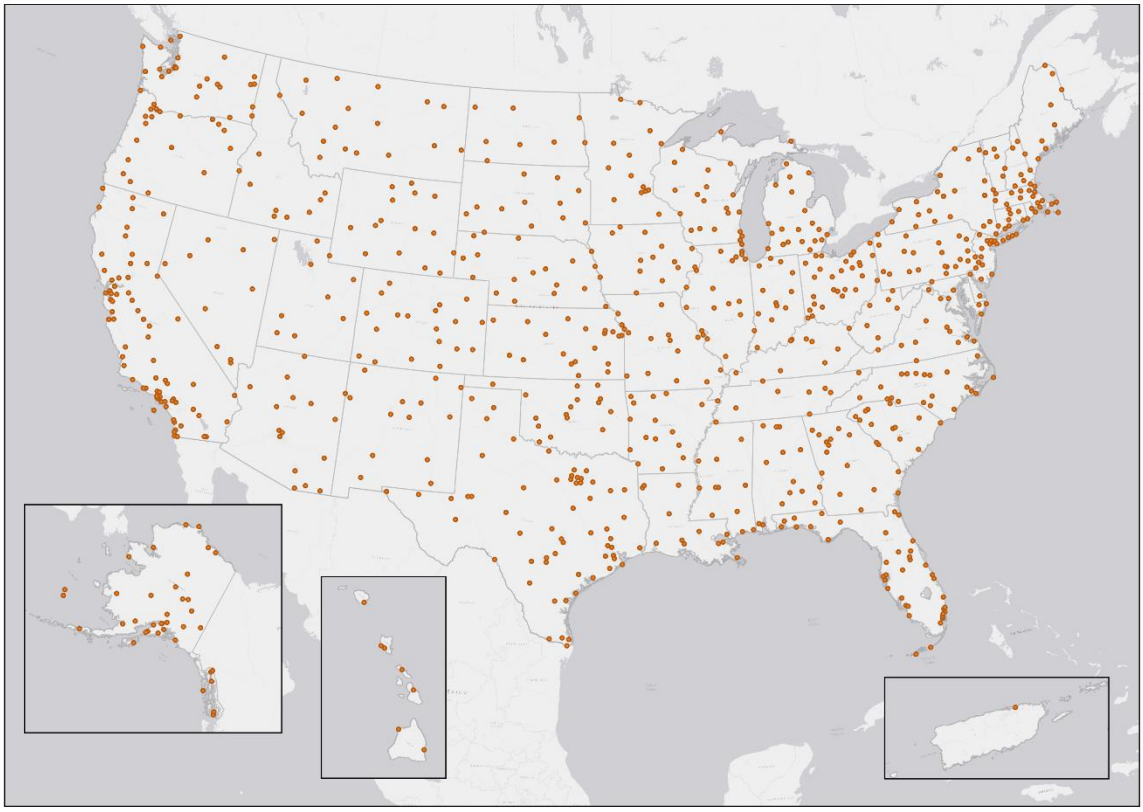
AERMET Options	Version	19191
	ASOS Site	Yes
	Surface Data Format	NCDC TD-3505 (ISHD)
	Upper Air Data Format	FSL, all levels, tenths m/s
	Wind Speed Threshold	0.5 m/s
	Beta Option (U*)	Yes
AERMINUTE Options	Version	15272
	Include 1 minute ASOS Data	Yes, where available TD-6405 format
AERSURFACE Options	Version	20060
	Landcover data	USGS NLC for 2011
	Radius for Surface Roughness Calculations	1 km
	Seasons	Winter – Dec, Jan, Feb Spring – Mar, Apr, May Summer – June, July, Aug Fall – Sept, Oct, Nov
	Temporal resolution	Monthly, 12 sectors
	Site Surface Moisture	See Attachment 1
	Snow Cover	See Attachment 1

RESULTS

To assure that the data would support an AERMOD run, USEPA meteorologists ran AERMOD using a model plant with each AERMET SFC and PLF pairs. Further, the surface files were examined for completeness. If more than 10 percent of specific data including the Monin-Obukhov length, wind speed, or cloud cover were missing, the station was not considered suitable for the meteorological database and therefore excluded.

In all, 838 met station pairs ran successfully in AERMOD and passed completeness criteria. Figure 1 is a map that shows the locations of the 838 surface stations. The processed meteorological data generated by the above approach is posted on the EPA's FERA (Fate, Exposure, and Risk Analysis) website under the HEM model page.

Figure 1. Location of meteorological stations used in HEM.



Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
25308	PANT	ANN	52606	ANNETTE WSO AP	55.0389	-131.579	33	-9	10	2016
25309	PAJN	JNU	82206	JUNEAU INTL AP	58.3566	-134.564	5	-9	10	2019
25323	PAHN	HNS	102705	HAINES AP	59.2433	-135.509	5	-9	10	2019
25325	PAKT	KTN	11003	KETCHIKAN INTL AP	55.35667	-131.712	23	-9	8	2019
25331	PAAQ	PAQ	91906	PALMER MUNI AP	61.5961	-149.092	70	-9	10	2019
25333	PASI	SIT	12403	SITKA AP	57.0481	-135.365	4	-9	8	2019
25335	PAGY	SGY	110705	SKAGWAY AP	59.4556	-135.324	6	-9	8	2019
25501	PADQ	ADQ	41007	KODIAK AP	57.75111	-152.486	24	-9	10	2019
25503	PAKN	AKN	32107	KING SALMON AP	58.6829	-156.656	20	-9	10	2019
25506	PAIL	ILI	11407	ILIAMNA AP	59.7494	-154.909	44	-9	10	2019
25507	PAHO	HOM	92306	HOMER AP	59.642	-151.491	20	-9	8	2019
25516	PASO	SOV	103005	SELDOVIA AP	59.44333	-151.702	19	-9	10	2019
25624	PACD	CDB	91906	COLD BAY AP	55.22083	-162.733	24	-9	10	2019
25628	PAPB	PBV	70906	ST GEORGE ISLAND AP	56.6	-169.565	27	-9	10	2019
25713	PASN	SNP	100106	ST PAUL ISLAND AP	57.15528	-170.222	11	-9	10	2019
26409	PAMR	MRI	41707	ANCHORAGE MERRILL FLD	61.21694	-149.855	42	-9	5	2019
26410	PACV	CDV	110705	CORDOVA M K SMITH AP	60.4888	-145.451	9	-9	8	2019
26411	PAFA	FAI	82306	FAIRBANKS INTL AP	64.8039	-147.876	132	-9	10	2019
26412	PAOR	ORT	82406	NORTHWAY AP	62.9617	-141.938	522	-9	10	2018
26415	PABI	BIG	100705	BIG DELTA AP	63.9944	-145.721	389	-9	10	2019
26425	PAGK	GKN	111705	GULKANA AP	62.1591	-145.459	476	-9	10	2019
26435	PANN	ENN	102705	NENANA MUNI AP	64.55	-149.072	110	-9	10	2019
26438	PAWD	SWD	102705	SEWARD AP	60.12833	-149.417	15	-9	8	2019
26451	PANC	ANC	91806	ANCHORAGE INTL AP	61.169	-150.028	37	-9	8	2019
26492	PATO	POR	41707	PORTAGE GLACIER V C	60.785	-148.839	31	-9	10	2019
26510	PAMC	MCG	60106	MCGRATH AP	62.9574	-155.61	101	-9	10	2016
26523	PAEN	ENA	92106	KENAI MUNI AP	60.5797	-151.239	28	-9	8	2019
26528	PATK	TKA	70203	TALKEETNA AP	62.32	-150.095	107	-9	8	2019
26529	PATA	TAL	111705	TANANA CALHOUN MEM AP	65.175	-152.107	68	-9	10	2018

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26533	PABT	BTT	51806	BETTLES AP	66.9167	-151.519	196	-9	10	2019
26615	PABE	BET	91306	BETHEL AP	60.785	-161.829	31	-9	8	2019
26616	PAOT	OTZ	83006	KOTZEBUE RALPH WEIN AP	66.86667	-162.633	9	-9	8	2019
26617	PAOM	OME	90206	NOME MUNI AP	64.5111	-165.44	4	-9	8	2019
27406	PASC	SCC	82406	DEADHORSE AP	70.1917	-148.477	19	-9	8	2019
27502	PABR	BRW	61703	BARROW POST ROGERS AP	71.2834	-156.782	9	-9	8	2019
27503	PAWI	AWI	81606	WAINWRIGHT AP	70.63917	-159.995	8	-9	8	2019
27515	PAQT	AQT	82206	NUIQSUT AP	70.21167	-151.002	18	-9	8	2019
3856	KHSV	HSV	50807	HUNTSVILLE INTL AP	34.64389	-86.7861	190	-6	10	2019
3878	KTOI	TOI	12109	TROY MUNI AP	31.86056	-86.0122	120	-6	10	2019
13838	KBFM	BFM	41307	MOBILE DWTN AP	30.62639	-88.0681	6	-6	10	2019
13839	KDHN	DHN	53007	DOTHAN RGNL AP	31.3167	-85.45	114	-6	10	2019
13871	KANB	ANB	11409	ANNISTON METRO AP	33.5872	-85.8556	181	-6	8	2019
13876	KBHM	BHM	30509	BIRMINGHAM AP	33.56556	-86.745	187	-6	10	2019
13894	KMOB	MOB	30507	MOBILE RGNL AP	30.68833	-88.2456	66	-6	10	2019
13895	KMGM	MGM	22009	MONTGOMERY AP	32.2997	-86.4075	62	-6	10	2019
13896	KMSL	MSL	52407	MUSCLE SHOALS RGNL AP	34.7441	-87.5997	165	-6	10	2019
53820	KGZH	GZH	32007	EVERGREEN MIDDLETON FLD	31.41556	-87.0442	77	-6	10	2019
53852	KDCU	DCU	51007	DECATUR PRYOR FLD	34.6525	-86.9453	179	-6	10	2019
63872	KEUF	NA		WEEDON FLD AP	31.95139	-85.1289	87	-6	10	2016
63874	KPRN	NA		GREENVILLE CRENSHAW AP	31.84556	-86.6108	132	-6	10	2018
93806	KTCL	TCL	11209	TUSCALOOSA MUNI AP	33.2119	-87.6161	46	-6	10	2019
3953	KJBR	JBR	100108	JONESBORO MUNI AP	35.83111	-90.6464	78	-6	10	2019
3962	KHOT	HOT	72407	HOT SPRINGS ASOS	34.479	-93.096	163	-6	8	2019
13963	KLIT	LIT	52109	LITTLE ROCK AP ADAMS FLD	34.7273	-92.2389	79	-6	10	2019
13964	KFSM	FSM	21909	FT SMITH RGNL AP	35.333	-94.3625	137	-6	10	2019
13971	KHRO	HRO	52709	HARRISON BOONE CO AP	36.2668	-93.1566	419	-6	8	2019
13977	KTXK	TXK	81607	TEXARKANA WEBB FLD	33.4536	-94.0074	110	-6	8	2019
53869	KHKA	HKA	92508	BLYTHEVILLE MUNI AP	35.94028	-89.8308	77	-6	10	2019

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53918	KBPK	BPK	71107	MOUNTAIN HOME BAXTER AP	36.36889	-92.4703	281	-6	8	2019
53919	KLLQ	LLQ	71707	MONTICELLO MUNI AP	33.6361	-91.7556	88	-6	10	2016
53920	KRUE	RUE	120606	RUSSELLVILLE MUNI AP	35.25778	-93.0947	116	-6	10	2019
53921	KMWT	MWT	60607	MOUNT IDA ASOS	34.5467	-93.5781	214	-6	10	2016
53922	KXNA	XNA	103008	FAYETTEVILLE NW AR AP	36.28333	-94.3	392	-6	10	2019
53925	KDEQ	DEQ	42607	DE QUEEN SEVIER CO AP	34.05	-94.4008	108	-6	8	2019
93988	KPBF	PBF	61907	PINE BLUFF GRIDER FLD	34.175	-91.9347	61	-6	8	2019
93992	KELD	ELD	71107	EL DORADO S AR RGNL AP	33.22083	-92.8142	77	-6	10	2019
93993	KFYV	FYV	42409	FAYETTEVILLE DRAKE FLD	36.0097	-94.1694	381	-6	10	2019
3029	KRQE	RQE	13006	WINDOW ROCK AP	35.6575	-109.061	2054	-7	8	2019
3103	KFLG	FLG	20807	FLAGSTAFF PULLIAM AP	35.1441	-111.666	2135	-7	10	2019
3124	KFHU	NA		FORT HUACHUCA	31.58833	-110.344	1415	-7	10	2016
3162	KPGA	PGA	21507	PAGE MUNI AP	36.92611	-111.448	1314	-7	8	2019
3184	KDVT	DVT	22107	PHOENIX DEER VALLEY MUNI AP	33.68833	-112.082	443	-7	10	2019
3192	KSDL	SDL	32007	SCOTTSDALE MUNI AP	33.62278	-111.911	449	-7	10	2019
3195	KGCN	GCN	21207	GRAND CANYON NP AP	35.94611	-112.155	2014	-7	10	2019
3196	KOLS	OLS	92606	NOGALES INTL AP	31.42083	-110.846	1194	-7	10	2019
23160	KTUS	TUS	41007	TUCSON INTL AP	32.1313	-110.955	777	-7	10	2019
23183	KPHX	PHX	40307	PHOENIX SKY HARBOR INTL AP	33.4277	-112.004	337	-7	10	2019
23184	KPRC	PRC	20907	PRESCOTT LOVE FLD	34.65167	-112.421	1524	-7	10	2019
23194	KINW	INW	13006	WINSLOW MUNI AP	35.0281	-110.721	1489	-7	10	2019
93026	KDUG	DUG	22706	DOUGLAS BISBEE INL AP	31.4583	-109.606	1251	-7	10	2019
93027	KSJN	SJN	13006	ST JOHNS INDUSTRIAL AP	34.51833	-109.379	1746	-7	10	2019
93084	KSAD	SAD	30706	SAFFORD MUNI AP	32.85472	-109.635	968	-7	10	2019
93167	KIGM	IGM	22007	KINGMAN MOHAVE CO AP	35.2577	-113.933	1042	-7	10	2019
3102	KONT	ONT	92407	ONTARIO INTL AP	34.05611	-117.6	289	-8	8	2019
3104	KTRM	TRM	92806	DESERT RESORTS RGNL AP	33.62667	-116.159	-39	-8	10	2019
3131	KMYF	MYF	30707	SAN DIEGO MONTGOMERY FLD	32.81583	-117.139	127	-8	8	2019

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3144	KIPL	IPL	101706	IMPERIAL CO AP	32.83417	-115.579	-18	-8	10	2019
3159	KWJF	WJF	40507	LANCASTER WM J FOX FLD	34.7411	-118.212	713	-8	10	2019
3166	KFUL	FUL	40307	FULLERTON MUNI AP	33.87194	-117.979	29	-8	10	2019
3167	KHHR	HHR	12507	HAWTHORNE MUNI AP	33.92278	-118.334	19	-8	8	2019
3171	KRAL	RAL	71008	RIVERSIDE MUNI AP	33.95194	-117.439	245	-8	10	2019
3177	KCRQ	CRQ	41107	CARLSBAD PALOMAR AP	33.12806	-117.279	93	-8	8	2019
3178	KSDM	SDM	83007	SAN DIEGO BROWN FLD	32.57222	-116.979	157	-8	10	2019
3179	KCNO	CNO	32807	CHINO AP	33.97528	-117.636	192	-8	8	2019
23129	KLGB	LGB	40407	LONG BEACH DAUGHERTY FLD	33.8116	-118.146	9	-8	8	2019
23130	KVNY	VNY	60707	VAN NUYS AP	34.20972	-118.489	235	-8	8	2019
23136	KCMA	CMA	12507	CAMARILLO AP	34.21667	-119.083	25	-8	10	2019
23152	KBUR	BUR	20707	BURBANK GLENDALE PASADENA AP	34.20056	-118.358	222	-8	8	2019
23155	KBFL	BFL	31407	BAKERSFIELD AP	35.4344	-119.054	149	-8	10	2019
23157	KBIH	BIH	102705	BISHOP AP	37.3711	-118.358	1250	-8	10	2019
23158	KBLH	BLH	102705	BLYTHE AP	33.6186	-114.714	120	-8	10	2019
23161	KDAG	DAG	13006	BARSTOW DAGGETT AP	34.8536	-116.786	584	-8	10	2019
23174	KLAX	LAX	102706	LOS ANGELES INTL AP	33.938	-118.389	30	-8	10	2019
23179	KEED	EED	20507	NEEDLES AP	34.7675	-114.619	271	-8	10	2019
23182	KPMD	PMD	20807	PALMDALE AP	34.62944	-118.084	769	-8	10	2019
23187	KSDB	SDB	21306	SANDBERG	34.7436	-118.724	1375	-8	10	2018
23188	KSAN	SAN	82307	SAN DIEGO LINDBERGH FLD	32.7336	-117.183	5	-8	10	2019
23190	KSBA	SBA	62207	SANTA BARBARA MUNI AP	34.4258	-119.843	3	-8	8	2019
23191	KAVX	AVX	90507	AVALON CATALINA AP	33.405	-118.416	472	-8	10	2019
23199	KNJK	NA		EL CENTRO NAF	32.81667	-115.683	-14	-8	10	2019
23213	KSTS	STS	31407	SANTA ROSA SONOMA CO AP	38.5038	-122.81	35	-8	10	2019
23225	KBLU	BLU	103102	BLUE CANYON AP	39.2774	-120.71	1608	-8	8	2019
23230	KOAK	OAK	21507	OAKLAND METRO INTL AP	37.72139	-122.221	2	-8	10	2019
23232	KSAC	SAC	81507	SACRAMENTO EXECUTIVE AP	38.5069	-121.495	5	-8	10	2019

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23233	KSNS	SNS	20607	SALINAS MUNICIPAL AP	36.6636	-121.608	23	-8	10	2019
23234	KSFO	SFO	73103	SAN FRANCISCO INTL AP	37.6197	-122.365	2	-8	10	2019
23237	KSCK	SCK	81607	STOCKTON METRO AP	37.8891	-121.226	8	-8	10	2019
23244	KNUQ	NA		MOFFETT FEDERAL AIRFIELD	37.40583	-122.048	12	-8	10	2016
23254	KCCR	CCR	82605	CONCORD BUCHANAN FLD	37.9917	-122.055	5	-8	10	2019
23257	KMCE	MCE	22706	MERCED MUNI AP	37.28472	-120.513	46	-8	8	2019
23258	KMOD	MOD	40207	MODESTO CITY CO AP	37.6241	-120.951	22	-8	8	2019
23259	KMRY	MRY	20607	MONTEREY PENINSUL AP	36.58806	-121.845	50	-8	8	2019
23273	KSMX	SMX	60607	SANTA MARIA PUBLIC AP	34.8994	-120.449	74	-8	10	2019
23275	KUKI	UKI	101206	UKIAH MUNI AP	39.12583	-123.201	183	-8	6	2019
23277	KWVI	WVI	20607	WATSONVILLE MUNI AP	36.93583	-121.789	47	-8	10	2019
23285	KLVK	LVK	32307	LIVERMORE MUNI AP	37.6927	-121.814	120	-8	8	2019
23293	KSJC	SJC	30807	SAN JOSE	37.3591	-121.924	16	-8	8	2019
24215	KMHS	MHS	22706	MT SHASTA	41.3325	-122.333	1077	-8	10	2018
24216	KRBL	RBL	21306	RED BLUFF MUNI AP	40.1519	-122.254	108	-8	10	2019
24257	KRDD	RDD	80907	REDDING MUNI AP	40.5175	-122.299	151	-8	10	2019
24259	KSIY	SIY	102705	MONTAGUE SISKIYOU AP	41.78139	-122.468	807	-8	10	2019
24283	KACV	ACV	13107	ARCATA EUREKA AP	40.97806	-124.109	61	-8	10	2019
24286	KCEC	CEC	90706	CRESCENT CITY MCNAMARA AP	41.78028	-124.237	18	-8	8	2019
53119	KHJO	HJO	110705	HANFORD MUNI AP	36.31889	-119.629	77	-8	10	2019
53120	KRNM	RNM	21306	RAMONA AP	33.0375	-116.916	423	-8	8	2019
53121	KOKB	OKB	20306	OCEANSIDE MUNI AP	33.21944	-117.349	10	-8	10	2019
93110	KOXR	OXR	11007	OXNARD VENTURA CO AP	34.20083	-119.207	11	-8	8	2019
93115	KNRS	NA		IMPERIAL BEACH REAM FLD NAS	32.56667	-117.117	7	-8	10	2018
93134	KCQT	CQT	20306	LOS ANGELES DOWNTOWN_USC	34.0236	-118.291	55	-8	6	2018
93138	KPSP	PSP	92607	PALM SPRINGS RGNL AP	33.8222	-116.504	125	-8	10	2019
93184	KSNA	SNA	81507	SANTA ANA JOHN WAYNE AP	33.68	-117.866	13	-8	6	2019

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93193	KFAT	FAT	40307	FRESNO YOSEMITE INTL AP	36.78	-119.719	101	-8	8	2019
93197	KSMO	SMO	41807	SANTA MONICA MUNI AP	34.01583	-118.451	53	-8	10	2019
93205	KMYV	MYV	21306	MARYSVILLE YUBA CO AP	39.1019	-121.568	19	-8	10	2019
93206	KSBP	SBP	41707	SAN LUIS OBISPO AP	35.23722	-120.641	61	-8	10	2019
93209	KPRB	PRB	22706	PASO ROBLES MUNI AP	35.6697	-120.628	247	-8	10	2019
93210	KOVE	OVE	21306	OROVILLE MUNI AP	39.49	-121.618	57	-8	10	2019
93227	KAPC	APC	31808	NAPA CO AP	38.2102	-122.285	4	-8	10	2019
93228	KHWD	HWD	20807	HAYWARD AIR TERMINAL	37.6542	-122.115	13	-8	10	2019
93230	KTVL	TVL	51707	SOUTH LAKE TAHOE AP	38.8983	-119.995	1925	-8	10	2019
93241	KVCB	VCB	80707	VACAVILLE NUT TREE AP	38.3775	-121.958	33	-8	10	2019
93242	KMAE	MAE	21306	MADERA MUNI AP	36.98778	-120.111	77	-8	10	2019
94299	KAAT	AAT	42406	ALTURAS MUNI AP	41.49139	-120.564	1334	-8	10	2019
3013	KLAA	LAA	82608	LAMAR MUNI AP	38.07	-102.688	1124	-7	10	2019
3017	KDEN	DEN	91205	DENVER INTL AP	39.8328	-104.658	1650	-7	10	2019
3026	KITR	ITR	110705	BURLINGTON CARSON AP	39.24472	-102.284	1278	-7	10	2019
23061	KALS	ALS	52407	ALAMOSA SAN LUIS AP	37.4389	-105.861	2296	-7	10	2019
23066	KGJT	GJT	31307	GRAND JUNCTION WALKER FLD	39.1342	-108.54	1481	-7	10	2019
23067	KLHX	LHX	121605	LA JUNTA MUNI AP	38.0494	-103.512	1278	-7	10	2019
23070	KTAD	TAD	102808	TRINIDAD PERRY STOKES AP	37.26222	-104.338	1750	-7	10	2019
24015	KAKO	AKO	12507	AKRON WASHINGTON CO AP	40.16667	-103.217	1421	-7	10	2019
24046	KCAG	CAG	32607	CRAIG MOFFAT COUNTY AP	40.49278	-107.524	1887	-7	10	2019
93005	KDRO	DRO	40307	DURANGO LA PLATA CO AP	37.14306	-107.76	2033	-7	10	2019
93009	KLXV	LXV	82808	LEADVILLE LAKE CO AP	39.22917	-106.317	3011	-7	10	2019
93010	KLIC	LIC	100405	LIMON WSMO	39.18944	-103.716	1635	-7	10	2019
93013	KMTJ	MTJ	102705	MONTROSE REGIONAL AP	38.50583	-107.899	1743	-7	10	2019
93037	KCOS	COS	92308	COLORADO SPRINGS MUNI AP	38.81	-104.688	1884	-7	10	2019
93058	KPUB	PUB	40407	PUEBLO MEM AP	38.2901	-104.498	1439	-7	10	2019
93067	KAPA	APA	20607	DENVER CENTENNIAL AP	39.57028	-104.849	1793	-7	10	2019

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93069	KCEZ	CEZ	40407	CORTEZ MONTEZUMA COUNTY AP	37.30694	-108.626	1801	-7	10	2019
93073	KASE	ASE	31507	ASPEN PITKIN CO AP	39.23	-106.871	2353	-7	8	2019
94050	KEEO	EEO	31307	MEEKER AIRPORT	40.04417	-107.889	1940	-7	10	2019
14707	KGON	GON	111708	GROTON NEW LONDON AP	41.3275	-72.0494	3	-5	10	2019
14740	KBDL	BDL	40907	HARTFORD BRADLEY INTL AP	41.9381	-72.6825	58	-5	10	2019
14752	KHFD	HFD	102308	HARTFORD BRAINARD FLD	41.73611	-72.6506	6	-5	10	2019
14758	KHVN	HVN	33109	NEW HAVEN TWEED AP	41.26389	-72.8872	1	-5	8	2019
54734	KDXR	DXR	71509	DANBURY MUNI AP	41.37139	-73.4828	138	-5	8	2019
54767	KIJD	IJD	102705	WILLIMANTIC WINDHAM AP	41.74194	-72.1836	75	-5	1	2019
54788	KMMK	MMK	100708	MERIDEN MARKHAM MUNI AP	41.50972	-72.8278	30	-5	10	2019
94702	KBDR	BDR	61709	BRIDGEPORT SIKORSKY MEM AP	41.15833	-73.1289	2	-5	8	2019
13764	KGED	GED	82608	GEORGETOWN SUSSEX CO AP	38.68917	-75.3592	15	-5	10	2018
13781	KILG	ILG	91808	WILMINGTON NEW CASTLE CO AP	39.6728	-75.6008	24	-5	10	2019
3818	KMAI	MAI	52507	MARIANNA MUNI AP	30.83556	-85.1839	33	-6	10	2019
12812	KPGD	PGD	20409	PUNTA GORDA CHARLOTTE CO AP	26.91722	-81.9914	7	-5	10	2019
12815	KMCO	MCO	53107	ORLANDO INTL AP	28.4339	-81.325	27	-5	8	2019
12816	KGNV	GNV	30907	GAINESVILLE RGNL AP	29.6919	-82.2755	37	-5	10	2019
12818	KBKV	BKV	52407	BROOKSVILLE HERNANDO CO AP	28.47361	-82.4544	20	-5	10	2019
12819	KLEE	LEE	60607	LEESBURG MUNI AP	28.82083	-81.8097	20	-5	10	2019
12832	KAAF	AAF	52207	APALACHICOLA AP	29.73333	-85.0333	6	-5	10	2019
12834	KDAB	DAB	13107	DAYTONA BEACH INTL AP	29.1828	-81.0483	9	-5	10	2019
12835	KFMY	FMY	20609	FT MYERS PAGE FLD AP	26.585	-81.8614	5	-5	8	2019
12836	KEYW	EYW	102204	KEY WEST INTL AP	24.555	-81.7522	1	-5	10	2019
12838	KMLB	MLB	91506	MELBOURNE INTL AP	28.1011	-80.6439	8	-5	10	2019

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12839	KMIA	MIA	71409	MIAMI INTL AP	25.7905	-80.3163	9	-5	10	2019
12841	KORL	ORL	51007	ORLANDO EXECUTIVE AP	28.54528	-81.3331	33	-5	10	2019
12842	KTPA	TPA	12709	TAMPA INTL AP	27.96194	-82.5403	6	-5	8	2019
12843	KVRB	VRB	30707	VERO BEACH INTL AP	27.651	-80.4199	9	-5	10	2019
12844	KPBI	PBI	72109	WEST PALM BEACH INTL AP	26.6847	-80.0994	6	-5	10	2019
12849	KFLL	FLL	80109	FT LAUDERDALE HOLLYWOOD AP	26.0719	-80.1536	3	-5	10	2019
12854	KSFB	SFB	50307	ORLANDO SANFORD AP	28.77972	-81.2436	15	-5	10	2019
12871	KSRQ	SRQ	11409	SARASOTA BRADENTON AP	27.40139	-82.5586	7	-5	10	2019
12873	KPIE	PIE	41607	ST PETERSBURG INTL AP	27.91056	-82.6875	2	-5	10	2019
12876	KGIF	GIF	10509	WINTER HAVEN GILBERT AP	28.06222	-81.7542	44	-5	10	2019
12882	KOPF	OPF	70809	MIAMI OPA LOCKA AP	25.90694	-80.2803	3	-5	10	2019
12885	KFXE	FXE	73009	FT LAUDERDALE EXECUTIVE AP	26.19694	-80.1708	4	-5	10	2019
12888	KTMB	TMB	81309	MIAMI KENDALL TAMIAMI EXEC AP	25.6475	-80.4331	2	-5	10	2019
12894	KRSW	RSW	20909	FT MYERS SW FL RGNL AP	26.53611	-81.755	9	-5	10	2019
12895	KFPR	FPR	41607	FT PIERCE ST LUCIE CO INTL AP	27.49806	-80.3767	7	-5	8	2019
12896	KMTH	MTH	22707	MARATHON AP	24.72583	-81.0517	2	-5	8	2019
12897	KAPF	APF	72809	NAPLES MUNI AP	26.1522	-81.7752	3	-5	10	2019
13884	KCEW	CEW	32907	CRESTVIEW BOB SIKES AP	30.77972	-86.5225	58	-6	10	2019
13889	KJAX	JAX	22707	JACKSONVILLE INTL AP	30.495	-81.6936	8	-5	10	2019
13899	KPNS	PNS	32707	PENSACOLA RGNL AP	30.47806	-87.1869	34	-6	10	2019
53847	KNDZ	NA		WHITING FIELD NAS SOUTH	30.70444	-87.0231	54	-6	10	2016
53853	KDTS	DTS	31407	DESTIN FT WALTON AP	30.4	-86.4717	4	-6	8	2019
53860	KCRG	CRG	30507	JACKSONVILLE CRAIG MUNI AP	30.3361	-81.5147	12	-5	8	2019
73805	KECP	NA		NW FLORIDA BEACHES INTL AP	30.349	-85.788	17	-6	10	2018
92805	KPMP	PMP	71709	POMPANO BEACH AIRPARK	26.25	-80.1083	5	-5	10	2019
92806	KSPG	SPG	10809	ST PETERSBURG ALBERT WHITTED	27.76472	-82.6275	2	-5	8	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
92809	KHWO	HWO	80109	HOLLYWOOD NORTH PERRY AP	25.99889	-80.2411	2	-5	10	2019
93805	KTLH	TLH	50907	TALLAHASSEE RGNL AP	30.39306	-84.3533	17	-5	10	2019
3813	KMCN	MCN	72407	MACON MIDDLE GA RGNL AP	32.6847	-83.6527	105	-5	10	2019
3820	KAGS	AGS	51209	AUGUSTA BUSH FLD AP	33.3644	-81.9633	40	-5	10	2019
3822	KSAV	SAV	21209	SAVANNAH INTL AP	32.13	-81.21	14	-5	10	2019
3888	KFTY	FTY	32007	ATLANTA FULTON CO AP	33.77917	-84.5214	256	-5	8	2019
13837	KDNL	DNL	50409	AUGUSTA DANIEL FLD AP	33.46694	-82.0386	125	-5	10	2019
13869	KABY	ABY	53107	ALBANY SW GA RGNL AP	31.53556	-84.1944	58	-5	10	2019
13870	KAMG	AMG	10609	ALMA BACON CO AP	31.5358	-82.5067	59	-5	10	2019
13873	KAHN	AHN	51007	ATHENS BEN EPPS AP	33.948	-83.3275	239	-5	8	2019
13874	KATL	ATL	32707	ATLANTA HARTSFIELD INTL AP	33.6301	-84.4418	308	-5	10	2019
13878	KSSI	SSI	30707	BRUNSWICK MALCOLM MCKINNON AP	31.1522	-81.3908	5	-5	10	2019
53819	KFFC	FFC	20306	PEACHTREE CITY FALCON FLD	33.35528	-84.5669	243	-5	10	2019
53838	KGVL	GVL	41207	GAINESVILLE GILMER AP	34.27194	-83.8303	387	-5	8	2019
53863	KPDK	PDK	32107	ATLANTA PEACHTREE AP	33.875	-84.3022	303	-5	10	2019
53873	KVPC	VPC	32207	CARTERSVILLE AP	34.12306	-84.8486	228	-5	10	2019
93801	KRMG	RMG	51707	ROME R B RUSSELL AP	34.34778	-85.1611	195	-5	10	2019
93842	KCSG	CSG	52407	COLUMBUS METRO AP	32.5161	-84.9422	119	-5	10	2019
93845	KVLD	VLD	60707	VALDOSTA RGNL AP	30.7825	-83.2767	60	-5	10	2019
21504	PHTO	ITO	62603	HILO INTL AP	19.7191	-155.053	12	-10	10	2019
21510	PHKO	KOA	50809	KAILUA KONA KE-AHOLE AP	19.73556	-156.049	9	-10	10	2019
22516	PHOG	OGG	62909	KAHULUI AP	20.89972	-156.429	16	-10	10	2019
22521	PHNL	HNL	51209	HONOLULU INTL AP	21.324	-157.929	2	-10	8	2019
22534	PHMK	MKK	61509	MOLOKAI AP	21.1545	-157.096	135	-10	10	2019
22536	PHLI	LIH	61109	LIHUE WSO AP 1020.1	21.98389	-159.341	30	-10	10	2019
22551	PHJR	NA		EWA KALAELOA AP	21.31667	-158.067	15	-10	10	2019
14931	KBRL	BRL	41707	BURLINGTON MUNI AP	40.78333	-91.1253	211	-6	10	2019
14933	KDSM	DSM	41807	DES MOINES INTL AP	41.5338	-93.653	292	-6	10	2019

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14937	KIOW	IOW	102005	IOWA CITY MUNI AP	41.63278	-91.5431	198	-6	10	2019
14940	KMCW	MCW	51707	MASON CITY MUNI AP	43.1544	-93.3269	373	-6	10	2019
14943	KSUX	SUX	43009	SIOUX CITY GATEWAY AP	42.3913	-96.3791	334	-6	10	2019
14950	KOTM	OTM	61307	OTTUMWA INDUSTRIAL AP	41.1077	-92.4466	257	-6	10	2019
14972	KSPW	SPW	110705	SPENCER MUNI AP	43.16444	-95.2017	407	-6	10	2019
14990	KCID	CID	41807	CEDAR RAPIDS MUNI AP	41.8833	-91.7166	265	-6	8	2019
94908	KDBQ	DBQ	42007	DUBUQUE RGNL AP	42.39778	-90.7036	322	-6	10	2019
94910	KALO	ALO	62507	WATERLOO MUNI AP	42.5544	-92.4011	265	-6	10	2019
94971	KEST	EST	50207	ESTHERVILLE MUNICIPAL AP	43.40111	-94.7472	401	-6	10	2019
94982	KDVN	DVN	102005	DAVENPORT MUNI AP	41.61389	-90.5914	229	-6	10	2016
94988	KMIW	MIW	102005	MARSHALLTOWN MUNICIPAL AP	42.11056	-92.9161	297	-6	10	2019
94989	KAMW	AMW	102705	AMES MUNICIPAL AP	41.99056	-93.6189	291	-6	10	2019
94991	KLWD	LWD	52907	LAMONI MUNICIPAL AP	40.6306	-93.9008	346	-6	10	2019
4110	KJER	JER	50406	JEROME CO AP	42.72667	-114.456	1223	-7	8	2019
4114	KLLJ	LLJ	10203	CHALLIS AP	44.52278	-114.215	1534	-7	8	2016
24131	KBOI	BOI	10907	BOISE AIR TERMINAL	43.5666	-116.241	858	-7	10	2019
24133	KBYI	BYI	110705	BURLEY MUNI AP	42.5416	-113.766	1266	-7	10	2019
24145	KIDA	IDA	13007	IDAHO FALLS FANNING FLD	43.51639	-112.067	1441	-7	8	2019
24149	KLWS	LWS	41107	LEWISTON NEZ PERCE CO AP	46.3747	-117.016	438	-8	8	2019
24154	KMLP	MLP	70306	MULLAN PASS VOR_DME	47.45694	-115.645	1837	-8	8	2019
24156	KPIH	PIH	30607	POCATELLO RGNL AP	42.9202	-112.571	1357	-7	10	2019
94178	KTWF	TWF	71807	TWIN FALLS SUN VLY RGNL AP	42.48194	-114.487	1261	-7	10	2019
94182	KMYL	MYL	60706	MCCALL AP	44.88889	-116.102	1528	-7	10	2019
94194	KRXE	RXE	102005	REXBURG MADISON CO AP	43.83389	-111.804	1481	-7	10	2019
3887	KDEC	DEC	32007	DECATUR AP	39.83444	-88.8656	206	-6	10	2019
3960	KCPS	CPS	51109	CAHOKIA ST LOUIS AP	38.57139	-90.1572	126	-6	10	2019
4808	KARR	ARR	120602	CHICAGO AURORA MUNI AP	41.77	-88.4814	216	-6	8	2019
4838	KPWK	PWK	62607	CHICAGO PALWAUKEE AP	42.12083	-87.9047	194	-6	8	2019

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13809	KLWV	LWV	110705	LAWRENCEVILLE INTL AP	38.76417	-87.6056	131	-6	10	2019
14819	KMDW	MDW	61307	CHICAGO MIDWAY AP	41.78611	-87.7522	187	-6	10	2019
14842	KPIA	PIA	91806	PEORIA GTR PEORIA AP	40.6675	-89.6839	198	-6	10	2019
14880	KUGN	UGN	52407	CHICAGO WAUKEGAN RGNL AP	42.41667	-87.8667	216	-6	10	2019
14923	KMLI	MLI	41607	MOLINE QUAD CITY INTL AP	41.46528	-90.5233	180	-6	10	2019
53802	KMTO	MTO	102005	MATTOON COLES CO AP	39.47806	-88.2803	217	-6	8	2019
93810	KMDH	MDH	52407	CARBONDALE SOUTHERN IL AP	37.77972	-89.2497	124	-6	10	2019
93822	KSPI	SPI	92506	SPRINGFIELD CAPITAL AP	39.8447	-89.6839	181	-6	10	2019
93989	KUIN	UIN	92006	QUINCY RGNL AP	39.93694	-91.1919	234	-6	8	2019
94822	KRFD	RFD	52207	ROCKFORD GTR ROCKFORD AP	42.1927	-89.093	223	-6	10	2019
94846	KORD	ORD	62707	CHICAGO OHARE INTL AP	41.995	-87.9336	202	-6	10	2019
94870	KCMI	CMI	51007	CHAMPAIGN WILLARD AP	40.03972	-88.2778	229	-6	8	2019
94892	KDPA	DPA	62907	WEST CHICAGO DUPAGE AP	41.91444	-88.2464	230	-6	8	2019
3868	KHUF	HUF	11603	TERRE HAUTE HULMAN RGNL AP	39.45194	-87.3089	175	-5	8	2019
3893	KBMG	BMG	52507	BLOOMINGTON MONROE CO AP	39.13333	-86.6167	257	-5	8	2019
4846	KVPZ	VPZ	110705	VALPARAISO PORTER CO MUNI AP	41.4525	-87.0058	232	-6	8	2019
14827	KFWA	FWA	92106	FT WAYNE INTL AP	40.9705	-85.2063	241	-5	10	2019
14829	KGSH	GSH	121605	GOSHEN MUNI AP	41.5333	-85.7833	253	-5	10	2019
14835	KLAF	LAF	91406	LAFAYETTE PURDUE UNIV AP	40.41222	-86.9369	183	-5	10	2019
14848	KSBN	SBN	92706	S BEND AP	41.7072	-86.3163	236	-5	10	2019
53842	KEYE	EYE	100405	INDIANAPOLIS EAGLE CREEK AP	39.825	-86.2958	249	-5	10	2019
53866	KGEZ	GEZ	100405	SHELBYVILLE MUNI AP	39.57806	-85.8033	245	-5	10	2019
93817	KEVV	EVV	92606	EVANSVILLE REGIONAL AP	38.0441	-87.5205	122	-6	8	2019
93819	KIND	IND	52207	INDIANAPOLIS INTL AP	39.7318	-86.2788	241	-5	10	2019
94895	KMIE	MIE	52907	MUNCIE DELAWARE CO AP	40.23417	-85.3936	286	-5	10	2019

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3928	KICT	ICT	100605	WICHITA DWIGHT D EISENHOWER NA	37.6475	-97.43	403	-6	10	2019
3936	KMHK	MHK	22107	MANHATTAN MUNI AP	39.1346	-96.6788	322	-6	8	2018
3967	KOJC	OJC	42007	OLATHE JOHNSON CO EXEC AP	38.85	-94.7392	326	-6	10	2019
3974	KAAO	AAO	102005	WICHITA COLONEL JAMES JABARA A	37.74611	-97.2211	431	-6	10	2019
3997	KLWC	LWC	100705	LAWRENCE MUNI AP	39.00778	-95.2117	254	-6	10	2019
3998	KPPF	PPF	40307	PARSONS TRI CITY AP	37.32778	-95.5042	265	-6	8	2019
13920	KFOE	FOE	90706	TOPEKA FORBES FLD	38.95028	-95.6639	325	-6	10	2019
13932	KWLD	WLD	101305	WINFIELD STROTHER FLD AP	37.16806	-97.0369	351	-6	8	2019
13981	KCNU	CNU	60706	CHANUTE MARTIN JOHNSON AP	37.67028	-95.4842	300	-6	10	2019
13984	KCNK	CNK	11007	CONCORDIA MUNI AP	39.5514	-97.6508	448	-6	10	2019
13985	KDDC	DDC	91306	DODGE CITY RGNL AP	37.7686	-99.9678	787	-6	8	2019
13986	KHUT	HUT	12907	HUTCHINSON MUNI AP	38.06528	-97.8606	463	-6	10	2019
13989	KEMP	EMP	40207	EMPORIA MUNI AP	38.32917	-96.1947	365	-6	10	2019
13996	KTOP	TOP	101702	TOPEKA MUNI AP	39.0725	-95.6261	267	-6	8	2019
23064	KGCK	GCK	12407	GARDEN CITY RGNL AP	37.92722	-100.725	878	-6	8	2019
23065	KGLD	GLD	102705	GOODLAND RENNER FLD	39.36722	-101.693	1114	-7	10	2019
93909	KIXD	IXD	12607	OLATHE JOHNSON CO AP	38.83167	-94.8897	327	-6	10	2019
93990	KHLC	HLC	20607	HILL CITY MUNI AP	39.37556	-99.8297	667	-6	10	2019
93997	KRSL	RSL	90606	RUSSELL MUNI AP	38.87611	-98.8092	568	-6	10	2019
3816	KPAH	PAH	22207	PADUCAH BARKLEY RGNL AP	37.0563	-88.7744	126	-6	10	2019
3849	KLOZ	LOZ	110705	LONDON CORBIN AP	37.08722	-84.0769	362	-5	10	2019
3889	KJKL	JKL	102005	JACKSON JULIAN CARROLL AP	37.59139	-83.3144	416	-5	10	2019
13810	KLOU	LOU	52307	LOUISVILLE BOWMAN FLD	38.22806	-85.6636	165	-5	10	2019
53841	KFFT	FFT	102005	FRANKFORT CAPITAL CITY AP	38.18472	-84.9033	238	-5	10	2019
93808	KBWG	BWG	110705	BOWLING GREEN WARREN CO AP	36.9647	-86.4238	161	-6	8	2019

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93814	KCVG	CVG	42407	CINCINNATI NORTHERN KY AP	39.04306	-84.6717	265	-5	10	2019
93820	KLEX	LEX	92706	LEXINGTON BLUEGRASS AP	38.0408	-84.6058	299	-5	10	2019
93821	KSDF	SDF	61407	LOUISVILLE INTL AP	38.1811	-85.7391	149	-5	10	2019
3937	KLCH	LCH	41907	LAKE CHARLES RGNL AP	30.12472	-93.2283	3	-6	10	2019
3996	KTVR	TVR	60507	TALLULAH VICKSBURG AP	32.35	-91.0278	26	-6	10	2019
12884	KBVE	BVE	41807	BOOTHVILLE ASOS	29.333	-89.4075	1	-6	10	2018
12916	KMSY	MSY	32307	NEW ORLEANS INTL AP	29.9933	-90.2511	1	-6	10	2019
13942	KMLU	MLU	100908	MONROE REGIONAL AP	32.5155	-92.0405	24	-6	8	2019
13957	KSHV	SHV	60707	SHREVEPORT RGNL AP	32.4472	-93.8244	77	-6	10	2019
13970	KBTR	BTR	92606	BATON ROUGE RYAN AP	30.5372	-91.1469	20	-6	10	2019
13976	KLFT	LFT	60107	LAFAYETTE RGNL AP	30.205	-91.9875	12	-6	8	2018
53865	KASD	ASD	30207	SLIDELL AP	30.34333	-89.8222	8	-6	10	2016
53905	KDTN	DTN	41907	SHREVEPORT DWTN AP	32.54278	-93.745	55	-6	10	2019
53915	KARA	ARA	61207	NEW IBERIA AP - ACADIANA RGNL	30.0375	-91.8839	7	-6	8	2019
53917	KNEW	NEW	10803	NEW ORLEANS LAKEFRONT AP	30.0494	-90.0288	3	-6	8	2019
93915	KAEX	AEX	42607	ALEXANDRIA INTL AP	31.33472	-92.5586	26	-6	8	2019
4780	KFIT	FIT	102005	FITCHBURG MUNI AP	42.55194	-71.7558	101	-5	10	2019
14702	KBED	BED	52907	BEDFORD HANSCOM FLD	42.47	-71.2894	38	-5	10	2019
14739	KBOS	BOS	100506	BOSTON LOGAN INTL AP	42.3606	-71.0106	4	-5	8	2019
14756	KACK	ACK	51909	NANTUCKET MEM AP	41.25306	-70.0608	10	-5	10	2019
14763	KPSF	PSF	102705	PITTSFIELD MUNI AP	42.42722	-73.2892	351	-5	10	2019
14775	KBAF	BAF	100208	WESTFIELD BARNES MUNI AP	42.15778	-72.7161	80	-5	10	2019
54704	KOWD	OWD	111808	NORWOOD MEM AP	42.19083	-71.1736	15	-5	8	2019
54733	KBVY	BVY	100808	BEVERLY MUNI AP	42.58417	-70.9175	29	-5	10	2019
54756	KORE	ORE	102005	ORANGE MUNI AP	42.57	-72.2911	167	-5	10	2019
54768	KAQW	AQW	110705	NORTH ADAMS HARRIMAN AP	42.7	-73.1667	200	-5	10	2019
54769	KPYM	PYM	102005	PLYMOUTH MUNI AP	41.90972	-70.7294	44	-5	10	2019
54777	KTAN	TAN	100206	TAUNTON MUNI AP	41.87556	-71.0211	9	-5	10	2019

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94624	KCQX	CQX	30107	CHATHAM MUNI AP	41.6875	-69.9933	17	-5	10	2019
94720	KHYA	HYA	43009	HYANNIS BARNSTABLE MUNI AP	41.66861	-70.28	14	-5	8	2019
94723	KLWM	LWM	110408	LAWRENCE MUNI AP	42.71722	-71.1239	42	-5	10	2019
94724	KMVY	MVY	51109	VINEYARD HAVEN AP	41.39306	-70.615	19	-5	10	2019
94726	KEWB	EWB	103008	NEW BEDFORD MUNI AP	41.67639	-70.9583	22	-5	8	2019
94746	KORH	ORH	32807	WORCESTER RGNL AP	42.2706	-71.8731	305	-5	10	2019
93706	KHGR	HGR	40307	HAGERSTOWN WASHINGTON CO AP	39.70778	-77.7297	213	-5	8	2019
93720	KSBY	SBY	41107	SALISBURY WICOMICO RGNL AP	38.34056	-75.5103	15	-5	8	2019
93721	KBWI	BWI	92006	BALTIMORE WASH INTL AP	39.1666	-76.6833	48	-5	10	2019
93786	KOXB	OXB	40507	OCEAN CITY MUNI AP	38.30833	-75.1239	4	-5	10	2019
4836	KFVE	FVE	121605	FRENCHVILLE AROOSTOOK AP	47.28556	-68.3133	302	-5	10	2019
14605	KAUG	AUG	102705	AUGUSTA STATE AP	44.3155	-69.7972	107	-5	8	2019
14606	KBGR	BGR	92706	BANGOR INTL AP	44.7978	-68.8185	45	-5	10	2019
14607	KCAR	CAR	92602	CARIBOU MUNI AP	46.8705	-68.0173	190	-5	8	2019
14609	KHUL	HUL	102705	HOULTON INTL AP	46.1236	-67.7928	145	-5	10	2019
14610	KMLT	MLT	101305	MILLINOCKET MUNI AP	45.6477	-68.6925	124	-5	10	2019
14764	KPWM	PWM	100606	PORTLAND INTL JETPORT	43.6497	-70.3002	14	-5	8	2019
54772	KIZG	IZG	91206	FRYEBURG E SLOPES AP	43.99056	-70.9475	136	-5	10	2019
94623	KIWI	IWI	91306	WISCASSET AP	43.96361	-69.7117	13	-5	10	2019
4839	KBIV	BIV	111705	HOLLAND TULIP CITY AP	42.74611	-86.0967	206	-5	10	2019
4847	KADG	ADG	100705	ADRIAN LENAWEE CO AP	41.86778	-84.0794	243	-5	10	2019
4854	KGLR	GLR	100705	GAYLORD OTSEGO CO AP	45.01333	-84.7014	407	-5	10	2019
14815	KBTL	BTL	22007	BATTLE CREEK KELLOGG AP	42.3075	-85.2511	283	-5	10	2019
14822	KDET	DET	101206	DETROIT CITY AP	42.40917	-83.01	191	-5	10	2019
14826	KFNT	FNT	91808	FLINT BISHOP INTL AP	42.9666	-83.7494	235	-5	10	2019
14833	KJXN	JXN	41607	JACKSON REYNOLDS FLD	42.2667	-84.4667	304	-5	8	2019
14836	KLAN	LAN	90706	LANSING CAPITAL CITY AP	42.78028	-84.5789	256	-5	10	2019

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14840	KMKG	MKG	32007	MUSKEGON CO AP	43.17111	-86.2367	191	-5	10	2019
14841	KPLN	PLN	100705	PELLSTON RGNL AP	45.5644	-84.7927	215	-5	8	2019
14845	KMBS	MBS	53107	SAGINAW MBS INTL AP	43.53306	-84.0797	201	-5	10	2019
14847	KANJ	ANJ	91406	SAULT STE MARIE SANDERSON FLD	46.4794	-84.3572	220	-5	10	2019
14850	KTVC	TVC	51707	TRAVERSE CITY CHERRY CPTL AP	44.74083	-85.5825	188	-5	8	2019
14853	KYIP	YIP	92608	DETROIT WILLOW RUN AP	42.23333	-83.5333	237	-5	10	2019
14858	KCMX	CMX	112602	HANCOCK HOUGHTON CO AP	47.16861	-88.4889	325	-5	8	2019
94814	KHTL	HTL	32907	HOUGHTON LK ROSCOMMON AP	44.3591	-84.6738	351	-5	10	2019
94815	KAZO	AZO	83106	KALAMAZOO BATTLE CK INTL AP	42.23472	-85.5519	265	-5	10	2019
94817	KPTK	PTK	42407	PONTIAC OAKLAND CO INTL AP	42.665	-83.4181	297	-5	10	2019
94847	KDTW	DTW	60707	DETROIT METRO AP	42.2313	-83.3308	192	-5	10	2019
94849	KAPN	APN	50407	ALPENA CO RGNL AP	45.0716	-83.5644	208	-5	10	2019
94860	KGRR	GRR	22107	GRAND RAPIDS INTL AP	42.8825	-85.5239	245	-5	10	2019
94871	KBEH	BEH	121605	BENTON HARBOR AIRPORT ASOS	42.1256	-86.4284	196	-5	10	2019
94889	KARB	ARB	92408	ANN ARBOR MUNI AP	42.22278	-83.7444	253	-5	10	2019
94893	KIMT	IMT	110705	IRON MTN FORD AP	45.81833	-88.1144	338	-6	8	2019
14910	KAXN	AXN	102705	ALEXANDRIA MUNI AP	45.8679	-95.3941	432	-6	10	2019
14913	KDLH	DLH	72507	DULUTH INTL AP	46.8369	-92.1833	437	-6	10	2019
14918	KINL	INL	90706	INTL FALLS INTL AP	48.5614	-93.3981	361	-6	10	2019
14922	KMSP	MSP	91306	MINNEAPOLIS_ST PAUL AP	44.8831	-93.2289	266	-6	10	2019
14925	KRST	RST	53007	ROCHESTER INTL AP	43.9041	-92.4916	397	-6	10	2019
14926	KSTC	STC	70306	ST CLOUD RGNL AP	45.5433	-94.0513	308	-6	10	2019
14927	KSTP	STP	91206	ST PAUL DOWNTOWN AP	44.93194	-93.0556	213	-6	10	2019
14992	KRWF	RWF	102005	REDWOOD FALLS MUNI AP	44.5483	-95.0804	311	-6	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
94931	KHIB	HIB	102005	HIBBING CHISHOLM HIBBING AP	47.38639	-92.8389	411	-6	10	2019
94938	KBRD	BRD	102705	BRAINERD CROW WING CO AP	46.40472	-94.1308	372	-6	10	2019
94960	KMIC	MIC	41807	MPLS CRYSTAL AP	45.06194	-93.3508	262	-6	10	2019
94961	KBDE	BDE	91206	BAUDETTE INTL AP	48.71667	-94.6	330	-6	10	2019
94963	KFCM	FCM	42507	MPLS FLYING CLOUD AP	44.8321	-93.4705	276	-6	10	2019
94967	KPKD	PKD	41807	PARK RAPIDS MUNI AP	46.90056	-95.0678	437	-6	10	2019
3935	KCGI	CGI	121605	CAPE GIRARDEAU MUNI AP	37.2252	-89.5705	102	-6	8	2019
3945	KCOU	COU	62007	COLUMBIA RGNL AP	38.8169	-92.2183	272	-6	10	2019
3947	KMCI	MCI	91906	KANSAS CITY INTL AP	39.2972	-94.7306	306	-6	10	2019
3963	KJEF	JEF	71107	JEFFERSON CITY MEM AP	38.59111	-92.1558	175	-6	10	2019
3966	KSUS	SUS	43007	ST LOUIS SPRT OF S L AP	38.65722	-90.6558	141	-6	8	2019
3975	KPOF	POF	121605	POPLAR BLUFF MUNI AP	36.7725	-90.3247	100	-6	8	2019
3994	KDMO	DMO	81406	SEDALIA MEM AP	38.70417	-93.1833	274	-6	10	2019
13987	KJLN	JLN	92706	JOPLIN REGIONAL AIRPORT	37.1466	-94.5022	299	-6	10	2019
13988	KMKC	MKC	91306	KANSAS CITY DOWNTOWN AP	39.1208	-94.5969	226	-6	8	2019
13993	KSTJ	STJ	30507	ST JOSEPH ROSECRANS AP	39.7736	-94.9233	249	-6	10	2019
13994	KSTL	STL	92606	ST LOUIS LAMBERT INTL AP	38.7525	-90.3736	162	-6	10	2019
13995	KSGF	SGF	92006	SPRINGFIELD RGNL AP	37.2397	-93.3897	384	-6	10	2019
13997	KVIH	VIH	12407	VICHY ROLLA NATIONAL AP	38.13111	-91.7683	344	-6	10	2019
14938	KIRK	IRK	100705	KIRKSVILLE RGNL AP	40.09722	-92.5433	293	-6	10	2019
53879	KLXT	LXT	41805	LEES SUMMIT MUNI AP	38.95972	-94.3714	304	-6	10	2019
53901	KUNO	UNO	101305	WEST PLAINS MUNI AP	36.87806	-91.9025	373	-6	10	2019
53904	KSET	SET	102705	ST CHARLES CO AP	38.92861	-90.4281	133	-6	10	2019
3940	KJAN	JAN	52207	JACKSON INTL AP	32.3205	-90.0777	101	-6	10	2019
13833	KHBG	HBG	22707	HATTIESBURG CHAIN MUNI AP	31.28194	-89.2531	46	-6	10	2019
13865	KMEI	MEI	60607	MERIDIAN KEY FLD	32.3347	-88.7442	90	-6	10	2019
13927	KHKS	HKS	22807	JACKSON HAWKINS FLD	32.33667	-90.2214	104	-6	10	2019
13939	KGLH	GLH	13007	GREENVILLE ASOS	33.4825	-90.9853	39	-6	10	2019

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13978	KGWO	GWO	30607	GREENWOOD LEFLORE AP	33.4963	-90.0866	41	-6	10	2019
53858	KPQL	PQL	32607	PASCAGOULA LOTT INTL AP	30.46361	-88.5319	5	-6	8	2019
93862	KTUP	TUP	91708	TUPELO RGNL AP	34.2622	-88.7713	110	-6	10	2019
93874	KGPT	GPT	30607	GULFPORT - BILOXI AP	30.4119	-89.0808	13	-6	10	2019
93919	KMCB	MCB	41607	MCCOMB_PIKE CO_JOHN E LEWIS AP	31.1827	-90.4708	126	-6	10	2019
24033	KBIL	BIL	90506	BILLINGS INTL AP	45.8069	-108.542	1091	-7	10	2019
24036	KLWT	LWT	41706	LEWISTOWN MUNI AP	47.0492	-109.458	1263	-7	10	2019
24037	KMLS	MLS	102705	MILES CITY AP	46.4266	-105.883	800	-7	10	2019
24132	KBZN	BZN	42507	BOZEMAN GALLATIN FLD	45.788	-111.161	1349	-7	10	2019
24135	KBTM	BTM	21306	BUTTE BERT MOONEY AP	45.9647	-112.501	1678	-7	10	2019
24137	KCTB	CTB	20306	CUT BANK MUNI AP	48.6033	-112.375	1170	-7	10	2019
24138	KDLN	DLN	13006	DILLON AP	45.2575	-112.554	1585	-7	10	2019
24143	KGTF	GTF	32607	GREAT FALLS INTL AP	47.4733	-111.382	1117	-7	10	2019
24144	KHLN	HLN	53107	HELENA RGNL AP	46.6056	-111.964	1167	-7	10	2019
24146	KGPI	GPI	91306	KALISPELL GLACIER AP	48.3042	-114.264	901	-7	8	2019
24150	KLVM	LVM	102005	LIVINGSTON AP	45.6983	-110.441	1415	-7	10	2019
24153	KMSO	MSO	53107	MISSOULA INTL AP	46.9208	-114.093	973	-7	10	2019
94008	KGGW	GGW	41405	GLASGOW INTL AP	48.2138	-106.621	696	-7	10	2019
94012	KHVR	HVR	110705	HAVRE CITY CO AP	48.5428	-109.763	788	-7	10	2019
94017	KOLF	OLF	102005	WOLF POINT INTL AP	48.09444	-105.574	605	-7	10	2019
94055	KBHK	BHK	102705	BAKER MUNI AP	46.3583	-104.25	906	-7	10	2019
3810	KHKY	HKY	110608	HICKORY FAA AP	35.7425	-81.3819	348	-5	8	2019
3812	KAVL	AVL	101608	ASHEVILLE RGNL AP	35.43194	-82.5375	645	-5	8	2019
13722	KRDU	RDU	70809	RALEIGH DURHAM INTL AP	35.8923	-78.7819	127	-5	10	2019
13723	KGSO	GSO	63009	PIEDMONT TRIAD INTL AP	36.0969	-79.9432	271	-5	10	2019
13748	KILM	ILM	41307	WILMINGTON INTL AP	34.2675	-77.8997	10	-5	10	2016
13754	KNKT	NA		CHERRY POINT MCAS	34.88333	-76.8667	30	-5	10	2019
13776	KLBT	LBT	41907	LUBERTION REGIONAL AP	34.608	-79.0591	37	-5	10	2018

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13786	KECG	ECG	32607	ELIZABETH CITY CGAS	36.26056	-76.175	4	-5	10	2019
13881	KCLT	CLT	60209	CHARLOTTE DOUGLAS AP	35.2236	-80.9552	222	-5	10	2019
53870	KAKH	AKH	112008	GASTONIA MUNI AP	35.19667	-81.1558	242	-5	10	2019
53872	KEQY	EQY	52009	MONROE AP	35.01694	-80.6206	204	-5	10	2019
93719	KEWN	EWN	92206	NEW BERN CRAVEN CO AP	35.0677	-77.048	6	-5	8	2019
93729	KHSE	HSE	31907	CAPE HATTERAS AP	35.2326	-75.6219	3	-5	10	2019
93740	KFAY	FAY	60209	FAYETTEVILLE RGNL AP	34.99139	-78.8803	57	-5	10	2019
93759	KRWI	RWI	51507	ROCKY MT WILSON AP	35.855	-77.8931	45	-5	8	2019
93765	KMRH	MRH	20807	BEAUFORT MICHAEL J SMITH FLD	34.73361	-76.6606	2	-5	10	2019
93782	KMEB	MEB	60209	LAURINBURG MAXTON AP	34.79167	-79.3661	66	-5	10	2019
93783	KBUY	BUY	60507	BURLINGTON ALAMANCE AP	36.04667	-79.4769	187	-5	10	2019
93785	KIGX	IGX	42905	CHAPEL HILL WILLIAMS AP	35.93333	-79.0642	152	-5	10	2016
93807	KINT	INT	62509	WINSTON SALEM RYNLDS AP	36.13361	-80.2222	292	-5	8	2019
14914	KFAR	FAR	92606	FARGO HECTOR INTL AP	46.92528	-96.8111	274	-6	10	2019
14916	KGFK	GFK	101702	GRAND FORKS INTL AP	47.9428	-97.1839	257	-6	8	2019
14919	KJMS	JMS	11007	JAMESTOWN MUNI AP	46.9258	-98.6691	455	-6	8	2019
24011	KBIS	BIS	50107	BISMARCK MUNI AP	46.7825	-100.757	503	-6	10	2019
24012	KDIK	DIK	11707	THEODORE ROOSEVELT AP	46.7994	-102.797	786	-7	10	2019
24013	KMOT	MOT	90606	MINOT INTL AP	48.2552	-101.273	507	-6	8	2019
94014	KISN	ISN	40407	WILLISTON SLOULIN INTL AP	48.1738	-103.637	580	-6	10	2018
94038	KHEI	HEI	100405	HETTINGER MUNI AP	46.01389	-102.655	824	-7	10	2018
14935	KGRI	GRI	91906	GRAND ISLAND AP	40.9611	-98.3136	561	-6	8	2019
14939	KLNK	LNK	32607	LINCOLN MUNI AP	40.8508	-96.7475	363	-6	10	2019
14941	KOFK	OFK	102005	NORFOLK KARL STEFAN AP	41.9855	-97.4352	473	-6	10	2019
14942	KOMA	OMA	91306	OMAHA EPPLEY AIRFIELD	41.3102	-95.8991	299	-6	10	2019
24017	KCDR	CDR	100708	CHADRON MUNI AP	42.8374	-103.098	1004	-7	10	2019
24023	KLBF	LBF	102005	NORTH PLATTE RGNL AP	41.1213	-100.669	847	-6	8	2019
24028	KBFF	BFF	22003	SCOTTSBLUFF HEILIG AP	41.8705	-103.593	1202	-7	8	2019

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24030	KSNY	SNY	92508	SIDNEY MUNI AP	41.0993	-102.986	1309	-7	10	2019
24032	KVTN	VTN	91306	VALENTINE MILLER FLD	42.8783	-100.55	789	-6	10	2019
24044	KAIA	AIA	92908	ALLIANCE MUNI AP	42.0573	-102.802	1198	-7	10	2019
24091	KIML	IML	60507	IMPERIAL MUNI AP	40.51	-101.62	996	-7	10	2019
94040	KMCK	MCK	22107	MCCOOK MUNI AP	40.20639	-100.591	779	-6	10	2019
94946	KBBW	BBW	100705	BROKEN BOW MUNI AP	41.43333	-99.6333	771	-6	10	2019
94949	KHSI	HSI	110705	HASTINGS MUNI AP	40.6005	-98.4258	598	-6	8	2019
94957	KFNB	FNB	91406	FALLS CITY BRENNER FLD	40.08028	-95.5919	299	-6	10	2019
94958	KODX	ODX	100405	ORD EVELYN SHARP FLD	41.62333	-98.9483	629	-6	8	2019
94978	KTQE	TQE	102005	TEKAMAH MUNI AP	41.76361	-96.1778	313	-6	10	2019
14710	KMHT	MHT	51309	MANCHESTER AP	42.93333	-71.4383	69	-5	10	2019
14745	KCON	CON	102005	CONCORD MUNI AP	43.1952	-71.5011	105	-5	8	2019
54728	KHIE	HIE	102005	WHITEFIELD MT WASHINGTON AP	44.3675	-71.545	320	-5	8	2016
54770	KAFN	AFN	111705	JAFFREY MUNI AP	42.805	-72.0036	317	-5	10	2019
54791	KDAW	DAW	102005	ROCHESTER SKYHAVEN AP	43.27806	-70.9222	96	-5	8	2019
94700	KBML	BML	102705	BERLIN MUNI AP	44.57611	-71.1786	342	-5	10	2019
94765	KLEB	LEB	11007	LEBANON MUNI AP	43.62639	-72.3047	182	-5	10	2019
13735	KMIV	MIV	92606	MILLVILLE MUNI AP	39.3667	-75.0667	21	-5	8	2019
14734	KEWR	EWR	70809	NEWARK INTL AP	40.6825	-74.1694	2	-5	10	2019
14792	KTTN	TTN	91708	TRENTON MERCER CO AP	40.27694	-74.8158	56	-5	8	2019
54743	KCDW	CDW	60909	CALDWELL ESSEX CO AP	40.87639	-74.2831	53	-5	8	2019
54785	KSMQ	SMQ	100708	SOMERVILLE SOMERSET AP	40.62389	-74.6694	33	-5	10	2019
54793	KFWN	FWN	92408	SUSSEX AP	41.20028	-74.6231	123	-5	10	2019
93730	KACY	ACY	112906	ATLANTIC CITY INTL AP	39.4494	-74.5672	18	-5	8	2019
93780	KVAY	VAY	91206	MT HOLLY S JERSEY AP	39.94917	-74.8417	14	-5	10	2019
94741	KTEB	TEB	51909	TETERBORO AP	40.85	-74.0614	2	-5	8	2019
3027	KCQC	CQC	32007	CLINES CORNERS	35.00278	-105.663	2160	-7	10	2019
23009	KROW	ROW	41607	ROSWELL IND AIR PK	33.3075	-104.508	1112	-7	8	2019

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23048	KTCC	TCC	40507	TUCUMCARI MUNI AP	35.18222	-103.603	1234	-7	10	2019
23049	KSAF	SAF	52307	SANTA FE CO MUNI AP	35.61694	-106.089	1923	-7	8	2018
23050	KABQ	ABQ	52207	ALBUQUERQUE INTL AP	35.0419	-106.616	1618	-7	10	2019
23051	KCAO	CAO	50307	CLAYTON MUNI AIR PK	36.4486	-103.154	1512	-7	10	2019
23052	KRTN	RTN	31407	RATON MUNI CREWS AP	36.74139	-104.502	1934	-7	10	2019
23054	KLVS	LVS	42607	LAS VEGAS MUNI AP	35.65417	-105.142	2092	-7	10	2019
23078	KDMN	DMN	92706	DEMING MUNI AP	32.26222	-107.721	1311	-7	10	2019
23081	KGUP	GUP	51507	GALLUP MUNI AP	35.5144	-108.794	1972	-7	10	2019
23090	KFMN	FMN	40407	FARMINGTON RGNL AP	36.74361	-108.229	1675	-7	10	2019
93033	KCNM	CNM	51007	CARLSBAD CAVERN CITY AP	32.3335	-104.258	985	-7	10	2019
93045	KTCS	TCS	31907	TRUTH OR CONSEQUENCE AP	33.23667	-107.268	1470	-7	8	2019
3160	KDRA	DRA	13006	MERCURY DESERT ROCK AP	36.6206	-116.028	985	-8	10	2019
23153	KTPH	TPH	20306	TONOPAH	38.0511	-117.09	1644	-8	10	2019
23154	KELY	ELY	121605	ELY YELLAND FLD AP	39.2952	-114.847	1909	-8	10	2019
23169	KLAS	LAS	42507	LAS VEGAS MCCARRAN AP	36.0719	-115.163	664	-8	10	2019
23185	KRNO	RNO	51507	RENO TAHOE INTL AP	39.4838	-119.771	1344	-8	10	2019
24121	KEKO	EKO	62807	ELKO RGNL AP	40.8288	-115.789	1533	-8	10	2019
24128	KWMC	WMC	111705	WINNEMUCCA MUNI AP	40.9017	-117.808	1309	-8	10	2019
24172	KLOL	LOL	101305	LOVELOCK DERBY FLD	40.0681	-118.569	1189	-8	10	2019
53123	KVGT	VGT	42607	LAS VEGAS AIR TERMINAL	36.21167	-115.196	670	-8	10	2019
4725	KBGM	BGM	21307	BINGHAMTON GREATER AP	42.2068	-75.98	486	-5	8	2019
4781	KISP	ISP		ISLIP LONG IS MACARTHUR AP	40.79389	-73.1017	26	-5	8	2019
4789	KMGJ	MGJ	71509	MONTGOMERY ORANGE AP	41.50917	-74.265	106	-5	10	2019
14719	KFOK	FOK	21109	WESTHAMPTN GABRESKI AP	40.84361	-72.6322	18	-5	10	2019
14732	KLGA	LGA	70609	NEW YORK LAGUARDIA AP	40.77944	-73.8803	3	-5	10	2019
14733	KBUF	BUF	60409	BUFFALO NIAGARA INTL AP	42.9408	-78.7358	218	-5	10	2019
14735	KALB	ALB	90806	ALBANY AP	42.7431	-73.8092	95	-5	10	2019
14747	KDKK	DKK	91908	DUNKIRK CHAUTAUQUA AP	42.49333	-79.2722	203	-5	10	2019
14748	KELM	ELM	42507	ELMIRA CORNING RGNL AP	42.15944	-76.8919	288	-5	10	2019

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14750	KGFL	GFL	102705	GLENS FALLS AP	43.35	-73.6167	98	-5	10	2019
14757	KPOU	POU	91206	POUGHKEEPSIE DUTCHESS CO AP	41.6266	-73.8842	51	-5	8	2019
14768	KROC	ROC	102008	ROCHESTER GTR INTL AP	43.1167	-77.6767	164	-5	10	2019
14771	KSYR	SYR	20107	SYRACUSE HANCOCK INTL AP	43.1111	-76.1038	126	-5	10	2019
54757	KELZ	ELZ	110705	WELLSVILLE MUNI AP	42.10944	-77.9919	647	-5	10	2019
54773	KFZY	FZY	102705	FULTON OSWEGO CO AP	43.34972	-76.3847	141	-5	8	2019
54778	KPEO	PEO	110705	PENN YAN AP	42.6425	-77.0564	263	-5	10	2019
54787	KFRG	FRG	51809	FARMINGDALE AP	40.73417	-73.4169	24	-5	10	2019
54790	KHWV	HWV	120308	SHIRLEY BROOKHAVEN AP	40.82167	-72.8689	20	-5	10	2019
64775	KRME	RME	32807	ROME GRIFFISS AIRFIELD	43.23389	-75.4117	147	-5	10	2019
64776	KPBG	PBG	110705	PLATTSBURGH INTL AP	44.65	-73.4667	71	-5	10	2019
94704	KDSV	DSV	92408	DANSVILLE MUNI AP	42.57083	-77.7133	196	-5	10	2019
94725	KMSS	MSS	111705	MASSENA INTL AP	44.93583	-74.8458	65	-5	10	2019
94728	KNYC	NYC	91806	NEW YORK CNTRL PK TWR	40.77889	-73.9692	40	-5	10	2017
94740	KSLK	SLK	111805	SARANAC RGNL AP	44.38528	-74.2067	501	-5	8	2019
94745	KHPN	HPN	52209	WESTCHESTER CO AP	41.06694	-73.7075	116	-5	10	2019
94789	KJFK	JFK	63009	NEW YORK JFK INTL AP	40.63861	-73.7622	3	-5	10	2019
94790	KART	ART	110705	WATERTOWN INTL AP	43.9922	-76.0217	97	-5	8	2019
4804	KOSU	OSU	61107	COLUMBUS OHIO STATE UNIV AP	40.07806	-83.0781	276	-5	8	2019
4842	KBJJ	BJJ	100406	WOOSTER WAYNE CO AP	40.87306	-81.8867	336	-5	10	2019
4848	KTDZ	TDZ	82008	TOLEDO METCALF FLD	41.56306	-83.4764	189	-5	10	2019
4849	KLPR	LPR	120606	ELYRIA LORAIN CO AP	41.34611	-82.1794	241	-5	10	2019
4850	KAOH	AOH	91906	LIMA ALLEN COUNTY AP	40.7075	-84.0272	297	-5	10	2019
4851	KDFI	DFI	42407	DEFIANCE AP	41.3375	-84.4289	215	-5	10	2019
4852	KPHD	PHD	90706	NEW PHILADELPHIA FLD	40.47194	-81.4236	272	-5	10	2019
4853	KBKL	BKL	81808	CLEVELAND BURKE AP	41.5175	-81.6836	177	-5	8	2019
4855	KMNN	MNN	120606	MARION MUNI AP	40.61611	-83.0636	301	-5	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
4857	KHZY	HZY	100606	ASHTABULA CO AP	41.77806	-80.6958	278	-5	10	2019
4858	KVTA	VTA	120606	NEWARK HEATH AP	40.02278	-82.4625	267	-5	10	2019
13841	KILN	ILN	102005	WILMINGTON AIRBORNE PARK	39.42028	-83.8217	321	-5	10	2019
14813	KAKR	AKR	100306	AKRON FULTON INTL AP	41.0375	-81.4642	318	-5	10	2019
14820	KCLE	CLE	52207	CLEVELAND HOPKINS INTL AP	41.405	-81.8528	235	-5	10	2019
14821	KCMH	CMH	53007	COLUMBUS PORT COLUMBUS INTL AP	39.99139	-82.8808	247	-5	10	2019
14825	KFDY	FDY	100506	FINDLAY AP	41.01361	-83.6686	244	-5	10	2019
14852	KYNG	YNG	90808	YOUNGSTOWN RGNL AP	41.25444	-80.6739	360	-5	10	2016
14891	KMFD	MFD	52307	MANSFIELD LAHM MUNI AP	40.82028	-82.5178	395	-5	10	2019
14895	KCAK	CAK	70709	AKRON CANTON RGNL AP	40.91667	-81.4333	368	-5	10	2019
53844	KLHQ	LHQ	61207	LANCASTER FAIRFIELD AP	39.75556	-82.6572	259	-5	10	2019
53855	KHAO	HAO	50807	HAMILTON BUTLER CO RGNL AP	39.36444	-84.5247	189	-5	10	2019
53859	KMGY	MGY	43007	DAYTON WRIGHT BROS AP	39.59361	-84.2264	290	-5	8	2019
93812	KLUK	LUK	42007	CINCINNATI LUNKEN AP	39.10333	-84.4189	149	-5	10	2019
93815	KDAY	DAY	50907	DAYTON INTL AP	39.90611	-84.2186	305	-5	10	2019
93824	KZZV	ZZV	30907	ZANESVILLE MUNI AP	39.94444	-81.8922	268	-5	8	2019
94830	KTOL	TOL	12007	TOLEDO EXPRESS AP	41.58861	-83.8014	204	-5	10	2019
3030	KGUY	GUY	90606	GUYMON MUNI AP	36.68167	-101.505	950	-6	8	2019
3932	KCSM	CSM	12209	CLINTON-SHERMAN AP	35.3568	-99.2042	586	-6	10	2019
3950	KLAW	LAW	22509	LAWTON MUNI AP	34.5584	-98.4172	326	-6	10	2019
3954	KPWA	PWA	10709	OKLAHOMA CITY POST AP	35.53417	-97.6469	395	-6	8	2019
3959	KBVO	BVO	21309	BARTLESVILLE F P FLD	36.7683	-96.0261	218	-6	10	2019
3965	KSWO	SWO	12009	STILLWATER RGNL AP	36.1624	-97.0894	300	-6	10	2019
3981	KFDR	FDR	21809	FREDERICK MUNI AP	34.21	-98.59	383	-6	10	2019
13967	KOKC	OKC	11409	OKLAHOMA CITY WILL ROGERS AP	35.3889	-97.6006	392	-6	8	2019
13968	KTUL	TUL	42209	TULSA INTL AP	36.1994	-95.8872	198	-6	10	2019
13969	KPNC	PNC	20609	PONCA CITY MUNI AP	36.73667	-97.1019	305	-6	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
13975	KGAG	GAG	12109	GAGE AP	36.2967	-99.7689	668	-6	10	2019
53908	KRVS	RVS	21209	TULSA R L JONES JR AP	36.03944	-95.9844	190	-6	10	2019
53913	KGOK	GOK	72607	GUTHRIE MUNI AP	35.8517	-97.4142	326	-6	10	2019
93950	KMLC	MLC	43009	MCALESTER RGNL AP	34.8822	-95.783	235	-6	10	2019
93953	KMKO	MKO	20907	MUSKOGEE DAVIS FLD	35.65667	-95.3614	184	-6	10	2019
93986	KHBR	HBR	80107	HOBART MUNI AP	34.9894	-99.0525	474	-6	10	2018
4113	KHRI	HRI	41907	HERMISTON MUNI AP	45.82583	-119.261	196	-8	10	2019
4201	KSPB	SPB	22706	SCAPPOOSE IND AP	45.77278	-122.861	16	-8	10	2019
24130	KBKE	BKE	50806	BAKER CITY MUNI AP	44.8428	-117.809	1024	-8	10	2019
24152	KMEH	MEH	92806	MEACHAM	45.51139	-118.425	1135	-8	10	2018
24155	KPDT	PDT	42607	PENDLETON E OR RGNL AP	45.6983	-118.855	453	-8	10	2019
24162	KONO	ONO	50806	ONTARIO MUNI AP	44.02056	-117.013	668	-7	10	2019
24221	KEUG	EUG	40507	EUGENE MAHLON SWEET AP	44.1278	-123.221	108	-8	10	2019
24225	KMFR	MFR	40607	MEDFORD ROGUE VLY AP	42.3811	-122.872	395	-8	10	2019
24229	KPDX	PDX	20107	PORTLAND INTL AP	45.5958	-122.609	6	-8	10	2019
24230	KRDM	RDM	32207	REDMOND ROBERTS FLD	44.2558	-121.139	928	-8	10	2019
24231	KRBG	RBG	22706	ROSEBURG RGNL AP	43.23889	-123.355	158	-8	10	2019
24232	KSLE	SLE	51507	SALEM MCNARY FLD	44.905	-123.001	62	-8	10	2019
24235	KSXT	SXT	121605	SEXTON SUMMIT	42.6003	-123.364	1168	-8	10	2019
24242	KTTD	TTD	40407	PORTLAND TROUTDALE AP	45.55111	-122.409	9	-8	10	2019
94185	KBNO	BNO	50806	BURNS MUNI AP	43.595	-118.956	1262	-8	10	2019
94224	KAST	AST	32006	ASTORIA RGNL AP	46.1569	-123.883	3	-8	10	2019
94236	KLMT	LMT	52507	KLAMATH FALLS INTL AP	42.14694	-121.724	1245	-8	10	2019
94261	KHIO	HIO	31607	PORTLAND-HILLSBORO AP	45.54056	-122.949	63	-8	10	2019
94273	KMMV	MMV	40306	MCMINNVILLE MUNI AP	45.19472	-123.134	48	-8	10	2019
94281	KUAO	UAO	11503	AURORA STATE AP	45.24861	-122.769	60	-8	8	2019
4726	KJST	JST	82506	JOHNSTOWN CAMBRIA CO AP	40.31611	-78.8339	695	-5	8	2019
4751	KBFD	BFD	111705	BRADFORD RGNL AP	41.8	-78.6333	653	-5	8	2019
4787	KDUJ	DUJ	40207	DUBOIS JEFFERSON CO AP	41.17833	-78.8989	553	-5	8	2019

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4843	KGKJ	GKJ	10606	PORT MEADVILLE AP	41.62639	-80.215	426	-5	10	2019
13739	KPHL	PHL	73009	PHILADELPHIA INTL AP	39.8683	-75.2311	3	-5	8	2019
14711	KMDT	MDT	82208	MIDDLETOWN HARRISBURG INTL AP	40.1962	-76.7724	95	-5	8	2019
14712	KRDG	RDG	111908	READING SPAATZ FLD	40.36667	-75.9667	87	-5	8	2019
14736	KAOO	AOO	82108	ALTOONA BLAIR CO AP	40.29639	-78.3203	451	-5	8	2019
14737	KABE	ABE	93008	ALLENTOWN INTL AP	40.65083	-75.4492	119	-5	8	2019
14751	KCXY	CXY	71207	HARRISBURG CPTL CY AP	40.21722	-76.8514	104	-5	8	2019
14762	KAGC	AGC	40307	PITTSBURGH ALLEGHENY CO AP	40.35472	-79.9217	380	-5	8	2019
14770	KSEG	SEG	81808	SELINSGROVE PENN VLY AP	40.82056	-76.8642	135	-5	10	2019
14777	KAVP	AVP	32807	WILKES-BARRE INTL AP	41.3336	-75.7269	283	-5	10	2019
14778	KIPT	IPT	53007	WILLIAMSPORT	41.2433	-76.9217	158	-5	8	2019
14860	KERI	ERI	82108	ERIE INTL AP	42.08	-80.1825	223	-5	10	2019
54737	KLNS	LNS	81508	LANCASTER AP	40.12028	-76.2944	122	-5	8	2019
54782	KPTW	PTW	90408	POTTSTOWN LIMERICK AP	40.23833	-75.5572	90	-5	8	2019
54786	KDYL	DYL	90208	DOYLESTOWN AP	40.33	-75.1225	119	-5	10	2019
54789	KMPO	MPO	91908	MT POCONO MOUNTAINS AP	41.13889	-75.3794	578	-5	10	2019
54792	KFIG	FIG	102705	CLEARFIELD LAWRENCE AP	41.04667	-78.4117	462	-5	10	2019
93778	KTHV	THV	31505	YORK AP	39.91806	-76.8742	141	-5	10	2019
94732	KPNE	PNE	71207	PHILADELPHIA NE AP	40.08194	-75.0111	30	-5	10	2019
94823	KPIT	PIT	72809	PITTSBURGH INTL AP	40.4846	-80.2144	367	-5	10	2019
11641	TJSJ	SJU	12709	SAN JUAN L M MARIN AP	18.4325	-66.0108	3	-4	10	2019
14765	KPVD	PVD	71709	PROVIDENCE T F GREEN AP	41.7219	-71.4325	18	-5	10	2019
14787	KUUU	UUU	92606	NEWPORT STATE AP	41.53333	-71.2833	43	-5	8	2019
14794	KWST	WST	32107	WESTERLY STATE AP	41.34972	-71.7989	21	-5	8	2019
3870	KGSP	GSP	110508	GRNVL SPART AP	34.8842	-82.2209	287	-5	8	2019
13744	KFLO	FLO	41707	FLORENCE RGNL AP	34.1852	-79.7238	45	-5	10	2019
13880	KCHS	CHS	61009	CHARLESTON INTL AP	32.8986	-80.0402	12	-5	10	2019
13883	KCAE	CAE	51209	COLUMBIA METRO AP	33.9419	-81.1181	69	-5	10	2019

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13886	KGMU	GMU	102808	GREENVILLE DWTN AP	34.84611	-82.3461	309	-5	8	2019
53850	KCEU	CEU	100208	CLEMSON OCONEE CO AP	34.67194	-82.8864	265	-5	8	2019
53854	KOGB	OGB	42909	ORANGEBURG MUNI AP	33.46167	-80.8581	55	-5	10	2019
53867	KCUB	CUB	42809	COLUMBIA OWENS DWTN AP	33.97056	-80.9958	55	-5	8	2019
53871	KUZA	UZA	51909	ROCK HILL YORK CO AP	34.98694	-81.0575	200	-5	10	2019
53874	KGRD	GRD	101508	GREENWOOD CO AP	34.24861	-82.1592	192	-5	10	2019
93718	KCRE	CRE	42007	N MYRTLE BCH AP	33.81167	-78.7239	10	-5	10	2019
93846	KAND	AND	102108	ANDERSON CO AP	34.4977	-82.7097	232	-5	10	2019
14929	KABR	ABR	102705	ABERDEEN RGNL AP	45.4433	-98.413	395	-6	8	2019
14936	KHON	HON	42809	HURON RGNL AP	44.3981	-98.2231	390	-6	10	2019
14944	KFSD	FSD	60706	SIOUX FALLS FOSS FLD	43.5778	-96.7539	435	-6	10	2019
14946	KATY	ATY	110705	WATERTOWN RGNL AP	44.9047	-97.1494	533	-6	8	2019
24024	KPHP	PHP	51507	PHILIP AP	44.05111	-101.601	672	-7	10	2019
24025	KPIR	PIR	111705	PIERRE RGNL AP	44.3813	-100.286	531	-6	10	2019
24090	KRAP	RAP	92806	RAPID CITY REGIONAL AP	44.0433	-103.054	963	-7	10	2019
94032	KCUT	CUT	102005	CUSTER CO AP	43.73306	-103.611	1690	-7	10	2019
94039	KIEN	IEN	102908	PINE RIDGE AP	43.02056	-102.518	1005	-7	10	2019
94052	KMBG	MBG	10907	MOBRIDGE MUNI AP	45.54639	-100.408	517	-6	10	2019
94950	KMHE	MHE	20306	MITCHELL MUNI AP	43.7743	-98.0384	396	-6	8	2019
94990	KICR	ICR	82108	WINNER WILEY FLD	43.39056	-99.8422	619	-6	10	2019
3811	KMKL	MKL	93008	JACKSON MCKELLAR AP	35.593	-88.9167	132	-6	10	2019
3847	KCSV	CSV	41007	CROSSVILLE MEM AP	35.9509	-85.0813	569	-6	8	2019
3894	KCKV	CKV	41907	CLARKSVILLE OUTLAW AP	36.62389	-87.4194	171	-6	10	2019
13877	KTRI	TRI	42307	BRISTOL TRI CITY AP	36.4731	-82.4044	457	-5	10	2019
13882	KCHA	CHA	32707	CHATTANOOGA LOVELL AP	35.0311	-85.2014	205	-5	10	2019
13891	KTYS	TYS	41707	KNOXVILLE MCGHEE TYSON AP	35.8181	-83.9858	293	-5	10	2019
13893	KMEM	MEM	100608	MEMPHIS INTL AP	35.0564	-89.9865	77	-6	10	2019
13897	KBNA	BNA	40507	NASHVILLE INTL AP	36.11889	-86.6892	183	-6	10	2019
53868	KOQT	OQT	32207	OAK RIDGE ASOS	36.0236	-84.2375	277	-5	10	2019

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3024	KBGD	BGD	90506	BORGER HUTCHINSON CO AP	35.695	-101.395	925	-6	10	2019
3031	KODO	ODO	32907	ODESSA SCHLEMEYER FLD	31.92056	-102.387	906	-6	10	2019
3901	KGGG	GGG	100808	LONGVIEW E TX RGNL AP	32.38472	-94.7117	111	-6	10	2019
3904	KCLL	CLL	62309	COLLEGE STN	30.58917	-96.3647	93	-6	8	2019
3927	KDFW	DFW	52709	DAL-FTW WSCMO AP	32.8978	-97.0189	171	-6	10	2019
3971	KRBD	RBD	30707	DALLAS REDBIRD AP	32.68083	-96.8681	201	-6	10	2019
3991	KDTO	DTO	22707	DENTON MUNI AP	33.20611	-97.1989	197	-6	10	2019
3999	KBMQ	BMQ	90308	BURNET MUNI AP	30.7406	-98.2354	393	-6	10	2019
12904	KHRL	HRL	50907	HARLINGEN RIO GRANDE AP	26.22806	-97.6542	10	-6	10	2019
12912	KVCT	VCT	22307	VICTORIA RGNL AP	28.8614	-96.9303	35	-6	10	2019
12917	KBPT	BPT	62007	PORT ARTHUR SE TX AP	29.95056	-94.0206	5	-6	10	2019
12918	KHOU	HOU	62707	HOUSTON HOBBY AP	29.63806	-95.2819	13	-6	10	2019
12919	KBRO	BRO	40607	BROWNSVILLE INTL AP	25.9141	-97.423	7	-6	10	2019
12921	KSAT	SAT	102208	SAN ANTONIO INTL AP	29.5443	-98.4839	240	-6	10	2019
12923	KGLS	GLS	53007	GALVESTON SCHOLES FLD	29.2733	-94.8592	2	-6	8	2019
12924	KCRP	CRP	21306	CORPUS CHRISTI INTL AP	27.7742	-97.5122	13	-6	10	2019
12932	KALI	ALI	22707	ALICE INTL AP	27.74111	-98.0247	53	-6	10	2019
12935	KPSX	PSX	61107	PALACIOS MUNI AP	28.72472	-96.2536	4	-6	10	2019
12947	KCOT	COT	22607	COTULLA LA SALLE CO AP	28.45667	-99.2183	145	-6	10	2019
12957	KPIL	PIL	40307	PORT ISABEL CAMERON AP	26.16583	-97.3458	4	-6	10	2019
12959	KMFE	MFE	51507	MCALLEN MILLER INTL AP	26.18389	-98.2539	30	-6	10	2019
12960	KIAH	IAH	61109	HOUSTON INTERCONT AP	29.98	-95.36	29	-6	10	2019
12962	KHDO	HDO	50207	HONDO MUNI AP	29.3601	-99.1742	280	-6	10	2019
12970	KSSF	SSF	90908	SAN ANTONIO STINSON AP	29.3389	-98.472	174	-6	10	2019
12971	KBAZ	BAZ	51305	NEW BRAUNFELS MUNI AP	29.7089	-98.0458	197	-6	10	2019
12972	KRKP	RKP	30107	ROCKPORT ARANSAS CO AP	28.08361	-97.0464	7	-6	10	2019
12975	KLVJ	LVJ	60607	HOUSTON CLOVER FLD	29.51889	-95.2417	13	-6	8	2019
12976	KLBX	LBX	62107	ANGLETON BRAZORIA AP	29.10972	-95.4619	8	-6	10	2019
12977	KSGR	SGR	62207	HOUSTON SUGARLAND MEM	29.62194	-95.6567	26	-6	8	2019

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13904	KAUS	AUS	103008	AUSTIN BERGSTROM AP	30.1831	-97.6799	146	-6	10	2019
13958	KATT	ATT	30807	AUSTIN-CAMP MABRY	30.3208	-97.7604	204	-6	10	2019
13959	KACT	ACT	30207	WACO RGNL AP	31.61889	-97.2283	152	-6	10	2019
13960	KDAL	DAL	52809	DALLAS FAA AP	32.8519	-96.8555	134	-6	10	2019
13961	KFTW	FTW	21003	FT WORTH MEACHAM FLD	32.81917	-97.3614	209	-6	8	2019
13962	KABI	ABI	12909	ABILENE RGNL AP	32.4105	-99.6822	546	-6	10	2019
13966	KSPS	SPS	32409	WICHITA FALLS MUNI AP	33.9786	-98.4928	310	-6	10	2019
13972	KTYR	TYR	103008	TYLER POUNDS FLD	32.35417	-95.4025	166	-6	10	2019
13973	KJCT	JCT	32807	JUNCTION KIMBLE CO AP	30.51083	-99.7664	524	-6	10	2019
22010	KDRT	DRT	60707	DEL RIO INTL AP	29.3784	-100.927	304	-6	10	2019
23007	KCDS	CDS	42607	CHILDRESS MUNI AP	34.4272	-100.283	595	-6	10	2019
23023	KMAF	MAF	41107	MIDLAND INTL AP	31.9475	-102.209	872	-6	8	2019
23034	KSJT	SJT	52307	SAN ANGELO MATHIS FLD	31.35167	-100.495	584	-6	10	2019
23040	KINK	INK	40307	WINKLER CO AP	31.7801	-103.202	856	-6	10	2019
23042	KLBB	LBB	41107	LUBBOCK INTL AP	33.6656	-101.823	992	-6	10	2019
23044	KELP	ELP	111308	EL PASO INTL AP	31.81111	-106.376	1194	-7	10	2019
23047	KAMA	AMA	82506	AMARILLO INTL AP	35.2295	-101.704	1098	-6	10	2019
23055	KGDP	GDP	52207	PINE SPRINGS NP	31.83111	-104.809	1663	-6	6	2019
23091	KFST	FST	50107	FT STOCKTON PECOS AP	30.91194	-102.917	917	-6	10	2016
53902	KCXO	CXO	52609	CONROE MONTGOMERY CO AP	30.35667	-95.4139	71	-6	8	2019
53903	KUTS	UTS	61909	HUNTSVILLE MUNI AP	30.74389	-95.5861	106	-6	10	2019
53907	KGKY	GKY	22607	ARLINGTON MUNI AP	32.66361	-97.0939	188	-6	10	2019
53909	KAFW	AFW	22007	FT WORTH ALLIANCE AP	32.97333	-97.3181	209	-6	10	2019
53910	KDWH	DWH	73107	HOUSTON HOOKS MEM AP	30.0675	-95.5561	47	-6	10	2019
53911	KTRL	TRL	30607	TERRELL MUNI AP	32.71	-96.2672	144	-6	8	2019
53912	KCRS	CRS	22207	CORSICANA CAMPBELL FLD	32.03111	-96.3989	136	-6	10	2019
53914	KTKI	TKI	30507	MCKINNEY MUNI AP	33.19028	-96.5914	179	-6	10	2019
93042	KDHT	DHT	90506	DALHART FAA AP	36.0167	-102.55	1216	-6	10	2019
93985	KMWL	MWL	22106	MINERAL WELLS AP	32.7816	-98.0602	283	-6	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
93987	KLFK	LFK	112008	LUFKIN ANGELINA CO AP	31.23611	-94.7544	88	-6	8	2019
23159	KBCE	BCE	91906	BRYCE CANYON AP	37.70639	-112.146	2307	-7	10	2019
23176	KMLF	MLF	21306	MILFORD MUNI AP	38.41667	-113.017	1538	-7	10	2017
24127	KSLC	SLC	52307	SALT LAKE CITY INTL AP	40.7781	-111.969	1288	-7	10	2019
93075	KCNY	CNY	50307	MOAB CANYONLAND AP	38.75	-109.763	1390	-7	10	2019
93129	KCDC	CDC	120606	CEDAR CITY MUNI AP	37.7086	-113.094	1703	-7	8	2019
93141	KPUC	PUC	110705	PRICE CARBON CO AP	39.60917	-110.755	1779	-7	10	2019
94030	KVEL	VEL	32707	VERNAL MUNI AP	40.44278	-109.513	1606	-7	10	2019
94128	KLGU	LGU	110705	LOGAN CACHE AP	41.78722	-111.853	1356	-7	10	2019
13728	KDAN	DAN	101508	DANVILLE RGNL AP	36.5728	-79.3361	174	-5	10	2019
13733	KLYH	LYH	103008	LYNCHBURG RGNL AP	37.3208	-79.2067	287	-5	10	2019
13737	KORF	ORF	32707	NORFOLK INTL AP	36.9033	-76.1922	9	-5	10	2019
13740	KRIC	RIC	32807	RICHMOND INTL AP	37.505	-77.3202	50	-5	10	2019
13741	KROA	ROA	102308	ROANOKE RGNL AP	37.3169	-79.9741	358	-5	10	2019
13743	KDCA	DCA	92606	WASHINGTON REAGAN AP	38.8483	-77.0341	3	-5	8	2019
93736	KCHO	CHO	42307	CHARLOTTESVILLE AP	38.13861	-78.4531	188	-5	8	2019
93738	KIAD	IAD	100306	WASHINGTON DC DULLES AP	38.9408	-77.4636	88	-5	10	2019
93739	KWAL	WAL	41107	WALLOPS ISLAND FLIGHT FAC	37.9372	-75.4708	14	-5	10	2019
93741	KPHF	PHF	32007	NEWPORT NEWS INTL AP	37.13194	-76.4931	11	-5	10	2019
93773	KAKQ	AKQ	31307	WAKEFIELD MUNI AP	36.98389	-77.0072	33	-5	8	2019
93775	KOFP	OFP	32907	ASHLAND HANOVER CO MUNI AP	37.70806	-77.4344	63	-5	10	2016
14742	KBTV	BTV	92402	BURLINGTON INTL AP	44.4683	-73.1499	101	-5	8	2019
54740	KVSF	VSF	110705	SPRINGFIELD HARTNESS AP	43.34361	-72.5178	176	-5	8	2019
54771	KMVL	MVL	110705	MORRISVILLE STOWE STATE AP	44.53444	-72.6144	225	-5	8	2019
54781	KDDH	DDH	110705	BENNINGTON MORSE ST AP	42.89139	-73.2469	243	-5	10	2019
94705	KMPV	MPV	102705	BARRE MONTPELIER AP	44.2035	-72.5623	343	-5	8	2019
24110	KMWH	MWH	81507	MOSES LAKE GRANT CO AP	47.20778	-119.319	357	-8	10	2019
24141	KEPH	EPH	111705	EPHRATA MUNI AP	47.3078	-119.515	382	-8	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
24157	KGEG	GEG	61407	SPOKANE INTL AP	47.6216	-117.528	717	-8	10	2019
24160	KALW	ALW	82207	WALLA WALLA RGNL AP	46.09472	-118.287	355	-8	10	2019
24217	KBLI	BLI	40307	BELLINGHAM INTL AP	48.79389	-122.537	45	-8	10	2016
24219	KDLS	DLS	62206	THE DALLES MUNI AP	45.6194	-121.166	72	-8	10	2016
24220	KELN	ELN	71107	ELLENSBURG BOWERS FLD	47.03389	-120.53	535	-8	10	2019
24222	KPAE	PAE	32907	EVERETT SNOHOMISH AP	47.90778	-122.28	181	-8	10	2019
24227	KOLM	OLM	51007	OLYMPIA AP	46.9733	-122.903	57	-8	8	2019
24233	KSEA	SEA	51707	SEATTLE TACOMA INTL AP	47.4444	-122.314	113	-8	10	2019
24234	KBFI	BFI	51707	SEATTLE BOEING FLD	47.53028	-122.301	5	-8	8	2016
24243	KYKM	YKM	80807	YAKIMA AIR TERMINAL	46.5683	-120.543	324	-8	10	2019
94119	KDEW	DEW	91206	DEER PARK AP	47.97417	-117.428	668	-8	10	2019
94129	KPUW	PUW	110705	PULLMAN MOSCOW RGNL AP	46.74389	-117.109	772	-8	10	2019
94176	KSFF	SFF	62607	SPOKANE FELTS FLD	47.68306	-117.321	595	-8	10	2019
94197	KOMK	OMK	62707	OMAK	48.46444	-119.517	396	-8	10	2016
94225	KHQM	HQM	41006	HOQUIAM BOWERMAN AP	46.9727	-123.93	4	-8	10	2019
94227	KSHN	SHN	111705	SHELTON SANDERSON FLD	47.238	-123.141	83	-8	10	2019
94239	KEAT	EAT	121605	WENATCHEE PANGBORN AP	47.3977	-120.201	375	-8	10	2019
94240	KUIL	UIL	52506	QUILLAYUTE STATE AP	47.9375	-124.555	56	-8	10	2019
94248	KRNT	RNT	33007	RENTON MUNI AP	47.49333	-122.214	7	-8	8	2019
94266	KCLM	CLM	50806	PORT ANGELES INTL AP	48.12028	-123.498	79	-8	10	2019
94274	KTIW	TIW	51607	TACOMA NARROWS AP	47.2675	-122.576	89	-8	8	2019
94276	KFHR	FHR	121605	FRIDAY HARBOR AP	48.52222	-123.023	27	-8	8	2019
94298	KVUO	VUO	21306	VANCOUVER PEARSON AP	45.62083	-122.657	8	-8	8	2019
4803	KRHI	RHI	100705	RHINELANDER ONEIDA AP	45.6314	-89.4823	495	-6	8	2019
4826	KISW	ISW	100405	WISCONSIN RAPIDS ALEXANDER FLD	44.35917	-89.8369	311	-6	10	2019
4840	KFLD	FLD	102005	FOND DU LAC CO AP	43.76944	-88.4908	246	-6	10	2019
4841	KSBM	SBM	100405	SHEBOYGAN CO MEM AP	43.76944	-87.8506	227	-6	10	2019
4845	KENW	ENW	32607	KENOSHA RGNL AP	42.595	-87.9381	225	-6	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
14837	KMSN	MSN	51007	MADISON DANE RGNL AP	43.1405	-89.3452	264	-6	10	2019
14839	KMKE	MKE	91406	MILWAUKEE MITCHELL AP	42.955	-87.9044	204	-6	10	2019
14897	KAUW	AUW	100405	WAUSAU ASOS	44.9288	-89.6277	366	-6	10	2019
14898	KGRB	GRB	82605	GREEN BAY A S INTL AP	44.4794	-88.1366	209	-6	10	2019
14920	KLSE	LSE	92006	LA CROSSE MUNI AP	43.8788	-91.2527	199	-6	10	2019
14921	KLNR	LNR	50907	LONE ROCK TRI CO AP	43.21194	-90.1814	219	-6	10	2019
14991	KEAU	EAU	32007	EAU CLAIRE RGNL AP	44.8665	-91.4879	270	-6	10	2019
94818	KRAC	RAC	102705	RACINE BATTEN AP	42.76111	-87.8136	202	-6	10	2019
94855	KOSH	OSH	110402	OSHKOSH WITTMAN AP	43.98444	-88.5569	238	-6	8	2019
94929	KASX	ASX	111705	ASHLAND KENNEDY MEM AP	46.54861	-90.9189	251	-6	10	2019
94973	KHYR	HYR	110705	HAYWARD MUNI AP	46.02611	-91.4442	367	-6	10	2019
94985	KMFI	MFI	100405	MARSHFIELD MUNI AP	44.63806	-90.1875	383	-6	10	2019
94994	KOVS	OVS	100705	BOSCOBEL AP	43.15611	-90.6775	203	-6	10	2019
3802	KCKB	CKB	52207	CLARKSBURG BENEDUM AP	39.29556	-80.2289	361	-5	8	2018
3804	KPKB	PKB	50307	PARKERSBURG WOOD CO AP	39.2	-81.27	253	-5	10	2018
3859	KBLF	BLF	100308	BLUEFIELD MERCER CO AP	37.2958	-81.2077	875	-5	8	2019
3860	KHTS	HTS	12607	HUNTINGTON TRI STATE AP	38.365	-82.555	251	-5	8	2018
3872	KBKW	BKW	30907	BECKLEY RALEIGH CO AP	37.7836	-81.123	766	-5	10	2019
13729	KEKN	EKN	92206	ELKINS RANDOLPH CO AP	38.8853	-79.8528	603	-5	8	2017
13734	KMRB	MRB	31407	MARTINSBURG E WV RGNL AP	39.4019	-77.9844	163	-5	8	2019
13736	KMGW	MGW	22807	MORGANTOWN HART FLD	39.64278	-79.9164	378	-5	8	2019
13866	KCRW	CRW	91906	CHARLESTON YEAGER AP	38.3794	-81.59	277	-5	8	2018
14894	KHLG	HLG	22707	WHEELING OHIO CO AP	40.17639	-80.6472	359	-5	10	2019
4111	KEVW	EVW	102005	EVANSTON BURNS FLD	41.27306	-111.031	2175	-7	10	2019
24018	KCYS	CYS	92606	CHEYENNE MUNI AP	41.15	-104.817	1868	-7	10	2019
24021	KLND	LND	111705	LANDER HUNT FLD AP	42.8154	-108.726	1704	-7	10	2019
24022	KLAR	LAR	92806	LARAMIE AP	41.3167	-105.683	2215	-7	10	2019
24027	KRKS	RKS	52907	ROCK SPRINGS AP	41.5944	-109.053	2055	-7	10	2019
24029	KSHR	SHR	83006	SHERIDAN AP	44.7694	-106.969	1202	-7	10	2019

Surface WBAN	Surface Call	Ice Free Call	Ice Free Date	Name	Surface Latitude	Surface Longitude	Surface Elevation	UTC	Anenom. Height	Year
24048	KGEY	GEY	71807	GREYBULL S BIG HORN AP	44.51694	-108.082	1194	-7	10	2019
24057	KRWL	RWL	90408	RAWLINS AP	41.8025	-107.206	2053	-7	10	2019
24061	KRIW	RIW	110705	RIVERTON RGNL AP	43.06417	-108.459	1660	-7	10	2019
24062	KWRL	WRL	53107	WORLAND	43.96583	-107.951	1272	-7	10	2019
24089	KCPR	CPR	41107	CASPER NATRONA CO AP	42.8977	-106.474	1619	-7	10	2019
24164	KBPI	BPI	61107	BIG PINEY MARBLETON AP	42.58444	-110.108	2124	-7	10	2019
94023	KGCC	GCC	12407	GILLETTE CAMPBELL AP	44.33944	-105.542	1327	-7	8	2019
94053	KTOR	TOR	91306	TORRINGTON MUNI AP	42.0613	-104.158	1280	-7	10	2019
94054	KBYG	BYG	90606	BUFFALO JOHNSON CO AP	44.38139	-106.721	1506	-7	10	2019
94057	KDGW	DGW	92308	CONVERSE CO AP ASOS	42.79611	-105.38	1504	-7	10	2019

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
25308	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25308_2016	70398	-9
25309	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25309_2019	71964	-8
25323	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25323_2019	71964	-8
25325	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25325_2019	70398	-9
25331	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25331_2019	70273	-9
25333	ASOS,COOP	AK	Y	N	A	AK	Y	AK25333_2019	71964	-8
25335	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25335_2019	71964	-8
25501	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25501_2019	70350	-9
25503	ASOS,COOP	AK	Y	N	A	AK	Y	AK25503_2019	70326	-9
25506	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25506_2019	70326	-9
25507	ASOS,COOP	AK	Y	N	A	AK	Y	AK25507_2019	70273	-9
25516	AIRWAYS,ASOS	AK	Y	N	A	AK	Y	AK25516_2019	70350	-9
25624	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25624_2019	70316	-9
25628	AIRWAYS,ASOS	AK	Y	N	A	AK	Y	AK25628_2019	70308	-9
25713	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK25713_2019	70308	-9
26409	AIRWAYS,ASOS	AK	Y	N	A	AK	Y	AK26409_2019	70273	-9
26410	ASOS,COOP	AK	Y	N	A	AK	Y	AK26410_2019	70273	-9
26411	ASOS,COOP	AK	Y	N	A	AK	Y	AK26411_2019	70261	-9
26412	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26412_2018	70361	-9
26415	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26415_2019	70261	-9
26425	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26425_2019	70261	-9
26435	ASOS	AK	Y	N	A	AK	Y	AK26435_2019	70261	-9
26438	AIRWAYS,ASOS	AK	Y	N	A	AK	Y	AK26438_2019	70273	-9
26451	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26451_2019	70273	-9
26492	ASOS,COOP,WXSVC	AK	Y	N	A	AK	N	AK26492_2019	70273	-9
26510	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26510_2016	70231	-9
26523	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26523_2019	70273	-9
26528	ASOS,COOP	AK	Y	N	A	AK	Y	AK26528_2019	70273	-9
26529	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26529_2018	70231	-9

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
26533	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26533_2019	70261	-9
26615	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26615_2019	70219	-9
26616	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26616_2019	70133	-9
26617	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK26617_2019	70200	-9
27406	AIRWAYS,ASOS,COOP	AK	Y	N	A	AK	Y	AK27406_2019	70261	-9
27502	ASOS,COOP	AK	Y	N	A	AK	Y	AK27502_2019	70026	-9
27503	AIRWAYS,ASOS	AK	Y	N	A	AK	Y	AK27503_2019	70026	-9
27515	AIRWAYS,ASOS	AK	Y	N	A	AK	Y	AK27515_2019	70026	-9
3856	ASOS,COOP	AL	N	N	A	AL	Y	AL03856_2019	72230	-6
3878	ASOS	AL	N	N	A	AL	Y	AL03878_2019	72230	-6
13838	AIRWAYS,ASOS	AL	N	N	A	AL	Y	AL13838_2019	72233	-6
13839	AIRWAYS,ASOS,COOP	AL	N	N	A	AL	Y	AL13839_2019	72214	-5
13871	AIRWAYS,ASOS,COOP	AL	N	N	A	AL	Y	AL13871_2019	72230	-6
13876	AIRSAMPLE,AIRWAYS,ASOS, COOP	AL	N	N	A	AL	Y	AL13876_2019	72230	-6
13894	ASOS,COOP,UPPERAIR	AL	N	N	A	AL	Y	AL13894_2019	72233	-6
13895	AIRSAMPLE,ASOS,COOP	AL	N	N	A	AL	Y	AL13895_2019	72230	-6
13896	AIRWAYS,ASOS,COOP,USHCN	AL	N	N	A	AL	Y	AL13896_2019	72230	-6
53820	AIRWAYS,ASOS	AL	N	N	A	AL	Y	AL53820_2019	72230	-6
53852	AIRWAYS,ASOS	AL	N	N	A	AL	Y	AL53852_2019	72230	-6
63872	ASOS,MILITARY	AL, GA	N	N	A	AL	Y	AL63872_2016	72215	-5
63874	ASOS,MILITARY	AL	N	N	A	AL	Y	AL63874_2018	72230	-6
93806	AIRWAYS,ASOS,COOP	AL	N	N	A	AL	Y	AL93806_2019	72230	-6
3953	AIRWAYS,ASOS	AR	N	N	A	AR	Y	AR03953_2019	72340	-6
3962	ASOS,COOP	AR	N	N	A	AR	Y	AR03962_2019	72340	-6
13963	AIRWAYS,ASOS,COOP	AR	N	N	A	AR	Y	AR13963_2019	72340	-6
13964	AIRSAMPLE,ASOS,COOP	AR	N	N	A	AR	Y	AR13964_2019	72440	-6
13971	ASOS,COOP	AR	N	N	A	AR	Y	AR13971_2019	72440	-6
13977	ASOS,COOP	TX, AR	N	N	A	AR	Y	AR13977_2019	72248	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
53869	AIRWAYS,ASOS	AR	N	N	A	AR	Y	AR53869_2019	72340	-6
53918	AIRWAYS,ASOS	AR	N	N	A	AR	Y	AR53918_2019	72440	-6
53919	ASOS,COOP	AR	N	N	A	AR	Y	AR53919_2016	72340	-6
53920	AIRWAYS,ASOS	AR	N	N	A	AR	Y	AR53920_2019	72340	-6
53921	AIRWAYS,ASOS,COOP	AR	N	N	A	AR	N	AR53921_2016	72340	-6
53922	AIRWAYS,ASOS	AR	N	N	A	AR	Y	AR53922_2019	72440	-6
53925	ASOS,COOP	AR	N	N	A	AR	Y	AR53925_2019	72248	-6
93988	ASOS	AR	N	N	A	AR	Y	AR93988_2019	72340	-6
93992	AIRWAYS,ASOS,COOP	AR	N	N	A	AR	Y	AR93992_2019	72248	-6
93993	ASOS,COOP	AR	N	N	A	AR	Y	AR93993_2019	72440	-6
3029	ASOS	AZ, NM	N	Y	A	AZ	Y	AZ03029_2019	72365	-7
3103	ASOS,COOP	AZ	N	Y	A	AZ	Y	AZ03103_2019	72376	-7
3124	ASOS	AZ	N	Y	A	AZ	Y	AZ03124_2016	72274	-7
3162	ASOS	AZ	N	Y	A	AZ	Y	AZ03162_2019	72376	-7
3184	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ03184_2019	72376	-7
3192	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ03192_2019	72376	-7
3195	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ03195_2019	72376	-7
3196	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ03196_2019	72274	-7
23160	ASOS,COOP	AZ	N	Y	A	AZ	Y	AZ23160_2019	72274	-7
23183	ASOS,COOP	AZ	N	Y	A	AZ	Y	AZ23183_2019	72274	-7
23184	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ23184_2019	72376	-7
23194	ASOS,COOP	AZ	N	Y	A	AZ	Y	AZ23194_2019	72376	-7
93026	ASOS,COOP	AZ	N	Y	A	AZ	Y	AZ93026_2019	72274	-7
93027	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ93027_2019	72376	-7
93084	AIRWAYS,ASOS	AZ	N	Y	A	AZ	Y	AZ93084_2019	72274	-7
93167	ASOS,COOP	AZ	N	Y	A	AZ	Y	AZ93167_2019	72388	-8
3102	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03102_2019	72293	-8
3104	ASOS	CA	N	N	A	CA	Y	CA03104_2019	72293	-8

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
3131	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03131_2019	72293	-8
3144	ASOS	CA	N	Y	A	CA	Y	CA03144_2019	72293	-8
3159	ASOS,COOP	CA	N	N	A	CA	Y	CA03159_2019	72293	-8
3166	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03166_2019	72293	-8
3167	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03167_2019	72293	-8
3171	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03171_2019	72293	-8
3177	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03177_2019	72293	-8
3178	ASOS	CA	N	N	A	CA	Y	CA03178_2019	72293	-8
3179	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA03179_2019	72293	-8
23129	ASOS,COOP	CA	N	N	A	CA	Y	CA23129_2019	72293	-8
23130	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23130_2019	72293	-8
23136	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23136_2019	72293	-8
23152	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23152_2019	72293	-8
23155	ASOS,COOP	CA	N	N	A	CA	Y	CA23155_2019	72293	-8
23157	ASOS,COOP	CA	N	N	A	CA	Y	CA23157_2019	72489	-8
23158	ASOS,COOP	CA	N	Y	A	CA	Y	CA23158_2019	72293	-8
23161	ASOS,COOP	CA	N	N	A	CA	Y	CA23161_2019	72388	-8
23174	ASOS,COOP	CA	N	N	A	CA	Y	CA23174_2019	72293	-8
23179	ASOS,COOP,USHCN,WXSVC	CA	N	Y	A	CA	Y	CA23179_2019	72388	-8
23182	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23182_2019	72293	-8
23187	ASOS,COOP	CA	N	N	A	CA	N	CA23187_2018	72293	-8
23188	ASOS,COOP	CA	N	N	A	CA	Y	CA23188_2019	72293	-8
23190	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA23190_2019	72293	-8
23191	ASOS	CA	N	N	A	CA	Y	CA23191_2019	72293	-8
23199	ASOS	CA	N	Y	A	CA	N	CA23199_2019	72293	-8
23213	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA23213_2019	72493	-8
23225	ASOS,COOP	CA	N	Y	A	CA	Y	CA23225_2019	72489	-8
23230	ASOS,UPPERAIR	CA	N	N	A	CA	Y	CA23230_2019	72493	-8
23232	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA23232_2019	72493	-8

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
23233	ASOS,COOP	CA	N	N	A	CA	Y	CA23233_2019	72493	-8
23234	ASOS,COOP	CA	N	N	A	CA	Y	CA23234_2019	72493	-8
23237	ASOS,COOP	CA	N	N	A	CA	Y	CA23237_2019	72493	-8
23244	ASOS	CA	N	N	A	CA	Y	CA23244_2016	72493	-8
23254	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA23254_2019	72493	-8
23257	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23257_2019	72493	-8
23258	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA23258_2019	72493	-8
23259	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23259_2019	72493	-8
23273	ASOS,COOP	CA	N	N	A	CA	Y	CA23273_2019	72493	-8
23275	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23275_2019	72493	-8
23277	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA23277_2019	72493	-8
23285	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA23285_2019	72493	-8
23293	ASOS,COOP	CA	N	N	A	CA	Y	CA23293_2019	72493	-8
24215	ASOS	CA	N	N	A	CA	N	CA24215_2018	72597	-8
24216	ASOS,COOP	CA	N	N	A	CA	Y	CA24216_2019	72597	-8
24257	ASOS,COOP,USHCN	CA	N	N	A	CA	Y	CA24257_2019	72597	-8
24259	ASOS	CA	N	N	A	CA	Y	CA24259_2019	72597	-8
24283	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA24283_2019	72597	-8
24286	ASOS	CA	N	N	A	CA	Y	CA24286_2019	72597	-8
53119	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA53119_2019	72493	-8
53120	ASOS	CA	N	N	A	CA	Y	CA53120_2019	72293	-8
53121	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA53121_2019	72293	-8
93110	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA93110_2019	72293	-8
93115	ASOS	CA	N	N	A	CA	Y	CA93115_2018	72293	-8
93134	ASOS,COOP	CA	N	N	A	CA	N	CA93134_2018	72293	-8
93138	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA93138_2019	72293	-8
93184	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA93184_2019	72293	-8
93193	ASOS,COOP,USHCN	CA	N	N	A	CA	Y	CA93193_2019	72493	-8
93197	ASOS	CA	N	N	A	CA	Y	CA93197_2019	72293	-8

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93205	ASOS,COOP	CA	N	N	A	CA	Y	CA93205_2019	72493	-8
93206	ASOS	CA	N	N	A	CA	Y	CA93206_2019	72493	-8
93209	ASOS,COOP	CA	N	N	A	CA	Y	CA93209_2019	72493	-8
93210	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA93210_2019	72489	-8
93227	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA93227_2019	72493	-8
93228	AIRWAYS,ASOS,COOP	CA	N	N	A	CA	Y	CA93228_2019	72493	-8
93230	ASOS,COOP	CA	N	Y	A	CA	Y	CA93230_2019	72489	-8
93241	ASOS,COOP	CA	N	N	A	CA	Y	CA93241_2019	72493	-8
93242	AIRWAYS,ASOS	CA	N	N	A	CA	Y	CA93242_2019	72493	-8
94299	ASOS	CA	N	Y	A	CA	Y	CA94299_2019	72489	-8
3013	AIRWAYS,ASOS	CO	N	Y	A	CO	Y	CO03013_2019	72451	-6
3017	ASOS,COOP	CO	N	N	A	CO	Y	CO03017_2019	72469	-7
3026	AIRWAYS,ASOS	CO	N	Y	A	CO	Y	CO03026_2019	72562	-6
23061	ASOS,COOP,WXSVC	CO	N	Y	A	CO	Y	CO23061_2019	72365	-7
23066	ASOS,COOP	CO	N	Y	A	CO	Y	CO23066_2019	72476	-7
23067	AIRWAYS,ASOS,COOP	CO	N	N	A	CO	Y	CO23067_2019	72469	-7
23070	AIRWAYS,ASOS,COOP	CO	N	N	A	CO	Y	CO23070_2019	72469	-7
24015	AIRWAYS,ASOS	CO	Y	N	A	CO	Y	CO24015_2019	72469	-7
24046	AIRWAYS,ASOS,COOP	CO	N	Y	A	CO	Y	CO24046_2019	72476	-7
93005	AIRWAYS,ASOS,COOP	CO	N	Y	A	CO	Y	CO93005_2019	72476	-7
93009	ASOS	CO	Y	N	A	CO	Y	CO93009_2019	72469	-7
93010	ASOS	CO	N	N	A	CO	N	CO93010_2019	72469	-7
93013	AIRWAYS,ASOS,COOP	CO	N	Y	A	CO	Y	CO93013_2019	72476	-7
93037	ASOS,COOP	CO	N	N	A	CO	Y	CO93037_2019	72469	-7
93058	ASOS,COOP,WXSVC	CO	N	N	A	CO	Y	CO93058_2019	72469	-7
93067	AIRWAYS,ASOS	CO	N	N	A	CO	Y	CO93067_2019	72469	-7
93069	AIRWAYS,ASOS,COOP	CO	N	Y	A	CO	Y	CO93069_2019	72476	-7
93073	AIRWAYS,ASOS,COOP	CO	N	Y	A	CO	Y	CO93073_2019	72476	-7
94050	AIRWAYS,ASOS,COOP	CO	N	Y	A	CO	Y	CO94050_2019	72476	-7

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
14707	ASOS	CT	Y	N	A	CT	Y	CT14707_2019	72501	-5
14740	ASOS,COOP	CT	Y	N	A	CT	Y	CT14740_2019	72501	-5
14752	ASOS	CT	Y	N	A	CT	Y	CT14752_2019	72501	-5
14758	AIRWAYS,ASOS	CT	Y	N	A	CT	Y	CT14758_2019	72501	-5
54734	AIRWAYS,ASOS	CT	Y	N	A	CT	Y	CT54734_2019	72501	-5
54767	AIRWAYS,ASOS	CT	Y	N	A	CT	Y	CT54767_2019	72501	-5
54788	AIRWAYS,ASOS	CT	Y	N	A	CT	Y	CT54788_2019	72501	-5
94702	ASOS,COOP	CT	Y	N	A	CT	Y	CT94702_2019	72501	-5
13764	AIRWAYS,ASOS	DE	N	N	A	DE	Y	DE13764_2018	72402	-5
13781	ASOS,COOP	DE	Y	N	A	DE	Y	DE13781_2019	72403	-5
3818	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL03818_2019	72214	-5
12812	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12812_2019	72210	-5
12815	ASOS,COOP	FL	N	N	A	FL	Y	FL12815_2019	72210	-5
12816	AIRWAYS,ASOS,COOP	FL	N	N	A	FL	Y	FL12816_2019	72206	-5
12818	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12818_2019	72210	-5
12819	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12819_2019	72210	-5
12832	ASOS	FL	N	N	A	FL	Y	FL12832_2019	72214	-5
12834	ASOS,COOP	FL	N	N	A	FL	Y	FL12834_2019	72206	-5
12835	AIRWAYS,ASOS,COOP,USHCN	FL	N	N	A	FL	Y	FL12835_2019	72210	-5
12836	AIRSAMPLE,AIRWAYS,ASOS, COOP,USHCN	FL	N	N	A	FL	Y	FL12836_2019	72201	-5
12838	ASOS,COOP	FL	N	N	A	FL	Y	FL12838_2019	72210	-5
12839	ASOS,COOP	FL	N	N	A	FL	Y	FL12839_2019	72202	-5
12841	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12841_2019	72210	-5
12842	ASOS,COOP	FL	N	N	A	FL	Y	FL12842_2019	72210	-5
12843	ASOS,COOP	FL	N	N	A	FL	Y	FL12843_2019	72210	-5
12844	ASOS,COOP,UPPERAIR	FL	N	N	A	FL	Y	FL12844_2019	72202	-5
12849	AIRWAYS,ASOS,COOP	FL	N	N	A	FL	Y	FL12849_2019	72202	-5
12854	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12854_2019	72210	-5

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12871	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12871_2019	72210	-5
12873	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12873_2019	72210	-5
12876	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12876_2019	72210	-5
12882	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12882_2019	72202	-5
12885	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12885_2019	72202	-5
12888	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12888_2019	72202	-5
12894	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12894_2019	72210	-5
12895	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12895_2019	72210	-5
12896	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL12896_2019	72201	-5
12897	AIRWAYS,ASOS,COOP	FL	N	N	A	FL	Y	FL12897_2019	72202	-5
13884	AIRWAYS,ASOS,COOP	FL	N	N	A	FL	Y	FL13884_2019	72214	-5
13889	ASOS,COOP	FL	N	N	A	FL	Y	FL13889_2019	72206	-5
13899	AIRWAYS,ASOS,COOP,USHCN	FL	N	N	A	FL	Y	FL13899_2019	72233	-6
53847	ASOS,MILITARY	FL	N	N	A	FL	Y	FL53847_2016	72214	-5
53853	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL53853_2019	72214	-5
53860	AIRWAYS,ASOS,COOP	FL	N	N	A	FL	Y	FL53860_2019	72206	-5
73805	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL73805_2018	72214	-5
92805	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL92805_2019	72202	-5
92806	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL92806_2019	72210	-5
92809	AIRWAYS,ASOS	FL	N	N	A	FL	Y	FL92809_2019	72202	-5
93805	ASOS,COOP,USHCN	FL	N	N	A	FL	Y	FL93805_2019	72214	-5
3813	ASOS,COOP	GA	N	N	A	GA	Y	GA03813_2019	72215	-5
3820	ASOS,COOP	GA, SC	N	N	A	GA	Y	GA03820_2019	72208	-5
3822	ASOS,COOP,USHCN	GA	N	N	A	GA	Y	GA03822_2019	72208	-5
3888	AIRWAYS,ASOS	GA	N	N	A	GA	Y	GA03888_2019	72215	-5
13837	ASOS	GA	N	N	A	GA	Y	GA13837_2019	72208	-5
13869	ASOS	GA	N	N	A	GA	Y	GA13869_2019	72214	-5
13870	AIRWAYS,ASOS,COOP	GA	N	N	A	GA	Y	GA13870_2019	72206	-5

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13873	AIRSAMPLE,AIRWAYS,ASOS, COOP	GA	N	N	A	GA	Y	GA13873_2019	72215	-5
13874	ASOS,COOP	GA	N	N	A	GA	Y	GA13874_2019	72215	-5
13878	ASOS,COOP	GA	N	N	A	GA	Y	GA13878_2019	72206	-5
53819	AIRWAYS,ASOS,UPPERAIR	GA	N	N	A	GA	Y	GA53819_2019	72215	-5
53838	AIRWAYS,ASOS	GA	N	N	A	GA	Y	GA53838_2019	72215	-5
53863	AIRWAYS,ASOS	GA	N	N	A	GA	Y	GA53863_2019	72215	-5
53873	ASOS	GA	N	N	A	GA	Y	GA53873_2019	72215	-5
93801	AIRWAYS,ASOS	GA	N	N	A	GA	Y	GA93801_2019	72215	-5
93842	AIRSAMPLE,AIRWAYS,ASOS, COOP	AL, GA	N	N	A	GA	Y	GA93842_2019	72215	-5
93845	ASOS	GA	N	N	A	GA	Y	GA93845_2019	72214	-5
21504	ASOS,COOP	HI	N	N	A	HI	Y	HI21504_2019	91285	-10
21510	AIRWAYS,ASOS	HI	N	N	A	HI	Y	HI21510_2019	91285	-10
22516	AIRWAYS,ASOS,COOP	HI	N	N	A	HI	Y	HI22516_2019	91285	-10
22521	ASOS,COOP	HI	N	N	A	HI	Y	HI22521_2019	91165	-10
22534	ASOS,COOP	HI	N	N	A	HI	Y	HI22534_2019	91165	-10
22536	ASOS,COOP	HI	N	N	A	HI	Y	HI22536_2019	91165	-10
22551	AIRWAYS,ASOS	HI	N	N	A	HI	Y	HI22551_2019	91165	-10
14931	ASOS	IA, IL	Y	N	A	IA	Y	IA14931_2019	74455	-6
14933	ASOS,COOP	IA	Y	N	A	IA	Y	IA14933_2019	72558	-6
14937	AIRWAYS,ASOS	IA	Y	N	A	IA	Y	IA14937_2019	74455	-6
14940	ASOS,COOP	IA	Y	N	A	IA	Y	IA14940_2019	72649	-6
14943	AIRWAYS,ASOS,COOP	IA, NE	Y	N	A	IA	Y	IA14943_2019	72558	-6
14950	ASOS,COOP	IA	Y	N	A	IA	Y	IA14950_2019	74455	-6
14972	AIRWAYS,ASOS	IA	Y	N	A	IA	Y	IA14972_2019	72558	-6
14990	AIRWAYS,ASOS,COOP	IA	Y	N	A	IA	Y	IA14990_2019	74455	-6
94908	ASOS,COOP	IA	Y	N	A	IA	Y	IA94908_2019	74455	-6
94910	AIRWAYS,ASOS,COOP,WXSVC	IA	Y	N	A	IA	Y	IA94910_2019	74455	-6

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94971	AIRWAYS,ASOS,COOP	IA	Y	N	A	IA	Y	IA94971_2019	72649	-6
94982	AIRWAYS,ASOS	IA	Y	N	A	IA	Y	IA94982_2016	74455	-6
94988	AIRWAYS,ASOS,COOP	IA	Y	N	A	IA	Y	IA94988_2019	74455	-6
94989	AIRWAYS,ASOS,COOP	IA	Y	N	A	IA	Y	IA94989_2019	72558	-6
94991	AIRWAYS,ASOS,COOP	IA	Y	N	A	IA	Y	IA94991_2019	72456	-6
4110	AIRWAYS,ASOS	ID	N	Y	A	ID	Y	ID04110_2019	72681	-7
4114	ASOS	ID	Y	N	A	ID	Y	ID04114_2016	72681	-7
24131	ASOS,COOP	ID	N	N	A	ID	Y	ID24131_2019	72681	-7
24133	ASOS,COOP	ID	N	Y	A	ID	Y	ID24133_2019	72572	-7
24145	AIRWAYS,ASOS	ID	N	Y	A	ID	Y	ID24145_2019	72572	-7
24149	AIRSAMPLE,ASOS,COOP, USHCN	WA, ID	N	N	A	ID	Y	ID24149_2019	72786	-8
24154	AIRWAYS,ASOS	MT, ID	Y	N	A	ID	N	ID24154_2019	72786	-8
24156	ASOS,COOP	ID	N	Y	A	ID	Y	ID24156_2019	72572	-7
94178	AIRWAYS,ASOS	ID	N	Y	A	ID	Y	ID94178_2019	72681	-7
94182	AIRWAYS,ASOS	ID	Y	N	A	ID	Y	ID94182_2016	72681	-7
94194	AIRWAYS,ASOS	ID	N	Y	A	ID	Y	ID94194_2019	72572	-7
3887	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL03887_2019	74560	-6
3960	AIRWAYS,ASOS	IL, MO	N	N	A	IL	Y	IL03960_2019	74560	-6
4808	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL04808_2019	74560	-6
4838	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL04838_2019	72645	-6
13809	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL13809_2019	74560	-6
14819	AIRWAYS,ASOS,WXSVC	IL	Y	N	A	IL	Y	IL14819_2019	74560	-6
14842	AIRSAMPLE,ASOS,COOP, WXSVC	IL	Y	N	A	IL	Y	IL14842_2019	74560	-6
14880	ASOS	IL	Y	N	A	IL	Y	IL14880_2019	72645	-6
14923	ASOS,COOP,WXSVC	IL	Y	N	A	IL	Y	IL14923_2019	74455	-6
53802	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL53802_2019	74560	-6
93810	AIRWAYS,ASOS	IL	N	N	A	IL	Y	IL93810_2019	74560	-6

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93822	AIRSAMPLE,AIRWAYS,ASOS, COOP	IL	Y	N	A	IL	Y	IL93822_2019	74560	-6
93989	ASOS,COOP	IL	N	N	A	IL	Y	IL93989_2019	74455	-6
94822	ASOS,COOP,WXSVC	IL	Y	N	A	IL	Y	IL94822_2019	74455	-6
94846	ASOS,COOP,WXSVC	IL	Y	N	A	IL	Y	IL94846_2019	74560	-6
94870	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL94870_2019	74560	-6
94892	AIRWAYS,ASOS	IL	Y	N	A	IL	Y	IL94892_2019	74560	-6
3868	AIRWAYS,ASOS	IN	Y	N	A	IN	Y	IN03868_2019	74560	-6
3893	AIRWAYS,ASOS	IN	Y	N	A	IN	Y	IN03893_2019	72426	-5
4846	AIRWAYS,ASOS	IN	Y	N	A	IN	Y	IN04846_2019	74560	-6
14827	AIRWAYS,ASOS,COOP	IN	Y	N	A	IN	Y	IN14827_2019	72426	-5
14829	AIRWAYS,ASOS,COOP	IN	Y	N	A	IN	Y	IN14829_2019	72632	-5
14835	AIRWAYS,ASOS,WXSVC	IN	Y	N	A	IN	Y	IN14835_2019	74560	-6
14848	AIRWAYS,ASOS,COOP	IN	Y	N	A	IN	Y	IN14848_2019	72632	-5
53842	AIRWAYS,ASOS	IN	Y	N	A	IN	Y	IN53842_2019	72426	-5
53866	AIRWAYS,ASOS	IN	Y	N	A	IN	Y	IN53866_2019	72426	-5
93817	AIRSAMPLE,AIRWAYS,ASOS, COOP	IN	N	N	A	IN	Y	IN93817_2019	72327	-6
93819	ASOS,COOP,WXSVC	IN	Y	N	A	IN	Y	IN93819_2019	72426	-5
94895	AIRWAYS,ASOS	IN	Y	N	A	IN	Y	IN94895_2019	72426	-5
3928	ASOS,COOP,WXSVC	KS	N	N	A	KS	Y	KS03928_2019	74646	-6
3936	AIRWAYS,ASOS,COOP,WXSVC	KS	Y	N	A	KS	Y	KS03936_2018	72456	-6
3967	AIRWAYS,ASOS	KS	N	N	A	KS	Y	KS03967_2019	72456	-6
3974	ASOS	KS	N	N	A	KS	Y	KS03974_2019	74646	-6
3997	AIRWAYS,ASOS,COOP	KS	Y	N	A	KS	Y	KS03997_2019	72456	-6
3998	AIRWAYS,ASOS	KS	Y	N	A	KS	Y	KS03998_2019	72456	-6
13920	AIRWAYS,ASOS	KS	N	N	A	KS	Y	KS13920_2019	72456	-6
13932	AIRWAYS,ASOS	KS	N	N	A	KS	Y	KS13932_2019	74646	-6
13981	ASOS	KS	Y	N	A	KS	Y	KS13981_2019	72456	-6

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13984	ASOS,COOP	KS	Y	N	A	KS	Y	KS13984_2019	72456	-6
13985	ASOS,COOP,WXSVC	KS	N	N	A	KS	Y	KS13985_2019	72451	-6
13986	ASOS	KS	N	N	A	KS	Y	KS13986_2019	74646	-6
13989	AIRWAYS,ASOS,BASIC,COOP, WXSVC	KS	N	N	A	KS	Y	KS13989_2019	72456	-6
13996	ASOS,COOP,WXSVC	KS	N	N	A	KS	Y	KS13996_2019	72456	-6
23064	AIRWAYS,ASOS	KS	N	N	A	KS	Y	KS23064_2019	72451	-6
23065	ASOS,COOP,WXSVC	KS	N	Y	A	KS	Y	KS23065_2019	72562	-6
93909	AIRWAYS,ASOS	KS	N	N	A	KS	Y	KS93909_2019	72456	-6
93990	AIRWAYS,ASOS	KS	Y	N	A	KS	Y	KS93990_2019	72451	-6
93997	ASOS	KS	N	N	A	KS	Y	KS93997_2019	72451	-6
3816	AIRSAMPLE,ASOS,COOP, WXSVC	KY	Y	N	A	KY	Y	KY03816_2019	72327	-6
3849	AIRWAYS,ASOS,COOP	KY	N	N	A	KY	Y	KY03849_2019	72426	-5
3889	ASOS,COOP	KY	N	N	A	KY	Y	KY03889_2019	72426	-5
13810	AIRWAYS,ASOS	KY	Y	N	A	KY	Y	KY13810_2019	72327	-6
53841	AIRWAYS,ASOS	KY	Y	N	A	KY	Y	KY53841_2019	72426	-5
93808	AIRWAYS,ASOS,COOP,USHCN	KY	N	N	A	KY	Y	KY93808_2019	72327	-6
93814	ASOS,COOP	OH, KY	Y	N	A	KY	Y	KY93814_2019	72426	-5
93820	ASOS,COOP,WXSVC	KY	Y	N	A	KY	Y	KY93820_2019	72426	-5
93821	ASOS,COOP,WXSVC	KY	Y	N	A	KY	Y	KY93821_2019	72327	-6
3937	ASOS,COOP,UPPERAIR	LA	N	N	A	LA	Y	LA03937_2019	72240	-6
3996	AIRWAYS,ASOS,COOP	MS, LA	N	N	A	LA	Y	LA03996_2019	72235	-6
12884	ASOS,COOP	LA	N	N	A	LA	N	LA12884_2018	72233	-6
12916	ASOS,COOP	LA	N	N	A	LA	Y	LA12916_2019	72233	-6
13942	ASOS,COOP	LA	N	N	A	LA	Y	LA13942_2019	72248	-6
13957	AIRSAMPLE,ASOS,COOP	LA	N	N	A	LA	Y	LA13957_2019	72248	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
13970	ASOS,COOP,USHCN	LA	N	N	A	LA	Y	LA13970_2019	72233	-6
13976	AIRWAYS,ASOS,COOP,USHCN	LA	N	N	A	LA	Y	LA13976_2018	72240	-6
53865	ASOS,COOP	LA	N	N	A	LA	Y	LA53865_2016	72233	-6
53905	AIRWAYS,ASOS,COOP	LA	N	N	A	LA	Y	LA53905_2019	72248	-6
53915	AIRWAYS,ASOS,COOP	LA	N	N	A	LA	Y	LA53915_2019	72240	-6
53917	AIRWAYS,ASOS,COOP	LA	N	N	A	LA	Y	LA53917_2019	72233	-6
93915	AIRWAYS,ASOS	LA	N	N	A	LA	Y	LA93915_2019	72240	-6
4780	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA04780_2019	72518	-5
14702	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA14702_2019	74494	-5
14739	ASOS,COOP	MA	Y	N	A	MA	Y	MA14739_2019	74494	-5
14756	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA14756_2019	74494	-5
14763	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA14763_2019	72518	-5
14775	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA14775_2019	72518	-5
54704	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA54704_2019	74494	-5
54733	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA54733_2019	74494	-5
54756	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA54756_2019	72518	-5
54768	AIRWAYS,ASOS,COOP	VT, MA	Y	N	A	MA	Y	MA54768_2019	72518	-5
54769	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA54769_2019	74494	-5
54777	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA54777_2019	74494	-5
94624	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA94624_2019	74494	-5
94720	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA94720_2019	74494	-5
94723	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA94723_2019	74389	-5
94724	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA94724_2019	74494	-5
94726	AIRWAYS,ASOS	MA	Y	N	A	MA	Y	MA94726_2019	74494	-5
94746	ASOS,COOP	MA	Y	N	A	MA	Y	MA94746_2019	72518	-5
93706	AIRWAYS,ASOS	PA, MD	N	N	A	MD	N	MD93706_2019	72403	-5
93720	AIRWAYS,ASOS,COOP	MD	N	N	A	MD	Y	MD93720_2019	72402	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
93721	ASOS,COOP	MD	N	N	A	MD	Y	MD93721_2019	72403	-5
93786	AIRWAYS,ASOS	MD	N	N	A	MD	Y	MD93786_2019	72402	-5
4836	AIRWAYS,ASOS	ME	Y	N	A	ME	Y	ME04836_2019	72712	-5
14605	ASOS,COOP	ME	Y	N	A	ME	Y	ME14605_2019	74389	-5
14606	AIRWAYS,ASOS,COOP	ME	Y	N	A	ME	Y	ME14606_2019	74389	-5
14607	ASOS,COOP	ME	Y	N	A	ME	Y	ME14607_2019	72712	-5
14609	AIRWAYS,ASOS,COOP	ME	Y	N	A	ME	Y	ME14609_2019	72712	-5
14610	AIRWAYS,ASOS	ME	Y	N	A	ME	Y	ME14610_2019	72712	-5
14764	ASOS,COOP,USHCN	ME	Y	N	A	ME	Y	ME14764_2019	74389	-5
54772	AIRWAYS,ASOS	ME, NH	Y	N	A	ME	Y	ME54772_2019	74389	-5
94623	AIRWAYS,ASOS	ME	Y	N	A	ME	Y	ME94623_2019	74389	-5
4839	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI04839_2019	72634	-5
4847	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI04847_2019	72632	-5
4854	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI04854_2019	72634	-5
14815	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI14815_2019	72632	-5
14822	ASOS	MI	Y	N	A	MI	Y	MI14822_2019	72632	-5
14826	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI14826_2019	72632	-5
14833	ASOS,COOP	MI	Y	N	A	MI	Y	MI14833_2019	72632	-5
14836	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI14836_2019	72632	-5
14840	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI14840_2019	72634	-5
14841	AIRWAYS,ASOS,COOP	MI	Y	N	A	MI	Y	MI14841_2019	72634	-5
14845	ASOS	MI	Y	N	A	MI	Y	MI14845_2019	72632	-5
14847	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI14847_2019	72634	-5
14850	AIRWAYS,ASOS,COOP	MI	Y	N	A	MI	Y	MI14850_2019	72634	-5
14853	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI14853_2019	72632	-5
14858	ASOS	MI	Y	N	A	MI	Y	MI14858_2019	72645	-6
94814	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI94814_2019	72634	-5
94815	AIRWAYS,ASOS,WXSVC	MI	Y	N	A	MI	Y	MI94815_2019	72632	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
94817	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI94817_2019	72632	-5
94847	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI94847_2019	72632	-5
94849	ASOS,COOP	MI	Y	N	A	MI	Y	MI94849_2019	72634	-5
94860	ASOS,COOP,WXSVC	MI	Y	N	A	MI	Y	MI94860_2019	72632	-5
94871	ASOS,COOP	MI	Y	N	A	MI	Y	MI94871_2019	72645	-6
94889	AIRWAYS,ASOS	MI	Y	N	A	MI	Y	MI94889_2019	72632	-5
94893	AIRWAYS,ASOS	WI, MI	Y	N	A	MI	Y	MI94893_2019	72645	-6
14910	AIRWAYS,ASOS,COOP	MN	Y	N	A	MN	Y	MN14910_2019	72649	-6
14913	AIRWAYS,ASOS,COOP,WXSVC	MN	Y	N	A	MN	Y	MN14913_2019	72747	-6
14918	ASOS,COOP,WXSVC	MN	Y	N	A	MN	Y	MN14918_2019	72747	-6
14922	ASOS,COOP,USHCN,WXSVC	MN	Y	N	A	MN	Y	MN14922_2019	72649	-6
14925	ASOS,COOP,WXSVC	MN	Y	N	A	MN	Y	MN14925_2019	72649	-6
14926	AIRWAYS,ASOS,COOP,WXSVC	MN	Y	N	A	MN	Y	MN14926_2019	72649	-6
14927	ASOS,COOP	MN	Y	N	A	MN	Y	MN14927_2019	72649	-6
14992	ASOS,COOP	MN	Y	N	A	MN	Y	MN14992_2019	72649	-6
94931	ASOS	MN	Y	N	A	MN	Y	MN94931_2019	72747	-6
94938	AIRWAYS,ASOS	MN	Y	N	A	MN	Y	MN94938_2019	72649	-6
94960	AIRWAYS,ASOS,COOP	MN	Y	N	A	MN	Y	MN94960_2019	72649	-6
94961	AIRWAYS,ASOS	MN	Y	N	A	MN	Y	MN94961_2019	72747	-6
94963	ASOS,COOP	MN	Y	N	A	MN	Y	MN94963_2019	72649	-6
94967	AIRWAYS,ASOS	MN	Y	N	A	MN	Y	MN94967_2019	72747	-6
3935	AIRWAYS,ASOS,COOP,WXSVC	MO	N	N	A	MO	Y	MO03935_2019	74560	-6
3945	AIRWAYS,ASOS,COOP	MO	Y	N	A	MO	Y	MO03945_2019	72440	-6
3947	AIRWAYS,ASOS,COOP	MO	Y	N	A	MO	Y	MO03947_2019	72456	-6
3963	AIRWAYS,ASOS	MO	Y	N	A	MO	Y	MO03963_2019	72440	-6
3966	AIRWAYS,ASOS	MO	N	N	A	MO	Y	MO03966_2019	74560	-6
3975	AIRWAYS,ASOS	MO	N	N	A	MO	Y	MO03975_2019	72340	-6
3994	AIRWAYS,ASOS	MO	N	N	A	MO	Y	MO03994_2019	72440	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
13987	ASOS,COOP	MO	N	N	A	MO	Y	MO13987_2019	72440	-6
13988	AIRWAYS,ASOS,COOP	KS, MO	Y	N	A	MO	Y	MO13988_2019	72456	-6
13993	AIRWAYS,ASOS,COOP	KS, MO	Y	N	A	MO	Y	MO13993_2019	72456	-6
13994	ASOS,COOP,WXSVC	MO	N	N	A	MO	Y	MO13994_2019	74560	-6
13995	ASOS,COOP,WXSVC	MO	N	N	A	MO	Y	MO13995_2019	72440	-6
13997	ASOS,COOP	MO	N	N	A	MO	Y	MO13997_2019	72440	-6
14938	ASOS	MO	Y	N	A	MO	Y	MO14938_2019	74455	-6
53879	AIRWAYS,ASOS	MO	Y	N	A	MO	Y	MO53879_2019	72456	-6
53901	AIRWAYS,ASOS	MO	N	N	A	MO	Y	MO53901_2019	72440	-6
53904	AIRWAYS,ASOS	IL, MO	N	N	A	MO	Y	MO53904_2019	74560	-6
3940	ASOS,COOP,UPPERAIR	MS	N	N	A	MS	Y	MS03940_2019	72235	-6
13833	ASOS,COOP	MS	N	N	A	MS	Y	MS13833_2019	72233	-6
13865	ASOS,COOP	MS	N	N	A	MS	Y	MS13865_2019	72235	-6
13927	ASOS,COOP	MS	N	N	A	MS	Y	MS13927_2019	72235	-6
13939	ASOS,COOP	MS	N	N	A	MS	Y	MS13939_2019	72235	-6
13978	AIRWAYS,ASOS,COOP	MS	N	N	A	MS	Y	MS13978_2019	72235	-6
53858	AIRWAYS,ASOS	MS	N	N	A	MS	Y	MS53858_2019	72233	-6
93862	AIRSAMPLE,ASOS,COOP	MS	N	N	A	MS	Y	MS93862_2019	72230	-6
93874	AIRWAYS,ASOS,COOP	MS	N	N	A	MS	Y	MS93874_2019	72233	-6
93919	AIRWAYS,ASOS,COOP	MS	N	N	A	MS	Y	MS93919_2019	72233	-6
24033	ASOS,COOP	MT	N	Y	A	MT	Y	MT24033_2019	72672	-7
24036	AIRWAYS,ASOS,COOP	MT	N	Y	A	MT	Y	MT24036_2019	72776	-7
24037	ASOS,COOP,USHCN	MT	N	Y	A	MT	Y	MT24037_2019	72768	-7
24132	AIRWAYS,ASOS,COOP	MT	N	Y	A	MT	Y	MT24132_2019	72776	-7
24135	ASOS,COOP	MT	N	Y	A	MT	Y	MT24135_2019	72776	-7
24137	ASOS,COOP,USHCN	MT	Y	N	A	MT	Y	MT24137_2019	72776	-7
24138	AIRWAYS,ASOS,COOP	MT	N	Y	A	MT	Y	MT24138_2019	72776	-7

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
24143	ASOS,COOP,USHCN	MT	Y	N	A	MT	Y	MT24143_2019	72776	-7
24144	ASOS,COOP,USHCN	MT	N	Y	A	MT	Y	MT24144_2019	72776	-7
24146	ASOS,COOP,USHCN	MT	Y	N	A	MT	Y	MT24146_2019	72776	-7
24150	ASOS,COOP	MT	N	Y	A	MT	Y	MT24150_2019	72776	-7
24153	ASOS,COOP	MT	N	Y	A	MT	Y	MT24153_2019	72776	-7
94008	ASOS,COOP,USHCN	MT	N	Y	A	MT	Y	MT94008_2019	72768	-7
94012	ASOS,COOP	MT	Y	N	A	MT	Y	MT94012_2019	72776	-7
94017	AIRWAYS,ASOS	MT	N	Y	A	MT	Y	MT94017_2019	72768	-7
94055	ASOS,COOP	MT	Y	N	A	MT	Y	MT94055_2019	72662	-7
3810	AIRWAYS,ASOS,COOP	NC	N	N	A	NC	Y	NC03810_2019	72317	-5
3812	ASOS,COOP,WXSVC	NC	N	N	A	NC	Y	NC03812_2019	72317	-5
13722	ASOS,COOP	NC	N	N	A	NC	Y	NC13722_2019	72317	-5
13723	ASOS,COOP	NC	N	N	A	NC	Y	NC13723_2019	72317	-5
13748	ASOS,COOP	NC	N	N	A	NC	Y	NC13748_2016	72305	-5
13754	ASOS	NC	N	N	A	NC	Y	NC13754_2019	72305	-5
13776	AIRWAYS,ASOS,COOP	NC	N	N	A	NC	Y	NC13776_2018	72317	-5
13786	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC13786_2019	72305	-5
13881	ASOS,COOP	NC	N	N	A	NC	Y	NC13881_2019	72317	-5
53870	AIRWAYS,ASOS	NC, SC	N	N	A	NC	Y	NC53870_2019	72317	-5
53872	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC53872_2019	72317	-5
93719	AIRWAYS,ASOS,COOP	NC	N	N	A	NC	Y	NC93719_2019	72305	-5
93729	ASOS,COOP,USHCN	NC	N	N	A	NC	Y	NC93729_2019	72305	-5
93740	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC93740_2019	72317	-5
93759	ASOS	NC	N	N	A	NC	Y	NC93759_2019	72305	-5
93765	ASOS	NC	N	N	A	NC	Y	NC93765_2019	72305	-5
93782	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC93782_2019	72317	-5
93783	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC93783_2019	72317	-5
93785	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC93785_2016	72317	-5
93807	AIRWAYS,ASOS	NC	N	N	A	NC	Y	NC93807_2019	72317	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
14914	AIRWAYS,ASOS,COOP	ND, MN	Y	N	A	ND	Y	ND14914_2019	72659	-6
14916	AIRWAYS,ASOS,COOP,WXSVC	ND	Y	N	A	ND	Y	ND14916_2019	72659	-6
14919	ASOS,COOP,WXSVC	ND	Y	N	A	ND	Y	ND14919_2019	72659	-6
24011	ASOS,COOP,WXSVC	ND	Y	N	A	ND	Y	ND24011_2019	72764	-6
24012	ASOS,COOP,WXSVC	ND	Y	N	A	ND	Y	ND24012_2019	72764	-6
24013	AIRWAYS,ASOS,COOP	ND	Y	N	A	ND	Y	ND24013_2019	72764	-6
94014	ASOS,COOP,WXSVC	ND	Y	N	A	ND	Y	ND94014_2018	72768	-7
94038	AIRWAYS,ASOS	ND	Y	N	A	ND	Y	ND94038_2018	72662	-7
14935	AIRWAYS,ASOS,COOP,WXSVC	NE	Y	N	A	NE	Y	NE14935_2019	72558	-6
14939	AIRWAYS,ASOS,COOP	NE	N	N	A	NE	Y	NE14939_2019	72558	-6
14941	ASOS,COOP,WXSVC	NE	N	Y	A	NE	Y	NE14941_2019	72558	-6
14942	AIRWAYS,ASOS,COOP	IA, NE	Y	N	A	NE	Y	NE14942_2019	72558	-6
24017	ASOS,COOP	NE	N	Y	A	NE	Y	NE24017_2019	72662	-7
24023	ASOS,COOP,WXSVC	NE	Y	N	A	NE	Y	NE24023_2019	72562	-6
24028	ASOS,COOP,WXSVC	NE	Y	N	A	NE	Y	NE24028_2019	72662	-7
24030	AIRWAYS,ASOS,COOP	NE	Y	N	A	NE	Y	NE24030_2019	72562	-6
24032	ASOS,COOP,WXSVC	NE	N	Y	A	NE	Y	NE24032_2019	72562	-6
24044	AIRWAYS,ASOS,COOP	NE	Y	N	A	NE	Y	NE24044_2019	72662	-7
24091	ASOS	NE	Y	N	A	NE	Y	NE24091_2019	72562	-6
94040	AIRWAYS,ASOS	NE	Y	N	A	NE	Y	NE94040_2019	72562	-6
94946	AIRWAYS,ASOS	NE	N	N	A	NE	Y	NE94946_2019	72562	-6
94949	AIRWAYS,ASOS,COOP	NE	N	N	A	NE	Y	NE94949_2019	72558	-6
94957	ASOS	NE	Y	N	A	NE	Y	NE94957_2019	72456	-6
94958	ASOS,COOP	NE	Y	N	A	NE	Y	NE94958_2019	72562	-6
94978	AIRWAYS,ASOS	NE	Y	N	A	NE	Y	NE94978_2019	72558	-6
14710	AIRWAYS,ASOS	NH	Y	N	A	NH	Y	NH14710_2019	74389	-5
14745	ASOS,COOP	NH	Y	N	A	NH	Y	NH14745_2019	74389	-5
54728	AIRWAYS,ASOS	NH	Y	N	A	NH	Y	NH54728_2016	74389	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
54770	AIRWAYS,ASOS	NH	Y	N	A	NH	Y	NH54770_2019	72518	-5
54791	AIRWAYS,ASOS	ME, NH	Y	N	A	NH	Y	NH54791_2019	74389	-5
94700	AIRWAYS,ASOS	NH	Y	N	A	NH	Y	NH94700_2019	74389	-5
94765	AIRWAYS,ASOS	VT, NH	Y	N	A	NH	Y	NH94765_2019	72518	-5
13735	AIRWAYS,ASOS,COOP	NJ	Y	N	A	NJ	Y	NJ13735_2019	72402	-5
14734	ASOS,COOP	NJ	Y	N	A	NJ	Y	NJ14734_2019	72501	-5
14792	AIRWAYS,ASOS	PA, NJ	Y	N	A	NJ	Y	NJ14792_2019	72501	-5
54743	ASOS	NJ	Y	N	A	NJ	Y	NJ54743_2019	72501	-5
54785	ASOS	NJ	Y	N	A	NJ	Y	NJ54785_2019	72501	-5
54793	ASOS	NJ	Y	N	A	NJ	Y	NJ54793_2019	72501	-5
93730	ASOS,COOP	NJ	N	N	A	NJ	Y	NJ93730_2019	72402	-5
93780	AIRWAYS,ASOS	NJ	Y	N	A	NJ	Y	NJ93780_2019	72501	-5
94741	ASOS	NJ	Y	N	A	NJ	Y	NJ94741_2019	72501	-5
3027	ASOS	NM	N	Y	A	NM	N	NM03027_2019	72365	-7
23009	AIRSAMPLE,AIRWAYS,ASOS, COOP,USHCN	NM	N	Y	A	NM	Y	NM23009_2019	72364	-7
23048	ASOS	NM	N	Y	A	NM	Y	NM23048_2019	72363	-6
23049	AIRWAYS,ASOS	NM	N	Y	A	NM	Y	NM23049_2018	72365	-7
23050	AIRSAMPLE,AIRWAYS,ASOS, COOP	NM	N	Y	A	NM	Y	NM23050_2019	72365	-7
23051	AIRSAMPLE,ASOS,COOP, USHCN	NM	N	Y	A	NM	Y	NM23051_2019	72363	-6
23052	ASOS	NM	N	Y	A	NM	Y	NM23052_2019	72365	-7
23054	ASOS	NM	N	Y	A	NM	Y	NM23054_2019	72365	-7
23078	AIRWAYS,ASOS	NM	N	Y	A	NM	Y	NM23078_2019	72364	-7
23081	ASOS,COOP	NM	N	Y	A	NM	Y	NM23081_2019	72365	-7
23090	AIRWAYS,ASOS	NM	N	Y	A	NM	Y	NM23090_2019	72365	-7

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
93033	AIRWAYS,ASOS,COOP,WXSVC	NM	N	Y	A	NM	Y	NM93033_2019	72265	-6
93045	ASOS	NM	N	Y	A	NM	Y	NM93045_2019	72364	-7
3160	ASOS,COOP	NV	N	Y	A	NV	Y	NV03160_2019	72388	-8
23153	AIRWAYS,ASOS,COOP	NV	N	Y	A	NV	Y	NV23153_2019	72388	-8
23154	AIRWAYS,ASOS,COOP	NV	N	Y	A	NV	Y	NV23154_2019	72582	-8
23169	AIRSAMPLE,AIRWAYS,ASOS, COOP	NV	N	Y	A	NV	Y	NV23169_2019	72388	-8
23185	ASOS,COOP,USHCN	NV	N	Y	A	NV	Y	NV23185_2019	72489	-8
24121	AIRWAYS,ASOS,COOP,USHCN	NV	N	Y	A	NV	Y	NV24121_2019	72582	-8
24128	AIRWAYS,ASOS,COOP,USHCN	NV	N	Y	A	NV	Y	NV24128_2019	72582	-8
24172	ASOS,COOP	NV	N	Y	A	NV	Y	NV24172_2019	72489	-8
53123	ASOS	NV	N	Y	A	NV	Y	NV53123_2019	72388	-8
4725	AIRWAYS,ASOS,COOP,USHCN	NY	Y	N	A	NY	Y	NY04725_2019	72518	-5
4781	AIRWAYS,ASOS,COOP	NY	Y	N	A	NY	Y	NY04781_2019	72501	-5
4789	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY04789_2019	72501	-5
14719	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY14719_2019	72501	-5
14732	ASOS,COOP	NY	Y	N	A	NY	Y	NY14732_2019	72501	-5
14733	ASOS,COOP,USHCN	NY	Y	N	A	NY	Y	NY14733_2019	72528	-5
14735	ASOS,COOP,USHCN	NY	Y	N	A	NY	Y	NY14735_2019	72518	-5
14747	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY14747_2019	72528	-5
14748	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY14748_2019	72528	-5
14750	ASOS,COOP	NY	Y	N	A	NY	Y	NY14750_2019	72518	-5
14757	ASOS,COOP	NY	Y	N	A	NY	Y	NY14757_2019	72501	-5
14768	ASOS,COOP,USHCN	NY	Y	N	A	NY	Y	NY14768_2019	72528	-5
14771	ASOS,COOP,USHCN	NY	Y	N	A	NY	Y	NY14771_2019	72518	-5
54757	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY54757_2019	72528	-5
54773	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY54773_2019	72528	-5
54778	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY54778_2019	72528	-5
54787	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY54787_2019	72501	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
54790	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY54790_2019	72501	-5
64775	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY64775_2019	72518	-5
64776	ASOS	NY	Y	N	A	NY	Y	NY64776_2019	72518	-5
94704	ASOS	NY	Y	N	A	NY	Y	NY94704_2019	72528	-5
94725	ASOS	NY	Y	N	A	NY	Y	NY94725_2019	71722	-5
94728	ASOS,COOP,USHCN	NY, NJ	Y	N	A	NY	N	NY94728_2017	72501	-5
94740	AIRWAYS,ASOS	NY	Y	N	A	NY	Y	NY94740_2019	72518	-5
94745	AIRWAYS,ASOS,COOP	NY, CT	Y	N	A	NY	Y	NY94745_2019	72501	-5
94789	ASOS,COOP	NY	Y	N	A	NY	Y	NY94789_2019	72501	-5
94790	ASOS,COOP	NY	Y	N	A	NY	Y	NY94790_2019	71722	-5
4804	ASOS	OH	Y	N	A	OH	Y	OH04804_2019	72426	-5
4842	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04842_2019	72520	-5
4848	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04848_2019	72632	-5
4849	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04849_2019	72632	-5
4850	AIRWAYS,ASOS,COOP	OH	Y	N	A	OH	Y	OH04850_2019	72426	-5
4851	ASOS,COOP	OH	Y	N	A	OH	Y	OH04851_2019	72632	-5
4852	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04852_2019	72520	-5
4853	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04853_2019	72520	-5
4855	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04855_2019	72426	-5
4857	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04857_2019	72520	-5
4858	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH04858_2019	72426	-5
13841	ASOS	OH	Y	N	A	OH	Y	OH13841_2019	72426	-5
14813	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH14813_2019	72520	-5
14820	ASOS,COOP	OH	Y	N	A	OH	Y	OH14820_2019	72520	-5
14821	ASOS,COOP	OH	Y	N	A	OH	Y	OH14821_2019	72426	-5
14825	ASOS,COOP	OH	Y	N	A	OH	Y	OH14825_2019	72426	-5
14852	ASOS,COOP	OH	Y	N	A	OH	Y	OH14852_2016	72520	-5
14891	ASOS,COOP	OH	Y	N	A	OH	Y	OH14891_2019	72426	-5
14895	ASOS,COOP	OH	Y	N	A	OH	Y	OH14895_2019	72520	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
53844	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH53844_2019	72426	-5
53855	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH53855_2019	72426	-5
53859	AIRWAYS,ASOS	OH	Y	N	A	OH	Y	OH53859_2019	72426	-5
93812	AIRWAYS,ASOS,COOP	OH, KY	Y	N	A	OH	Y	OH93812_2019	72426	-5
93815	ASOS,COOP	OH	Y	N	A	OH	Y	OH93815_2019	72426	-5
93824	ASOS,COOP	OH	Y	N	A	OH	Y	OH93824_2019	72520	-5
94830	ASOS,COOP	OH	Y	N	A	OH	Y	OH94830_2019	72632	-5
3030	ASOS	OK	N	Y	A	OK	Y	OK03030_2019	72363	-6
3932	ASOS,COOP	OK	N	N	A	OK	Y	OK03932_2019	72357	-6
3950	AIRWAYS,ASOS,COOP	OK	N	N	A	OK	Y	OK03950_2019	72357	-6
3954	AIRWAYS,ASOS	OK	N	N	A	OK	Y	OK03954_2019	72357	-6
3959	AIRWAYS,ASOS,COOP,USHCN	OK	N	N	A	OK	Y	OK03959_2019	74646	-6
3965	ASOS,COOP	OK	N	N	A	OK	Y	OK03965_2019	74646	-6
3981	ASOS,COOP	OK	N	N	A	OK	Y	OK03981_2019	72357	-6
13967	ASOS,COOP	OK	N	N	A	OK	Y	OK13967_2019	72357	-6
13968	AIRSAMPLE,ASOS,COOP	OK	N	N	A	OK	Y	OK13968_2019	74646	-6
13969	ASOS,COOP	OK	N	N	A	OK	Y	OK13969_2019	74646	-6
13975	AIRWAYS,ASOS,COOP	OK	N	N	A	OK	Y	OK13975_2019	72451	-6
53908	AIRWAYS,ASOS	OK	N	N	A	OK	Y	OK53908_2019	74646	-6
53913	AIRWAYS,ASOS,COOP	OK	N	N	A	OK	Y	OK53913_2019	72357	-6
93950	AIRWAYS,ASOS,COOP	OK	N	N	A	OK	Y	OK93950_2019	72357	-6
93953	AIRWAYS,ASOS	OK	N	N	A	OK	Y	OK93953_2019	72357	-6
93986	AIRWAYS,ASOS,COOP,USHCN	OK	N	N	A	OK	Y	OK93986_2018	72357	-6
4113	AIRWAYS,ASOS	OR	N	N	A	OR	Y	OR04113_2019	72786	-8
4201	AIRWAYS,ASOS	OR	N	N	A	OR	Y	OR04201_2019	72694	-8
24130	AIRWAYS,ASOS,COOP,USHCN	OR	Y	N	A	OR	Y	OR24130_2019	72681	-7
24152	ASOS	OR	Y	N	A	OR	N	OR24152_2018	72786	-8
24155	ASOS,COOP	OR	N	N	A	OR	Y	OR24155_2019	72786	-8

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
24162	AIRWAYS,ASOS,COOP	OR	N	N	A	OR	Y	OR24162_2019	72681	-7
24221	ASOS,COOP	OR	N	N	A	OR	Y	OR24221_2019	72694	-8
24225	ASOS,COOP	OR	N	N	A	OR	Y	OR24225_2019	72597	-8
24229	ASOS,COOP	WA, OR	N	N	A	OR	Y	OR24229_2019	72694	-8
24230	AIRWAYS,ASOS,COOP	OR	N	N	A	OR	Y	OR24230_2019	72694	-8
24231	AIRWAYS,ASOS	OR	N	N	A	OR	Y	OR24231_2019	72597	-8
24232	ASOS,COOP	OR	N	N	A	OR	Y	OR24232_2019	72694	-8
24235	ASOS,COOP	OR	N	N	A	OR	N	OR24235_2019	72597	-8
24242	AIRWAYS,ASOS	WA, OR	N	N	A	OR	Y	OR24242_2019	72694	-8
94185	ASOS,COOP	OR	N	N	A	OR	Y	OR94185_2019	72681	-7
94224	ASOS,COOP,USHCN	OR	N	N	A	OR	Y	OR94224_2019	72694	-8
94236	AIRWAYS,ASOS,COOP	OR	N	N	A	OR	Y	OR94236_2019	72597	-8
94261	AIRWAYS,ASOS	OR	N	N	A	OR	Y	OR94261_2019	72694	-8
94273	AIRWAYS,ASOS	OR	N	N	A	OR	Y	OR94273_2019	72694	-8
94281	AIRWAYS,ASOS	OR	N	N	A	OR	Y	OR94281_2019	72694	-8
4726	ASOS	PA	Y	N	A	PA	Y	PA04726_2019	72520	-5
4751	AIRWAYS,ASOS,COOP	PA	Y	N	A	PA	Y	PA04751_2019	72528	-5
4787	ASOS,COOP	PA	Y	N	A	PA	Y	PA04787_2019	72520	-5
4843	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA04843_2019	72520	-5
13739	ASOS,COOP	PA, NJ	Y	N	A	PA	Y	PA13739_2019	72403	-5
14711	AIRWAYS,ASOS,COOP	PA	Y	N	A	PA	Y	PA14711_2019	72403	-5
14712	ASOS	PA	Y	N	A	PA	Y	PA14712_2019	72403	-5
14736	ASOS	PA	Y	N	A	PA	Y	PA14736_2019	72403	-5
14737	ASOS,COOP,USHCN	PA	Y	N	A	PA	Y	PA14737_2019	72501	-5
14751	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA14751_2019	72403	-5
14762	AIRWAYS,ASOS,WXSVC	PA	N	N	A	PA	Y	PA14762_2019	72520	-5
14770	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA14770_2019	72403	-5

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
14777	ASOS,COOP	PA	Y	N	A	PA	Y	PA14777_2019	72518	-5
14778	ASOS,COOP,USHCN	PA	Y	N	A	PA	Y	PA14778_2019	72528	-5
14860	ASOS,COOP,USHCN	PA	Y	N	A	PA	Y	PA14860_2019	72520	-5
54737	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA54737_2019	72403	-5
54782	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA54782_2019	72403	-5
54786	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA54786_2019	72501	-5
54789	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA54789_2019	72501	-5
54792	ASOS	PA	Y	N	A	PA	Y	PA54792_2019	72520	-5
93778	AIRWAYS,ASOS	PA	Y	N	A	PA	Y	PA93778_2019	72403	-5
94732	ASOS	PA	Y	N	A	PA	Y	PA94732_2019	72501	-5
94823	ASOS,COOP	PA	Y	N	A	PA	Y	PA94823_2019	72520	-5
11641	ASOS,COOP	PR	N	N	A	PR	Y	PR11641_2019	78526	-4
14765	ASOS,COOP,USHCN	RI	Y	N	A	RI	Y	RI14765_2019	74494	-5
14787	AIRWAYS,ASOS	RI	Y	N	A	RI	Y	RI14787_2019	74494	-5
14794	AIRWAYS,ASOS	CT, RI	Y	N	A	RI	Y	RI14794_2019	72501	-5
3870	ASOS,COOP,USHCN	SC	N	N	A	SC	Y	SC03870_2019	72317	-5
13744	AIRWAYS,ASOS,COOP	SC	N	N	A	SC	Y	SC13744_2019	72208	-5
13880	ASOS,COOP,UPPERAIR	SC	N	N	A	SC	Y	SC13880_2019	72208	-5
13883	ASOS,COOP	SC	N	N	A	SC	Y	SC13883_2019	72208	-5
13886	AIRWAYS,ASOS	SC	N	N	A	SC	Y	SC13886_2019	72215	-5
53850	ASOS	SC	N	N	A	SC	Y	SC53850_2019	72215	-5
53854	AIRWAYS,ASOS	SC	N	N	A	SC	Y	SC53854_2019	72208	-5
53867	AIRWAYS,ASOS	SC	N	N	A	SC	Y	SC53867_2019	72208	-5
53871	AIRWAYS,ASOS	SC	N	N	A	SC	Y	SC53871_2019	72317	-5
53874	ASOS	SC	N	N	A	SC	Y	SC53874_2019	72208	-5
93718	ASOS,COOP	SC	N	N	A	SC	Y	SC93718_2019	72208	-5
93846	AIRWAYS,ASOS,COOP	SC	N	N	A	SC	Y	SC93846_2019	72215	-5
14929	ASOS,COOP,USHCN,WXSVC	SD	Y	N	A	SD	N	SD14929_2019	72659	-6
14936	ASOS,COOP,WXSVC	SD	Y	N	A	SD	Y	SD14936_2019	72659	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
14944	ASOS,COOP,WXSVC	SD	Y	N	A	SD	Y	SD14944_2019	72558	-6
14946	AIRWAYS,ASOS,COOP,USHCN	SD	Y	N	A	SD	Y	SD14946_2019	72659	-6
24024	ASOS	SD	N	Y	A	SD	Y	SD24024_2019	72662	-7
24025	AIRWAYS,ASOS,COOP,USHCN	SD	N	Y	A	SD	Y	SD24025_2019	72659	-6
24090	ASOS,COOP	SD	N	Y	A	SD	Y	SD24090_2019	72662	-7
94032	ASOS	SD	N	Y	A	SD	Y	SD94032_2019	72662	-7
94039	AIRWAYS,ASOS	SD, NE	N	Y	A	SD	Y	SD94039_2019	72662	-7
94052	AIRWAYS,ASOS	SD	Y	N	A	SD	Y	SD94052_2019	72764	-6
94950	AIRWAYS,ASOS,COOP	SD	Y	N	A	SD	Y	SD94950_2019	72659	-6
94990	AIRWAYS,ASOS	SD	N	Y	A	SD	Y	SD94990_2019	72562	-6
3811	AIRWAYS,ASOS,COOP	TN	N	N	A	TN	Y	TN03811_2019	72327	-6
3847	ASOS,COOP	TN	N	N	A	TN	Y	TN03847_2019	72327	-6
3894	ASOS,COOP	KY, TN	N	N	A	TN	Y	TN03894_2019	72327	-6
13877	AIRSAMPLE,ASOS,COOP	TN	N	N	A	TN	Y	TN13877_2019	72318	-5
13882	AIRSAMPLE,AIRWAYS,ASOS, COOP,WXSVC	TN, GA	N	N	A	TN	Y	TN13882_2019	72215	-5
13891	AIRSAMPLE,AIRWAYS,ASOS, COOP	TN	N	N	A	TN	Y	TN13891_2019	72215	-5
13893	AIRSAMPLE,ASOS,COOP	TN	N	N	A	TN	Y	TN13893_2019	72340	-6
13897	AIRSAMPLE,ASOS,COOP	TN	N	N	A	TN	Y	TN13897_2019	72327	-6
53868	AIRSAMPLE,ASOS,COOP	TN	N	N	A	TN	N	TN53868_2019	72327	-6
3024	AIRWAYS,ASOS	TX	N	Y	A	TX	Y	TX03024_2019	72363	-6
3031	AIRWAYS,ASOS	TX	N	Y	A	TX	Y	TX03031_2019	72265	-6
3901	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX03901_2019	72248	-6
3904	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX03904_2019	72249	-6
3927	ASOS,COOP	TX	N	N	A	TX	Y	TX03927_2019	72249	-6
3971	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX03971_2019	72249	-6
3991	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX03991_2019	72249	-6
3999	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX03999_2019	72249	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
12904	AIRWAYS,ASOS	TX	N	Y	A	TX	Y	TX12904_2019	72250	-6
12912	ASOS,COOP	TX	N	N	A	TX	Y	TX12912_2019	72251	-6
12917	ASOS,COOP	TX	N	N	A	TX	Y	TX12917_2019	72240	-6
12918	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12918_2019	72240	-6
12919	AIRWAYS,ASOS,COOP, UPPERAIR	TX	N	Y	A	TX	Y	TX12919_2019	72250	-6
12921	ASOS,COOP,USHCN	TX	N	N	A	TX	Y	TX12921_2019	72251	-6
12923	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12923_2019	72240	-6
12924	ASOS,COOP,USHCN,WXSVC	TX	N	N	A	TX	Y	TX12924_2019	72251	-6
12932	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12932_2019	72251	-6
12935	ASOS,COOP	TX	N	N	A	TX	Y	TX12935_2019	72251	-6
12947	ASOS,COOP	TX	N	N	A	TX	Y	TX12947_2019	72251	-6
12957	AIRWAYS,ASOS	TX	N	Y	A	TX	Y	TX12957_2019	72250	-6
12959	AIRWAYS,ASOS,COOP,WXSVC	TX	N	Y	A	TX	Y	TX12959_2019	72250	-6
12960	ASOS,COOP	TX	N	N	A	TX	Y	TX12960_2019	72240	-6
12962	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12962_2019	72261	-6
12970	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12970_2019	72251	-6
12971	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12971_2019	72251	-6
12972	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX12972_2019	72251	-6
12975	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX12975_2019	72240	-6
12976	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX12976_2019	72251	-6
12977	ASOS,COOP	TX	N	N	A	TX	Y	TX12977_2019	72240	-6
13904	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX13904_2019	72251	-6
13958	ASOS,COOP	TX	N	N	A	TX	N	TX13958_2019	72249	-6
13959	ASOS,COOP	TX	N	N	A	TX	Y	TX13959_2019	72249	-6
13960	ASOS,COOP	TX	N	N	A	TX	Y	TX13960_2019	72249	-6
13961	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX13961_2019	72249	-6
13962	AIRSAMPLE,ASOS,COOP	TX	N	Y	A	TX	Y	TX13962_2019	72249	-6
13966	ASOS,COOP	TX	N	N	A	TX	Y	TX13966_2019	72357	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
13972	AIRWAYS,ASOS,COOP,WXSVC	TX	N	N	A	TX	Y	TX13972_2019	72248	-6
13973	AIRWAYS,ASOS	TX	N	Y	A	TX	Y	TX13973_2019	72261	-6
22010	ASOS,COOP	TX	N	Y	A	TX	Y	TX22010_2019	72261	-6
23007	AIRWAYS,ASOS,COOP	TX	N	Y	A	TX	Y	TX23007_2019	72363	-6
23023	ASOS,COOP,WXSVC	TX	N	Y	A	TX	Y	TX23023_2019	72265	-6
23034	AIRSAMPLE,ASOS,COOP	TX	N	Y	A	TX	Y	TX23034_2019	72265	-6
23040	ASOS,COOP,WXSVC	TX	N	Y	A	TX	Y	TX23040_2019	72265	-6
23042	AIRWAYS,ASOS,COOP	TX	N	Y	A	TX	Y	TX23042_2019	72363	-6
23044	ASOS,COOP,USHCN	TX	N	Y	A	TX	Y	TX23044_2019	72364	-7
23047	ASOS,COOP	TX	N	Y	A	TX	Y	TX23047_2019	72363	-6
23055	ASOS	TX	N	Y	A	TX	N	TX23055_2019	72364	-7
23091	AIRWAYS,ASOS	TX	N	Y	A	TX	Y	TX23091_2016	72265	-6
53902	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53902_2019	72240	-6
53903	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53903_2019	72240	-6
53907	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53907_2019	72249	-6
53909	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53909_2019	72249	-6
53910	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53910_2019	72240	-6
53911	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53911_2019	72249	-6
53912	AIRWAYS,ASOS	TX	N	N	A	TX	Y	TX53912_2019	72249	-6
53914	AIRWAYS,ASOS,COOP	TX	N	N	A	TX	Y	TX53914_2019	72249	-6
93042	ASOS,COOP	TX	N	Y	A	TX	Y	TX93042_2019	72363	-6
93985	ASOS,COOP	TX	N	Y	A	TX	Y	TX93985_2019	72249	-6
93987	ASOS,COOP	TX	N	N	A	TX	Y	TX93987_2019	72248	-6
23159	ASOS	UT	N	Y	A	UT	Y	UT23159_2019	72376	-7
23176	ASOS	UT	N	Y	A	UT	Y	UT23176_2017	72572	-7
24127	ASOS,COOP	UT	N	Y	A	UT	Y	UT24127_2019	72572	-7
93075	AIRWAYS,ASOS,COOP	UT	N	Y	A	UT	Y	UT93075_2019	72476	-7
93129	AIRWAYS,ASOS,COOP	UT	N	Y	A	UT	Y	UT93129_2019	72388	-8
93141	AIRWAYS,ASOS	UT	N	Y	A	UT	Y	UT93141_2019	72572	-7

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
94030	ASOS,COOP	UT	N	Y	A	UT	Y	UT94030_2019	72476	-7
94128	AIRWAYS,ASOS	UT	N	Y	A	UT	Y	UT94128_2019	72572	-7
13728	ASOS,COOP	VA, NC	N	N	A	VA	Y	VA13728_2019	72317	-5
13733	ASOS,COOP	VA	N	N	A	VA	Y	VA13733_2019	72318	-5
13737	ASOS,COOP,USHCN	VA	N	N	A	VA	Y	VA13737_2019	72402	-5
13740	ASOS,COOP	VA	N	N	A	VA	Y	VA13740_2019	72403	-5
13741	ASOS,COOP	VA	N	N	A	VA	Y	VA13741_2019	72318	-5
13743	ASOS,COOP	MD, DC, VA	N	N	A	VA	Y	VA13743_2019	72403	-5
93736	AIRWAYS,ASOS	VA	N	N	A	VA	Y	VA93736_2019	72403	-5
93738	ASOS,COOP	VA	N	N	A	VA	Y	VA93738_2019	72403	-5
93739	ASOS,COOP	VA	N	N	A	VA	Y	VA93739_2019	72402	-5
93741	ASOS	VA	N	N	A	VA	Y	VA93741_2019	72402	-5
93773	AIRWAYS,ASOS	VA	N	N	A	VA	Y	VA93773_2019	72402	-5
93775	AIRWAYS,ASOS	VA	Y	N	A	VA	Y	VA93775_2016	72403	-5
14742	ASOS,COOP,USHCN	VT	Y	N	A	VT	Y	VT14742_2019	72518	-5
54740	AIRWAYS,ASOS	VT	Y	N	A	VT	Y	VT54740_2019	72518	-5
54771	AIRWAYS,ASOS	VT	Y	N	A	VT	Y	VT54771_2019	72518	-5
54781	AIRWAYS,ASOS	VT, NY	Y	N	A	VT	Y	VT54781_2019	72518	-5
94705	AIRWAYS,ASOS,COOP	VT	Y	N	A	VT	Y	VT94705_2019	72518	-5
24110	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA24110_2019	72786	-8
24141	AIRWAYS,ASOS,COOP	WA	Y	N	A	WA	Y	WA24141_2019	72786	-8
24157	AIRSAMPLE,ASOS,COOP, USHCN	WA	Y	N	A	WA	Y	WA24157_2019	72786	-8
24160	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA24160_2019	72786	-8
24217	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA24217_2016	72797	-8

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
24219	AIRWAYS,ASOS,COOP	WA, OR	Y	N	A	WA	Y	WA24219_2016	72694	-8
24220	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA24220_2019	72786	-8
24222	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA24222_2019	72797	-8
24227	ASOS,COOP	WA	N	N	A	WA	Y	WA24227_2019	72797	-8
24233	ASOS,COOP	WA	N	N	A	WA	Y	WA24233_2019	72797	-8
24234	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA24234_2016	72797	-8
24243	ASOS,COOP	WA	N	N	A	WA	Y	WA24243_2019	72694	-8
94119	AIRWAYS,ASOS,COOP	WA	Y	N	A	WA	Y	WA94119_2019	72786	-8
94129	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA94129_2019	72786	-8
94176	AIRWAYS,ASOS	WA	Y	N	A	WA	Y	WA94176_2019	72786	-8
94197	ASOS	WA	Y	N	A	WA	N	WA94197_2016	71203	-8
94225	ASOS,COOP	WA	N	N	A	WA	Y	WA94225_2019	72797	-8
94227	ASOS,COOP	WA	N	N	A	WA	Y	WA94227_2019	72797	-8
94239	ASOS,COOP	WA	Y	N	A	WA	Y	WA94239_2019	72786	-8
94240	ASOS,COOP	WA	N	N	A	WA	Y	WA94240_2019	72797	-8
94248	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA94248_2019	72797	-8
94266	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA94266_2019	72797	-8
94274	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA94274_2019	72797	-8
94276	AIRWAYS,ASOS	WA	N	N	A	WA	Y	WA94276_2019	72797	-8
94298	AIRWAYS,ASOS	WA, OR	N	N	A	WA	Y	WA94298_2019	72694	-8
4803	AIRWAYS,ASOS,COOP	WI	Y	N	A	WI	Y	WI04803_2019	72645	-6
4826	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI04826_2019	72645	-6
4840	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI04840_2019	72645	-6
4841	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI04841_2019	72645	-6
4845	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI04845_2019	72645	-6
14837	ASOS,COOP,WXSVC	WI	Y	N	A	WI	Y	WI14837_2019	72645	-6
14839	AIRSAMPLE,ASOS,COOP	WI	Y	N	A	WI	Y	WI14839_2019	72645	-6

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
14897	ASOS,COOP	WI	Y	N	A	WI	Y	WI14897_2019	72645	-6
14898	ASOS,COOP,WXSVC	WI	Y	N	A	WI	Y	WI14898_2019	72645	-6
14920	AIRWAYS,ASOS,COOP	WI, MN	Y	N	A	WI	Y	WI14920_2019	74455	-6
14921	ASOS	WI	Y	N	A	WI	Y	WI14921_2019	74455	-6
14991	ASOS,COOP,WXSVC	WI	Y	N	A	WI	Y	WI14991_2019	72649	-6
94818	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI94818_2019	72645	-6
94855	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI94855_2019	72645	-6
94929	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI94929_2019	72649	-6
94973	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI94973_2019	72649	-6
94985	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI94985_2019	72645	-6
94994	AIRWAYS,ASOS	WI	Y	N	A	WI	Y	WI94994_2019	74455	-6
3802	AIRWAYS,ASOS	WV	Y	N	A	WV	Y	WV03802_2018	72520	-5
3804	ASOS,COOP	WV	Y	N	A	WV	Y	WV03804_2018	72520	-5
3859	ASOS,COOP	WV, VA	Y	N	A	WV	Y	WV03859_2019	72318	-5
3860	ASOS,COOP	WV, OH, KY	N	N	A	WV	Y	WV03860_2018	72426	-5
3872	ASOS,COOP	WV	Y	N	A	WV	Y	WV03872_2019	72318	-5
13729	ASOS,COOP	WV	Y	N	A	WV	Y	WV13729_2017	72520	-5
13734	ASOS,COOP,USHCN	WV	N	N	A	WV	Y	WV13734_2019	72403	-5
13736	AIRWAYS,ASOS,COOP	WV	Y	N	A	WV	Y	WV13736_2019	72520	-5
13866	ASOS,COOP	WV	Y	N	A	WV	Y	WV13866_2018	72318	-5
14894	AIRWAYS,ASOS	OH, WV	N	N	A	WV	Y	WV14894_2019	72520	-5
4111	AIRWAYS,ASOS	WY, UT	N	Y	A	WY	Y	WY04111_2019	72572	-7
24018	ASOS,COOP,USHCN,WXSVC	WY	Y	N	A	WY	Y	WY24018_2019	72469	-7

Surface WBAN	Type Station	State tif file	snow	arid	moisture	state	Airport	AERMOD File	Upper Air WMO	Upper Air UTC
24021	ASOS,COOP,WXSVC	WY	N	Y	A	WY	Y	WY24021_2019	72672	-7
24022	ASOS,COOP,USHCN	WY	Y	N	A	WY	Y	WY24022_2019	72469	-7
24027	AIRWAYS,ASOS,AWOS,COOP, USHCN,WXSVC	WY	N	Y	A	WY	Y	WY24027_2019	72672	-7
24029	ASOS,COOP	WY	N	Y	A	WY	Y	WY24029_2019	72672	-7
24048	AIRWAYS,ASOS	WY	N	Y	A	WY	Y	WY24048_2019	72672	-7
24057	ASOS,COOP	WY	N	Y	A	WY	Y	WY24057_2019	72672	-7
24061	AIRWAYS,ASOS,WXSVC	WY	Y	N	A	WY	Y	WY24061_2019	72672	-7
24062	AIRWAYS,ASOS	WY	Y	N	A	WY	Y	WY24062_2019	72672	-7
24089	AIRWAYS,ASOS,COOP,WXSVC	WY	N	Y	A	WY	Y	WY24089_2019	72672	-7
24164	AIRWAYS,ASOS	WY	N	Y	A	WY	Y	WY24164_2019	72672	-7
94023	AIRWAYS,ASOS	WY	N	Y	A	WY	Y	WY94023_2019	72662	-7
94053	AIRWAYS,ASOS,COOP	WY	N	N	A	WY	Y	WY94053_2019	72662	-7
94054	AIRWAYS,ASOS	WY	N	Y	A	WY	Y	WY94054_2019	72672	-7
94057	AIRWAYS,ASOS,COOP	WY	N	Y	A	WY	Y	WY94057_2019	72662	-7

Appendix 4

Dispersion Model Receptor Revisions and Additions

Dispersion Model Receptor Revisions and Additions
Neoprene Production Source Category

To estimate ambient concentrations for evaluating long-term exposures, the HEM4 model uses the geographic centroids of census blocks (currently utilizing the 2010 Census) as dispersion model receptors. The census block centroids are generally good surrogates for where people live within a census block. A census block generally encompasses about 40 people or 10-15 households. However, in cases where a block centroid is located on industrial property, or where a census block is large and the centroid less likely to be representative of the block's residential locations, the block centroid may not be an appropriate surrogate.

Census block centroids that are on facility property can sometimes be identified by their proximity to emission sources. In cases where a census block centroid was within 300 meters of any emission source, we viewed aerial images of the facility to determine whether the block centroid was likely located on facility property. The selection of the 300-meter distance reflects a compromise between too few and too many blocks identified as being potentially on facility property. Distances smaller than 300 meters would identify only block centroids near the emission sources and could exclude some block centroids that are still within facility boundaries, particularly for large facilities. Distances significantly larger than 300 meters would identify many block centroids that are outside facility boundaries, particularly for small facilities. Where we confirmed a block centroid on facility property, we moved the block centroid to a location that best represents the residential locations in the block.

In addition, census block centroids for blocks with large areas may not be representative of residential locations. Risk estimates based on such centroids can be understated if there are residences nearer to a facility than the centroid, and overstated if the residences are farther from the facility than the centroid. To avoid understating the maximum individual risk associated with a facility, in some cases we relocated block centroids, or added dispersion model receptors other than the block centroid. We examined aerial images of all large census blocks within one kilometer of any emission source. Experience from previous risks characterizations show that in most cases the MIR is generally located within 1 km of the facility boundary. If the block centroid did not represent the residential locations, we relocated it to better represent them. If residential locations could not be represented by a single receptor (that is, the residences were spread out over the block), we added additional receptors for residences nearer to the facility than the centroid.

For this source category, the table below contains each census block for which we changed the centroid location because it was on facility property or was otherwise not representative of the residential locations in the block. The table also contains the locations of additional receptors that were included to represent residential locations nearer to the facility than the block centroid.

Dispersion Model Receptor Revisions:

CENSUS Block	Updated Rec Lat	Updated Rec Long	Note
220950708001021	30.05453	-90.53023	Relocate receptor to represent house locations
220950708001033			Make Zero Population and Remove

Additional Receptors for the Neoprene Production Source Category:

EIS ID	Latitude	Longitude	Note
17640111	30.05114	-90.52887	Add User Defined Receptor

Appendix 5:

Technical Support Document for Acute Risk Screening Assessment

Table of Contents

I. Analysis of Data on Short-Term Emission Rates Relative to Long-Term Emission Rates

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EPA/OAQPS/ATAG
Revised September 19, 2011

1. Introduction

1.1. The problem

The process of listing hazardous air pollutants (HAPs) provided by the Clean Air Act (CAA, section 112(b)(2)) explicitly includes acute toxicity as a listing criterion. For this reason, in addition to chronic exposures, EPA considers acute exposures in risk-based decision-making for the HAP regulatory program. Estimating acute exposures via dispersion modeling requires input data on hourly meteorological conditions (available for most areas of the US) and short-term emission rates of individual facilities (almost universally absent from the National Emissions Inventory (NEI), the Toxic Release Inventory (TRI), and state emission databases).

Lacking short-term emission rates, we must estimate peak short-term rates based on annual average rates, which are available. For Risk and Technology Review (RTR) rulemakings, we have assumed that the 1-hour emission rate for each facility could exceed the annual average hourly emission rate by up to tenfold for most sources, and further assumed that this emission spike could coincide with worst-case meteorological conditions and the presence of a human receptor at the facility boundary, as a means of screening for potentially significant acute exposures.

In a consultation on the "RTR Assessment Plan", a panel of the EPA's Science Advisory Board (SAB), several reviewers questioned the appropriateness of these factors; some even suggested that this tenfold assumption may underestimate actual maximum short-term emissions for some facilities, and thereby also underestimate maximum acute risks. The SAB recommended an analysis of available short-term emissions data for HAP to test this assumption. This analysis responds to that SAB recommendation and attempts to test the protectiveness of the two-tenfold assumption using a database of "event emissions" collected from facilities in the Houston-Galveston area, to compare events representative of HAP releases to long-term release rates. We welcome comments from the public on the methods used and the conclusions reached by this analysis.

2. Methods

2.1. Texas Commission on Environmental Quality event emissions database

The Texas Commission on Environmental Quality (TCEQ) collects emissions data using online reporting required of any facility releasing 100 pounds or more of a listed chemical (primarily ozone-forming VOCs) during a non-routine event. The TCEQ data are intended to improve the state's knowledge of how short-term releases affect tropospheric ozone levels in that area. The database we utilized in our analysis was a subset of the TCEQ data covering emission events that

occurred in an eight-county area in eastern Texas during a 756-day period between January 31, 2003, and February 25, 2005.

The complete emissions event data were obtained in April 2007 from Cynthia Folsom Murphy, a research scientist with the University of Texas at Austin (UTA) Center for Energy and Environmental Resources. The data were provided in four Excel spreadsheets generated from an original MS Access file. We used these Excel files to reconstruct a MS Access database in order to facilitate selection of a representative subset of records for this analysis.

Although some of the released substances were HAPs, this was incidental to the database's primary purpose of enhancing the TCEQ's knowledge of photochemical activity. Thus, more than 80% of the released mass was ethene and propene, neither of which are HAPs. The database included release events caused by accidents, equipment failures, maintenance, startup, and shutdown. It also contained facility names, information on amounts of individual compounds released. To provide a basis for comparing the event releases with "typical" emissions, the UTA staff included total VOC emissions data for each facility for calendar year 2004, obtained from the EPA Toxic Release Inventory (TRI). The database did *not* contain any records for facilities that did not experience any reportable events during this period.

2.2. Data filtering

Because the event release data were intended for modeling short-term releases of ozone-producing VOCs, the database includes releases from accidents (which are regulated under section 112(r) of the CAA and are therefore not considered in residual risk assessments) and releases of light hydrocarbon compounds that are not HAPs and are much more volatile than most HAPs. This intent of this analysis, on the other hand, was to evaluate short-term releases of HAPs due to normal process variability or scheduled startups, shutdowns, and maintenance, relative to long-term release rates. Because the full emission events database was not representative of likely HAP emissions normally considered under the residual risk program, we filtered the release data as follows in an attempt to improve its representativeness:

1. Hydrocarbons of C5 or less were dropped, except that all HAPs (including non-VOCs) were retained regardless of molecular structure;

2. Accidental releases were dropped, but all others (including startup, shutdown, and maintenance) were retained;

3. Only facilities whose long-term VOC releases exceeded 0.068 tons per day (25 tons per year) were retained, to approximate the population of facilities likely to be subject to residual risk standards (i.e., major facilities);

4. A few release records had to be dropped because their facility numbers did not link to any facility in the database;

5. A few facilities had to be dropped because the database did not include their 2004 TRI VOC release information.

2.3. Analysis

Annual VOC emissions and emission event release data were both converted to lb/hr. In order to conform to our atmospheric dispersion models, which estimate ambient concentrations for periods of 1 hour or more, amounts released during events shorter than 1 hour were assigned to the whole hour. For example, a release of 100 lb in ten minutes was converted to 100 lb/hr. Events longer than 1 hour were converted normally, e.g., a release of 100 lb in 120 minutes was converted to 50 lb/hr. The event release rates for individual compounds were summed, yielding a total release rate for each event. This total release rate for each event was divided by the annual VOC release rate for the facility to derive the ratio of peak-to-mean emission rate for the event.

3. Results and Discussion

3.1. Database filtering

The original database contained 505 individual contaminants, including multiple redundancies. These redundancies did not affect this analysis, so we did not resolve them. After filtering out light, non-HAP, VOCs, 317 contaminants remained (Table 1).

The database contained release records for 150 unique facilities. Of these, 48 facilities (Table 2) were major VOC emitters that reported releases of at least one of the contaminants in Table 1.

The database contained 3641 individual release events reported by the original 150 facilities. Of these, 319 events involved a Table 1 contaminant released by a Table 2 facility during startup, shutdown, or maintenance. For evaluating short-term releases for residual risk assessments, these 319 events comprise the most representative subset of the full database.

3.2. Descriptive statistics

For this subset of emission events, ratios of event release rate to long-term release rate varied from 0.00000004 to 74. Distribution statistics appear in Tables 3 and 4. The 99^{th} percentile ratio was 9 (i.e., an event release rate nine times the long-term average). Only 3 ratios exceeded a factor of 10, and of these only one exceeded 11. The full cumulative probability density of the ratios is shown in Figure 1.

Figure 2 shows the relationship between ratio and event duration. As expected, the ratio declined as duration increased. Only 18 events lasted less than 2 hours, but these events produced the three highest ratios. Figure 3 is a similar ratio vs. duration plot, but with duration as a percentage of total time. Only 35 events exceeded 1% of the total period covered by the database. Figure 4 shows the relationship between ratio and total amount released, and suggests that the highest ratios were produced by facilities whose routine VOC emissions were relatively small (all less than 200 lbs/hr). Thus, the events themselves also tended to be relatively small in absolute terms. This suggests that for larger emitting facilities that a factor of ten may be overly protective and for at least the key source sectors represented by the study (petroleum and chemical sectors), that a factor of twofold for facilities with VOC emissions greater than 200 lb/hr may be more appropriate.

3.3. Discussion

These results suggest that the tenfold ratio assumption for short-term releases is protective, and that the facilities for which it may underestimate event releases may tend to be smaller emitters.

However, this analysis is limited in the following ways by the nature of the database and the filtering that we applied:

1. The only long-term release data available from the database were total VOC emissions for 2004. Ideally, we would have preferred to have routine release rates for each individual contaminant. However, retrieving these data from other sources and linking them to this database was not feasible.

2. Removing VOCs that are not representative of HAPs, and comparing the releases against all VOCs, would tend to underestimate the true ratios. This effect could be quantitatively large.

3. Retaining HAPs that are not VOCs (such as toxic metals) and including them in the total to be compared against all VOCs would tend to overestimate the true ratios. The size of this effect is not known but seems likely to be less than for (2) above.

4. The database contains only facilities that had at least one release event during the reporting period. The number of facilities in the statistical population that did not experience an event is not known. The lack of data for these facilities (whose ratios in this analysis would have been zero) would cause the descriptive statistics to be skewed toward an overestimate. The size of this effect is unknown.

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
2-Methyloctane	No	3221-61-2	90008
2-Methylpentane	No	107-83-5	43229
2-methylhexane	No	591-76-4	43263
2-Methylpentane	No	107-83-5	43229
2,2,3-Trimethylpentane	No	564-02-3	
2,2,4-Trimethylpentane	Yes	540-84-1	43250
dimethyl butane	No	75-83-2	43291
2,3-Dimethylbutane	No	79-29-8	43276
2,3,4-Trimethylpentane	No	565-75-3	43252
2,3-Dimethylbutane	No	79-29-8	43276
2,4-Dimethylpentane	No	108-08-7	43247
2-methylheptane	No	592-27-8	43296
2-methylhexane	No	591-76-4	43263
2-Methylpentane	No	107-83-5	43229
3-Methylhexane	No	589-34-4	43295
3-Methylpentane	No	96-14-0	43230

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
3-Methylhexane	No	589-34-4	43295
3-Methylpentane	No	96-14-0	43230
3-Methylheptane	No	589-81-1	43253
3-Methylhexane	No	589-34-4	43295
3-Methylpentane	No	96-14-0	43230
Acetaldehyde	Yes	75-07-0	43503
Acetic Acid	No	64-19-7	43404
Acetonitrile	Yes	75-05-8	70016
Acetophenone	Yes	98-86-2	
Acrolein	Yes	107-02-8	43505
Acrylic acid	Yes	79-10-7	43407
Acrylonitrile	Yes	107-13-1	43704
alkylphenol	No	none	
Benzene	Yes	71-43-2	45201
Benzo[a]anthracene	Yes	56-55-3	46716
Benzo[a]pyrene	Yes	50-32-8	46719
Benzo[b]fluoranthene	Yes	205-99-2	46717
Biphenyl	Yes	92-52-4	45226
Butanol	No	35296-72-1	
Butyl Acrylate	No	141-32-2	43440
t-Butyl Alcohol	No	75-65-0	43309
butylcyclohexane	No	1678-93-9	90101
Butyraldehyde	No	123-72-8	43510
C9 Aromatics	No	none	
Naphthalene	Yes	91-20-3	46701
Nonane	No	111-84-2	43235
C9+	No	none	
Carbon tetrachloride	Yes	56-23-5	43804
Carbonyl Sulfide	Yes	463-58-1	43933
Chloral	No	75-87-6	
Trichloromethane	Yes	67-66-3	43803
Chlorothalonil	No	1897-45-6	
Petroleum	No	8002-05-9	
Petroleum	No	8002-05-9	
Cumene	Yes	98-82-8	45210
Cyclohexane	No	110-82-7	43248
Cyclohexanol	No	108-93-0	43317
Cyclohexanone	No	108-94-1	43561
Cyclohexanone	No	108-94-1	43561
Decane	No	124-18-5	43238
Decane	No	124-18-5	43238

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
1,2-Dichloroethane	No	107-06-2	43815
Diethylbenzene (mixture)	No	25340-17-4	45106
Methyl Ether	No	115-10-6	43350
Dimethylcyclohexane	No	27195-67-1	98059
Dimethylcyclopentane	No	28729-52-4	90064
Dimethylcyclopentane	No	28729-52-4	90064
Dimethyl formamide	Yes	68-12-2	43450
Dimethylhexane	No	28777-67-5	90067
Dimethyl pentane	No	38815-29-1	90063
Epichlorohydrin	Yes	106-89-8	43863
Ethyl Alcohol	No	64-17-5	43302
Ethyl Acrylate	Yes	140-88-5	43438
Ethyl Alcohol	No	64-17-5	43302
Ethyl Benzene	Yes	100-41-4	45203
Ethyl Chloride	Yes	75-00-3	43812
Ethylcyclohexane	No	1678-91-7	43288
ethylacetylene	No	107-00-6	43281
Ethyl Benzene	Yes	100-41-4	45203
Ethylene Oxide	Yes	75-21-8	43601
ethylmethylbenzene	No	25550-14-5	45104
formaldehyde	Yes	50-00-0	43502
Furfural	No	98-01-1	45503
straight-run middle distillate	No	64741-44-2	
Gasoline	No	86290-81-5	
Gasoline	No	86290-81-5	
Heavy Olefins	No	none	
n-Heptane	No	142-82-5	43232
n-Heptane	No	142-82-5	43232
Heptylene	No	25339-56-4	
hexane	Yes	110-54-3	43231
hexane	Yes	110-54-3	43231
2-Methylpentane	No	107-83-5	43229
hexane	Yes	110-54-3	43231
Hexene	No	25264-93-1	43289
Indeno[1,2,3-cd]pyrene	Yes	193-39-5	46720
Isobutyraldehyde	No	78-84-2	43511
2-Methyl-1-propanol	No	78-83-1	43306
2-Methyl-1-propanol	No	78-83-1	43306
Isobutyraldehyde	No	78-84-2	43511
Isoheptanes (mixture)	No	31394-54-4	43106
2-Methylpentane	No	107-83-5	43229

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
2,2,4-Trimethylpentane	No	540-84-1	43250
2,2,4-Trimethylpentane	No	540-84-1	43250
Isopar E	No		
Isoprene	No	78-79-5	43243
2-Propanol	No	67-63-0	43304
2-Propanol	No	67-63-0	43304
Cumene	Yes	98-82-8	45210
Isopropylcyclohexane	No	696-29-7	90128
Diisopropyl ether	No	108-20-3	85005
Kerosene	No	64742-81-0	
Methyl ethyl ketone	No	78-93-3	43552
Methyl isobutenyl ketone	Yes	141-79-7	
Methanol	Yes	67-56-1	43301
Methyl Acetylene	No	74-99-7	43209
Cresol	Yes	1319-77-3	45605
Methyl Chloride	Yes	74-87-3	43801
methyl cyclohexane	No	108-87-2	43261
Methyl ethyl ketone	No	78-93-3	43552
Iodomethane	No	74-88-4	86025
Methyl Mercaptan	No	74-93-1	43901
methyl cyclohexane	No	108-87-2	43261
Methylcyclopentane	No	96-37-7	43262
2-Methyldecane	No	6975-98-0	98155
Methylheptane	No	50985-84-7	90045
2-methylheptane	No	592-27-8	43296
2-Methyl nonane	No	871-83-0	90047
Tert-butyl methyl ether	No	1634-04-4	43376
meta-xylene	No	108-38-3	45205
Nonane	No	111-84-2	43235
Naphtha	No	8030-30-6	45101
Naphthalene	Yes	91-20-3	46701
Naphtha	No	8030-30-6	45101
Naphthalene	No	91-20-3	46701
Butyl acetate	No	123-86-4	43435
Butyraldehyde	No	123-72-8	43510
Nonane	No	111-84-2	43235
Nonane	No	111-84-2	43235
Octadecene	No	27070-58-2	
n-Octane	No	111-65-9	43233
Octene (mixed isomers)	No	25377-83-7	
ortho-xylene	No	95-47-6	45204

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
Parathion	Yes	56-38-2	
4-Aminohippuric Acid	No	61-78-9	
Phenol	Yes	108-95-2	45300
Silicone	No	63148-62-9	
Naphtha	No	8030-30-6	45101
Naphtha	No	8030-30-6	45101
Polyethylene	No	9002-88-4	
Poly(Isobutylene)	No	9003-27-4	
Chloromethyl pivalate	No	18997-19-8	
Process fuel gas	No	none	
Propionic Acid	No	79-09-4	43405
Propylene oxide	No	75-56-9	43602
para-xylene	No	106-42-3	45206
Styrene	Yes	100-42-5	45220
Sulfolane	No	126-33-0	
t-Butyl Alcohol	No	75-65-0	43309
t-Butyl Alcohol	No	75-65-0	43309
tert-butyl hydroperoxide	No	75-91-2	
Toluene	Yes	108-88-3	45202
Aqualyte(TM), LSC cocktail	No	25551-13-7	45107
1,3,4-Trimethylbenzene	No	95-63-6	45208
trimethylcyclopentane	No	30498-64-7	98058
trimethylpentane	No	29222-48-8	90092
Undecane	No	1120-21-4	43241
Vinyl acetate	Yes	108-05-4	43453
Vinyl acetate	Yes	108-05-4	43453
Vinyl chloride	Yes	75-01-4	43860
vinyl resin	No	none	
Vinylcyclohexane	No	695-12-5	
xylenes	Yes	1330-20-7	45102
xylenes	Yes	1330-20-7	45102
meta-xylene	Yes	108-38-3	45205
ortho-xylene	Yes	95-47-6	45204
para-xylene	Yes	106-42-3	45206
Mineral spirits	No	64475-85-0	43118
Propylene glycol	No	57-55-6	43369
Vinyl chloride	Yes	75-01-4	43860
1-Decene	No	872-05-9	90014
2-Ethyl-1-hexanol	No	104-76-7	43318
2-Pyrrolidone	No	616-45-5	
Aromatic	No	none	

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
Decene	No	25339-53-1	90014
2-N,N-Dibutylaminoethanol	No	102-81-8	86007
Diisopropanolamine	No	110-97-4	86004
N,N-Dimethylethanolamine	No	108-01-0	84004
trifluoroethane	No	27987-06-0	
2,2'-Oxybisethanol	No	111-46-6	43367
Hydrocarbons	No	none	
Methyl Formate	No	107-31-3	43430
Isopropylamine	No	75-31-0	86014
n-Butanol	No	71-36-3	43305
Polypropylene glycol ether	No		
N-Vinyl-2-Pyrrolidinone	No	88-12-0	
1,1-Di(t-Amylperoxy) Cyclohexane	No	15667-10-4	
1,2,3-Trimethyl-4-ethylbenzene	No	none	
2-Methyldecane	No	6975-98-0	98155
2-methylheptane	No	592-27-8	43296
2-Methyl nonane	No	871-83-0	90047
2,5-Dimethylhexane-2,5-dihydroperoxide	No	3025-88-5	
Butyl ether	No	142-96-1	43372
1,2-Dichloroethane	Yes	107-06-2	43815
Hydrindene	No	496-11-7	98044
Methylheptane	No	50985-84-7	90045
methyl methacrylate	No	80-62-6	43441
Naphtha	No	8030-30-6	45101
hexane	Yes	110-54-3	43231
tert-amyl hydroperoxide	No	3425-61-4	
1,3,4-Trimethylbenzene	No	95-63-6	45208
n-Butanol	No	71-36-3	43305
2-Butoxy ethanol	Yes	111-76-2	43308
hexane	Yes	110-54-3	43231
cycloheptane	No	291-64-5	43115
n-Heptane	No	142-82-5	43232
n-Octane	No	111-65-9	43233
Hexyl Carbitol	No	112-59-4	
Nonene	No	27215-95-8	
Silane, ethenyltrimethoxy	No	2768-02-7	
tetrahydrofuran	No	109-99-9	70014
Vinyl chloride	Yes	75-01-4	43860
Methyl Formate	No	107-31-3	43430
Phenyl ether	No	101-84-8	

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
phosgene	Yes	75-44-5	
1,2-Dichloroethane	No	107-06-2	43815
2-Butoxy ethanol	Yes	111-76-2	43308
Gasoline	No	86290-81-5	
1-Tridecanol	No	112-70-9	
1,2,4-Trichlorobenzene	Yes	120-82-1	45208
2-(2-Butoxyethoxy)ethanol	Yes	112-34-5	43312
2,3,4-trihydroxybenzophenone Ester	No	1143-72-2	
Methyl n-amyl ketone	No	110-43-0	43562
4,4-Cyclohexylidenebis[phenol]	No	843-55-0	
Anisole	No	100-66-3	
2-Butoxy ethanol	Yes	111-76-2	43308
Cresol-Formaldehyde novolac Resin	No	proprietary	
Decane	No	124-18-5	43238
gamma-Butyrolactone	No	96-48-0	
Dimethyl pentane	No	38815-29-1	90063
Dodecyl Benzenesulfonic Acid	No	27176-87-0	
Ethanol Amine	No	141-43-5	43777
ethyl lactate	No	687-47-8	
Hexamethyldisilazane	No	999-97-3	
Methyl ethyl ketone	No	78-93-3	43552
Cresol	Yes	1319-77-3	45605
Naphthalene Sulfonic Acid Resin	No		
Naphthalene Sulfonic Acid Resin	No		
n-Butanol	No	71-36-3	43305
Decane	No	124-18-5	43238
1-Methyl-2-pyrrolidinone	No	872-50-4	70008
Pentyl Ester Acetic Acid	No		
Phenol Formaldehyde Resin, Novolac	No		
Phenol Formaldehyde Resin, Novolac	No		
Propylene Glycol Monomethyl Ether	No	107-98-2	70011
Pyrocatechol	No	120-80-9	
Carbon Disulfide	Yes	75-15-0	43934
Hexene	No	592-41-6	43245
VOC	No	none	
Methacrylic acid	No	79-41-4	84009
Methyl 3-hydroxybutyrate	No	1487-49-6	
t-Butyl Alcohol	No	75-65-0	43309

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
methyl valeraldehyde	No	123-15-9	
Butyl Methacrylate	No	97-88-1	85008
dipropyl ether	No	111-43-3	
n-Propanol	No	71-23-8	43303
Propyl propionate	No	106-36-5	86052
1,2-Epoxybutane	Yes	106-88-7	
Methylamine	No	74-89-5	
1,1-Dimethylcyclohexane	No	590-66-9	
1,1-Dimethylcyclopentane	No	1638-26-2	
2-Methylpentane	No	107-83-5	43229
dimethyl butane	No	75-83-2	43291
2,3,3-Trimethylpentane	No	560-21-4	
2,3-Dimethylhexane	No	584-94-1	
2,3-Dimethylpentane	No	565-59-3	
2,4-Dimethylhexane	No	589-43-5	
2,5-Dimethyl-hexane	No	592-13-2	
2-Butoxy ethanol	Yes	111-76-2	43308
2-mercaptoethanol	No	60-24-2	
Bisphenol A	No	80-05-7	
straight-run middle distillate	No	64741-44-2	
4-Vinylcyclohexene	No	100-40-3	
straight-run middle distillate	No	64741-44-2	
Allyl alcohol	No	107-18-6	
xylenes	Yes	1330-20-7	45102
Naphthalene	Yes	91-20-3	46701
3-Methylethylcyclohexane	No		
VOC	No	none	
Gasoline	No	86290-81-5	
Butyl ether	No	142-96-1	
dimethyl butane	No	75-83-2	
Dodecene	No	25378-22-7	
Styrene	Yes	100-42-5	45220
tetrahydrofuran	No	109-99-9	70014
hexane	Yes	110-54-3	43231
2-Propanol	No	67-63-0	43304
liquified petroleum gas	No	68476-85-7	
Methyl acetylene propadiene	No		
methyl isobutyl ketone	Yes	108-10-1	
Methyl n-amyl ketone	No	110-43-0	43562
Methylpentane	No	43133-95-5	
Tert-butyl methyl ether	Yes	1634-04-4	43376

Table 1. Event emissions in the Houston-Galveston area. Representative contaminants included in the analysis, selected because they are either HAPs or VOCs with more than 5 carbon atoms. (These data were retrieved directly from the original database, which included multiple redundancies that did not affect the analysis and were left intact.)

Contaminant	*HAP*	*CAS*	*SAROAD*
Toluene	Yes	108-88-3	45202
Mineral oil	No	8012-95-1	
Gasoline	No	86290-81-5	
2,2-Dimethylpropane	No	463-82-1	43222
n-propylbenzene	No	103-65-1	
propylcyclohexane	No	1678-92-8	
n-Octane	No	111-65-9	43233
ortho-xylene	No	95-47-6	45204
Gasoline	No	86290-81-5	
propylenimine	No	75-55-8	
Gasoline	No	86290-81-5	
Technical White Oil	No		
Total Alkylate - non-speciated	No		
Trichloroethylene	Yes	79-01-6	
Di(2-ethylhexyl) peroxydicarbonate	No	16111-62-9	
trimethylcyclopentane	No	30498-64-7	98058
Ultraformate	No		
4-Vinylcyclohexene	No	100-40-3	

Table 2. Event emissions in the Houston-Galveston area. Major emitters reporting at least one release event of a representative substance.	
Company Name	*2004 VOC Emission Rate (lb/h)*
ATOFINA PETROCHEMICALS LA PORTE PLANT	47.88
BALL METAL BEVERAGE CONTAINER CONROE FACILITY	24.18
BASF FREEPORT SITE	46.47
BELVIEU ENVIRONMENTAL FUELS	112.3
BOC GROUP CLEAR LAKE BOC GASES PLANT	9.52
BP AMOCO CHEMICAL CHOCOLATE BAYOU PLANT	130.4
BP AMOCO CHEMICAL PASADENA PLANT	36.92
BP AMOCO POLYMERS	57.18
BP PRODUCTS NORTH AMERICA TEXAS CITY	737.4
BP TEXAS CITY CHEMICAL PLANT B	112.2
CELANESE BAY CITY PLANT	17.12
CELANESE CLEAR LAKE PLANT	53.11
CELANESE PASADENA PLANT	5.934
CHEVRON PHILLIPS CEDAR BAYOU PLANT	105.3
CHEVRON PHILLIPS CHEMICAL SWEENY COMPLEX	106.7
CHEVRON PHILLIPS HOUSTON CHEMICAL COMPLEX	215.7
CROWN BEVERAGE PACKAGING	18.05
CROWN CENTRAL PETROLEUM PASADENA PLANT	114.3
CROWN CORK & SEAL	18.10
DEER PARK LIQUID STORAGE TERMINAL	124.8
DOW CHEMICAL LA PORTE SITE	5.902
DOW TEXAS OPERATIONS FREEPORT	203.2
E I DUPONT DE NEMOURS AND COMPANY - LA PORTE PLANT	51.30
EQUISTAR CHEMICALS CHANNELVIEW COMPLEX	275.4
EQUISTAR CHEMICALS CHOCOLATE BAYOU COMPLEX	84.87
EQUISTAR CHEMICALS LA PORTE COMPLEX	90.97
EXXON MOBIL CHEMICAL BAYTOWN OLEFINS PLANT	84.73
EXXONMOBIL CHEMICAL BAYTOWN CHEMICAL PLANT	313.7
EXXONMOBIL CHEMICAL MONT BELVIEU PLASTICS PLANT	40.64
GOODYEAR HOUSTON CHEMICAL PLANT	85.68
ISP TECHNOLOGIES TEXAS CITY PLANT	22.12
KANEKA TEXAS CORPORATION	20.55
KINDER MORGAN LIQUID TERMINALS PASADENA	913.9
KINDER MORGAN LIQUIDS TERMINALS	132.7
LBC HOUSTON BAYPORT TERMINAL	12.83
LYONDELL CHEMICAL BAYPORT PLANT	30.04
LYONDELL CHEMICAL CHANNELVIEW	74.15
MARATHON ASHLAND PETROLEUM TEXAS CITY REFINERY	111.8
MOBIL CHEMICAL HOUSTON OLEFINS PLANT	26.29
MORGANS POINT PLANT	31.03
PASADENA PLANT	13.40

Table 2. Event emissions in the Houston-Galveston area. Major emitters reporting at least one release event of a representative substance.

Company Name	*2004 VOC Emission Rate (lb/h)*
SHELL OIL DEER PARK	405.2
SOLUTIA CHOCOLATE BAYOU PLANT	53.09
STOLTHAVEN HOUSTON TERMINAL	7.347
SWEENY COMPLEX	157.1
UNION CARBIDE TEXAS CITY OPERATIONS	174.4
VALERO REFINING TEXAS CITY	260.1
WHARTON GAS PLANT	7.552

Table 3. Frequency distribution for ratio of event emission rate to long-term emission rate

Bin	*Frequency*	*Cumulative Frequency*
1.00E-08	0	0
3.16E-08	0	0
1.00E-07	2	2
3.16E-07	1	3
1.00E-06	0	3
3.16E-06	2	5
1.00E-05	1	6
3.16E-05	2	8
1.00E-04	5	13
3.16E-04	9	22
1.00E-03	15	37
3.16E-03	28	65
1.00E-02	33	98
3.16E-02	41	139
1.00E-01	59	198
3.16E-01	38	236
1.00E+00	33	269
3.16E+00	31	300
1.00E+01	16	316
3.16E+01	2	318
1.00E+02	1	319
3.16E+02	0	319

Table 4. Statistics for ratio of event emission rate to long-term emission rate	
Statistic for Ratio	*Value*
Median	0.043923
75th %ile	0.342655
90th %ile	2.204754
95th %ile	3.344422
96th %ile	3.400832
97th %ile	3.8126
98th %ile	4.790098
99th %ile	8.973897
Max	74.37138
Average	0.815352

Figure 1. Cumulative probability density for ratio of event to routine emission rates.

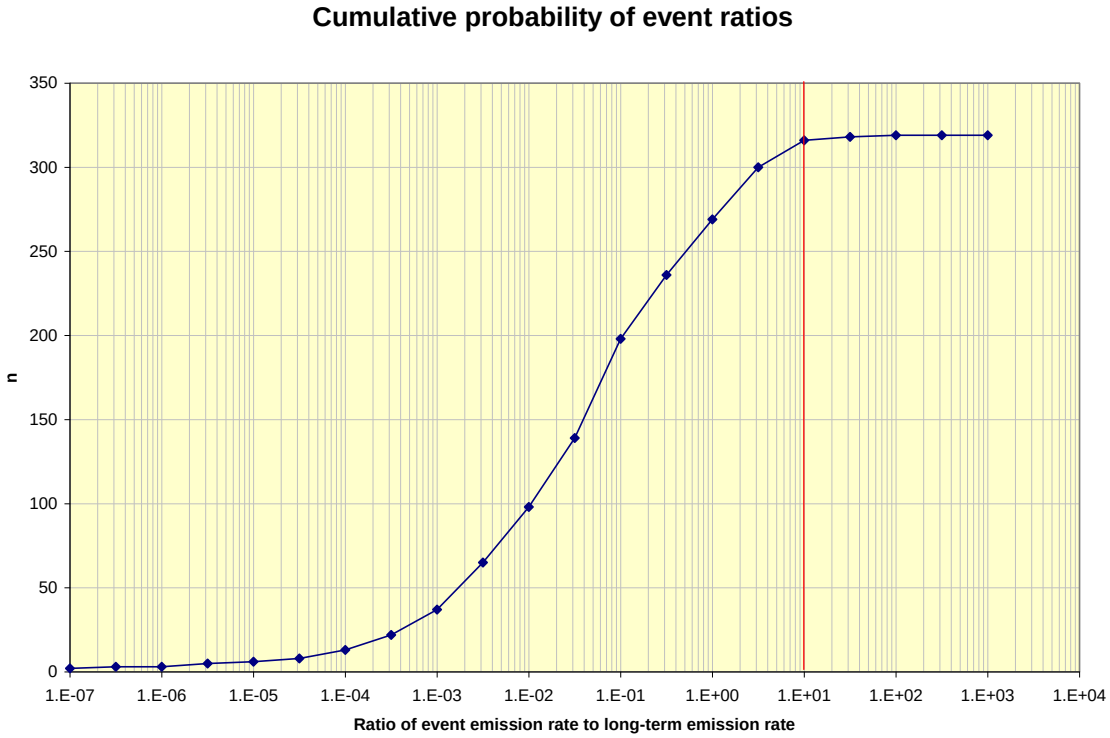


Figure 2. Relationship between ratio of event to duration emission rate and emission duration.

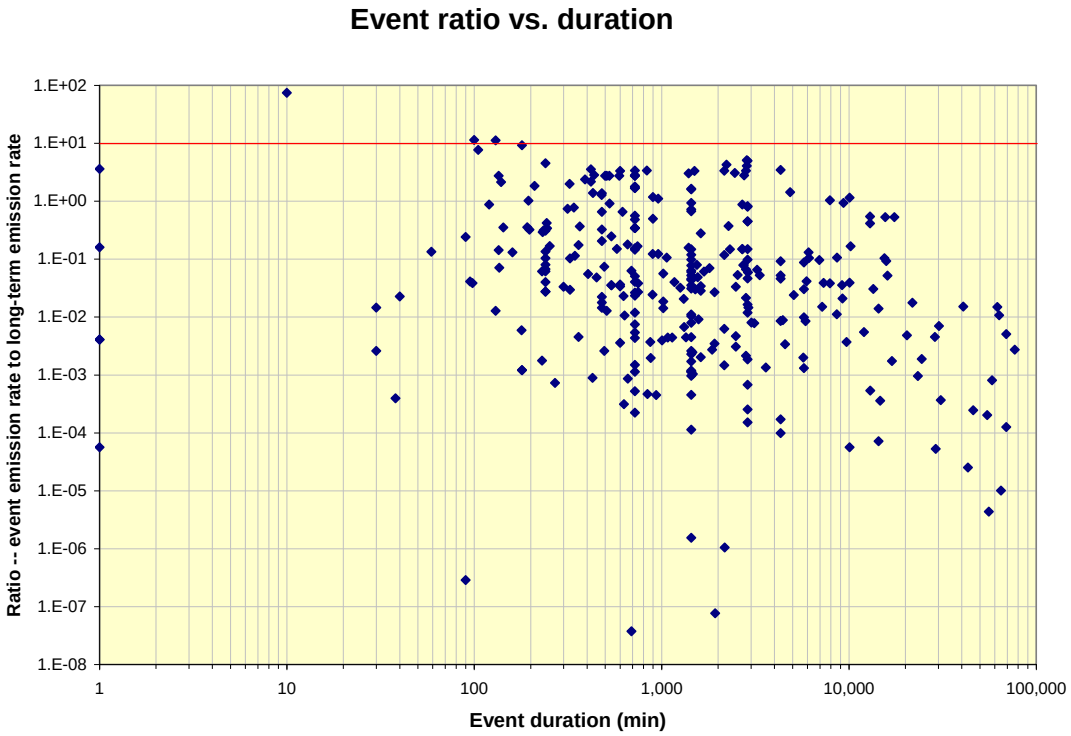


Figure 3. Relationship between ratio of event to duration emission rate and emission duration, as percentage of total time.

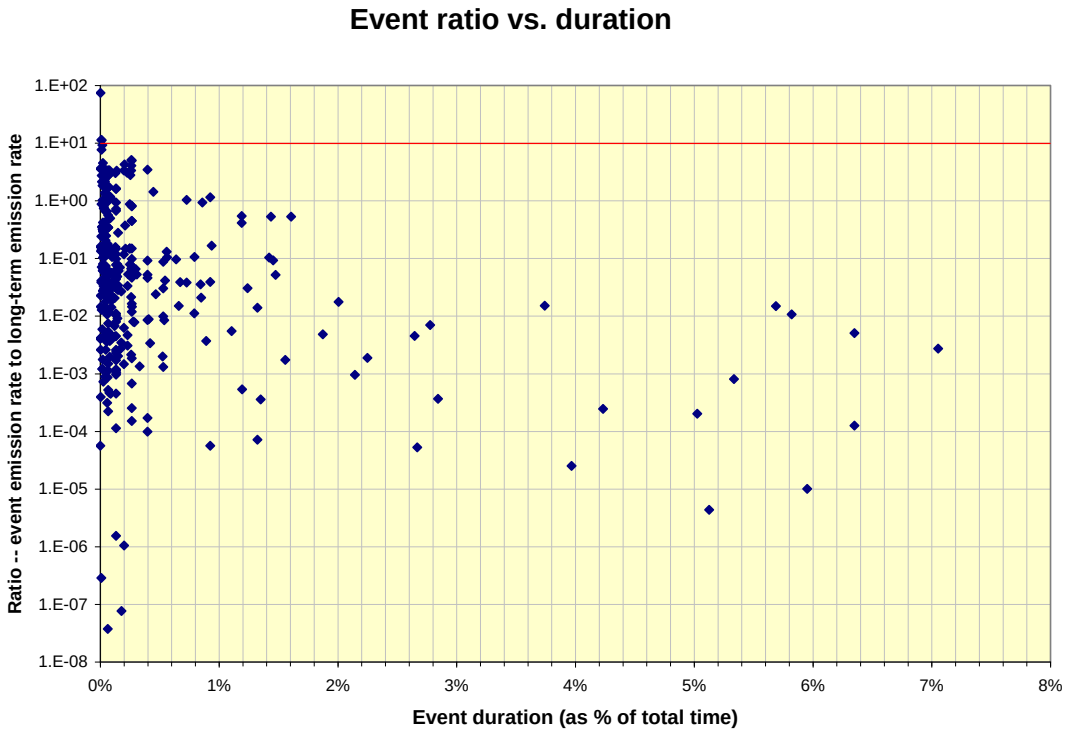
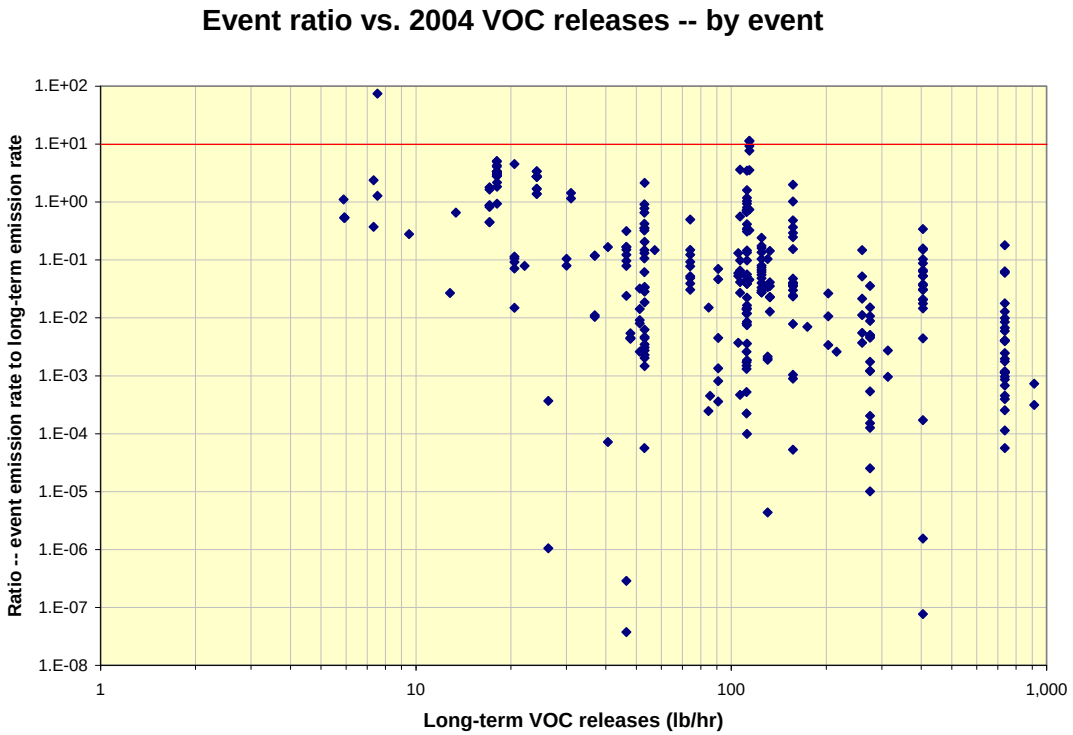


Figure 4. Relationship between ratio of event to duration emission rate and total amount emitted during the event.



II. Basis for Reasonable Worst-Case Air Dispersion Conditions

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May 16, 2019

Introduction

In developing an acute exposure scenario, we estimate 1-hour exposure concentrations through air dispersion modeling during hours of peak emissions. However, hourly emissions data are not typically available, and the exact hours of peak emissions are often unknown, making it difficult to determine the air dispersion conditions to model with the peak emissions. Therefore, we make assumptions about when peak hourly emissions occur. In a worst-case scenario, peak hourly emissions would occur during the one hour of the year with the worst-case air dispersion conditions (i.e., low, continuous wind speeds blowing in a specific direction). However, the probability of these two events occurring simultaneously is, in most cases, extremely low. For example, if we select, from the set of data presented in Section I of this document (which represent accidents, equipment failures, maintenance, startup, and shutdown for facilities in one state and may not representative all types of peak emission events, e.g., batch processes, across different source categories), the facility with the greatest number of hours of peak emission events (i.e., hours where the ratio of the peak short-term emission rate to the long-term emission rate is greater than 1), we find that the probability of these peak emission events occurring at the same hour as the worst-case air dispersion conditions is 1 in 200,000 (or a 0.0005% chance). Alternatively, if we use the average number of hours from all facilities where the ratio of the peak short-term emission rate to the long-term emission rate is greater than 1, the probability decreases to 1 in 1,000,000. Finally, if we use only hours when the ratio of the peak short-term emission rate to the long-term emission rate is 10 or more, the probability decreases further to 1 in 15,000,000. Therefore, using the one hour of worst-case air dispersion conditions would reflect an exposure scenario with little probability of occurring and therefore likely overestimate potential exposure events (i.e., estimate false positive acute exposures).

As an alternative approach, we could assume peak hourly emissions occur during mean or median air dispersion conditions; however, this would likely underestimate potential exposure events, as approximately half of all modeled acute exposures would be higher than estimated with this assumption. This scenario would have a much higher probability of occurring (a 1 in 50 chance for the one facility where the ratio of the peak short-term emission rate to the long-term emission rate is greater than 1 from the set of data in Section I of this document) but would not necessarily be health protective.

This points to a need to identify air dispersion conditions that would estimate an acute exposure scenario that: 1) is health protective without overestimating acute exposures (i.e., false positives), and 2) has a reasonable probability of occurrence.

Methods

To identify reasonable worst-case air dispersion conditions that satisfy the two criteria described above, air dispersion modeling was performed with AERMOD (v18081). Unit emissions from a model plant were modeled along with meteorological input from 824 ASOS meteorological

stations (see Appendix 3 for a full list of stations), which are located throughout the United States. The model plant consisted of a single 1 m^2 area source located at ground level. Modeling was performed for two sets of meteorological data, one for the year 2014 and the other for the year 2016.

Hourly modeling results were then analyzed to determine the distribution of values, with analysis performed both on each individual model plant output as well as the entire dataset. As emissions were constant, differences in concentrations are directly attributed to differences in meteorological (i.e., air dispersion) conditions.

Results

Table 1 provides the average concentrations estimated for all model scenarios, normalized by the mean. When comparing the hours with the maximum concentrations (i.e., worst-case dispersion) to the average, the data indicate that the 1-hour worst-case air dispersion conditions, which in most cases occurred in winter months and the hours just before sunrise (i.e., 6-8 AM LST), predict a concentration 22.5 times higher than the average. The 99th percentile worst-case dispersion conditions (i.e., the 88th highest value for a year, out of 8,760 hours) is 11.4 times higher than the mean.

Table 1. Average metrics for concentrations modeled across all model plants and years, normalized by the mean concentration.

Metric	Value
Mean	1
Standard Deviation	2.2
90% Percentile	2.8
95% Percentile	5.3
98% Percentile	9.0
99% Percentile	11.4
Maximum	22.5

Upon examining the concentrations at individual model plants, we found that for each model scenario the distribution was skewed right (Figure 1). The maximum concentration estimated using the worst-case air dispersion conditions was significantly higher than the most commonly occurring concentrations and is an extreme value compared to the rest of the distribution.

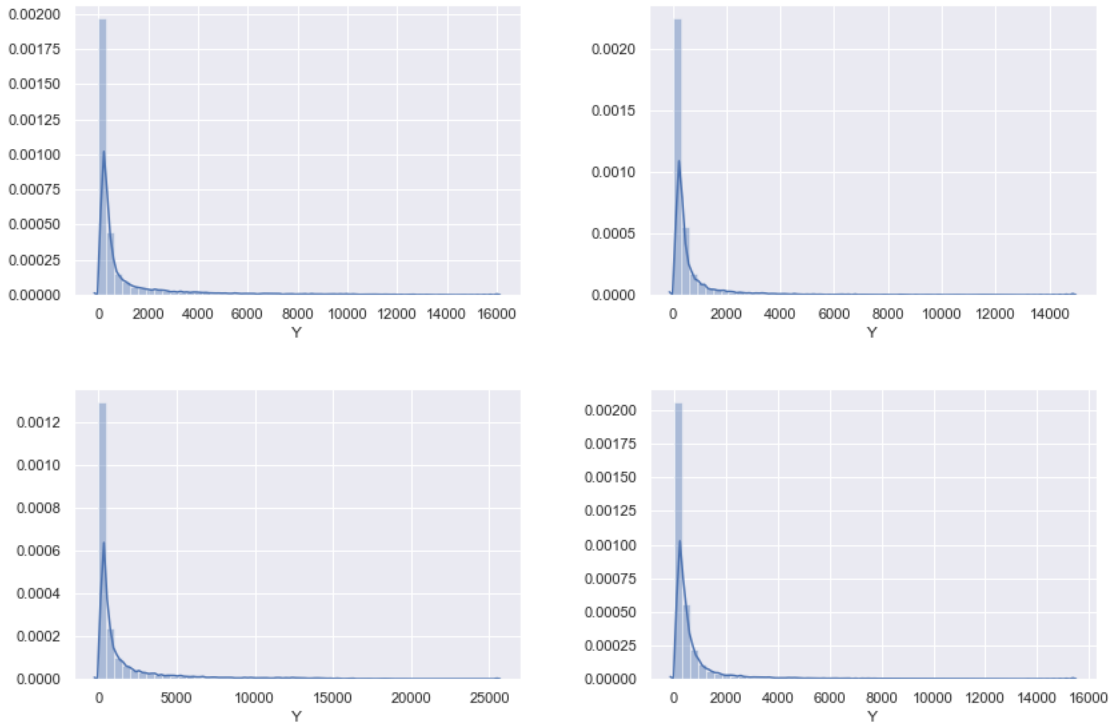

Figure 1. Representative histograms and probability density functions for model scenarios performed with meteorological inputs from meterological stations located in Tennessee (top left), California (top right), Michigan (bottom left), and Alaska (bottom right). The x-axis is the relative concentration based on unit emissions and the y-axis is the probability of that concentration occurring. Note that all model scenarios produced similar results.

To provide a statistical basis for identifying the maximum concentration as an extreme value, we used the adjusted boxplot for skewed distributions.[1] This tool was specifically designed for skewed distributions and able to identify extreme values in the distribution (i.e., outliers). The results of that analysis indicated that in all modeled cases, the maximum concentration was always statistically identified as an extreme value. For comparison, the 99th percentile highest concentration was found to be an extreme value in 99 percent of scenarios, the 98th percentile would be an extreme value in 92 percent of cases, the 95th percentile would be an extreme value in 22 percent of cases, and the 90th percentile was never identified as an extreme value. For reference, Figure 2 shows representative adjusted boxplots for 4 randomly selected model plants.

[1] Hubert, M. and Vandervieren, E., 2008. An adjusted boxplot for skewed distributions. *Computational statistics & data analysis*, *52*(12), pp.5186-5201.

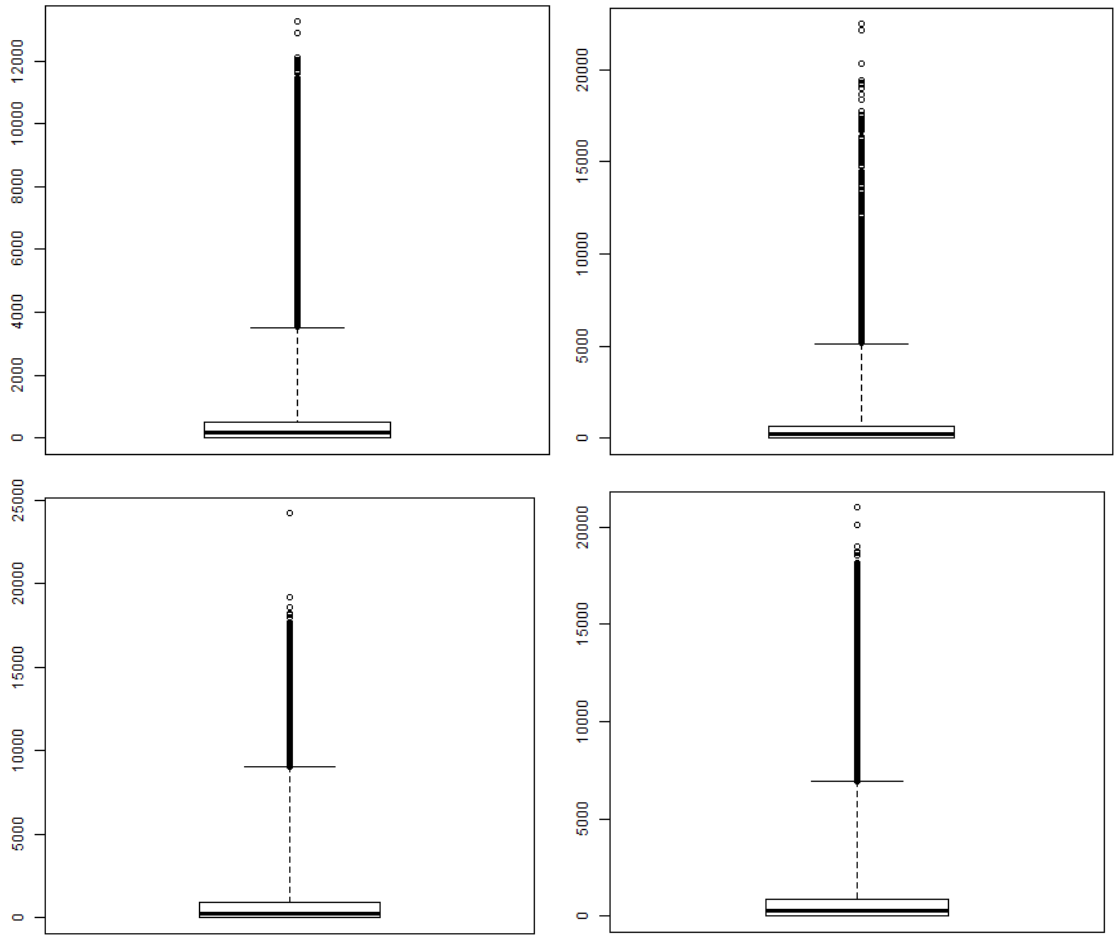

Figure 2. Representative adjusted box and whisker plots for model scenarios performed with meteorological inputs from meterological stations located in Alabama (top left), Iowa (top right), New York (bottom left), and Oregon (bottom right). The x-axis is the relative concentration based on unit emissions. Extreme values (i.e., outliers) are represented by open circles. Note that all model scenarios produced similar results.

Discussion

As discussed in the introduction to this section, our goal was to identify air dispersion conditions that provided an exposure scenario that was 1) health protective without overestimating acute exposures (i.e., false positives), and 2) has a reasonable probability of occurring. We also previously noted that neither the worst-case hour nor the mean hour fits this description. Therefore, we considered other meteorological hours and corresponding air dispersion conditions to use to estimate exposure scenarios. Hours initially considered included the 90th percentile, 95th percentile, 98th percentile, and 99th percentile air dispersion conditions.

Figure 3 illustrates the probability density function and adjusted boxplot for a representative model scenario and locates each of these hours on the plots.

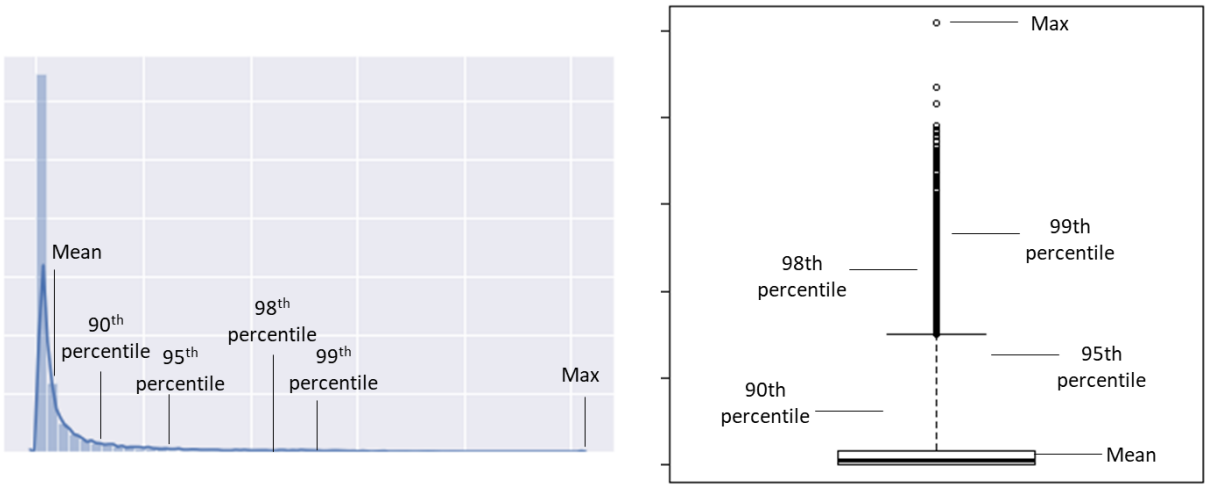

Figure 3. Histogram and probability density function (left) and adjusted box and whisker (right) plots for a representative model scenario. The location of the mean, 90th, 95th, 98th, 99th, and max concentrations are identified on each plot. Extreme values (i.e., outliers) on the box and whisker plot are represented by open circles.

Conclusion

Based on this analysis, we selected the 99th percentile air dispersion conditions as the value to represent a reasonable worst-case air dispersion. The 99th percentile value has a higher probability of occurring (approximately 88 in 200,000, or 1 in 2,273 (a 0.044% chance) for the one facility with the most hours with a peak short-term emission rate to long-term emission rate greater than 1 from Part I of this Appendix) but is still considered an extreme value in essentially all the modeled cases (i.e., reasonable worst-case air dispersion conditions), and therefore health protective. Thus, the HEM-3 acute analysis will utilize the 99th percentile highest hourly ambient concentration (the 88th highest concentration for a 1-year simulation) when estimating acute level noncancer risks.

Appendix 6

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

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

February 2021

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Contents

Exhibits

Acronyms

3MRA	Multimedia, Multipathway, and Multireceptor Risk Assessment Modeling System
ADAF	age-dependent adjustment factor
ADD	average daily dose
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
AT	averaging time
BAF	bioaccumulation factor
BaP	benzo[a]pyrene
BC	benthic carnivore (fish)
BCF	bioconcentration factor
BI	benthic invertebrate
BMF	biomagnification factor
BO	benthic omnivore (fish)
BSAF	biota-sediment accumulation factor
BW	body weight
CSF	cancer slope factor
DDE	dichlorodiphenyldichloroethylene
ED	exposure duration
EEF	exposure equivalency factor
EF	exposure frequency
EPA	U.S. Environmental Protection Agency
ER	emission rate
ESRI	Environmental Systems Research Institute
FC	fraction contaminated
HAP	hazardous air pollutant
HHRAP	Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities
HQ	hazard quotient
IR	ingestion rate
IRIS	Integrated Risk Information System
LADD	lifetime average daily dose
MACT	maximum achievable control technology
MVP	minimum viable population
NAAQS	National Ambient Air Quality Standards
NATA	National Air Toxics Assessment
NCDC	National Climatic Data Center
NEI	National Emissions Inventory
OAQPS	Office of Air Quality Planning and Standards (U.S. EPA)
ORD	Office of Research and Development (U.S. EPA)
PAH	polycyclic aromatic hydrocarbon
PB	persistent and bioaccumulative
PB-HAP	persistent and bioaccumulative hazardous air pollutant
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
POM	polycyclic organic matter
REF	risk equivalency factor
RfD	reference dose

RGP	reactive gaseous phase
RTR	Risk and Technology Review
RZ	root zone
SAB	Science Advisory Board
SV	screening value
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin, termed “dioxin” in this report
TEF	toxic equivalency factor
TL	trophic level
TL2	trophic level 2
TL3	trophic level 3
TL3.5	between trophic level 3 and 4
TL4	trophic level 4
TPY	short tons per a year
TRIM	Total Risk Integrated Methodology
TRIM.FaTE	TRIM’s Fate, Transport, and Ecological Exposure module
TSD	Technical Support Document
USGS	U.S. Geological Survey
USLE	universal soil loss equation
WBAN	Weather Bureau-Army-Navy
WCC	water-column carnivore (fish)
WCH	water-column herbivore (fish)
WCO	water-column omnivore (fish)

1. Introduction

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. These risk assessments are a major component of EPA's Risk and Technology Review (RTR) program. One aspect of human health that EPA must consider under RTR is the potential for health effects resulting from exposures to HAPs via non-inhalation pathways, namely ingestion and dermal exposure. These non-inhalation human health risks are considered in combination with estimated inhalation human health risks, potential ecological impacts, and other factors to support RTR decisions. This report documents the technical bases and methods used for RTR non-inhalation human health risk screens.

This section introduces the reader to the Total Risk Integrated Methodology (TRIM)-Based Multipathway Tiered Screening Methodology. It describes the purpose of the RTR program and this Technical Support Document (TSD, Section 1.1) and provides an overview of the multipathway screening approach (Section 1.2). This section also provides an overview of the tiered implementation of the screen (Section 1.3), the chemicals that are evaluated in the RTR mulitpathway screen (Section 1.4), and the organization of the remainder of the TSD (Section 1.5). The subsequent main sections, 2 through 4 of this report, describe Tiers 1 through 3 of the screen in greater detail. References are listed in Section 5.

1.1 Purpose of RTR Multipathway Screens

As noted above, Section 112 of the CAA directs EPA to assess the residual risk from emissions of HAPs following the implementation of MACT standards for emission sources. Facilities are grouped into source categories, and each source category is evaluated independently. As part of this program, EPA considers additional emission controls for a source category if the current MACT does not provide an "ample margin of safety" to protect human health.

EPA's Office of Air Quality Planning and Standards (OAQPS) has identified specific persistent and bioaccumulative HAPs (PB-HAPs) for which it must consider all possible routes of exposure—inhalation, ingestion, and dermal. EPA must evaluate potential ingestion and dermal exposures to PB-HAPs deposited from air to ground-level surfaces, considering subsequent transport and fate of those chemicals in the environment. For PB-HAPs, exposures via ingestion have been shown to be much higher than exposures via dermal absorption (see Attachment C.

EPA OAQPS has developed an iterative, tiered approach to screen exposure and risk specifically for multimedia ingestion of PB-HAPs for its RTR program. The iterative, tiered screening approach described in this document allows EPA to efficiently gauge the largest potential exposures and health risks from non-inhalation exposure to emitted PB-HAPs in a source category. If the conclusion of a screen is that exposures and health risks above levels of concern cannot be ruled out, EPA can conduct refined, complex, site-specific modeling of potential risks (which is not discussed in this document).

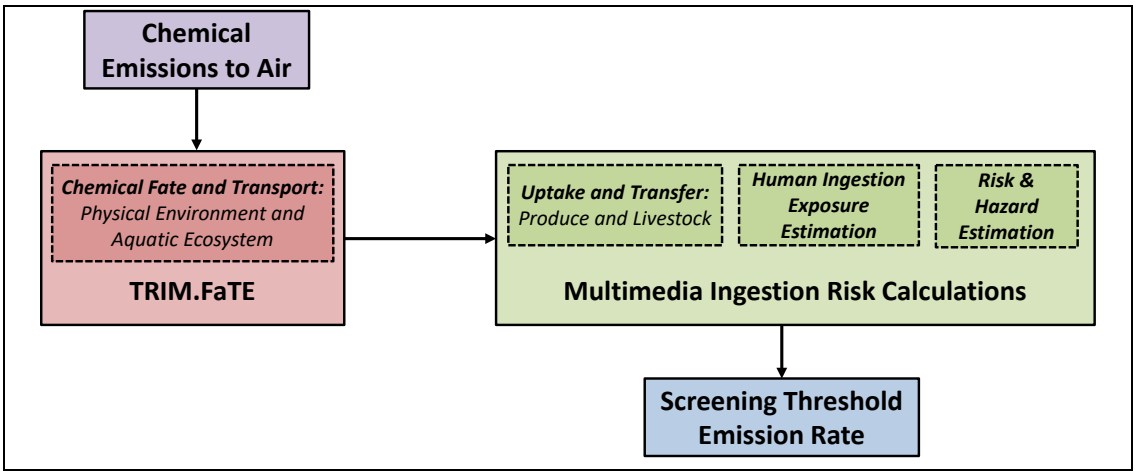
EPA evaluates human inhalation exposures to HAPs separately using other tools. For each source category, EPA OAQPS considers risks to humans from ingestion exposures along with risks from inhalation, potential ecological and other environmental impacts, and other factors when deciding if regulatory action is needed.

1.2 Overview of Multimedia Ingestion Screening Methods

The screening approach and tools are summarized in Exhibit 1 and described below.

1. We use TRIM.FaTE—the Fate, Transport, and Ecological Exposure module of TRIM—to model fate and transport of air emissions of PB-HAPs using a base emission rate of 1 g/d. This modeling includes chemical partitioning across soil, water, and other environmental media (including fish). TRIM.FaTE outputs include chemical concentrations in fish (mg/kg wet weight), soil (µg/g dry weight), and water (mg/L), and deposition rates for chemicals from air via wet and dry deposition.

Exhibit 1. Overview of Ingestion Exposure and Risk Screening Evaluation Method



2. We use TRIM.FaTE outputs (e.g., chemical air deposition and environmental media concentrations) as inputs to multimedia ingestion risk calculations that include ingestion of PB-HAPs in locally raised foods (e.g., produce, livestock, and dairy products). The multimedia risk estimation methods are based on EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (U.S. EPA 2005a).
3. The calculated chemical concentrations in the ingested media, along with food ingestion rates and other exposure factors, are used to estimate ingestion exposures from the selected media for hypothetical human receptors. Specifically, estimates are made of average daily doses (ADDs) for the noncarcinogenic chemicals assessed (i.e., for cadmium and mercury) and lifetime ADDs (LADDs) for the carcinogenic chemicals (i.e., for arsenic, dioxins/furans [abbreviated in this document as dioxins]), and polycyclic organic matter [POM]).
4. Chemical-specific lifetime cancer risk or chronic noncancer hazard (expressed as a hazard quotient [HQ]) are estimated for each PB-HAP at a modeled emission rate of 1 g/d.
5. For each PB-HAP, based on the estimated cancer risk or HQ at the 1 g/d emission rate, we determine the emission rate at which the excess lifetime cancer risk equals 1-in-one million or the noncancer HQ equals 1. These emission rates are termed "screening threshold emission rates."
6. We then compare a facility's PB-HAP emission rate to the screening threshold emission rate for each PB-HAP emitted (e.g., a facility's actual cadmium emission rate would be compared to the screening threshold emission rate for cadmium). The resulting ratio of a facility's

actual emission rate to the screening threshold emission rate is termed a "screening value" or SV.

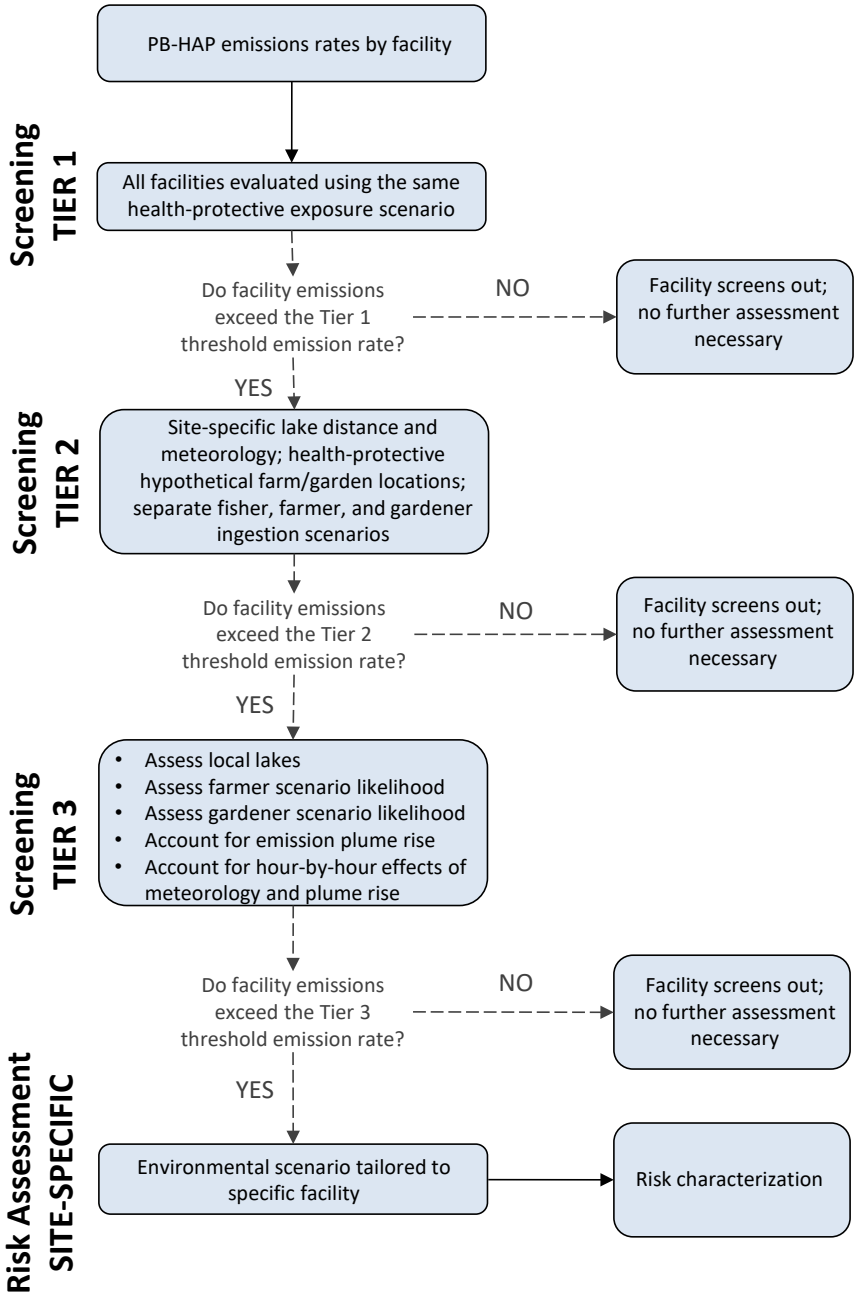
1.3 Tiered Approach

EPA developed the tiered approach to screen out PB-HAP emissions unlikely to pose health risks above levels of concern, allowing the Agency focus on facilities and chemicals of greatest concern within a source category. Sensitivity analyses and model testing revealed 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) influence estimated chemical concentrations in air, soil, water, sediment, and fish more than physical/chemical parameter values of the PB-HAPs. As discussed in detail below, the Tier 1 assumptions about meteorological data and lake location are refined with more site-specific data in subsequent tiers. In addition, if a facility does not screen out, we further evaluate the surrounding land use to determine if the exposure scenario is realistic, and if not, we remove the exposure scenario from evaluation. For example, if a farmer scenario does not screen out, and we determine that exposures are in an urban setting and it is unlikely that a full-scale farming operation will operate in the vicinity, we will remove the farmer exposure scenario. The iterative approach is divided into three tiers of increasing refinement as illustrated in Exhibit 2 and described below.

- Tier 1 compares facility-specific PB-HAP emissions to the screening threshold emission rates for a hypothetical scenario in which an individual eats locally caught fish; consumes only homegrown produce, livestock, and livestock products (e.g., eggs, meat, dairy products); and incidentally ingests local soil. The ingestion rate for each ingested medium was set to an upper percentile value. This approach overestimates total chemical exposure for a single hypothetical individual, but it will not miss an important exposure pathway. The screening scenario represents a "worst-case" ingestion exposure that is unlikely to be exceeded at any actual facility evaluated for the RTR program. For a facility, if the emission rate of each PB-HAP is less than the Tier 1 screening threshold emission rate (i.e., if the SVs are less than or equal to 2, when rounded to one significant figure), no additional multipathway screening is done. If, however, the emission rate of any PB-HAP exceeds the Tier 1 screening threshold emission rate (i.e., an SV of 2 or more, when rounded to one significant figure), the facility can be evaluated further in Tier 2.
- In Tier 2, the actual location of each modeled facility is used to refine some assumptions associated with the environmental scenario. Combinations of meteorological conditions, lake locations, and farming locations were systematically varied, and TRIM.FaTE and multimedia exposure algorithms were used to calculate screening threshold emission rates for PB-HAPs for each combination, or bin (see Section 3.2). For each facility, an algorithm identifies the predefined bin that most closely matches the local weather conditions and relative location(s) of fishable lakes for that facility. Multiple hypothetical farming locations also are evaluated for each facility. The facility's emissions are compared to the screening threshold emission rates for the best-match bin for each PB-HAP to determine SVs. Unlike Tier 1, which considers combined ingestion of fish, farm foods, and soil, Tier 2 separately screens a hypothetical person consuming fish and a hypothetical person consuming farm foods and soil (i.e., the Tier 1 ingestion scenario is disaggregated into separate hypothetical subsistence farmer and subsistence fisher exposure scenarios). In addition, a gardener exposure scenario is added in Tier 2 to represent exposures to individuals who garden and eat eggs from home-raised chickens, but who do not raise animals for meat or dairy ingestion. Hypothetical gardeners and hypothetical farmers are

evaluated at identical locations (and thus use the same calculated media concentrations). The gardener's ingestion rates for consumed media depend upon whether or not the facility is located in an urban or rural area (lower ingestion rates are assumed for gardeners in urban areas compared with rural areas, see: Section 3.2.3). If the resulting SVs are all less than 2 (when rounded to one significant figure), no additional screening is needed. Facilities with SVs greater than or equal to 2 (when rounded to one significant figure) for one or more PB-HAPs, for any of the exposure scenarios, can be further analyzed in Tier 3.

Exhibit 2. Conceptual Decision Tree for Evaluating Non-Inhalation Exposures for PB-HAPs



- In Tier 3, further site-specific refinements are included in the screen.
  - To further evaluate a fisher scenario SV exceedance (i.e., an SV of 2 or greater), nearby lakes are examined more closely for suitability for fishing; unsuitable lakes are removed from the lake database, and the facility is rescreened (using Tier 2 methods) with the revised lake database.
  - To further evaluate a farmer SV exceedance, EPA uses census data, aerial imagery, and other available data to further assess the likelihood of subsistence farmer operations within 50 km of the facility. If, based on the additional analysis and review, it cannot be determined that subsistence farming operations are in the area, then the farmer scenario is not used in Tier 3 and only gardener SVs are reported.
  - To further evaluate a gardener exceedance, EPA will examine information such as Census data, aerial imagery, and land-use data to determine the likelihood that people reside at the location of the gardener exceedance. If EPA determines that people likely reside at that location, the Tier 2 gardener SV will be retained in Tier 3. Otherwise, EPA will report the highest gardener SV for locations at which EPA determines people likely reside.
  - Each of the next two refinements (i.e., plume-rise and hourly weather data) can result in different Tier 3 screening threshold emission rates. Facilities having emissions that exceed the refined screening threshold emission rates for Tier 3 (i.e., SVs are 2 or more as described previously) may require additional analysis.

If, based on results of the screens, a risk assessor concludes that there is a reasonable probability that individual humans could be adversely affected by the facility emissions, a refined site-specific multipathway assessment can be performed. The land parcels are defined using geographic features around a facility that define the magnitude of runoff and erosion. The lake parcels follow the general shapes of the actual lakes. 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, location of local farms/gardens and water bodies, types of land use, soil properties, erosion and runoff rates with slope features, surface water and sediment properties, water transfer rates, and aquatic ecosystem information. If available, other site-specific information could be included (e.g., crops grown, local fish ingestion rates, typical growing season).

1.4 Chemicals of Potential Concern

EPA's assessment of multipathway human exposures for RTR focuses on PB-HAPs that OAQPS has identified as candidates for multipathway risk assessments. OAQPS developed a list of 14 chemicals and chemical groups considered to be PB-HAPs using two criteria:

- Their presence on three 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 (U.S. EPA 2004a). Exhibit 3, below, presents the 14 PB-HAP chemicals and chemical groups, with the addition of arsenic, which was not in the original list (see Exhibit endnote). TRIM.FaTE is not parameterized to evaluate risk for all PB-HAPs on the list. Currently, TRIM.FaTE includes chemical-specific parameter values required for modeling exposure and risk for four of the 14 PB-HAPs (as indicated in Exhibit 3) plus arsenic. These five PB-HAPs are the focus of the RTR multimedia screen 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.[1]

The five PB-HAPs assessed under RTR include:

- Arsenic compounds,
- Cadmium compounds,
- Chlorinated dibenzodioxins and furans (dioxins),
- Mercury compounds, and
- Polycyclic organic matter (POM[2]).

Exhibit 3. OAQPS PB-HAP Compounds

PB-HAP Compound[a]	Addressed by Screening Scenario?
Arsenic[b]	Yes
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

[1]Potential impacts on human health from non-inhalation exposures to lead are evaluated for RTR using the National Ambient Air Quality Standard (NAAQS) for lead, which accounts for 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.

[2]Although POM (polycyclic organic matter) is the HAP listed in the Clean Air Act, most of the POM chemicals evaluated are “polycyclic aromatic hydrocarbons” or PAHs. Throughout this document, PAH and POM can generally be considered interchangeable. There are, however, instances where the discussion is specific to one or the other group of chemicals; for example, when discussing regulatory chemical groups or properties that are specific to a specific chemical class, or when providing information from a referenced source we use the chemical class specified in that source.

PB-HAP Compound[a]	Addressed by Screening Scenario?
Toxaphene	No
Trifluralin	No

[a]Source of list: U.S. EPA (2004a).
[b]Arsenic was not in the OAQPS initial list of PB-HAPs because its bioaccumulation potential is limited. It was recently added, however, because it is carcinogenic at very low doses, is persistent in the environment, and is emitted from many source categories. We refer to it as one of five PB-HAPs in the RTR multipathway assessment.

1.5 Report Organization

The remainder of this document is organized into four sections. Section 2 describes the Tier 1 screen, including the spatial layout of the hypothetical facility environment, the Tier 1 exposure scenario, and derivation of Tier 1 screening threshold emission rates.

Section 3 describes use of readily available site-specific information to refine estimates of screening threshold emission rates for Tier 2, and other aspects of the Tier 2 assessment. Section 4 discusses additional refinements that can be applied, sequentially, in Tier 3. References are listed in Section 5.

2. Tier 1 Screen

EPA's multimedia risk screen for RTR focuses on PB-HAPs that OAQPS identified as candidates for multimedia ingestion risk assessments (Section 1.4). Sources that are "screened out" at Tier 1 are assumed to pose no risks to human health. For sources that do not pass the Tier 1 screen, more refined screens, up to and including site-specific assessments, can be conducted as appropriate.

Using a worst-case hypothetical screening scenario for Tier 1 minimizes the chance that a facility that actually poses a risk to human health screens out. However, the scenario is not so biased that it never screens out facilities. An abundance of "false positives" would not help EPA focus on the facilities and PB-HAPs with emissions of actual concern.

This section describes the technical basis for Tier 1 of EPA's human multimedia ingestion screen of PB-HAP emissions from RTR sources. Specifically, the scenarios, models, configurations, and inputs used to derive screening threshold emission rates are described in detail in four subsections:

- Section 2.1 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 2.2 and 2.3 present technical descriptions of the hypothetical environmental setting, the exposure scenario used in Tier 1, and the models used in the screen.
- Section 2.4 provides a brief discussion of the screening threshold emission rates for each of the chemicals assessed.

Finally, Section 2.5 provides evaluations of the screening scenario for each of the modeled chemicals or chemical groups.

2.1 Overview of Tier 1

An ideal screening approach strikes a balance between being health-protective—to ensure that risks above levels of concern are identified (i.e., no false negatives)— and being accurate—to minimize false positives (i.e., results suggesting that additional analysis is required when, in fact, the actual risk is low). Typically, gains in accuracy in environmental modeling (i.e., reductions of both false positives and false negatives) require additional resources.

The Tier 1 hypothetical watershed includes a farm homestead and a fishable lake near the facility, 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 health-protective; i.e., designed to maximize PB-HAP chemical concentrations in the food sources. The many 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. Health-protective values (e.g., upper-percentile values from a national distribution) are used for parameters that most influence exposure and risk. Including central-tendency values for the remaining parameters should help limit the number of false positives. False positives (i.e., results that suggest more assessment is required when in fact the actual risk is low) waste resources by leading to additional, unnecessary analysis. The Tier 1, TRIM.FaTE-based, multipathway fate and transport modeling scenario, or "Tier 1 scenario," is used to determine the Tier 1 screening threshold emission rates for comparison with individually reported facility emissions. The Tier 1 scenario includes the Tier 1 spatial layout for a hypothetical watershed and the assumptions and input values for a health-protective exposure and risk screen. The Tier 1 scenario is a static configuration that calculates a Tier 1 screening threshold emission rate for each of the five PB-HAP chemical groups.

The Tier 1 approach for evaluating multimedia ingestion exposures to PB-HAPs for RTR is diagrammed in Exhibit 4. Air toxics emitted by a source under consideration are reviewed to determine, first, whether emissions are reported for any of the five PB-HAPs of concern for non-inhalation pathways. If such emissions are reported, the emission rates are compared to Tier 1 screening threshold emission rates derived for each PB-HAP as described in this section. A screening threshold emission rate is the rate that corresponds to a cancer risk of 1-in-one million or an HQ of 1.

Exhibit 5 presents those rates for the five PB-HAP groups.[3]

As depicted in Exhibit 4, the final decision point in the Tier 1 evaluation for a given facility has two possible outcomes:

- Emissions are equal to or less than the threshold emission rate of concern and therefore the facility screens out from further evaluation (SV ≤1); or
- Emissions are above the threshold emission rate of concern (SV >1), and risks from ingestion exposures cannot be ruled out (the facility does not screen out).

[3]For chemicals known to cause both cancer and chronic noncancer impacts, *and* for which acceptable quantitative dose-response values are available for both cancer and noncancer endpoints, the endpoint that results in the lower screening threshold emission rate is used for screening (i.e., the screening threshold emission rate will be based on the effect that occurs at the lower exposure level). For the set of PB-HAPs for which screening threshold emission rates have been derived, arsenic and chlorinated dibenzo-dioxins and -furans cause both types of effects. Because the cancer dose-response value at a risk of 1-in-one million is lower than that for the noncancer reference toxicity dose, the screening threshold emission rate is based on the cancer endpoint.

Exhibit 4. Conceptual Decision Tree for Tier 1 Evaluation of Multimedia Ingestion Exposures to PB-HAPs

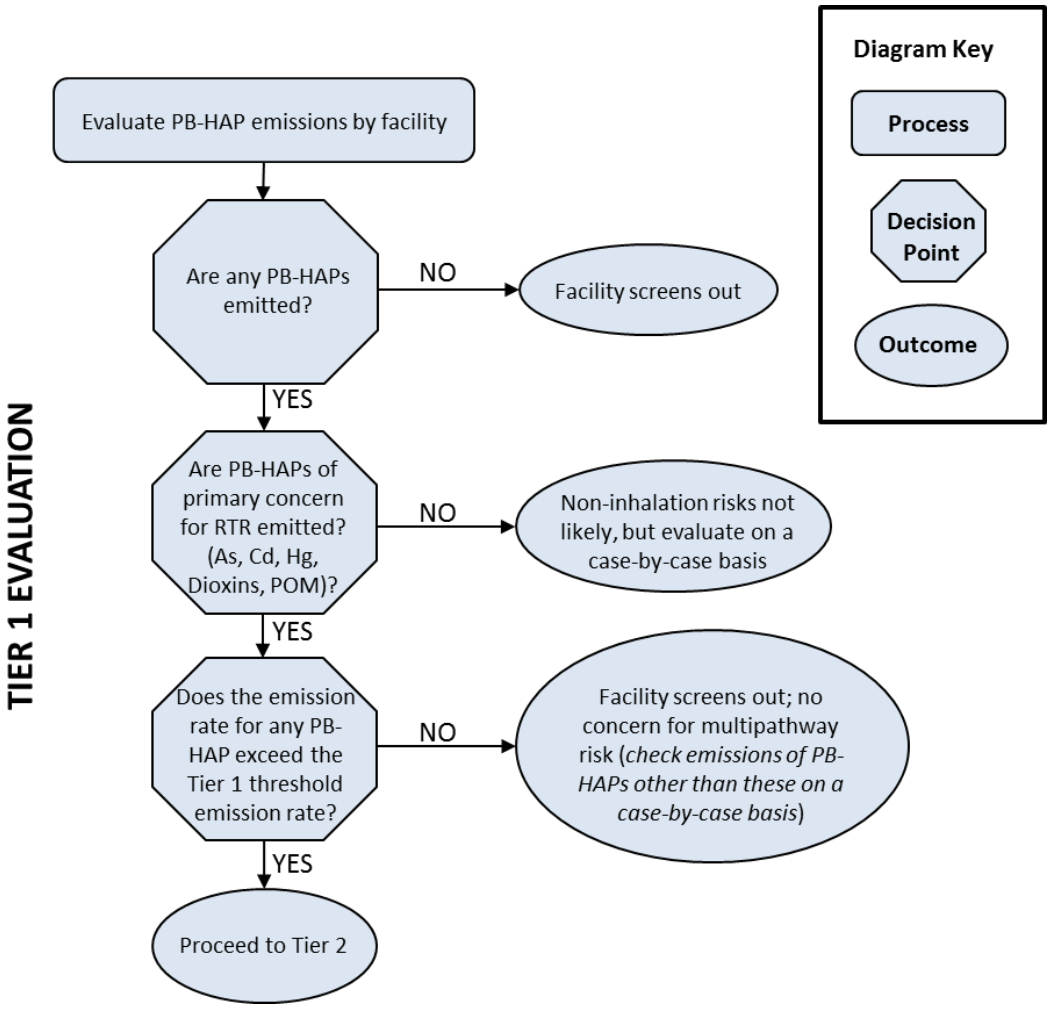


Exhibit 5. Screening Threshold Emission Rates for Multimedia Ingestion Exposures

Chemical	Screening Threshold Emission Rate (TPY)	Basis of Threshold (Type of Health Endpoint)
Arsenic	2.08E−04	Cancer
Cadmium	2.38E−03	Noncancer
Mercury (as divalent mercury emissions)	1.46E−04	Noncancer
POM (as benzo[a]pyrene equivalents)[a]	9.58E−04	Cancer
Dioxins (as 2,3,7,8-TCDD equivalents)[a]	2.65E−10	Cancer

Note: TPY = U.S. short tons per year.
[a]See Section 2.2.4 for a discussion on the derivation of equivalent emissions.

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,

accounting for 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 range of emission rates for each chemical. The estimated screening threshold emission rates are verified by performing model runs using the estimated screening threshold emission rate to confirm that the emission rates result in a cancer risk of 1-in-one million or an HQ of 1.0. Actual risks for each screening threshold emission rate would be lower than the levels of concern in nearly all circumstances, given the health protective nature of the Tier 1 scenario configuration.

Tier 1 screening threshold emission rates were developed individually for elemental and divalent mercury. Both were based on the lower of the screening threshold emission rates associated with multimedia ingestion exposures to divalent mercury and methyl mercury.[4] Only 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 emission rate. Moreover, elemental mercury has a high vapor pressure and generally remains in air; deposited only during precipitation events and rapidly revolatilizing.

2.2 Conceptual Exposure Scenario

A conceptual model for exposure pathways describes the movement of chemicals from the point of release to the points where exposure occurs. An exposure model generally includes several elements:

- Release to the environment (i.e., emissions);
- A receiving medium (e.g., air);
- Transport processes within and between media;
- Transformation to other chemicals via one or more physical, chemical, or biological processes;
- Continued tracking of a transformed chemical, if of concern (e.g., methyl mercury), or loss of chemical from the modeling domain via degradation;
- Estimates of chemical concentrations in human exposure media (e.g., air, foods, soils); and
- Human uptake of chemicals from those media by specific routes of exposure (i.e., inhalation, ingestion, dermal absorption).

PB-HAPs can persist in the environment for many years and, therefore, can build up in soils and lakes (sediments) and accumulate in biota, including fish, fruits and vegetables, and animal products (e.g., meat, dairy, eggs). For this reason, ingestion of foods grown near facilities that release PB-HAPs to air can be an important source of exposure.

Previously, to assess risks from hazardous waste combustion facilities, EPA identified several hypothetical receptor scenarios, noting that the scenarios can be appropriate for a broad range of situations where emissions to air are evaluated. The scenarios are described in EPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities,* or

[4]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.

HHRAP (U.S. EPA 2005a). In HHRAP, EPA recommends assessing several hypothetical receptors: Farmer, Farmer Child, Resident, Resident Child, Fisher, Fisher Child, Acute Receptor, and Nursing Infant. These receptors are distinguished by their pathways of exposure and contact rates (e.g., food ingestion rates, hand-to-mouth soil ingestion, skin surface area). EPA further notes in HHRAP that some exposure settings might warrant including additional exposure pathways, such as fish ingestion by the Farmer.

For the RTR Tier 1 screen, ingestion exposure is estimated for a single hypothetical receptor who ingests both locally caught fish and home-raised or home-produced farm foods. The ingestion exposure scenario for the PB-HAP Tier 1 screen includes several media:

- Soil,
- Farm-grown fruits and vegetables,
- Farm-raised beef,
- Dairy products from local farm-raised cows,
- Farm-raised poultry and eggs,
- Farm-raised pork,
- Locally caught fish, and
- For children less than 1 year old, breast milk from a woman exposed via the media listed above (for dioxins only).[5]

As discussed in detail in Section 2.4.2, aside from ingestion of breast milk, ingestion exposure for all other media is assessed for adults and several age categories of children.

Other non-inhalation exposures possible for PB-HAPs discussed in HHRAP include using surface water or groundwater as a drinking water source and dermal exposure to chemicals in surface water and in soils; however, those exposure pathways are not evaluated for RTR. First, farmers are unlikely to use untreated surface water for drinking (or other household water uses).[6] HHRAP also recommends that exposure to groundwater not be evaluated because EPA found that groundwater is an insignificant exposure pathway for airborne combustion emissions (U.S. EPA 2005a). In addition, based on numerous evaluations of groundwater concentrations developed during RTR evaluations using TRIM.FaTE, we have confirmed that exposure from groundwater ingestion is a small fraction of overall exposure. Dermal absorption of deposited PB-chemicals that are originally airborne generally is relatively minor compared with other exposures (U.S. EPA 2006, Cal/EPA 2012). Preliminary calculations of estimated dermal exposure and risk of PB-HAPs, presented in Attachment C, show that the dermal exposure route is not a significant risk pathway relative to ingestion exposures. In addition, HHRAP recommends that dermal exposure not be assessed because available data indicate that the contribution to overall risk from dermal exposure to soils typically is small (U.S. EPA 2005a).

[5]Breast milk ingestion is an important exposure pathway for lipophilic compounds like dioxins. Breast milk does not contribute meaningfully to exposures to the other PB-HAPs assessed. See Section 2.4.2.2 below and Attachment B, Section B.3.4 for full discussions of infant exposures via breast milk ingestion.

[6]An exception to this generality would be reservoirs used for drinking water supplies, although treatment facilities would remove some proportion of PB-HAPs prior to water distribution. Such a situation might be worthy of additional analysis, if warranted for a given assessment (e.g., several facilities close to a reservoir).

2.2.1 Approach to Development of the Tier 1 Scenario

The TRIM-based Tier 1 scenario described in this document does not represent any particular facility. The Tier 1 scenario is hypothetical and designed to estimate screening threshold emission rates 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 human, any potential long-term exposures for any given geographic region would be unlikely to exceed those estimated for the Tier 1 configuration.

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* (U.S. EPA 1999); Volumes I and II of the *Air Toxics Risk Assessment Reference Library* (U.S. EPA 2004a, 2005a); and other EPA publications (e.g., U.S. EPA 2003a, 2005a).The scenario described herein is the culmination of assessments completed since 2005. It allows an efficient and scientifically defensible screen of multipathway human health risk and provides a solid baseline from which to perform Tier 2 and Tier 3 screens, as described in Sections 3 and 4, respectively. All attributes of this scenario should not be considered "final," however. Some will continue to evolve based on feedback from the scientific community and Agency reviewers, on lessons learned as the scenario is further applied for RTR, and on future changes in legislated requirements.

2.2.1.1 Modeling Framework

The approach for multimedia ingestion risk screening and evaluation for RTR can be divided into four steps as shown in Exhibit 1:

1. Model the fate and transport of PB-HAPs emitted to air including partitioning to soil, water, and other environmental media (including fish[7]);
2. Estimate uptake of PB-HAPs by farm-grown foods (e.g., produce, livestock, dairy products) from soil and air and calculate the resulting concentrations in each food category;
3. Estimate human ingestion of PB-HAPs in farm-grown foods and in fish and through incidental ingestion of soils; and
4. Calculate estimates of lifetime cancer risk or chronic noncancer HQs, as appropriate, for each PB-HAP and compare these to selected evaluation criteria.

As shown in Exhibit 1, EPA's TRIM.FaTE model provides multimedia fate and transport modeling. Subsequent uptake of chemicals into farm foods and human ingestion exposures and risk is estimated using the multimedia exposure algorithms.

EPA's TRIM 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

[7]Concentrations in fish calculated by TRIM.FaTE are used to estimate ingestion exposures for humans consuming fish (except for arsenic, as provided below). Modeling of fish concentrations is therefore discussed herein as part of the TRIM.FaTE fate and transport modeling. TRIM.FaTE media concentration outputs are used to calculate the uptake of PB-HAPs into all other biotic media assumed to be ingested as part of the second step of the modeling framework.

screening ingestion risk (Exhibit 1).[8] TRIM.FaTE—the fate and transport module—is available for application. EPA has completed some development activities for TRIM.Expo-Ingestion and TRIM.Risk-Human Health, two additional modules that cover the other three steps. Software development, however, is not yet complete for these modules. Thus, the RTR screening approach uses separate multimedia exposure and risk calculations to estimate PB-HAP concentrations in farm-grown foods, average daily ingestion doses, and cancer risks and chronic noncancer HQs. TRIM.FaTE plus the exposure and risk algorithms that are used are conceptually identical to the ingestion exposure and risk assessments that TRIM is intended to cover.

TRIM.FaTE outputs that are used as inputs to exposure and risk calculations 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, and
- PB-HAP concentrations in surface soil and root zone soil.

Using the exposure and risk algorithms, the RTR screening approach then estimates chemical concentrations in crop products based on deposition from air and uptake from soils, ingestion of PB-HAPs by farm animals via plant and soil ingestion and transfer to livestock products that are consumed by humans (e.g., eggs, milk, meat), and ingestion of PB-HAPs through these media by humans at various age groups from toddlers to adults (breast milk ingestion is also considered for infants for dioxins). The screening approach sums cancer risks across different age-groups to calculate a total lifetime cancer risk and calculates HQs for each age group for noncancer effects.

2.2.1.2 Model Configuration and Parameterization

The Tier 1 scenario is intended to minimize the chance that EPA would underestimate potential human multimedia ingestion risks. Although the health-protective approach likely overestimates risk for any given facility, it is appropriate for an initial screen. As in the 2006 preliminary multipathway screening for RTR (U.S. EPA 2006), exposures are modeled for a hypothetical farm homestead and fishable lake located adjacent to an emissions source. The hypothetical individual for which exposures are calculated derives all foods and soil from potentially contaminated adjacent locations and food and soil ingestion rates are from the upper ends of a nationally representative distribution of values (e.g., from EPA's 2011 *Exposure Factors Handbook*).

The physical/chemical environment represented in the screening scenario was parameterized with two types of values: typical and health-protective. In general, the spatial layout and the components of the scenario that influence air concentrations and deposition rates (which in turn affect PB-HAP concentrations in all other media) are defined or set to be health protective. Properties of environmental media are set with either typical or health protective values, as further discussed below and provided in Attachment A.

[8]Information about the current status of TRIM modules and comprehensive documentation of modules developed thus far can be accessed on EPA's Fate, Exposure, and Risk Analysis website (https://www.epa.gov/fera/total-risk-integrated-methodology-trim-trimfate).

Calculated TRIM.FaTE concentrations generally are more sensitive to attributes of the spatial layout and the meteorological data than to other attributes of the scenario. For example, the dominant wind direction influences the direction of greatest deposition of emissions from a source, 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. Thus, health-protective values for meteorological data and a spatial layout that maximizes PB-HAP concentrations in the farm and lake are used for TRIM.FaTE in Tier 1.

2.2.2 Fate and Transport Modeling (TRIM.FaTE)

In developing the Tier 1 scenario, Version 3.6.2 of TRIM.FaTE was used to model the fate and transport of emitted PB-HAPs and to estimate concentrations in relevant environmental media. Additional information about TRIM.FaTE, including support documentation, software, and the TRIM.FaTE public reference library, is available at https://www.epa.gov/fera/total-risk-integrated-methodology-trim-trimfate.

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.

Algorithms used to model mercury species and POM are described in Volume II of the *TRIM.FaTE Technical Support Document* (U.S. 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* (U.S. EPA 2002b, 2005b). Algorithms specific to the fate and transport of chlorinated dibenzo-dioxin and -furan congeners are documented in the third volume of the *TRIM.FaTE Evaluation Report* (U.S. EPA 2004b).

Since 2005, the TRIM.FaTE master library was updated to include cadmium and, most recently, arsenic. In general, many of the algorithms and properties that are used to model mercury (except for the mercury transformation algorithms) are also applicable to cadmium and arsenic, although different empirical data are used for chemical-specific parameters values. Comprehensive technical documentation of TRIM.FaTE algorithms specific to cadmium and arsenic have not yet been compiled; however, all chemical-specific properties used by TRIM.FaTE to model cadmium and arsenic (as well as POM, mercury, and dioxins) are documented in Attachment A.

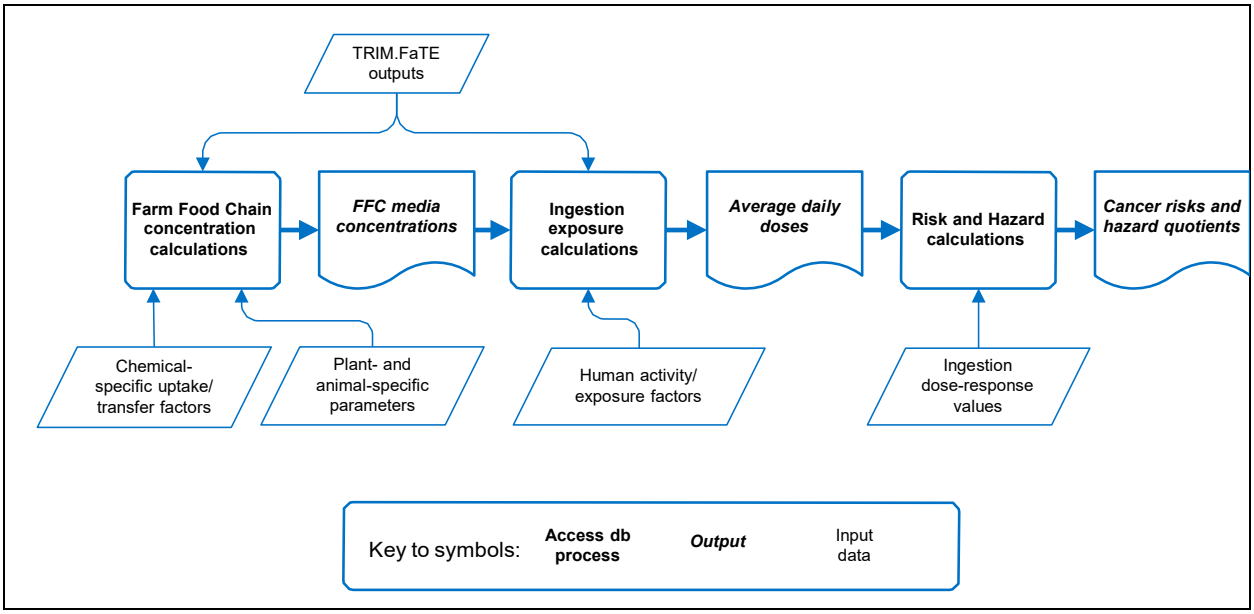
Based on a thorough 2011 evaluation of TRIM.FaTE performance in modeling the aquatic food web, a zooplankton compartment was added to TRIM.FaTE's aquatic compartment to facilitate comparison of TRIM.FaTE results for organic chemicals to those from other aquatic food-web models which include zooplankton separately from phytoplankton. Performance of the model was then recalibrated for mercury comparing the ratio and concentrations of inorganic and methylated mercury in each component of the aquatic food web with data from field studies. Parameterization of the TRIM.FaTE scenario used for RTR screening is described in more detail in Section 2.3.

2.2.3 Exposure Modeling and Risk Characterization

The algorithms that calculate chemical concentrations in farm-grown foods and ingestion exposures for hypothetical individuals are from EPA's Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, or HHRAP (U.S. EPA 2005a). An overview of the input data and flow of computations for these calculations is presented in Exhibit 6. This exhibit

demonstrates the general relationships between the relevant TRIM.FaTE outputs (i.e., chemical concentrations in environmental media and fish) and the calculations of ingestion exposure and risk. 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.

Exhibit 6. Overview of Multimedia Ingestion Risk Calculations for RTR



Two of the five PB-HAPs for which screening threshold emission rates have been developed for RTR—POM and dioxins—are chemical groups comprising numerous individual compounds. The members of these groups as 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 because they have a similar mode of toxic action and because they share attributes of environmental behavior.

2.2.4 Implementation of Risk-based Equivalency Factors for POM and Dioxin Congeners

To facilitate application of the multimedia ingestion screening methods for RTR, reported emissions of POM and dioxins are compared with a single reference (or index) chemical for each group: benzo[a]pyrene for POM and 2,3,7,8-TCDD for dioxins. These reference chemicals are both relatively well-studied and among the most toxic compounds within each group.

Derivation of equivalency factors begins with the basic relationship used to characterize health risk:

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

For a given air pollutant, exposure concentration increases in direct proportion to increases in air emissions of that substance. Furthermore, risks of toxic effects increase linearly with concentration. Consequently, emissions of one substance (e.g., chrysene) can be scaled to the risk equivalent of the emissions of the reference compound (e.g., benzo[a]pyrene or BaP) by

multiplying by relative toxicity equivalency factors (TEFs) and relative exposure equivalency factors (EEFs). Using the dioxin group as an example, and 2,3,7,8-TCDD as the reference compound, scaling emissions follows Equation 1:

$$Emiss_{Dioxin(i):TCDD} = Emiss_{Dioxin(i)} \times EEF_{Dioxin(i):TCDD} \times TEF_{Dioxin(i):TCDD} \qquad \textbf{Eqn. 1}$$

where:

$Emiss_{Dioxin(i):TCDD}$	=	Risk-weighted emissions of Dioxin$_{(i)}$ (weighted according to cancer risk relative to 2,3,7,8-TCDD for oral exposures)
$Emiss_{Dioxin(i)}$	=	Emission rate of Dioxin$_{(i)}$
$EEF_{Dioxin(i):TCDD}$	=	Exposure equivalency factor accounting for the ratio of final Dioxin$_{(i)}$ exposure dose compared with initial Dioxin$_{(i)}$ emissions relative to the final BaP dose compared with initial 2,3,7,8-TCDD emissions
$TEF_{Dioxin(i):TCDD}$	=	Toxicity equivalency factor accounting for the toxicity of Dioxin$_{(i)}$ relative to the toxicity of 2,3,7,8-TCDD via ingestion

After all the emissions of all congeners of dioxins (*i … z*) have been converted to TCDD-equivalent emissions, they can be summed to a total TCDD-equivalent emissions rate. This TCDD-equivalent emission rate is compared with the TCDD screening threshold emission rate to develop a screening value (to determine if there is a possibility of adverse health effects.)

The oral TEF for each POM and dioxin compound is based on the compound's oral toxicity relative to the oral toxicity of the index chemical for the group. The oral TEFs for POMs and dioxins were obtained from previous EPA analyses (U.S. EPA 2008b and 2017a, respectively). For POM, oral toxicity values for individual compounds have been derived following the same approach used to develop inhalation toxicity values (U.S. EPA 2017a). For dioxins, oral TEFs are those published by U.S. EPA (2008b), which were adopted from the values developed for the World Health Organization for its 2005 TEF reevaluation (van den Berg et al. 2006). Refer to Attachment B, Section B.4 for more information on these values.

The EEFs are calculated for each individual chemical that is modeled. TRIM.FaTE is parameterized for 14 POM and 17 dioxin congeners. For these chemicals, EEFs were calculated using the Tier 1 screening scenario described in this document. A release rate of 1 g/sec was modeled for each of the congeners. A chemical's EEF equals the ratio of its exposure concentration or dose to that of the index chemical for the group, also modeled with an emission rate of 1 g/sec. Emissions of several additional POM chemicals, however, are reported in the NEI. The determination of EEFs for these chemicals, and chemical groups, are discussed in the subsections below.

The product of the EEF and TEF for a given substance is called its "risk equivalency factor" (REF) for the purposes of RTR evaluations. POM (or dioxin) emissions from a facility can be quickly evaluated by summing the products of chemical-specific REFs and chemical-specific emission rates.

2.2.4.1 Calculation of Exposure, Toxicity, and Risk Equivalency Factors for POM Congeners

There is a large universe of POM chemicals, though only a subset of 36 POMs traditionally are reported to the NEI. Of those 36 POMs, 14 are parameterized in TRIM.FaTE; that is, values for all chemical-specific parameters required by TRIM.FaTE (e.g., solubility, vapor pressure, octanol-water partition coefficient [Kow], Henry's law constant) for its multimedia transport and fate algorithms are included in the TRIM.FaTE library. The other 22 POMs (or POM groups) in this subset of 36 are reported to the NEI less frequently than the 14 and are not currently parameterized in TRIM.FaTE (their chemical and physical parameter values are not included).

The calculated EEFs, TEFs, and REFs for the 14 POM congeners that are parameterized in TRIM.FaTE, plus the 22 others, are shown in Exhibit 7. To determine appropriate exposure surrogates for chemicals not parameterized in TRIM.FaTE, EPA evaluated the relationships between chemical-specific properties (e.g., Kow, Henry's law constant), intermediate modeled values (e.g., deposition, soil concentration), and exposures in terms of lifetime average daily dose (LADD), 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 possible mutagenic mode of action of POMs (U.S. EPA 2005c,d,e). The correlation between Kow and LADD is stronger than any other chemical-specific property and a power regression was developed to estimate LADD based on congener-specific Kow. Based on this analysis, total LADD (age-adjusted) for each congener is calculated based on the congener's Kow and the power regression of the modeled POMs, as provided in Exhibit 8. Exhibit 8 shows that, in general, as Kow increases, so too does exposure.

Exhibit 7. Exposure, Toxicity, and Risk Equivalency Factors Relative to Benzo[a]pyrene for POM Congeners Currently Evaluated in the Screens

PB-HAP[a]	Fully Characterized for TRIM.FaTE Modeling?[b]	Tier 1 Exposure-equivalency Factor (EEF)	Toxic-equivalency Factor (TEF)[c]	Tier 1 Risk-equivalency Factor (REF)
2-Methylnaphthalene	Yes	0.003	0.05	0.0001
7,12-Dimethylbenz[a]anthracene	Yes	1.3	250	314
Acenaphthene	Yes	0.004	0.05	0.0002
Acenaphthylene	Yes	0.006	0.05	0.0003
Benz[a]anthracene	Yes	0.07	0.1	0.007
Benzo[a]pyrene	Yes	1	1	1
Benzo[b]fluoranthene	Yes	3.6	0.1	0.4
Benzo[ghi]perylene	Yes	2.9	0.05	0.1
Benzo[k]fluoranthene	Yes	5.5	0.01	0.05
Chrysene	Yes	0.2	0.001	0.0002
Dibenzo[a,h]anthracene	Yes	4	1	4
Fluoranthene	Yes	0.01	0.05	0.0007
Fluorene	Yes	0.005	0.05	0.0002
Indeno[1,2,3-c,d]pyrene	Yes	2.9	0.1	0.3

PB-HAP[a]	Fully Characterized for TRIM.FaTE Modeling?[b]	Tier 1 Exposure-equivalency Factor (EEF)	Toxic-equivalency Factor (TEF)[c]	Tier 1 Risk-equivalency Factor (REF)
1-Methylnaphthalene	No	0.003	0.05	0.0001
2-Acetylaminofluorene	No	0.0006	1	0.0006
3-Methylcholanthrene	No	2.6	22	56.4
Anthracene	No	0.01	0	0
Benz[a]anthracene/Chrysene	No	3.2	0.05	0.2
Benzo[a]fluoranthene	No	1.1	0.05	0.06
Benzo[b+k]fluoranthene	No	5.5	0.01	0.05
Benzo[c]phenanthrene	No	0.2	0.05	0.01
Benzo[e]pyrene	No	2.7	0.05	0.1
Benzo[g,h,i]fluoranthene	No	0.2	0.05	0.01
Benzo[j]fluoranthene	No	2.4	0.1	0.2
Benzofluoranthenes	No	5.4	0.05	0.3
beta-Chloronaphthalene	No	0.006	0.05	0.0003
Carbazole	No	0.002	0.02	0.00004
Dibenz[a,j]acridine	No	0.3	0.1	0.03
Dibenzo[a,i]pyrene	No	25.5	10	255
PAH, total	No	3.2	0.05	0.2
Perylene	No	0.5	0.05	0.03
Phenanthrene	No	0.01	0	0
Polycyclic organic matter	No	3.2	0.05	0.2
Pyrene	No	0.04	0	0
Retene	No	2.1	0.05	0.1

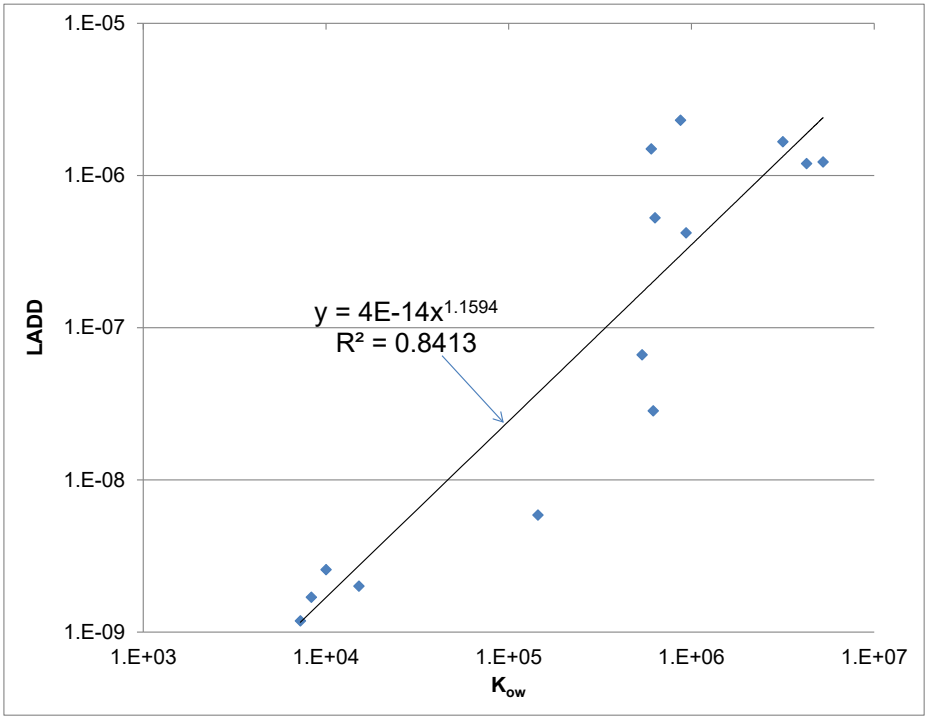
Notes: Rounding artifacts present. HAP = hazardous air pollutant; PB-HAP = persistent and bioaccumulative HAP; TRIM.FaTE = Total Risk Integrated Methodology (Fate and Transport Ecological model); POM = polycyclic organic matter; BaP = benzo[a]pyrene; RTR = Risk and Technology Review program; Kow = octanol-water partition coefficient; PAH = polycyclic aromatic hydrocarbon.

[a]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). Although naphthalene is a POM as defined in the Clean Air Act, unlike the other POM chemicals modeled in the multipathway assessment, naphthalene remains primarily (>98–99%) in vapor phase at ambient temperatures; thus, it disperses far away from a facility in air with negligible local deposition. Given its volatility (solid phase sublimates to vapor phase at ambient temperatures), it does not accumulate in localized environmental media over time (ATSDR 2005). Additionally, based on a log Kow of 3.29, it has a low affinity for lipids compared with other POMs. For these reasons, EPA does not consider naphthalene to be a persistent and bioaccumulative POM; inhalation is the only pathway of concern for RTR assessment of naphthalene.

[b]Some POM congeners are not fully characterized in TRIM.FaTE (with their chemical properties, partition coefficients, etc.) and so cannot be modeled directly. As discussed in the text, EEFs for these uncharacterized POM congeners are estimated based on Kow.

[c]Sources: U.S. EPA (2017a); professional judgment.

Exhibit 8. Relationship between Ingestion Exposure and Kow for POM Chemicals



For POM reported as undefined groups (i.e., "PAH, total" and "Polycyclic Organic Matter"), EPA assigned Kow values near the upper end of the range of all of the Kow values, corresponding to an exposure near the upper end of the range (logKow = 6.5) (see Exhibit 9). This assignment is assumed to be health protective and is unlikely to under predict exposure.

For POM chemicals that are not fully parameterized in TRIM.FaTE ("No" in Exhibit 7), we use the regression equation in Exhibit 8 with the Kow values listed in Exhibit 9 to extrapolate the EEFs in Exhibit 7. Thus, all POM have EEF, TEF, and REF values relative to BaP.

Exhibit 9. LogKow Values for POM Chemical Congeners

Chemical	LogKow (Kow)	Source
1-Methylnaphthalene	3.87 (7.41E+03)	Mackay et al. 2006[a]
2-Acetylaminofluorene	3.28 (1.91E+03)	Montgomery 2007[e]
3-Methylcholanthrene	6.42 (2.63E+06)	Mackay et al. 2006[a]
Anthracene	4.45 (2.82E+04)	Mackay et al. 2006[a]
Benzo[a]fluoranthene	6.11 (1.29E+06)	U.S. EPA 2012a (EPI Suite, estimate)
Benzo[c]phenanthrene	5.52 (3.31E+05)	U.S. EPA 2012a (EPI Suite, estimate)
Benzo[e]pyrene	6.44 (2.75E+06)	Mackay et al. 2006[b]
Benzo[g,h,i]fluoranthene	5.52 (3.31E+05)	U.S. EPA 2012a (EPI Suite, estimate)
Benzo[j]fluoranthene	6.40 (2.51E+06)	Mackay et al. 2006[f]

Chemical	LogKow (Kow)	Source
Benzofluoranthenes	6.70 (5.01E+06)	U.S. EPA 2012a (EPI Suite, estimate)
beta-Chloronaphthalene	4.14 (1.38E+04)	Mackay et al. 2006[a]
Carbazole	3.72 (5.25E+03)	U.S. EPA 2012a (EPI Suite)[a]
Dibenz[a,j]acridine	5.63 (4.27E+05)	U.S. EPA 2012a (EPI Suite)[c]
Dibenzo[a,i]pyrene	7.28 (1.91E+07)	U.S. EPA 2012a (EPI Suite, estimate)
PAH, total[d]	6.50 (3.16E+06)	EPA assigned
Perylene	5.82 (6.61E+05)	Mackay et al. 2006[a]
Phenanthrene	4.46 (2.88E+04)	Mackay et al. 2006[a]
Polycyclic organic matter[d]	6.50 (3.16E+06)	EPA assigned
Pyrene	4.88 (7.59E+04)	Mackay et al. 2006[a]
Retene	6.35 (2.24E+06)	U.S. EPA 2012a (EPI Suite, estimate)

Note: Benz[a]anthracene/chrysene and benzo[b+k]fluoranthene are not provided in this exhibit because benz[a]anthracene/chrysene is modeled as "polycyclic organic matter" and benzo[b+k]fluoranthene is modeled as benzo[k]fluoranthene) for RTR screens due to data limitations.

[a]Original source is Hansch et al. 1995.

[b]Original source is Sangster 1993.

[c]Original source is Helweg et al. 1997.

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

[e]Original source is Mercer et al. 1990.

[f]Original source is Bayona et al. 1991.

One POM chemical that is not evaluated for ingestion exposure is naphthalene, which 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 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, at ambient temperatures, naphthalene remains in vapor phase; generally, only 2–3 percent of naphthalene emitted to air deposits to ground level (ATSDR 2005). Naphthalene in other environmental media is short-lived due to its tendency to volatilize. Thus, it does not build up in soils, sediments, water, or biota over time (ATSDR 2005). With a logKow of 3.29, naphthalene has a moderate affinity for lipids and can accumulate in some tissues over the short term; however, it is rapidly exhaled or metabolized to other readily eliminated chemicals. For these reasons, EPA is not including naphthalene in its multipathway risk assessment.

2.2.4.2 Calculation of Scaling Factors for Dioxin Congeners

The calculated EEFs, TEFs, and REFs for the 17 dioxin congeners that are chlorinated in the lateral 2, 3, 7, and 8 positions are presented in Exhibit 10.

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

PB-HAP	Tier 1 Exposure-equivalency Factor (EEF)	Toxic-equivalency Factor (TEF)[a]	Tier 1 Risk-equivalency Factor (REF)
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	1.2	0.01	0.01
1,2,3,4,6,7,8-Heptachlorodibenzofuran	3.0	0.01	0.03
1,2,3,4,7,8,9-Heptachlorodibenzofuran	6	0.01	0.06
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	1.3	0.1	0.1
1,2,3,4,7,8-Hexachlorodibenzofuran	1.2	0.1	0.1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	0.6	0.04[a]	0.03
1,2,3,6,7,8-Hexachlorodibenzofuran	0.3	0.1	0.03
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	0.6	0.04[a]	0.03
1,2,3,7,8,9-Hexachlorodibenzofuran	0.6	0.1	0.06
2,3,4,6,7,8-Hexachlorodibenzofuran	0.3	0.1	0.03
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	0.7	0.0003	0.0002
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	0.4	0.0003	0.0001
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	2	1	2
1,2,3,7,8-Pentachlorodibenzofuran	0.8	0.03	0.02
2,3,4,7,8-Pentachlorodibenzofuran	1	0.3	0.3
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1	1	1
2,3,7,8-Tetrachlorodibenzofuran	0.6	0.1	0.06

Notes: Rounding artifacts present; HAP = hazardous air pollutant; PB-HAP = persistent and bioaccumulative HAP; TCDD = tetrachlorodibenzo-p-dioxin; IRIS = EPA's Integrated Risk Information System; CSF = cancer slope factor.
[a]Sources: van den Berg et al. (2006), except for 1,2,3,6,7,8-hexachlorodibenzo-p-dioxin and 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin, which are calculated based on the ratio of the IRIS-based CSF for the respective congener to the IRIS-based CSF for 2,3,7,8-TCDD (available at U.S. EPA 2017b)

As provided in Exhibit 10, WHO TEFs from van den Berg et al. (2006) are used except for two congeners for which EPA's IRIS program has developed a CSF—1,2,3,6,7,8-hexachlorodibenzo-p-dioxin and 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin. Collectively across RTR assessments that EPA has conducted in recent years, these two congeners together constitute roughly 4 percent of total dioxin emissions from point sources. When the dioxin emissions are weighted by TEFs (to calculate TEQs), the two congeners constitute about 4 percent of the total dioxin TEQ emissions from point sources using TEF=0.1 from van den Berg et al. (2006) and about 2 percent using TEF=0.04 derived from the IRIS-based CSF. Therefore, the impact of changing the TEFs of the two congeners is small.

Some 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 2,3,7,8-TCDD in the environment. We assume that the toxicity of unspecified total "Dioxins" equals that of the same quantity of 2,3,7,8-TCDD. This approach could be improved by obtaining information on the speciation of dioxin emissions for each facility or data that might allow calculation of an average speciation profile that could be applied to all facilities in a source category.

2.3 Description of Environmental Modeling Scenario

As described in Section 2.2.1.2, the physical configuration of the RTR Screening Scenario was designed to encompass the upper end of possible long-term PB-HAP exposures. Values for environmental and chemical-specific properties were selected to be either health protective or central-tendency. Scenario configuration and parameterization, the rationale for selecting particular property values, and model uncertainties are presented in the sections that follow. Comprehensive documentation of TRIM.FaTE property values for the Tier 1 screening scenario is provided in Attachment A.

2.3.1 Chemical Properties

The chemical-specific chemical/physical properties that TRIM.FaTE requires to simulate transport and fate through multiple environmental media (e.g., Henry's law constant, molecular weight, melting point) were obtained from peer-reviewed and standard chemical reference sources. Numerous other chemical-specific properties also depend on the particular abiotic or biotic compartment type; those properties are discussed generally in the sections that follow and are documented in Attachment A.

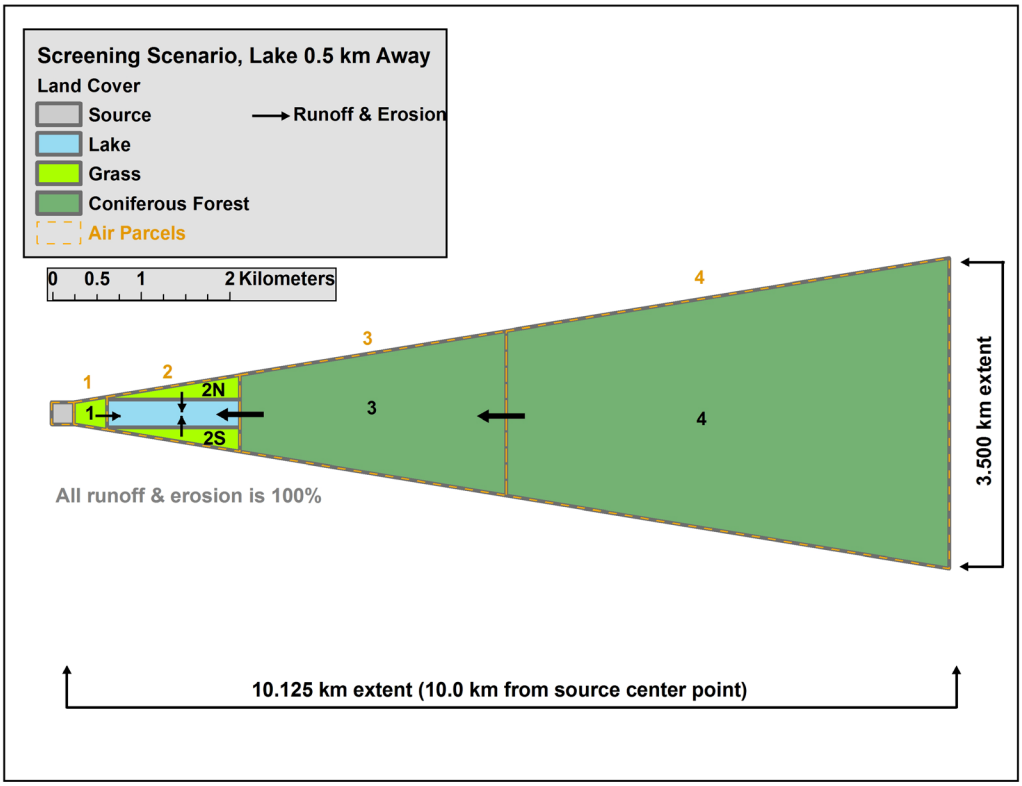
2.3.2 Spatial Layout

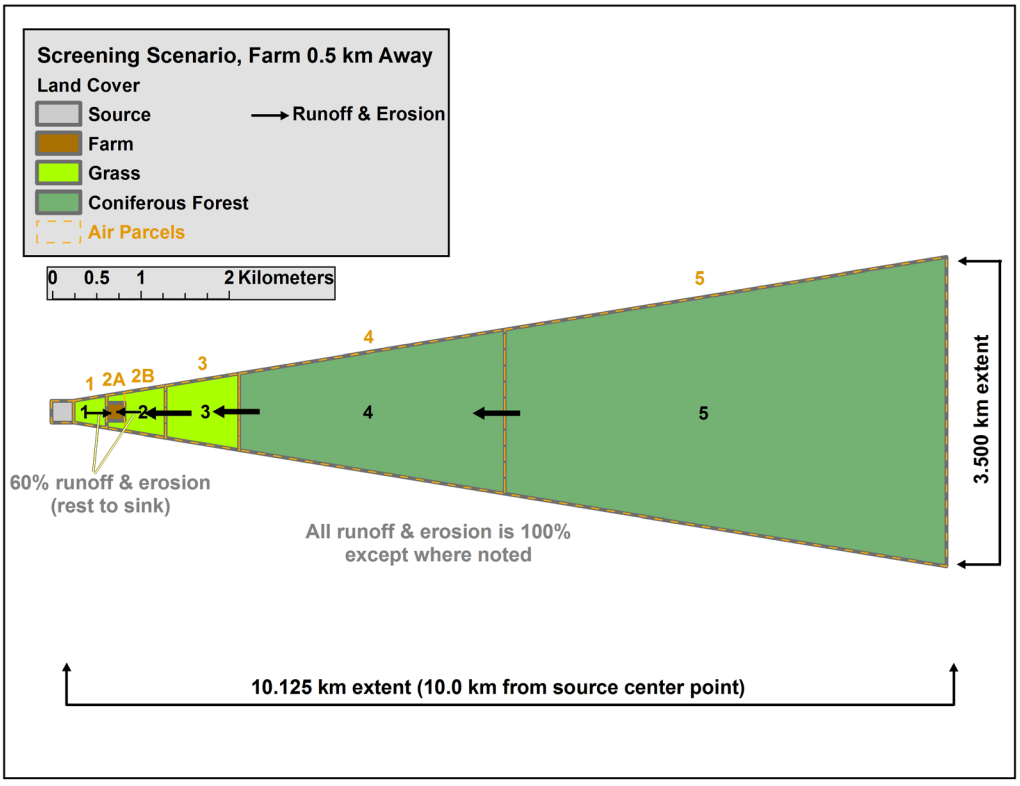
The Tier 1 spatial layout for TRIM.FaTE, provided in Exhibit 11, represents a farm homestead with a fishable lake (and its surrounding watershed) located near a facility emissions source. The source parcel is a square with sides of 250 m to represent a relatively small-to-medium facility at the fence 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 emissions plume.

The modeled wedge extends 10 km downwind (eastward) from the facility. Air dispersion modeling indicates the maximum air concentration and deposition rates occur relatively close to the facility (probably within a few hundred meters, with the exact location varying with stack height and other parameters), which is well within a 10-km radius. TRIM.FaTE modeling also indicates that at 10 km downwind of a source, deposition rates for the PB-HAPs are expected to be lower by about two orders of magnitude than deposition rates at a few hundred meters of the source. Extending the modeling layout beyond 10-km downwind 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. Moreover, the additional mass deposited beyond 10 km is expected to cause a negligible increase in total ingestion exposure.[9] Given these conditions, a downwind length of 10 km is appropriate for the screening scenario.

[9]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 TRIM.FaTE runs supporting Tier 1 (discussed in this section) indicate that average chemical deposition rates at the parcel farthest from the emission source (e.g., parcel 5 in the farm layout of Exhibit 11, which is 5–10 km from the emission source) are between 1 and 2 orders of magnitude smaller than those within 1 km of the source (e.g., parcels 1 and 2 in the farm layout of Exhibit 11), depending on the chemical. The large distance from the eastern edge of the watershed to the lake or farm attenuates transport of chemical mass by erosion and runoff, dampening the effect of including additional deposition beyond 10 km.

Exhibit 11. TRIM.FaTE Surface Parcel Layouts





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).[10] For a relatively neutral atmosphere (stability class D), σ at 10 km 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 north and south from the centerline at a distance of 10 km. The total plume width at 10 km is twice that 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 area of each parcel would encompass similar chemical mass (i.e., larger area for a parcel farther from the source would encompass a similar total chemical mass because concentrations per unit area would be lower than for a smaller parcel closer to the source with higher concentrations per unit area).

The depth of the surface soil compartments was set to 1 cm, except for the farm parcel, 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 air parcel layouts mirror those of the surface parcel layout, except that the air parcels over the lake and farm encompass the areas north and south of the lake and the farm.

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 discusses the selection of values used for key properties of the soil, water, and sediment compartments. Also discussed are chemical properties related to watershed and water body 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 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, parameter values were set to satisfy two equations to balance water volume. The first equation (Equation 2) maintains a balance of water entering and leaving the terrestrial portion of the scenario:

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

[total precipitation] = [evapotranspiration] + [total runoff] ***Eqn. 2***

In Equation 2, total runoff is equal to the sum of overland runoff to the lake and seepage to the lake via groundwater. Evapotranspiration represents that water released to air from plants in vegetated parcels.

Equation 3 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] ***Eqn. 3***

Note that TRIM.FaTE uses all these properties with the exception of evapotranspiration, which is part of the water balance calculation outside TRIM.FaTE. 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 facility 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/year based on data reported by Morton (1986) for various lakes. The runoff rate was defined to be both spatially 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/year, 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 Erosion and Runoff

Erosion and runoff are important surface transport algorithms for modeling chemical transport in TRIM.FaTE. Model input parameters for erosion include (1) parcel-specific erosion rates (in kg/m^2-day); and (2) inter-parcel erosion links (directing erosion to a specific parcel or parcels). Model input parameters for runoff include (1) parcel-specific runoff rates (in m^3/m^2-day); and (2) inter-parcel runoff links (as defined above). TRIM.FaTE uses those properties for chemical transport only; movement of soil and water into and out of parcels are assumed to balance so that there is no net change.

To establish soil erosion and runoff rates into the lake and onto the farm parcel, mean values, as estimated or measured in several studies, were used (Bajracharya et al., 1998; Gaspar et al., 2013; Schimmack et al., 2002; Young et al., 2014). Separate sites and measurement methods across the studies were treated as distinct observations, for a total of eight mean deposition rates to represent a distribution of values for varying landscapes. Use of mean values from multiple data sets limits the influence of extreme measured values within any one data set. Combining observations from different sites and measurement methods effectively combines

variability and uncertainty distributions. To ensure an appropriate level of health protectiveness in this context, the 90th percentile of the mean soil deposition rate was used in the RTR screening scenario for all chemicals and for all tiers. This corresponds to a soil deposition rate of 3 mm/year onto the farm parcel, which is achieved in the Tier 1 layout by setting erosion and runoff onto the farm parcel from neighboring parcels at 60 percent. Runoff and erosion patterns were exactly aligned, instead of setting distinct values for the two processes. For the lake only scenario, 100 percent of the erosion and runoff from neighboring parcels enters the lake. This assumption is both health protective and physically plausible in terms watershed dynamics and based on the lake flush rate it implies.

2.3.3.3 Sediment Balance

A simplified balance of sediment transfers between the watershed and the lake also was maintained for the scenario via parameterization of sediment-related properties. As with water, TRIM.FaTE does not internally balance sediment mass; calculations external to TRIM.FaTE balanced sediment gains and losses to set relevant parameter values. The sediment balance maintained is described by Equation 4, 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] ***Eqn. 4***

The second term (removal of sediment from the water column via outflow) is represented in TRIM.FaTE by the lake flush (or turnover) rate. The third term (sediment burial) is the transfer of sediment from the unconsolidated benthic sediment to the consolidated sediment layer below.

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 in the lake is assumed to remain constant, and the flush rate of the lake (calculated via the water balance approach described above) allows an estimate of sediment removal from the modeling domain via lake water outflow. The difference between these sediment fluxes equals the sediment burial rate, which 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. TRIM.FaTE calculates burial rate as 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 top, unconsolidated benthic sediment layer). TRIM.FaTE keeps a constant volume of particles in the unconsolidated sediment layer. The density of solid particles is the same for both particles suspended in the water column and for benthic sediments; therefore, the mass of solid 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 0.0026 kg/m^2-day, based on calculations using the USLE. The HHRAP documentation notes that the USLE equation sometimes overestimates sediment loading to a lake from the surrounding watershed (U.S. EPA 2005a). For the Tier 1 scenario,

however, this possible bias is appropriate because it is health protective.[11] 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 move directly to a sink and, therefore, do not enter the Tier 1 scenario lake. The overland transport of sediment to the lake from Parcel 4 also occurs via a direct link; however, in reality, the overland runoff and erosion would be attenuated by the intervening soil parcels. That attenuation is simulated by using a lower sediment delivery ratio in the USLE as applied to Parcel 4.

Using the calculated surface soil erosion rates for the scenario, the total average daily sediment load to the lake from the watershed is about 12,050 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 eventually transferred to the sediment burial sink.

2.3.4 Meteorology

Meteorological properties used in TRIM.FaTE algorithms include air temperature, air 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 to 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 homegrown farm foods and self-caught fish, with all farm foods and fish obtained from locations receiving chemicals emitted from the local 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 represent a location with a low wind speed, a wind direction primarily over the simulated watershed, a low mixing height, and a relatively high amount of total precipitation falling on the watershed. The values used were based on the distribution of values for U.S. locations as specified in Exhibit 12, but an artificial data set was compiled for this screen and not linked to any real location (for example, temporally variable meteorological parameters were changed only on a daily basis). Using a daily time step instead of an hourly time step substantially reduces required model run time. Meteorological inputs are summarized in Exhibit 12.

[11]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 water body.

Exhibit 12. Summary of Key Meteorological Parameter Inputs

Parameter	Selected Value	Justification
Air temperature	Constant at 298 Kelvin	Recommended default value listed in HHRAP (U.S. EPA 2005a). Value is similar to the mean maximum daily temperatures in May and September in much of the U.S. mid-Atlantic, mid-West, and Great Plains, according to 1981–2010 climatology.[a]
Mixing height	Constant at 226 m	Value is ~5th percentile of median hourly mixing heights recorded at 824 meteorological stations across the United States from January 1–December 31, 2016.
Wind direction	Blows from source parcel into scenario domain (west to east) 3 days per week (roughly 43% of the week); during other times does not blow into domain	Wind blowing toward a location of interest (e.g., toward a lake or farm) will move more emitted chemical mass over the location of interest than wind blowing in other directions. For much of the U.S. mid-Atlantic and western regions, the wind generally blows eastward.[a] Among the NOAA 1981–2010 normalized wind-vector data, the average wind direction had a strong eastward component at over one-third of the stations.[b] 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% of the time (review of wind direction data compiled by the National Weather Service; NCDC 1995). This pattern is approximated in the RTR scenario with a configuration in which the modeled domain is downwind of the source 3 out of every 7 days.
Horizontal wind speed	Constant at 1.6 m/sec	Set to ~5th percentile of median hourly wind speeds, partitioned by eight wind directions, recorded at 824 meteorological stations across the United States from January 1–December 31, 2016.
Precipitation frequency	Precipitation occurs 3 days per week (roughly 43% of the week); wind direction blows into domain 2 of these days (roughly 29% of the week)	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, according to 1961-1990 climatology.[c]
Total Precipitation	1.47 m/yr	1.47 m/yr approximates the 95th percentile of annual average precipitation for 824 meteorological stations across the United States. Where available (813 meteorological stations), annual precipitation is the 30-year normal value[b]; where normal values were unavailable, annual average precipitation was calculated from precipitation measured at the station from January 1–December 31, 2016.

[a]National Oceanic and Atmospheric Administration U.S. Climate Atlas for 1981–2010; https://www.ncdc.noaa.gov/climateatlas/.
[b]National Oceanic and Atmospheric Administration 1981–2010 Climate Normals; https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data.
[c]A graphical view of U.S. rainfall for 1981–2010 climate normals was available for precipitation amount but not precipitation frequency. Instead, we used a map of precipitation frequency based on 1961–1990 climate normals; https://www.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl. Regional patterns of rainfall frequency could have changed between 1961–1990 and 1981–2010.

The sensitivity of modeled PB-HAPs to changes in these meteorological variables was tested. Lower wind speeds and mixing heights affected concentrations the most. Lower wind speeds should increase localized pollutant deposition onto the soil and lower mixing heights reduces the volume of air in which emissions are mixed and diluted. The wind speed and mixing height used

for the screening scenario were 1.6 m/s and 226 m, respectively, approximating the 5th percentile values among 824 meteorological stations in the contiguous United States.

2.3.5 Aquatic Food Web

The lake aquatic food web is an important part of the screening scenario because 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 for all chemicals except arsenic, for which water-biota and sediment-biota bioaccumulation factors were used instead.

For the biokinetic approach, primary producers (first trophic level) in the TRIM.FaTE lake are algae and macrophytes in the water column and detritus in the sediments (the latter simulated as sediment particles). Algae are represented as a phase in the water column and macrophytes are represented in a single but separate compartment. Zooplankton (another compartment) feed on algae in the water column, while benthic invertebrates (a separate compartment) consume detritus that settles to the sediment compartment. In the water column, small young-of-the-year fish and minnows that feed on zooplankton and phytoplankton are represented by a single water-column herbivore (WCH) compartment. The small fish are in turn consumed by larger or "pan" fish (e.g., bluegills, white perch), represented by a single water-column omnivore (WCO) compartment, which are in turn consumed by the top consumers (e.g., gar, pickerel) represented as a single water-column carnivore (WCC) compartment. The invertebrates in the sediments of the benthic environment support bottom-feeding fish, or benthic omnivores (BO), of small to moderate size, which in turn are consumed by large bottom-feeding fish (e.g., catfish) in the benthic carnivore (BC) compartment. For TRIM.FaTE to provide reasonable predictions of the distribution of a chemical mass (and thereby chemical concentrations) across biotic and abiotic compartments in aquatic systems, the biomass of the biotic compartments must represent all biota in the system and the distribution of biomass among trophic groups (or compartments) 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). As expected, 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). That initial research suggested that a lake of approximately 50 hectares (ha) or 120 acres could support high trophic level predatory fish (i.e., WCC).

The RTR Tier 1 scenario includes a 47-hectare (116-acre) lake, given the lake parcel shape and overall size of the defined watershed in the screening scenario. The fish types, biomass, diet fractions, and average individual body weights for the Tier 1 scenario are listed in Exhibit 13. The total biomass for all fish compartments was assumed to be 5.7 grams wet weight per square meter based on Kelso and Johnson (1991) for clear-water lakes in Ontario. That assumption yields health protective (i.e., higher) estimates of chemical concentrations in fish than would the assumption of higher standing fish biomass and fish productivity for lakes characteristic of warmer climates.

For arsenic, freshwater fish bioaccumulation factors (BAFs) and biota-sediment accumulation factors (BSAFs) were identified from the literature (see Attachment A).

Exhibit 13. Aquatic Biota Parameter Values for the TRIM.FaTE Screening Scenario

TRIM.FaTE Compartment	Organisms in Compartment	Biomass		Diet	Avg. Body Weight (kg)
		Areal density ($g_{wet\ weight}/m^2$)	Fraction of Total Fish Biomass		
Algae[a]	green algae, diatoms, blue-green algae	7.95	–	Autotrophic	–
Zooplankton	water fleas, rotifers, protozoans	6.36	–	100% algae[a]	5.7E−8
Macrophyte	hydrilla, milfoil	500	–	–	–
Water column planktivore/ herbivore (WCH)	young-of-the-year, minnows	2.0	0.35	100% zooplankton	0.025
Water column omnivore (WCO)	bluegill, white perch	0.5	0.08	100% water column planktivore	0.25
Water column carnivore (WCC)	largemouth bass, walleye	0.2	0.035	100% water column omnivore	2.0
Benthic invertebrates (BI)[b]	aquatic insect larvae, crustaceans	20	–	detritus in sediments	0.000255
Benthic omnivore (BO)	small catfish, rock bass	2.0	0.351	100% benthic invert.	0.25
Benthic carnivore (BC)	large catfish, sculpins	1.0	0.175	50% benthic invert. 50% benthic omniv.	2.0
Total Fish Biomass[c]		**5.7**	1.00	–	–

Acronyms and abbreviations: Avg. = average; invert. = invertebrate; omniv. = omnivore.
[a]Algae is modeled as a phase of surface water in TRIM.FaTE (i.e., surface water has three phases: aqueous, particulate, and algal).
[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 TRIM.FaTE outputs include average PB-HAP concentrations in air and air deposition rates for each year and for each air parcel of the model scenario. In each surface parcel of the scenario, TRIM.FaTE models wet and dry deposition of chemicals to surface soil compartments (and surface water). From surface soils, for each parcel TRIM.FaTE estimates transport of chemicals downward through root-zone and vadose–zone soils as well as runoff and erosion to the lake. For each air parcel, air concentrations are provided. For the lake, the multimedia risk screening approach uses TRIM.FaTE-estimated concentrations in the BC and WCC fish compartments along with adult human fish-ingestion rates to estimate an adult's exposure via local fish consumption. For the farm ingestion exposure calculations, the RTR multimedia screening approach calculates direct exposures via incidental soil ingestion and

indirect exposures via transfers from soil and air into various types of produce, livestock, and animal products, which then are ingested by humans.

To ensure health protective calculations, the locations (i.e., parcels) with the highest chemical concentrations predicted by TRIM.FaTE provide the input data for the multimedia exposure calculations. For Tier 1, we assume that the highest air concentrations and deposition rates occur in the parcels closest to the source. For the farm, those locations also receive the majority of chemical from the rest of the simulated watershed by erosion and runoff. The assumptions are summarized in Exhibit 14.

Exhibit 14. Spatial Considerations—TRIM.FaTE Results Selected for Calculating Farm-food and Fish Media Concentrations and Receptor Exposures

TRIM.FaTE Output Used in Human Exposure Calculations	Representative Compartment	Layout[a]
Concentration in air, for uptake by plants via vapor transfer	Air compartment in air Parcel 2A (air over tilled soil)	Farm (bottom of Exhibit 11)
Deposition rates, for uptake by farm produce	Deposition to surface soil compartment in surface Parcel Farm (tilled soil)	Farm (bottom of Exhibit 11)
Concentration in surface soil, for incidental ingestion by humans and farm animals	Surface soil compartment in surface Parcel Farm (tilled soil)	Farm (bottom of Exhibit 11)
Concentration in soil, for uptake by farm produce and animal feed	Surface soil compartment in surface Parcel Farm (tilled soil)	Farm (bottom of Exhibit 11)
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)	Lake (top of Exhibit 11)

[a]The Tier 1 screening scenario is based on the combination of exposures from soil, farm produce, and farm animals (from the farmer scenario, spatial layout shown at the bottom of Exhibit 11) and from fish (from the fisher scenario, spatial layout shown at the top of Exhibit 11). Both the farm and the lake are located 0.5 km from the facility.

TRIM.FaTE can output “instantaneous” chemical concentrations at the end of a short, user-specified time step (e.g., 1 hour, 4 hours, 1 day) and also can be configured to calculate temporal averages (e.g., annual averages). For the Tier 1 scenario, TRIM.FaTE results are saved for each 24-hour period, because wind direction and precipitation input to TRIM.FaTE change on a daily (not hourly) basis. The annual average concentration equals the average of the 365 daily estimates. The simulation runs for 50 years, and the concentrations at the end of year 50 are used to estimate human exposures (i.e., we do not use earlier or time-weighted concentrations for PB-HAPs in soils and fish over the duration of the facility operation to estimate human exposures).

For arsenic, cadmium, POM, and dioxins, TRIM.FaTE-estimated concentrations in environmental media are close to steady state (i.e., almost constant from year to year) by year 50. Although mercury concentrations are continuing to increase by year 50 in the screening scenario, the rate of increase in mercury concentrations in soils and fish is much slower by year 50 than in the first 3–4 decades

2.4 Description of Human Exposure and Risk Estimates

This section describes the approach for estimating chemical concentrations in farm-food products (Section 2.4.1); estimating human exposures associated with ingestion of those products, incidental ingestion of soil, ingestion of fish, and infant consumption of breast milk (Section 2.4.2); and characterizing screening-level human health ingestion risks (Section 2.4.3). The multimedia risk screening approach uses calculates partitioning of PB-HAPs into farm produce using TRIM.FaTE-estimated chemical concentrations in soil, air concentrations, and wet and dry chemical deposition rates. It also computes total ingestion exposure as described in this section. Attachment B describes the multimedia exposure and risk calculations further. Section 2.4.4 summarizes the Tier 1 assumptions.

2.4.1 Calculating Concentrations in Farm Foods

As discussed above and shown Exhibit 6, the RTR multimedia risk screening approach estimates PB-HAPs concentrations in farm foods, including:

- Exposed and protected fruit,
- Exposed and protected vegetables,
- Root vegetables,
- Beef,
- Dairy products,
- Pork, and
- Poultry and eggs.

PB-HAP concentrations in these products are calculated with algorithms from HHRAP (U.S. EPA 2005a). HHRAP also provides plant- and animal-specific parameter values that can be used to calculate media concentrations, including chemical-specific transfer factors.

2.4.2 Ingestion Exposure

The multimedia risk screening approach estimates average daily doses (ADDs) of ingested chemical, normalized to body weight, for the exposure pathways listed in Exhibit 15.

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 a 99th percentile value). All media are from locations receiving the highest rate of deposition from the modeled source. Although this approach could overestimate total chemical exposure for an individual (i.e., total food ingestion rate is extremely high with an upper-percentile rate for each food type), it avoids underestimating exposure for any single farm-food type. The exposure characteristics selected for the Tier 1 scenario are summarized in Exhibit 16.

Exhibit 15. Summary of Ingestion Exposure Pathways

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

Abbreviations: NA = not applicable; RZ = root-zone.

[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 infant consumption of breast milk pathway is discussed in Section 2.4.2.2.

Exhibit 16. Overview of Exposure Factors Used for RTR Tier 1 Ingestion Screen[a,b]

Exposure Factor	Selection for Screen
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 up to 70 years)
Body weight (BW; varies by age)	Weighted mean of national distribution (from Chapter 8 of U.S. EPA 2011a; see Exhibit B-14 in Attachment B).
Ingestion rate (IR) for farm produce and animal products other than fish (varies by age and food type)	90th percentile of distribution of consumers who produce own food (see Exhibit B-16 in Attachment B); values from Chapter 13 of U.S. EPA (2011a) not adjusted for proportion of those surveyed who did not eat food type during the week covered by the survey.
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 (see Exhibit B-17 in Attachment B).
Exposure frequency (EF)	350 days/year (i.e., 2 weeks away from home per year) (from Chapter 6 of U.S. EPA 2005a).
Exposure duration (ED)	For carcinogens: 70-yr lifetime. For noncancer effects: varies by chemical (i.e., whether effect occurs during critical window in development or effect requires chronic exposure (i.e., more than 7 years of a human lifespan).
Fraction contaminated (FC) (could vary by media consumed)[c]	1.0 (i.e., all ingested fish and farm foods and soils are from most contaminated parcel).
Cooking losses[d]	Assumed to be “typical”; varies by food product (see Exhibit B-24 in Attachment B). Cooking losses were not considered for fish consumption because ingestion rates are “as prepared” values.
Chemical concentration adjustment factors due to fish cooking[e]	Arsenic = 1.5 Cadmium = 1.5 Mercury = 1.5 Dioxin = 0.7 POM = 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* (U.S. EPA 2011a). 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 screen are provided in Attachment B.

[c]“Fraction contaminated” represents the fraction of food product that is from the contaminated parcels in the screening scenario. Because ingestion rates reflect intake of home-produced foods, a fraction contaminated of 1.0 is used.

[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, adjustment factors are applied to the fish tissue concentrations to reflect changes in concentrations due to cooking. See Attachment B, Section B.6.4.4 for additional discussion.

2.4.2.1 Calculating Average Daily Doses

The multimedia risk screening approach 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 in EPA's *Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Modeling System* (U.S. EPA 2003a), with the exception of values for exposure factors, which were updated using EPA's 2011 *Exposure Factors Handbook*. The ingestion exposure modeling approach in 3MRA is conceptually similar to that presented in HHRAP and frequently used in risk assessments (Equation 5).

$$ADD_{(y,i)} = \left(\frac{C_{(i)} \times IR_{(y,i)} \times FC_{(i)} \times ED_{(y)}}{BW_{(y)} \times AT_{(y)}} \right) \left(\frac{EF_{(y)}}{365 \text{ days}} \right) \qquad \textbf{Eqn. 5}$$

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

$EF_{(y)}$ = Annual exposure frequency for age group *y* (days)

A discussion of exposure dose estimation and the equations to calculate ADDs for each ingestion pathway are provided in Attachment B.

2.4.2.2 Infant Ingestion of Breast Milk

A nursing mother exposed to contaminants by ingestion can pass the contaminants to her infant through breast milk (ATSDR 1998). The nursing infant's exposure is estimated from chemical concentrations in breast milk, which are estimated based on the mother's chemical intake rates.

Reports of bioaccumulation of lipophilic compounds, such as polychlorinated biphenyls (PCBs), polychlorinated dibenzofurans (PCDFs), and dioxins (PCDDs), are prevalent in the scientific literature. Due to their high lipophilicity, these compounds partition almost exclusively into body fats, which include the high-fat content of a mother's breast milk (U.S. EPA 1998). PCBs, PCDFs, and PCDDs are frequently reported as contaminants in human breast milk, usually at concentrations resulting in higher daily doses to infants than their mothers were likely to have ingested (Trapp et al. 2008). Lipophilic compounds accumulated over time in maternal fat reserves can be mobilized into the fats of breast milk, and lactation is a mode of excreting the compounds. Once ingested by an infant, they can accumulate in their body fats. Other organic compounds, with lower octanol-water partition coefficients, such as phenol, benzene,

halobenzenes, and POM, are found in both the fat and the aqueous phases of breast milk. Those compounds accumulate to a limited degree in body fats and are excreted from the mother in bile (to feces) and in aqueous phase in urine. In addition, humans can metabolize many POMs to polar metabolites which also are excreted in urine (ATSDR 1995). Inorganic forms of heavy metals, such as arsenic, lead, cadmium, and mercury, tend not to partition to body fats and are excreted from the body in urine, although they also have detected in the aqueous phase of the breast milk. Thus, for the PB-HAPs assessed for RTR, only for PCDFs and PCDDs is it possible for a substantial proportion of an individual's total lifetime cancer risk to result from breast feeding in the first year of life; therefore, dioxins are the only PB-HAP evaluated for infant exposures via breast milk for RTR at this time. This approach is consistent with EPA's HHRAP (U.S. EPA 2005a). Methyl mercury is evaluated for RTR using its RfD for pregnant women.

The breast-milk ingestion pathway is included in computing total exposure of a person to dioxins over their lifetime for developing the screening threshold emission rate for dioxins. In the absence of congener-specific data, all dioxin congeners were assumed to accumulate in breast milk to the same degree as 2,3,7,8-TCDD.

2.4.3 Calculating Risk

The multimedia risk screening approach calculates excess lifetime cancer risk and noncancer hazard (expressed as the hazard quotient or HQ) using the calculated ADDs and oral cancer slope factors (CSFs) and toxicity reference doses (RfDs), respectively. The CSFs and RfDs for the PB-HAPs included in the RTR tiered screening approach are presented in Exhibit 17 and are discussed in more detail in Attachment B.

Exhibit 17. Dose-response Values for PB-HAPs in RTR Ingestion Screening Scenario

PB-HAP	CSF ([mg/kg-day]$^{-1}$)	Source	RfD (mg/kg-day)	Source
Inorganics				
Arsenic compounds (as As)[a]	1.5	IRIS	not critical health endpoint	
Cadmium compounds (as Cd)[a,b]	not available		1E−3	IRIS
Elemental mercury[c]	not available		not available	
Divalent mercury[a,c]	not available		3E−4	IRIS
Methyl mercury[a]	not available		1E−4	IRIS
Organics				
Benzo[a]pyrene (BaP)[a,d]	1.0	IRIS	not critical health endpoint and no RfD	
2,3,7,8-TCDD[e]	1.5E+5	ORD	not critical health endpoint	

Notes: CSF = cancer slope factor; RfD = reference dose; IRIS = EPA's Integrated Risk Information System; ORD = EPA's Office of Research and Development; TCDD = tetrachlorodibenzo-p-dioxin; POM = polycyclic organic matter; PB-HAP = persistent and bioaccumulative hazardous air pollutant.

[a]Source: U.S. EPA Integrated Risk Information System (see U.S. EPA 2017b).

[b]RfD for cadmium in food (not water).

[c]Exposure to elemental mercury is not assessed in the multipathway screening due to limited information on oral dose-response. Exposure to divalent mercury is not assessed in the multipathway screening due to its higher (i.e., less stringent) RfD and lower bioaccumulation potential in the ingested food products in the screening, relative to methyl mercury.

[d]EPA considers BaP to be a mutagenic carcinogen (IRIS).

[e]Source: U.S. EPA (1997a).

The equations used to estimate cancer risk and noncancer hazard also are provided in Attachment B. Exposure and risk estimation follows the age-groupings EPA recommends for estimating cancer risks for each life-stage (U.S. EPA 2005c), and total lifetime cancer risk is the sum of those age-specific cancer risks. The approach also conforms with EPA guidance on estimating cancer risks for chemicals with a demonstrated mutagenic mode of action, applying, as appropriate, age-adjustment factor to account for the higher sensitivity of developing children to mutagens compared with adults (U.S. EPA 2005c,d,e).

Accordingly, estimated individual cancer risks for BaP (and other POM), which has a mutagenic mode of carcinogenesis, were adjusted upward to account for the stronger mutagenic potency of these compounds during childhood, as specified by EPA in its supplemental guidance for cancer risk assessment (U.S. EPA 2005c). Specifically, cancer potency for BaP (and all POM) is assumed to be tenfold greater for the first 2 years of life and threefold greater for the next 14 years (U.S. EPA 2005c,e). The cancer potency adjustment for chemicals with a mutagenic mode of action is discussed in Attachment B, Section B.5.1.

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 out. The degree to which the scenario is health protective overall depends on the combination of parameters for which “upper-end” percentile or health protective values are used instead of nationwide mean values. Exhibit 18 summarizes influential parameter values for this scenario and indicates the likely degree of health protectiveness associated with each. Although this summary does not quantify overall health-protective bias, it does demonstrate qualitatively that the scenario generally overestimates exposure and therefore is unlikely to screen out facilities that might pose risks to human health.

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 influences soil and air concentrations and deposition rates used to calculate chemical levels in farm foods.
Lake location	375 m from source; generally downwind	Health Protective	Location influences contamination levels in fish.
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 (i.e., not “diluted” by averaging with less contaminated areas farther from the source).

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
Size of lake	47 ha; about 3 m average depth	Health Protective	Lake is just large enough to support an aquatic ecosystem with high trophic-level fish. The higher water content of larger or deeper lakes would provide more dilution of chemicals received.
Meteorological Inputs			
Total precipitation	1.47 m/yr	Health Protective	Reflects particularly rainy areas of the United States (see Exhibit 12 for source). Higher precipitation rates result in more wet deposition over the modeled domain.
Precipitation frequency (with respect to impacted farm/lake)	Two thirds of total precipitation fall on farm/lake and watershed	Health Protective	Most precipitation occurs when the farm/lake are downwind of the source (see Exhibit 12 for additional justification).
Wind direction	Farm/lake are downwind 40% of the time	Health Protective	Reflects areas of the United States with particularly persistent wind flows (see Exhibit 12 for additional justification). Farm/lake located in the predominantly downwind direction. Chemical deposition over the watershed increases when winds blow from the facility into the watershed.
Wind speed	1.6 m/sec	Health Protective	Reflects areas of the United States with particularly low wind speeds (see Exhibit 12 for source). Slower wind speeds lead to more chemical deposition closer to the facility (i.e., over the farm/lake).
Air temperature	298 K	Neutral	Recommended default value listed in HHRAP (U.S. EPA 2005a). See Exhibit 12 for additional context.
Mixing height	226 m	Health Protective	Reflects areas of the United States with particularly low mixing heights (see Exhibit 12 for source). Lower mixing heights decrease the volume of air in which chemical mixing occurs, resulting in higher chemical concentrations in air and higher chemical deposition rates to the watershed.
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 over-estimate concentration in surface water.
Surface runoff into lake, onto farm	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/farm.

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
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.
Soil erosion from surface soil into lake	Varies by parcel; ranges from 0.002 to 0.005 kg/m^2-day	Health Protective	Erosion rates calculated using the universal soil loss equation (USLE); input parameter values were selected to favor higher erosion rates (i.e., to move more chemical from the watershed into the lake). Might underestimate erosion for locations with steeper slopes or more exposed soils.
Soil erosion from surface soil onto farm	About 0.003 kg/m^2-day	Health Protective	Erosion rates calculated using the USLE; inputs parameter values were selected to favor higher erosion rates. Might underestimate erosion for locations susceptible to high erosion rates; might overestimate erosion for locations where a farm is not an erosion sink in the watershed. Higher erosion increases concentration in soil (and farm foods).
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 bioaccumulation of chemicals in consumed fish. Linear food-chains (instead of more realistic food webs) maximizes concentration of bioaccumulative chemicals in higher trophic-level fish.
Parameters for Estimating Concentrations in Farm-Food-Chain Media[12]			
Fraction of plants and soil ingested by farm animals that is contaminated	1.0 (all food and soil from contaminated areas)	Health Protective	Assumes all livestock feed sources (including grains and silage) are derived from land parcel with highest chemical concentrations.
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.

[12] The terms “farm foods” and “farm-food-chain” or “FFC” generally are interchangeable. In specific context, the farm-food-chain includes soil in addition to farm foods.

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
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.
Human Ingestion Exposure Assumptions			
Combined ingestion of farm-food-chain media and fish	High-end, subsistence ingestion rates for both (i.e., 90th to 99th percentile)	Health Protective	Assuming combined high-end consumption, consistent with subsistence farming and fishing, likely overestimates exposure to any single individual.
Ingestion rates for all farm foods	All ingested foods are home-grown from impacted farm; 90th percentile ingestion rate for each of 10 foods	Health Protective	All food from contaminated farm; total food ingestion rate (across 10 food categories) for individual exceeds expected body weight-normalized ingestion rates (prevents underestimating any individual food type). See Exhibit 16 for source.
Fish ingestion rate	Adult: 373 g/day Child age groups: 1–2: 108 g/day 3–5: 159 g/day 6–11: 268 g/day 12–19: 331 g/day	Health Protective	The adult rate, the 99th percentile value for adult females from Burger (2002), is considered representative of subsistence fishers. Rates for children are based on the 99th percentile, consumer-only fish ingestion rates from EPA's 2002c *Estimated Per capita Fish Consumption in the United States*. Rates were adjusted to represent the age groups used in the screening scenario. See Exhibit B-17 in Attachment B for a detailed discussion.
Exposure frequency	Consumption of contaminated food items occurs 350 days/yr	Health Protective	All meals from local farm or fish products, except for two weeks per year when consumer is elsewhere. See Exhibit 16 for source.
Body weight	Mean of national distribution	Neutral	Note that this does not affect the body-weight-normalized ingestion rates for produce and animal products. See Exhibit 16 for source.
Chemical-Specific Characteristics			
General chemical properties used in fate and transport modeling (Henry's law, Kow, etc.)	Depends on chemical	Neutral	Obtained from peer-reviewed sources; intended to be representative of typical behavior and characteristics. See Attachment A and Attachment B for additional information.

Characteristic	Value	Neutral or Health Protective?	Comments on Assumptions
"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. See Attachment A and Attachment B for additional information.
Dose-response values		Neutral to Health Protective	Values used are those determined to be appropriate for risk assessment by OAQPS; values are developed to be health protective. See Exhibit 17 for source.

Tier 1 screening threshold emission rates were calculated by conducting iterative model simulations using the screening scenario described above to determine emission rates for arsenic, cadmium, mercury, dioxins, and POM that correspond to a cancer risk of 1-in-one million or a chronic noncancer HQ of 1. Given the generally health protective nature of the scenario inputs, these screening threshold emission rates are appropriate for a Tier 1 screen.

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 emission rate for any PB-HAP can be scrutinized further.

2.5 Evaluation of Screening Scenario

For a given source category, all facilities are reviewed to determine if emissions of any of five PB-HAPs are reported. If any facility emits one or more of the PB-HAPs, the Tier 1 screen is applied. Facility emissions of each PB-HAP are compared with the Tier 1 screening threshold emission rate to determine the resulting SV. In Tier 1, the magnitude of an SV has a limited implication for relative risk. For example, exceeding the screening threshold emission rate by a factor of 60 for dioxins does not imply an actual cancer risk of 60-in-one million. Rather, an SV of 60 implies that it is highly unlikely that the actual risk would exceed 60-in-one million, and likely would be much lower.

The Tier 1 methods evaluate congener-specific differences in fate and transport and in toxicity for dioxins and POMs. The final results are reported in 2,3,7,8-TCDD equivalents and benzo[a]pyrene equivalents, respectively.

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 arsenic (Section 2.5.1), 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 focused on assessing the behavior of these HAP categories in the environment, accumulation of these chemicals in fish and farm foods, and the exposure pathways and chemicals that contributed most to human risks.

2.5.1 Arsenic

Arsenic is a natural component of the earth's crust and is found naturally in minerals, most often as a compound with sulfide (HSDB 2009). Some of the largest anthropogenic sources of arsenic to air are nonferrous metal mining and smelting, pesticide application, coal combustion, wood combustion, and waste incineration (ATSDR, 2007). Inorganic arsenic has two stable oxidation states, +3 and +5 (arsenite and arsenate, respectively).

2.5.1.1 Behavior in the Environment

Depending on its chemical form and source, arsenic can undergo a variety of transformations, including oxidation or reduction, ligand exchange, precipitation out of solution when arsenate or arsenite combine with iron, sulfur, or chloride in water, and biotransformation to or from organic forms. Arsenic released to air from sources evaluated by the RTR program is primarily in particulate form as highly soluble oxides (pentavalent arsenate or As(V) as the arsenite ions $H_2AsO_4^-$ and $HAsO_4^{2-}$; trivalent arsenite or As(III) as arsenous acid, H_3AsO_3).Trivalent arsenite predominates in releases to air from industrial processes. Compounds detected in air include arsenic trisulfide from coal combustion, organic arsines from oil combustion, and arsenic trichloride from waste incineration (ATSDR 2007).

Arsenic is found in soil as a result of natural processes and anthropogenic sources including ash residue from power plants, smelting facilities, mining wastes, and industrial waste. Arsenic is found in mixtures of mineral phases (e.g., co-precipitates, sorbed to soil particles). Arsenic adsorbs to particulate matter in soils and sediments and tends to concentrate in the upper layers of soil. Iron content strongly affects arsenic adsorption to soil particles (ATSDR 2007). Arsenic has low to moderate mobility in clay soils, in which particles are small and total particle surface area high, and much higher mobility in loamy and sandy soils, for which particle sizes are larger, with less surface area per particle and per unit weight solid material.

Potential volatilization of arsenic from soil depends on its original form when deposited from air. Some microorganisms can methylate some inorganic arsenicals, with a proportion of dimethyl and trimethyl arsenic volatilizing to air. Soil particles adsorb other arsenic compounds, depending on iron oxide and organic carbon content, limiting bioavailability and future volatilization (HSDB 2009).

Arsenic exists primarily in the pentavalent form under oxidizing conditions, such as found in surface water, and in the trivalent form in reducing conditions, such as found in groundwater (ATSDR 2007). Arsenic transport in groundwater is determined by the chemical form of arsenic and adsorption is based on the other materials present in the aquifer, as well as the pH of the water (ATSDR 2007). Arsenic strongly sorbs onto sediments, and bacteria and fungi methylate arsenic compounds to form dimethyl and trimethylarsines (HSDB 2009).

Bioaccumulation of arsenic in plants and organisms in water depends on factors including type of water body, organism type, status in the food chain, concentration, and route of uptake. Bioconcentration of arsenic occurs primarily in algae and invertebrates; however, bottom feeders and predatory fish might accumulate arsenic from ingestion of sediments along with prey. Arsenic does not appear to biomagnify in the aquatic food chain (ATSDR 2007). In a study of bioaccumulation data for fish and invertebrates, bioconcentration factor (BCF) values ranged from 0.048 to 1,390 (U.S. EPA 2003b).

2.5.1.2 Arsenic Speciation Modeling Approach

Although inorganic arsenic exists in the environment as two predominant species—trivalent arsenic (arsenite) and pentavalent arsenic (arsenate)—with distinct characteristics, the modeling approach in TRIM.FaTE aggregated the two species for several reasons:

- EPA's Integrated Risk Information System (IRIS) provides one oral reference dose for inorganic arsenic (i.e., an undifferentiated species). Although some investigators report that trivalent arsenic is more toxic than pentavalent, the studies are in the context of aquatic toxicity to fish and invertebrates, not human ingestion toxicity.
- All sources of arsenic biotransfer factors (which represent the ratio of chemical concentration in produce to the chemical concentration in soil) and bioaccumulation factors (which represent the ratio of chemical concentration in various aquatic trophic levels to the chemical concentration in water) that we reviewed report values for total inorganic arsenic, without specifying oxidation state.
- NEI emissions data usually are reported in unspeciated terms, like "total inorganic arsenic." Estimating speciation for those emissions would require substantial research or simplifying assumptions.
- Other EPA programs also model a single inorganic arsenic species (e.g., the recent *Risk Assessment of Spent Foundry Sands in Soil-Related Applications,* U.S. EPA 2014c).

Modeling a single form of arsenic was implemented in both TRIM.FaTE and the multimedia exposure and risk calculations:

- For parameters for which different values are available for trivalent and pentavalent arsenic, the more health-protective value is used. If we could not predict which value would be more protective a priori, the screening approach was performed with each value, and the value that resulted in higher risk was chosen.
- Organic arsenic is not explicitly modeled. Ignoring potential methylation of inorganic arsenic in soils and sediments is a health-protective assumption because inorganic arsenic has been considered more toxic than organic forms (ATSDR 2007), although some recent studies suggest that a portion of ingested organic arsenic might be converted back to inorganic forms in animals (Carlin et al. 2005; U.S. EPA 2003b). For farm produce and livestock, biotransfer factors are reported for total arsenic only. Similarly, BAF and BSAF factors for fish are based on studies primarily of trivalent or unspecified inorganic arsenic in water and sediments, respectively. The BAF and BSAF factors are presumably based on total arsenic in the fish compared with dissolved inorganic arsenic in the environmental medium (U.S. EPA 2003b).

2.5.1.3 Arsenic Aquatic Bioaccumulation Modeling Approach

In modeling transfers of arsenic through the aquatic food web, empirical BAFs and BSAFs were used instead of the biokinetic approach, which is used for the other PB-HAPs in TRIM.FaTE. Fish tissue concentrations of arsenic are calculated as the product of water column and sediment arsenic concentrations (from TRIM.FaTE) and the empirical BAFs and BSAFs, respectively, for freshwater. The screening approach, therefore, estimates arsenic concentrations in fish in much the same way as in produce. Estimation of water-column fish concentration using the BAF approach requires, as an input, the concentration of dissolved

chemical in surface water. Because TRIM.FaTE outputs the total water-column concentration (i.e., as both dissolved and suspended solids), this total water-column concentration is multiplied by the fraction of mass dissolved (which is available from TRIM.FaTE HTML outputs) to estimate the dissolved chemical concentration. This dissolved concentration is then multiplied by the empirical BAFs to estimate water-column fish concentrations.

This approach can save time and effort because several arsenic-specific parameter values (e.g., gill uptake rate, metabolic transformations, absorption efficiency across the gut, form-specific elimination rates) are needed to implement the TRIM.FaTE aquatic food chain. Moreover, those arsenic values would need to be coded in the TRIM.FaTE Java library for the aquatic invertebrate and fish compartments. Although the empirical BAF approach is not mass-balanced (i.e., does not remove the arsenic transferred to fish compartments from the sediment and water-column compartments), we believe that the approach is adequate for the RTR screen for three reasons: (1) total chemical mass in the fish compartments typically is small compared with chemical mass in the surface water and sediment compartments; (2) RTR models focus on concentrations at year 50, by which time simulated environmental concentrations are typically close to steady-state; and (3) in past applications, the biokinetic food-chain models have been calibrated using measured chemical concentrations in algae, zooplankton, and fish at different trophic levels.

Arsenic concentrations tend to be the same or lower at successive trophic levels (e.g., it biodiminishes instead of bioaccumulates; Williams et al. 2006). BAF values for arsenic also tend to decrease with increasing water concentrations, indicating some physiological regulation by fish (Williams et al. 2006). The BAF/BSAF-based approach developed for arsenic can be applied to other chemicals in future.

2.5.1.4 Arsenic—Bioavailability in Soils Ingested by Humans

At the screening level, contaminants ingested with foods and with soils are assumed to be 100 percent bioavailable (i.e., all of the chemical ingested is absorbed from the exposure medium). Although unlikely to be true (e.g., a few percent is expected to be eliminated with feces, and some might be excreted in bile), the assumption is health protective and close to accurate for many organic chemicals. Inorganic chemicals, on the other hand, might or might not be well absorbed, particularly from soils with minerals and organic carbon to which inorganic chemicals adsorb. For example, the RfD for cadmium is higher (less stringent) for its ingestion with food (1E−03) than cadmium ingested with water (5E−04), meaning it is less bioavailable in food than in water. For arsenic, the CSF is based on ingestion in drinking water. EPA's Superfund Program has therefore investigated arsenic bioavailability from incidental ingestion of arsenic-contaminated soils compared with its bioavailability in water to assist in setting target concentrations in soils for site remediation.

Swine have served as an in vivo animal model by which to evaluate the bioavailability of chemicals in soils for many years (primates also have been used on occasion; U.S. EPA 2012b). In the past decade, in vivo animal models have been extended to mice. Examining the results across species, EPA developed an estimate of the bioavailability of arsenic in soils to mammals, finding the upper 95th percentile value to approximate 0.60. The upper 95th percentile values for swine, monkeys, and mice were estimated as 0.609, 0.327, and 0.502, respectively (U.S. EPA 2012b). Thus, the value of 0.60 is likely to be a health-protective value for humans and is used to estimate exposure from ingestion of soil.

2.5.1.5 Arsenic Concentrations in Ingestible Products

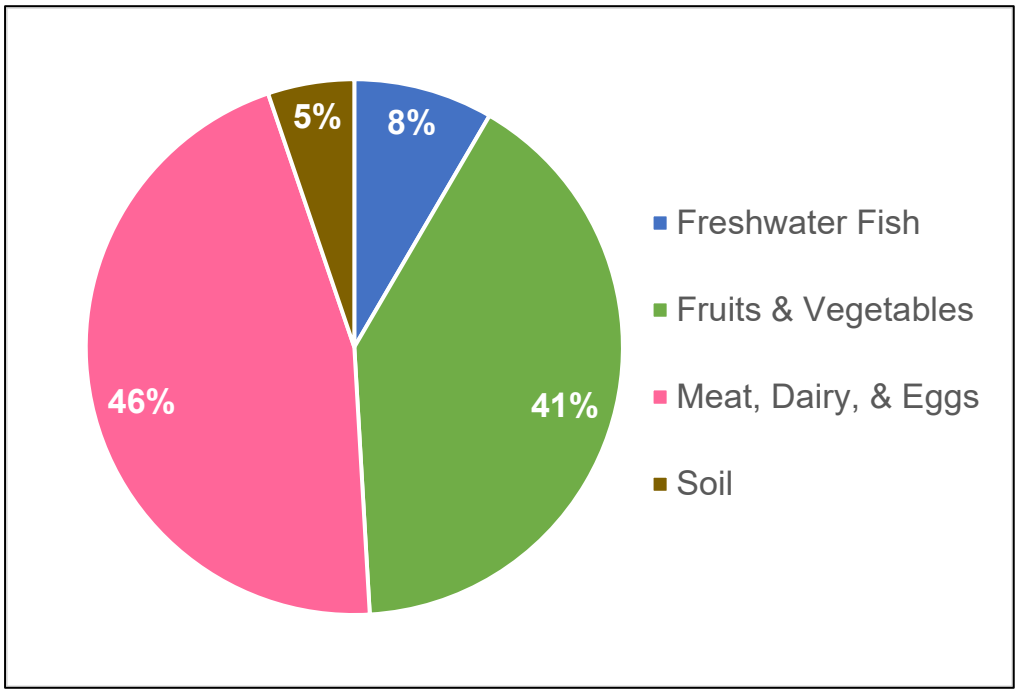
Most non-inhalation exposure to arsenic outside of occupational settings is through dietary intake. Arsenic in agricultural soils is largely immobile and remains in the upper soil levels (ATSDR 2007). Most plants would accumulate arsenic initially released to air from stationary facilities by uptake by the roots from the soil or by arsenic deposition on the leaves. Larsen et al. (1992) found that arsenic emitted from burning arsenic-treated wood was taken up by kale from arsenic deposited on leaves and that arsenic in potatoes and carrots came from both atmospheric deposition to leaves and root uptake. In general, arsenic accumulation by plants depends on the form(s) of arsenic in the environment and the species of plant. In the United States, seafood (i.e., marine and estuarine fish and shellfish), meat, and rice have been reported to contain the highest levels of arsenic. Arsenic has also been detected at low levels in other foods (ATSDR 2007).

For the RTR screening scenario, the relative arsenic concentration estimates were consistent with relative concentrations reported for soils, produce, and other farm-grown meat products.

2.5.1.6 Lifetime Average Daily Dose (LADD)

Exhibit 19 presents the contribution of the various ingested media to overall arsenic exposure for different age groups. Ingestion of freshwater fish contributes approximately 8 percent of total exposure, whereas direct soil ingestion contributes 5 percent. The remaining exposure is fairly evenly distributed across farm foods such as fruit, vegetables, dairy, eggs, and meat. That distribution appears reasonable, given that data (U.S. EPA 2012b; Williams et al. 2006) indicate that freshwater fish accumulate substantially less arsenic from water than marine or estuarine fish species.

Exhibit 19. Estimated Media Contributions to Arsenic Ingestion Exposures and Lifetime Cancer Risks



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). Cadmium has one stable oxidation (or valence) state, +2.

2.5.2.1 Behavior in the Environment

Once emitted to air, cadmium in or on small airborne particles can travel long distances before being deposited; however, most cadmium released to air is found in soils near facilities that released it (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 adsorbed 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 highly organic soils. Nonetheless, some plant species absorb cadmium efficiently via their roots, thus providing an entry point for cadmium into the terrestrial food chain (ATSDR 2008).

Cadmium in air can enter surface waters directly via wet and dry deposition and indirectly from runoff and erosion of cadmium deposited to soil. Most cadmium compounds entering the water column are quickly removed through adsorption to suspended particles or algae, with eventual sedimentation. Cadmium that remains in the water column is expected to exist primarily as dissolved cations, which are readily bioavailable to aquatic organisms.

Freshwater fish accumulate cadmium primarily through direct uptake of dissolved cadmium through the gills, but also can accumulate cadmium ingested with their foods (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, bioaccumulation in freshwater systems occurs mainly at lower trophic levels (Chen et al. 2000), primarily in phytoplankton and zooplankton and in filter-feeding macroinvertebrates (e.g., bivalves; 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 can biodiminish in fish from one trophic level to the next (Chen et al. 2000; Mason et al. 2000).

For the RTR screening scenario, the partitioning behavior modeled in TRIM.FaTE was consistent with monitoring data for cadmium in the environment.

2.5.2.2 Concentrations in Foods

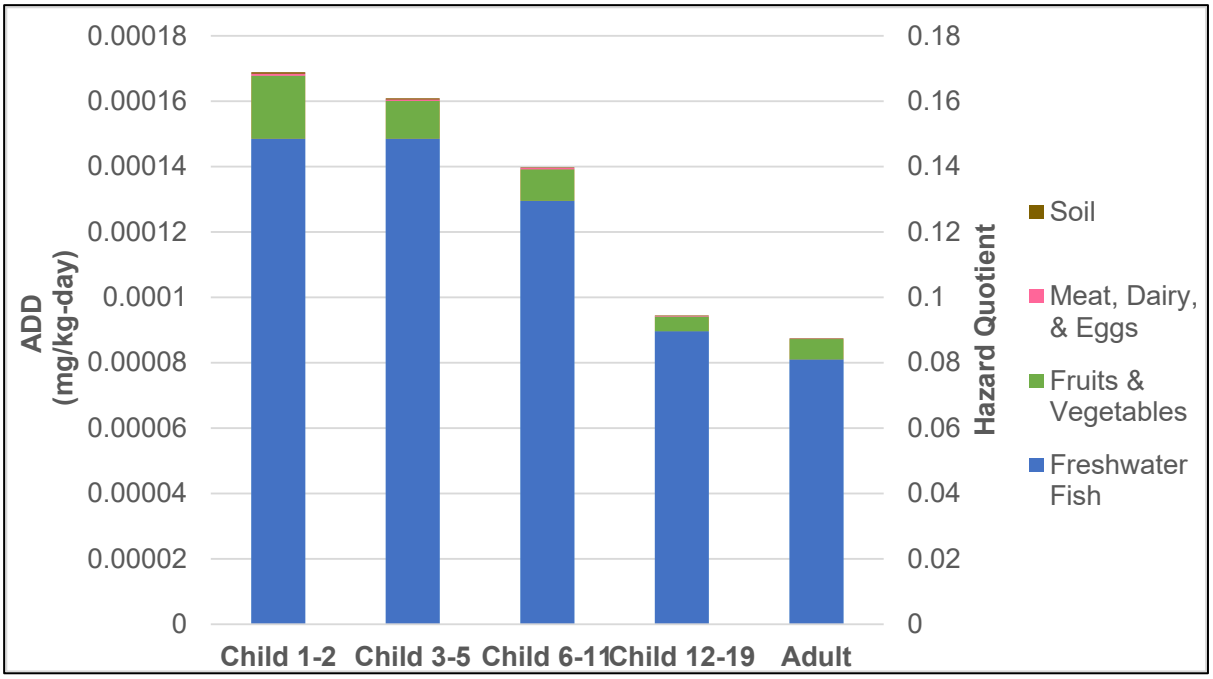
Most exposure to cadmium outside of occupational settings is through dietary intake. Available data indicate that cadmium accumulates in plants, aquatic organisms, and terrestrial animals, offering multiple ingestion exposure pathways (ATSDR 2008). Measured cadmium levels in foods vary based on type 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).

The cadmium concentrations estimated with the RTR screening approach were consistent with values reported in the literature. The products with higher reported cadmium levels in the literature also contained the higher modeled concentrations.

2.5.2.3 Average Daily Dose

Exhibit 20 presents the average daily dose (ADD) received through each of the ingested media, by age category, at a unit emission rate of 1-gram cadmium per day. This chart can be used to evaluate the relative contributions of ingested media to the chemical HQ. (Using the cadmium screening threshold emission rate would simply change the y-axis ADD and HQ labels; the media contributions relative to each other would be unchanged). Fish ingestion dominates risk for cadmium across all age categories, accounting for about 90 percent or more of the ADD for all groups. The combined contribution from all other ingested media accounts for less than 10 percent of the total ADD for all age groups. Most of the additional exposure was from ingestion of fruits and vegetables. The highest ADD is for children aged 1–2 years because of their high food ingestion rate relative to body weight; thus, the exposure corresponding to this group determines the screening threshold emission rate for cadmium (i.e., the rate at which the HQ for this age category equals 1.0).

Exhibit 20. Estimated Media Contributions to Cadmium Ingestion Exposures and HQs



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, but with some divalent forms bound to particles (U.S. EPA 1997b).

2.5.3.1 Behavior in the Environment

Once emitted to air, mercury form and valence state can change in the atmosphere. Elemental mercury (Hg_2^0) vapor is the most prevalent species of mercury in the atmosphere at ambient temperatures. Due to its high vapor pressure, generally more than 98 percent of elemental mercury remains in the atmosphere, where it is dispersed long distances on a global scale.

Divalent mercury can sorb to particles, but a large proportion is in vapor phase and quite reactive with surfaces. Divalent mercury therefore deposits from air relatively quickly, more so in its reactive gaseous phase (RGP) than in particulate phase (Landis et al. 2004; Cohen 2005). Thus, divalent mercury deposits locally via wet, dry, or reactive deposition, where it adsorbs tightly to soil particles (U.S. EPA 1997b). Divalent mercury also deposits to surface waters, where it sorbs to particulate or dissolved organic carbon (Driscoll et al. 2007). Divalent mercury in soil also can be methylated by microbes or reduced to elemental mercury, which volatilizes 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 (ATSDR 1999). Although complexing with organic matter and several minerals in soil significantly limits further aqueous mercury transport (e.g., via leaching or runoff), the tendency of mercury to form these complexes depends on soil conditions such as pH, temperature, and soil humic content (U.S. EPA 1997b). 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). More mercury in soil is likely to reach surface waters via erosion than via runoff or leaching.

Mercury also deposits to lakes directly from air. Once in the water body, microbes can methylate divalent mercury, particularly in the sediments. In addition, divalent and methyl mercury can be further reduced to elemental mercury, which can volatilize to the atmosphere. Solid forms of inorganic mercury compounds could adsorb to particulates in the water column or partition to the sediment bed (U.S. EPA 1997b).

The solubility of mercury in water depends on the species and form of mercury present as well as properties of the water such as pH and chloride ion concentration (ATSDR 1999). Low pH favors methylation of mercury in the water column and sediments, typically performed by sulfur-reducing bacteria in anaerobic conditions (e.g., anaerobic layer of sediments). Methyl mercury is typically of greatest concern because it readily bioaccumulates *and* biomagnifies in aquatic organisms. Once ingested by fish, methylmercury distributes to all tissues and binds to proteins, thereby sequestering large amounts in muscle.

A considerable amount (25–60 percent) of both divalent mercury compounds and methyl mercury is strongly bound to particulates in the water column (U.S. EPA 1997b). 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.

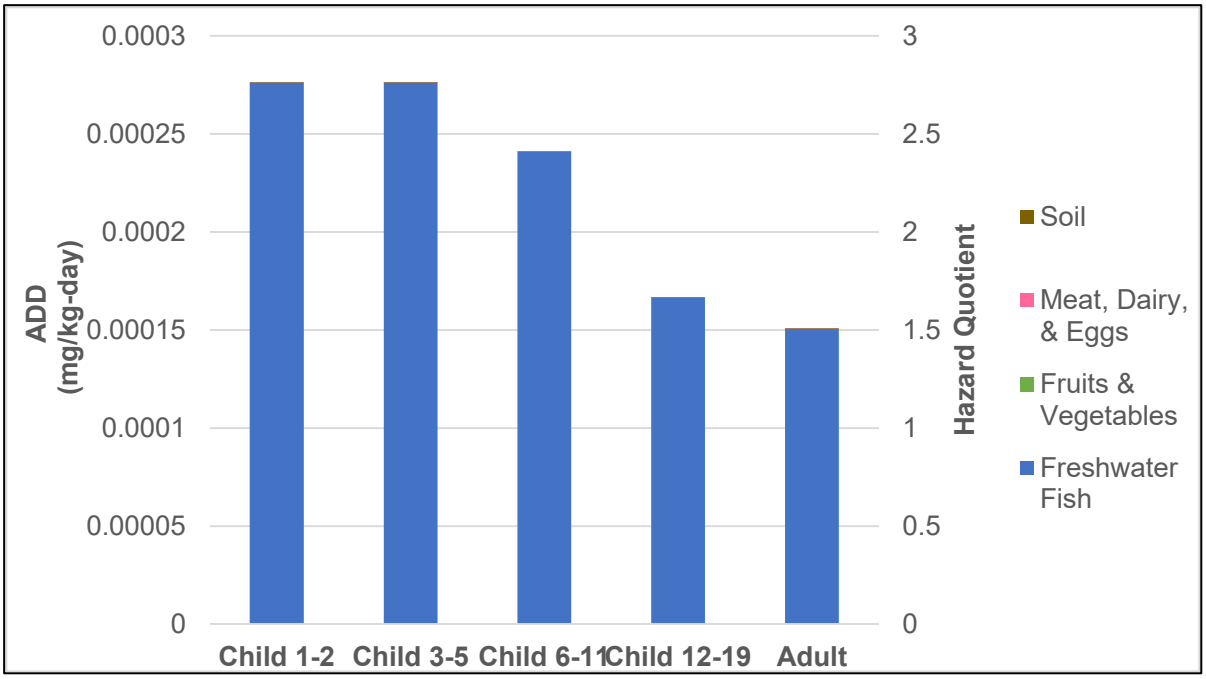
2.5.3.2 Concentrations in Foods

Available data indicate that mercury bioaccumulates in plants, aquatic organisms, and terrestrial animals, providing multiple ingestion exposure pathways (U.S. EPA 1997b; 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; U.S. EPA 1997b). 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 relatively low (ATSDR 1999). Concentrations of methyl mercury in fish are generally highest in larger, older fish at the higher trophic levels (U.S. EPA 1997b).

Although data on mercury in foods other than fish are not abundant in the literature, estimated relative mercury concentrations across food types are generally consistent with available environmental monitoring data. The ingested media that most influenced the mercury HQs in the model are presented in Exhibit 21. As shown, the dominant exposure pathway for all age groups is ingestion of fish. In top trophic level fish, methyl mercury accounts for more than 95 percent of total mercury.

Exhibit 21. Estimated Media Contributions to Methyl Mercury Ingestion Exposures and HQs



2.5.3.3 Average Daily Dose

Exhibit 21 presents the ADD received through each ingested medium, by age category, at a unit emission rate of 1 gram of divalent mercury per day. This chart can be used to judge the relative contribution of ingested media to the methyl mercury HQ. (Using the divalent mercury screening threshold emission rate would simply change the y-axis ADD and HQ labels; the media contributions relative to each other would be unchanged). 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 ingested media 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 is used to determine the screening threshold emission rate for mercury.

2.5.4 Dioxins

Incineration and combustion processes are believed to be the primary sources for emissions of 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. Forest fires and agricultural field burning also account for a large proportion of dioxins in soils and in ambient air (ATSDR 1998).

2.5.4.1 Behavior in the Environment

Dioxins emitted to the atmosphere can be transported long distances in vapor form or bound to small particulates, depositing to soils and water bodies primarily via precipitation events in otherwise pristine locations far from all sources. Although airborne dioxins are susceptible to wet and dry deposition, most dioxins emitted to the atmosphere through incineration/combustion processes that vent from tall stacks 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 in the subsurface soil profile, with erosion of contaminated soil particles the only significant mechanism for transport to water bodies. Dioxin volatilization from the soil surface can contribute to plant uptake via foliage because of the very high bioaccumulation potential for TCDD (and presumably the other dioxins/furans) by plant leaves from air (Trapp 1995).

Dry deposition of dioxins from the atmosphere to water bodies is another important transport process. Because of their hydrophobic nature, 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 (U.S. EPA 2004c). Although dioxins bound to aquatic sediment particles eventually become buried in consolidated sediments, some resuspension and remobilization of congeners can occur if sediments are disturbed (e.g., by benthic organisms; ATSDR 1998).

Bioaccumulation factors 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 (U.S. 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. Dioxins also readily partition into breast milk, which has a high fat content, due to the lipophilic nature of these compounds.

2.5.4.2 Concentrations in Foods

The primary source of non-inhalation exposure to dioxins outside of occupational settings is through dietary intake (ATSDR 1998). Available data indicate that dioxins concentrate in plants, aquatic organisms, and animals, offering multiple ingestion exposure pathways. Actual congener levels in foods, 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 uptake by plant foliage, which then can be consumed by larger animals. Another major source of animal exposure to dioxins is through ingestion of contaminated soil.

Observed trends indicate that meat, dairy, and fish consumption are the dominant exposure pathways for environmental dioxins, 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-equivalents 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 (ATSDR 1998). 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 screen.

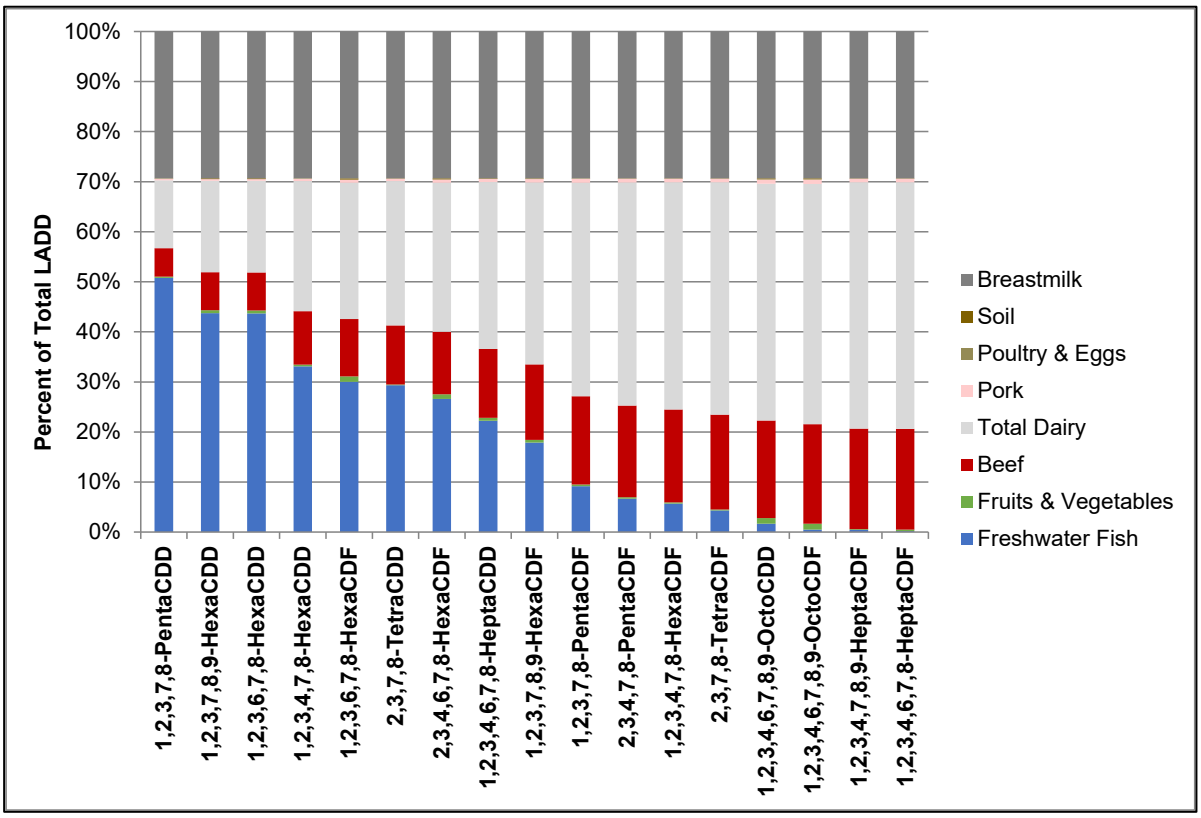
2.5.4.3 Lifetime Average Daily Dose (LADD)

The contributions of the various ingested media to the lifetime average daily dose (LADD) (and thus lifetime cancer risk) for the modeled dioxin congeners are presented in Exhibit 22. Based on the models and assumptions used, exposure via breast milk ingestion during the first year of life accounts for approximately 30 percent of the lifetime exposure for all congeners, while exposure via ingestion of fish, soil, and the various farm foods varies across congeners largely because of differences in physiochemical properties that drive environmental transport processes (e.g., Kow, molecular weight). Some differences are also likely due to different biological half-lives of congeners in plants and animals. The relative contribution of farm-raised livestock and produce to total congener exposure is higher for the more highly chlorinated dioxins, which are less soluble in water.

2.5.5 Polycyclic Aromatic Hydrocarbons and Other Polycyclic Organic Matter

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 anthropogenic PAH emissions (ATSDR 1995). 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 22. Estimated Media Contributions to Dioxin Ingestion Exposures



2.5.5.1 Behavior in the Environment

PAHs and other POM emitted to the atmosphere can travel long distances in vapor form or attached to small particles, or they can deposit relatively close to an emission source by wet or dry deposition onto surface waters, soils, and vegetation. In the atmosphere, PAHs occur primarily in the particle-bound phase, and climatic conditions and the size of the particles to which they are bound highly influence atmospheric residence time and transport distances (ATSDR 1995). Lower molecular weight PAHs are more volatile than higher molecular weight compounds. The smallest PAH, two-ringed naphthalene, is highly volatile and remains largely (e.g., 98 percent) in vapor phase in air. Thus, naphthalene is not evaluated as a PB-HAP.

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, which limits 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 of the smaller molecules 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 in fish does not occur because fish can rapidly metabolize PAHs (ATSDR 1995). As a result, concentrations of PAHs in fish have generally been observed to decrease with increasing trophic levels (ATSDR 1995). Sediment-dwelling invertebrates can accumulate

PAHs via filter feeding, consumption of detritus, and direct uptake from sediment pore water (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 Food

The primary source of non-inhalation exposure to benzo[a]pyrene and other PAHs and POM, outside of occupational settings, is through dietary intake. Exposure concentrations depend on the origin of the food (higher values are often recorded at contaminated sites). Moreover, because PAHs and POM are created by combustion of organic materials, cooking foods at high temperatures (e.g., grilling or broiling to a surface char) or smoking meats can create PAHs in and on foods from any location.

PAHs can bioaccumulate in aquatic organisms and terrestrial animals through uptake of contaminated water, soil, and food. These compounds are readily metabolized by vertebrates, however, so bioaccumulation in fish and livestock generally is considered to be insignificant (ATSDR 1995). Plants can accumulate vapor-phase PAHs through open leaf stomata during the day, and some particulate-phase POM deposited to leaf surfaces might transfer through the leaf cuticle. Monitored PAH concentrations in plants, however, tend to be below detection limits.

PAH concentrations in meat can vary widely, from below detection levels to high concentrations, particularly in smoked meats. 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 meat and fish products preserved or prepared using these processes. It is possible that concentrations of PAHs in foods grown near facilities that emit PAHs to air are lower than in foods grilled or smoked.

For the RTR screening scenario, estimated BaP concentrations in foods grown near a facility are generally lower than the reported ranges for BaP in cooked or smoked fish and meat products and generally are predicted to be near or below likely detection limits.

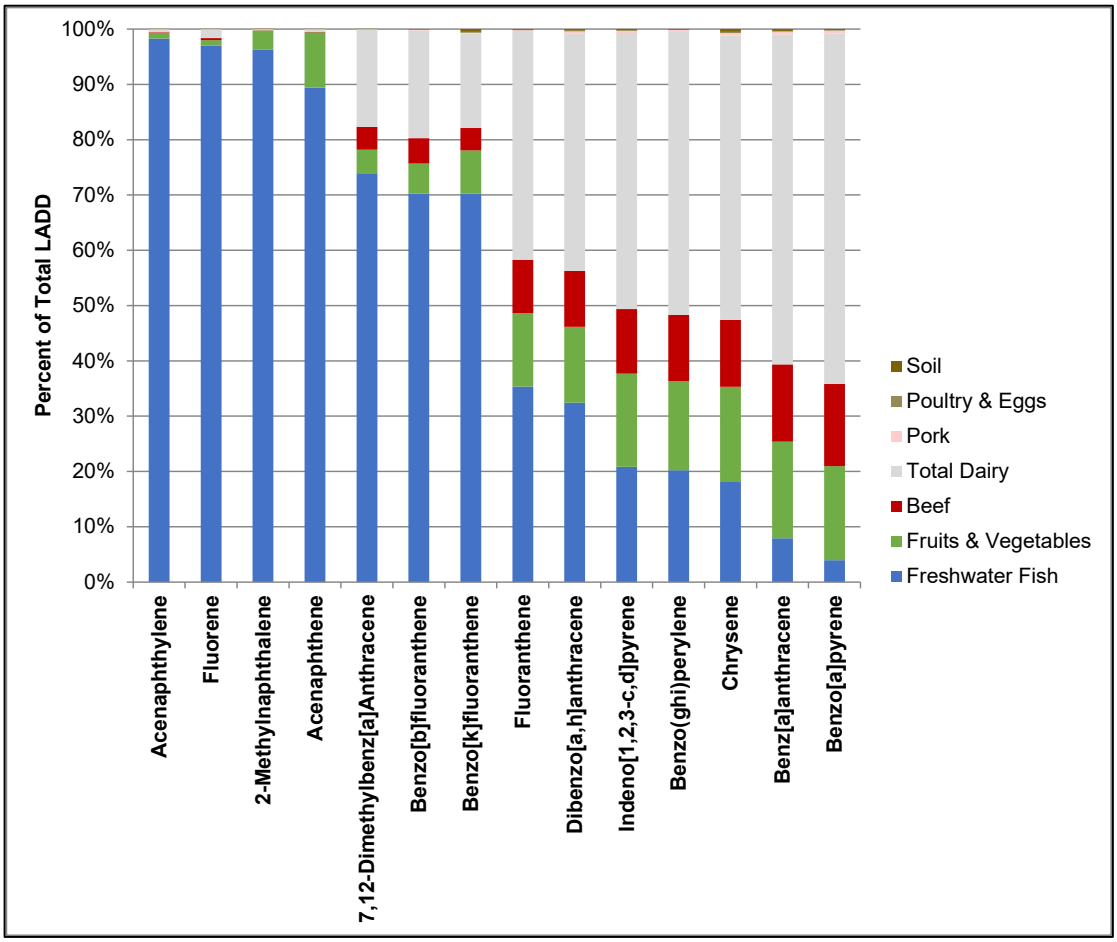
2.5.5.3. Lifetime Average Daily Dose

The contributions of the various ingested media to the LADD (and thus lifetime cancer risk) for various PAHs frequently reported in NEI for RTR source categories and that are fully parameterized in TRIM.FaTE are presented in Exhibit 23. As shown, the contribution of different ingested media to total ingestion of each compound varies, although fish and dairy comprise between 67 and 99 percent of exposure for different PAHs (with beef, fruits, and vegetables comprising nearly all the remainder).

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., Kow, molecular weight, chemical structure), differences in the PAH-specific half-life in abiotic media, and the degree to which the PAHs are metabolized by plants and animals. The variability across exposure pathways is consistent with information provided in the literature. The PAHs with lower molecular weights tend to be more volatile and more soluble in water than the PAHs with higher molecular weights; hence fish ingestion is a more important pathway for lighter-weight PAHs.

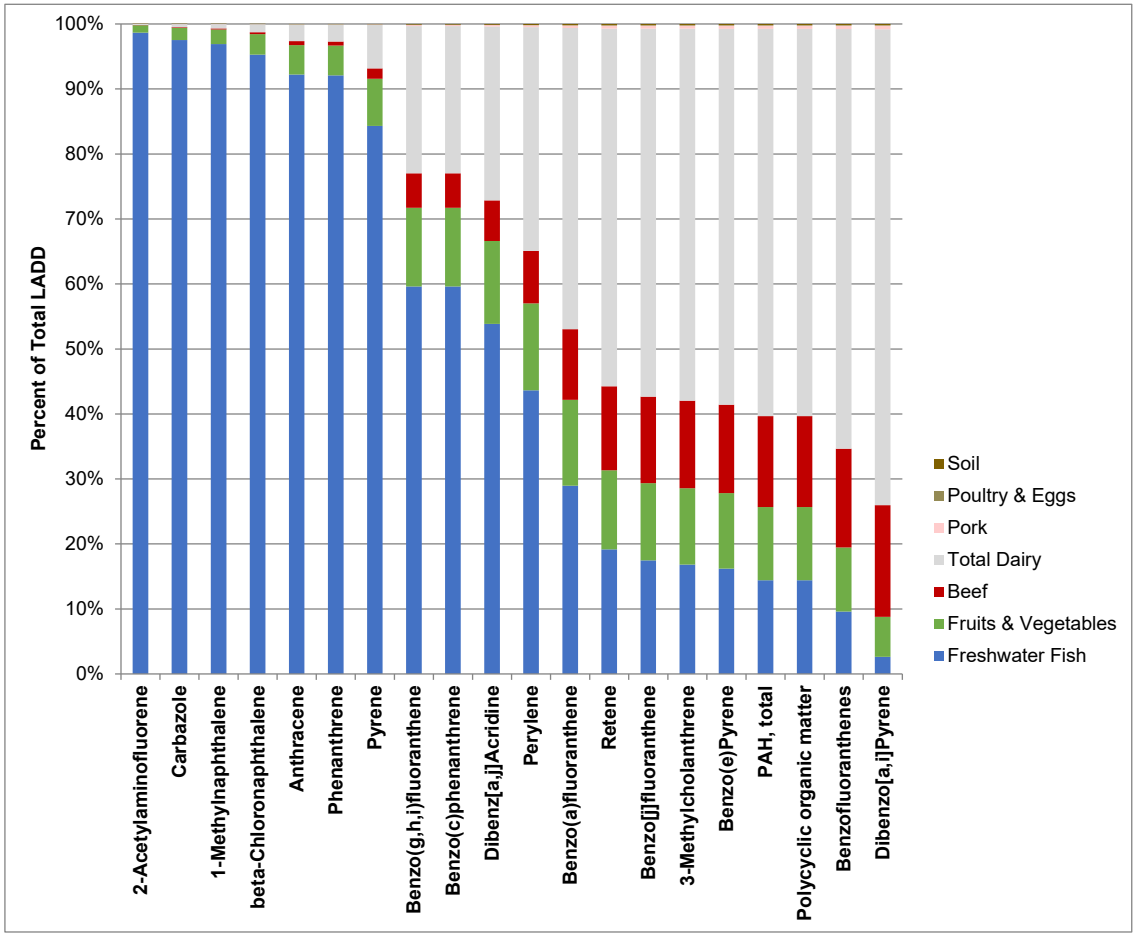
Exhibit 24 shows the contribution of the various ingested media to the LADD (and thus lifetime cancer risk) for each of the additional 22 POM chemicals evaluated for RTR, but not fully parameterized in TRIM.FaTE. The same trend with lower to higher molecular weight POM observed in Exhibit 23 is evident in Exhibit 24.

Exhibit 23. Estimated Media Contributions to Polycyclic Organic Matter Ingestion Exposures[a]



[a]POM chemicals that are fully parameterized in TRIM.FaTE.

Exhibit 24. Estimated Contributions of Modeled Food Types to Additional POM Chemical Ingestion Exposures[a]



[a]POM chemicals not fully parameterized in TRIM.FaTE (note that benz[a]anthracene/chrysene and benzo[b+k]fluoranthene are not provided in this exhibit because benz[a]anthracene/chrysene is modeled as "polycyclic organic matter" and benzo[b+k]fluoranthene is modeled as benzo[k]fluoranthene) for RTR screens due to data limitations).

2.5.6 Summary

Trends in the predominant media contributing to exposure for the PB-HAP categories assessed to date by EPA's RTR Program are generally consistent with trends in measured data and partitioning behavior reported in the literature. This assessment reveals that fish ingestion is a major route of exposure for cadmium, mercury, dioxins, and the lower molecular weight POM chemicals. For arsenic, farm-raised produce and livestock also contribute to ingestion exposures, with freshwater fish ingestion accounting for a comparatively small percentage of total exposure. For the lipophilic organic PB-HAPs (i.e., dioxins and POM), farm foods also contribute substantially to ingestion exposures, with beef and dairy contributing significantly to the LADD.

3. Tier 2 Screen

This section describes the Tier 2 screening methods and assumptions. Section 3.1 provides an overview and compares and contrasts the Tier 2 approach with the Tier 1 approach. Construction of the library of Tier 2 screening threshold emission rates is presented in

Section 3.2. Finally, Section 3.3 describes implementation of Tier 2: the one-time set of runs to define the library of emission thresholds values, and the facility-specific implementation of Tier 2 screens.

3.1 Overview of Approach

In Tier 2, some of the conservative assumptions in the Tier 1 screen are replaced with more site-specific information. These fall into two general categories: environmental assumptions and exposure assumptions. The remainder of this section describes in detail the Tier 2 environmental assumptions (Section 3.1.1), exposure assumptions (Section 3.1.2), and implementation of Tier 2 (Section 3.1.3).

3.1.1 Tier 2 Environmental Assumptions

In Tier 2, location-specific data on five environmental variables comprising two general types of data are evaluated:

- Meteorological characteristics: (1) the fraction of time the wind blows toward each farm and lake (based on wind direction), (2) wind speed, (3) precipitation rate, and (4) air mixing height; and
- (5) Distance from facility: Locations of farms/gardens and fishable lake(s) relative to the facility[13] (including the absence of a fishable lake).

Those inputs were selected for Tier 2 modifications based on:

- Relative influence on estimated risks,
- Ease of implementation in TRIM.FaTE (e.g., can the parameter be modified as a user input, or must the model code be modified and tested?), and
- Ease of obtaining reliable parameter values more representative of specific locations.

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 listed above (i.e., 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 in eight octants. The values of each of the four variables were varied independently from one another (i.e., other variable values held constant). The values (i.e., four to six different values 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 per variable resulted in a reasonable number of total runs and condition combinations.

For distance from the facility, lakes and farms/gardens were modeled at five different distances. In implementing Tier 2, actual locations of fishable lakes near the facility are determined and these locations are used in selecting the appropriate distance from the facility. For the fisher scenario, the Tier 2 screen allows for aggregate contributions from multiple facilities within a source category that are located near actual lakes. Actual farm/garden locations near the facility are not known in Tier 2 because there is no known national database of locations of farms and

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

home gardens. Therefore, each of the hypothetical locations in the modeling is evaluated (with no multi-facility aggregate contributions of deposited chemical), and the location with the highest SV is identified.

3.1.2 Tier 2 Exposure Assumptions

In Tier 2, several aspects of the exposure scenario are reevaluated. Although subsistence fisher and farmer scenarios still are evaluated (if needed based on the results of the Tier 1 screen), the ingestion is disaggregated into two exposure scenarios that represent a subsistence farmer (who ingests fruits and vegetables, meat and dairy products, eggs, and soil) and a subsistence fisher (who ingests only fish).

In addition, another exposure scenario is introduced in Tier 2: a gardener scenario. In many settings, it is unrealistic to assume that a farm that provides all exposure media for the farmer scenario can exist in the area surrounding a facility. The gardener scenario often will provide a more realistic exposure scenario where the resident grows and eats fruits and vegetables from a home garden and eats eggs from home-raised hens but does not produce and eat meat or dairy products. The gardener also is assumed to incidentally ingest the same high-end amount of soil as a farmer. The gardener scenario is further defined as either an urban gardener or a rural gardener based on Census data for the location being assessed. If the census block closest to the facility is in a Census-defined urbanized area based on population density, the area around the facility is considered urban (otherwise, it is considered rural). The rural gardener consumes produce at the same 90th percentile ingestion rates as the famer; however, the urban gardener consumes less food from the garden (i.e., mean ingestion rates) because they likely also consume store-bought produce and have a smaller footprint in which to grow produce. The gardener scenario uses the same media concentration data that are developed for the farmer scenario.

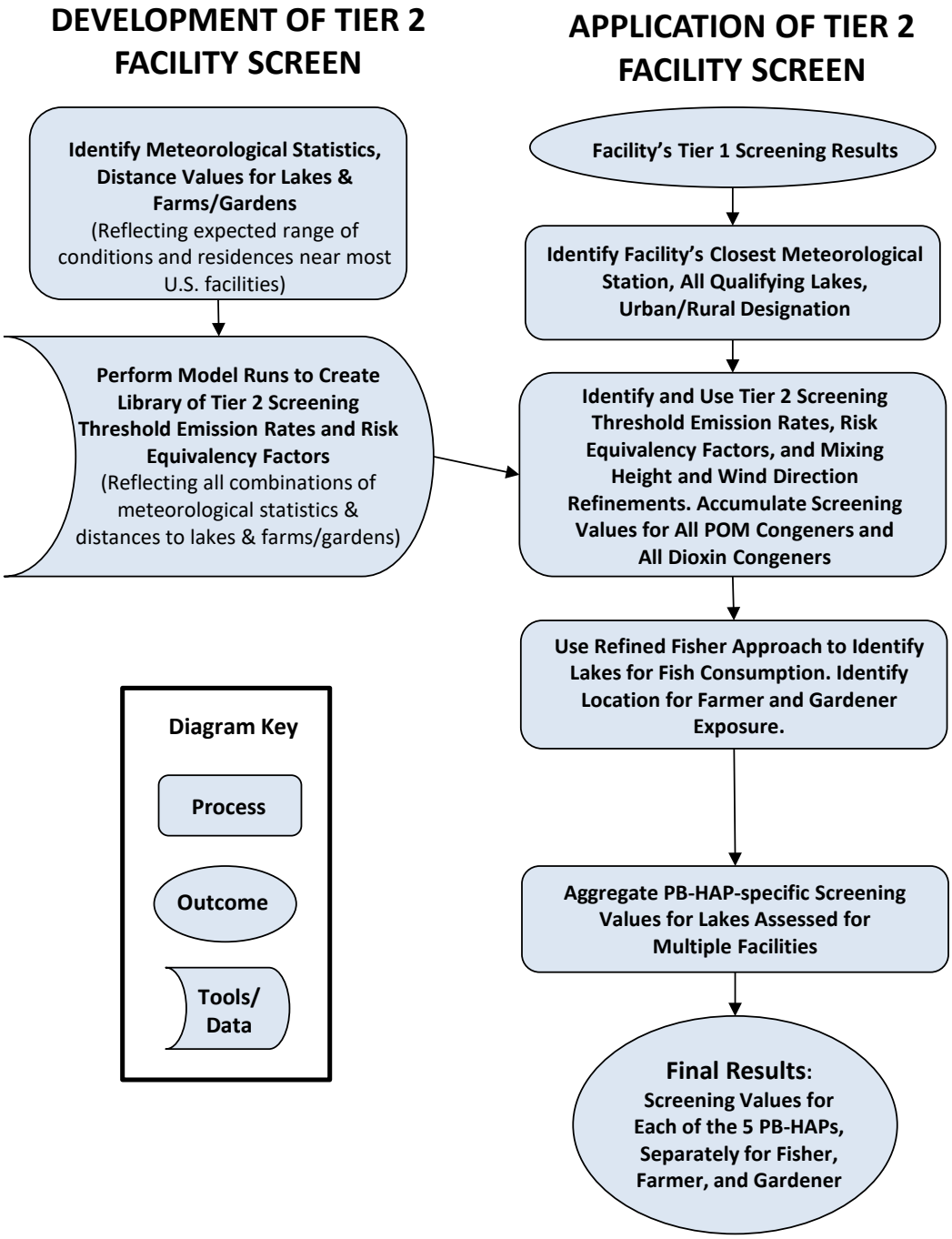
Tier 2 differs in two additional ways from the Tier 1 exposure scenario:

- Incidental soil ingestion and farm-food ingestion is evaluated at each of 40 locations around the facility (five distances and eight directions), not just at one location close to the source. The results reported for Tier 2 for the farmer and the gardener are from the location with the maximum SV (i.e., which corresponds to the area with maximum deposition).
- Fish are harvested at a sustainable rate based on lake size, so that the fisher might need to fish from multiple lakes to meet the subsistence fish ingestion rate.

3.1.3 Implementation of Tier 2

The overall implementation of the Tier 2 multipathway screen is illustrated in Exhibit 25. The steps on the left in Exhibit 25, which are discussed in Section 3.2, need only to be conducted once. The “one-time” steps include running 64 combinations of meteorological parameters through TRIM.FaTE for each of five separate lake-distance scenarios and five separate farm/garden-distance scenarios (i.e., distance from the facility). Resultant concentrations are processed assuming separate fisher, farmer, and gardener (both rural and urban gardener) ingestion scenarios. These runs result in Tier 2 REFs and screening threshold emission rates for all Tier 2 exposure scenarios.

Exhibit 25. Basic Process for Implementing the Tier 2 Multipathway Screen



The steps on the right in Exhibit 25 are conducted for each facility using a Microsoft® Access™ tool developed for RTR screens. For each facility, the tool identifies the same meteorology station used in RTR inhalation assessments, and it records the values for the four relevant meteorological parameters at that station. The tool also computes distances from the facility to real lakes in the RTR lake dataset within a user-specified distance (default is 50 km) and matches the lakes to their respective directional "octant" relative to the facility. These five parameter values become the set of facility-specific inputs for Tier 2.

The lake dataset for RTR is based on a U.S. Geological Survey (USGS) database, which includes information on location, surface area, use or type designation, and name (if available) for all lakes in the United States. The dataset 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. In general, smaller lakes and lakes closer to a facility are likely to be the most highly contaminated by air emissions from that facility.

Very large lakes (i.e., those larger than 100,000 acres) are not considered because their large volumes significantly dilute air deposition from point sources. Such large lakes, including the Great Lakes, the Great Salt Lake, Lake Okeechobee, Lake Pontchartrain, and Lake Champlain, also dilute contaminants in the vast biomass of fish in the large aquatic food webs. Contaminants derived from emissions to air by a point source would be distributed among populations of millions of fish resulting in negligible increases in fish tissue concentrations attributable to the point source. Also, very large lakes are rare (only 35 such lakes in the conterminous United States). Moreover, for facilities near large lakes, there usually are other, smaller lakes that we do consider for which contaminant dilution would be lower, and therefore risks likely higher. Thus, we do model exposure via fish consumption for populations that are near large lakes in a manner that generally will be more health protective than modeling the very large lake. If, on the other hand, multiple point sources from the same source category were clustered along several miles of shoreline of a very large lake, with no smaller lakes nearby, a health protective, simplified model of the near-shore environment could be simulated for a site-specific assessment.

Bays where rivers enter the ocean, such as Galveston Bay and San Francisco Bay, are not only very large, but also have complex patterns of tidal flow, sediment deposition, and fish migration between the oceanic, estuarine, and upstream river systems. Air deposition from air emissions from a given point source would be widely dispersed and diluted among large populations of many different estuarine and migratory fish species. Thus bays/estuaries are not considered relevant for estimating risks from point source air emissions.

Finally, very large lakes can have notable contamination from current and historical pollution produced by various industries as well as from agricultural and other land-use practices. The RTR program, however, regulates HAPs at the source-category level and does so by evaluating category facilities’ contributions to incremental, localized risk; cumulative risk from all sources and previous contamination is not relevant to the RTR program.

For the purposes of Tier 2, a “relevant” lake meets the size and designation criteria discussed in the previous paragraphs. Second, the lake names are reviewed, and lakes with names suggesting uses related to disposal, evaporation, or treatment may be removed from the dataset (sometimes the name indicates one of these uses while the USGS designations do not; for example, the Gavin Fly Ash Impoundment may 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 screen for the fisher.

For the farmer and gardener scenarios, each farm/garden-distance scenario is evaluated from the “one-time” modeling, and the facility’s emissions are compared with the Tier 2 screening threshold emission rates for those farm/garden-distance values and site-specific meteorological values. As noted previously, media concentrations developed for the farmer scenario are used for the gardener scenarios.

As with Tier 1, a facility screens out if none of the chemical specific facility emissions exceed the applicable Tier 2 screening threshold emission rates; otherwise, additional evaluation might be needed (i.e., Tier 3; see Section 4).

3.2 Library of Tier 2 Screening Threshold Emission Rates

This section describes the "one-time" steps presented on the left side of Exhibit 25. Section 3.2.1 discusses use of site-specific meteorological data, and Section 3.2.2 discusses the potential locations of lakes, farms, and gardens. Section 3.2.3 discusses the Gardener exposure scenario, which is introduced to the screening assessment during the Tier 2 screening. Finally, Section 3.2.4 describes the creation of a library of Tier 2 screening threshold emission rates, REFs, and mixing height refinements.

Attachment D provides information on all the TRIM.FaTE variables considered for the Tier 2 screen.[14] Using the criteria above, we ranked variables as high, medium, or low priority. Meteorological parameters and lake location were high priority and feasible to implement with input from public databases.

3.2.1 Meteorological Data

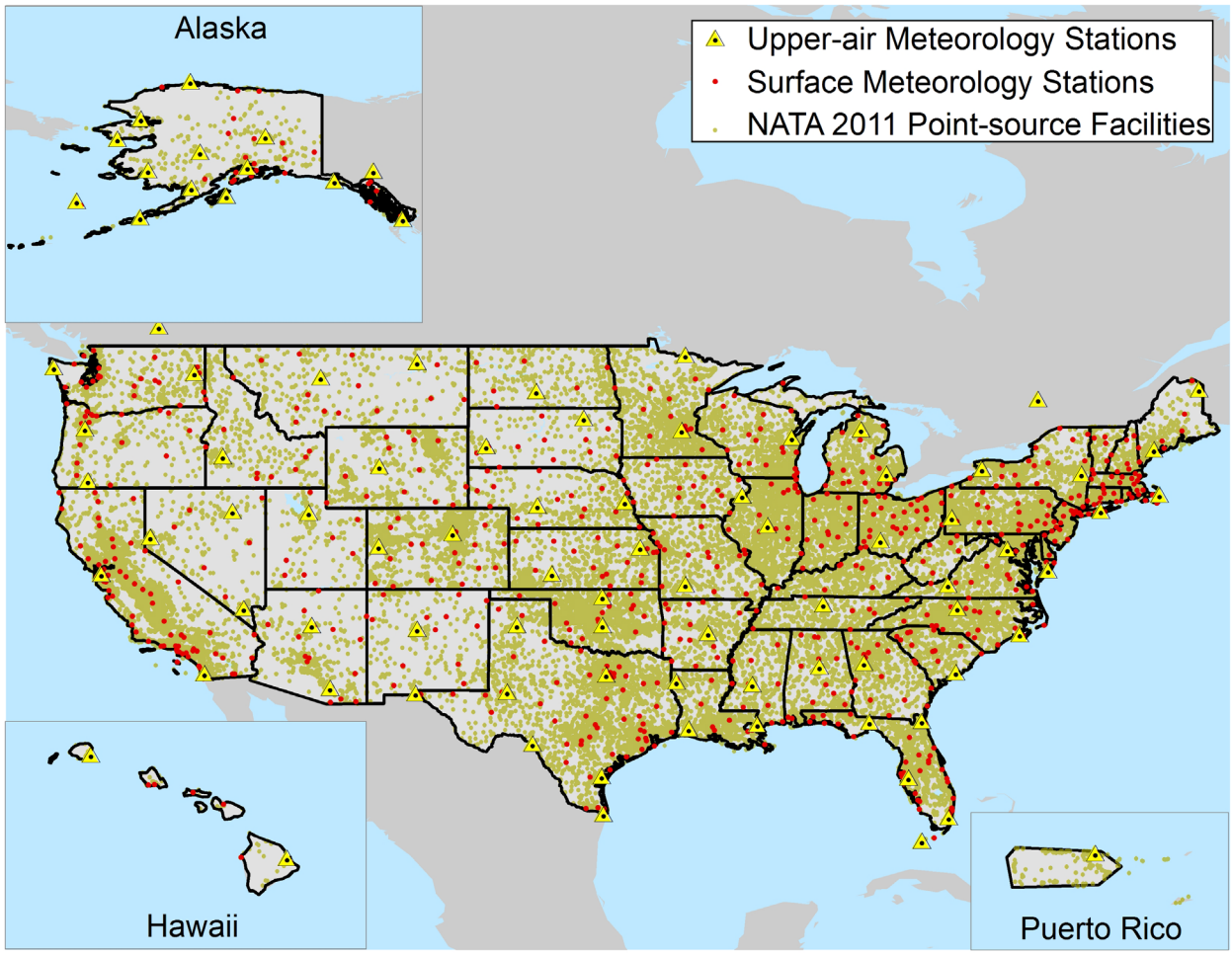
We created a database of the relevant U.S. meteorological data for 824 surface stations paired with their closest upper-air stations located throughout the country. The hourly surface data cover 2016 and are the same AERMOD-ready data used for RTR inhalation modeling. To provide a general sense of where these stations are relative to facilities that might be screened in the RTR program, Exhibit 26 shows the surface and upper-air meteorological stations represented in this database along with the locations of U.S. point-source facilities from the 2011 National Air Toxics Assessment (NATA; U.S. EPA 2015). Generally, the spatial density of the surface meteorological stations is similar to the spatial density of the 2011 NATA facilities—i.e., more stations and facilities in areas with more people: in the Great Lakes region, along the East and West Coasts, and in the Southern Plains; and fewer stations and facilities in the Rockies (except Colorado) and Northern Plains. We expect that an image reflecting a more recent NATA (e.g., the NATA released in 2018 and representing the 2014 facility inventory) would look very similar.

The meteorological database includes annual summary statistics on wind direction, wind speed, precipitation, and mixing heights. We gathered wind information in directional octants that could be linked to the direction (with respect to the facility location) of the relevant lakes and of the hypothetical locations of farmers/gardeners (facility screening is discussed in Section 3.3). The area around a facility is divided into the eight octants shown below, representing possible wind directions (e.g., N is north, NE is northeast).

N:	>337.5 to 360 or >0 to 22.5 degrees	S:	>157.5 to 202.5 degrees
NE:	>22.5 to 67.5 degrees	SW:	>202.5 to 247.5 degrees
E:	>67.5 to 112.5 degrees	W:	>247.5 to 292.5 degrees
SE:	>112.5 to 157.5 degrees	NW	>292.5 to 337.5 degrees

[14]Only TRIM.FaTE parameters were considered for site-specific refinements in Tier 2. Exposure characteristics are considered to be generally consistent across different locations and facilities.

Exhibit 26. The Locations of Meteorological Stations Used in RTR Modeling, and Locations of NATA 2011 Point-Source Facilities for Reference



Note: The NATA inventory is a comprehensive, finalized dataset of nationwide point source emitters of hazardous air pollutants. The 2011 NATA (released in 2015 and representing the 2011 facility inventory) is used here only for illustrative purposes, and we expect that a more recent NATA (e.g., the one released in 2018 and representing the 2014 facility inventory) would result in a very similar image. The meteorology locations shown here are those used in the RTR modeling described in this report; NATA used a different meteorology dataset.

From the hourly weather data, we calculated or gathered the annual statistics listed below for each of the 824 surface stations.

- Number of hourly observations,
- Number of hours with calm winds or no wind data reported,
- Fraction of time the wind blows into each octant (after excluding missing and calm wind hours),
- Median wind speed blowing into each octant (after excluding calm winds), and
- Median mixing height (irrespective of wind octant).

- Average annual precipitation (irrespective of wind octant and using 30-year normal data[15] if available, to avoid biasing the screening results in favor of any precipitation anomalies that existed in 2016)

We selected median instead of mean values because medians were usually smaller than mean values and because lower wind speed and mixing height are more health protective (i.e., typically lead to higher chemical deposition in areas near the emission source). We evaluated the distributions of median wind speeds, median mixing heights, and average annual precipitation across all 824 stations. From those distributions, we identified values to represent reasonable low, mid-range low-end, mid-range high-end, and high values across all sites (i.e., roughly 5th, 35th, 65th, and 95th percentile values). The values shown in Exhibit 27 are those used in TRIM.FaTE model runs as part of developing the library of Tier 2 screening threshold emission rates, REFs, and mixing height refinements (the library is discussed in Section 3.2.4).

Exhibit 27. Values for Meteorological Parameters Used to Develop the Tier 2 Screening Threshold Emission Rates and REFs

Parameter	Value	Risk Direction
Wind Speed (m/s)	**1.6**	As wind speed increases, it carries more airborne chemical out of the modeling domain and decreases risk. Slower wind speeds lead to more chemical deposition closer to the facility.
	2.8	
	3.7	
	5.4	
Precipitation (mm/yr)	240	As precipitation amounts increase, so does wet deposition over the modeled domain.
	706	
	1,069	
	1,474	
Mixing Height (m)	**226**	At higher mixing heights, pollutants released to air mix with larger volumes of air, resulting in lower air concentrations and modeled deposition to surfaces and, consequently, lower ingestion exposures.
	351	
	454	
	674	

Notes: Bold font indicates the value used in Tier 1. Also, we do not show wind direction here because it has a linear effect on exposure and risk modeled in TRIM.FaTE (using the scenario design of the screens). Use of site-specific wind direction data is discussed in Section 3.3.

3.2.2 Locations of Lakes and Farms/Gardens

We model lakes and hypothetical farms/gardens within a 50-km radius around a facility. We believe that a 50-km domain places a reasonable restriction on how far a nearby resident will travel to catch and consume fish from area lakes on a routine basis. Although extending the modeling domain beyond 50 km would increase the amount of deposition "captured" by the modeled watershed, the incremental chemical mass expected to accumulate in the watershed diminishes rapidly with distance. Areas beyond 50 km from the emission source are expected to

[15]We obtained 30-year-average annual precipitation for the period of 1981–2010, from the National Oceanic and Atmospheric Administration. https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data.

contribute relatively negligible amounts of chemical to the watershed, based on air-to-soil deposition values produced by TRIM.FaTE in the Tier 2 scenarios.[16]

As indicated in Exhibit 28, within the 50-km radius, we evaluate lake and farm/garden impacts at five distances in Tier 2: three distances within a 10-km radius where most chemical deposition occurs (i.e., at 0.5, 5, and 10 km from the facility), and two additional distances beyond 10 km (i.e., at 20 and 40 km from the facility). All farm/garden locations are hypothetical, so potential exposure is evaluated in Tier 2 at each possible distance and octant. Note if an actual lake distance is in between two of the distances in Exhibit 28, that lake will be assigned the closer location (i.e., the distance expected to yield the greatest risk). For example, if an actual lake is 7 km from the analyzed facility, that lake will be set 5 km from the facility for screening purposes.

Exhibit 28. Distances Used to Develop the Tier 2 REFs and Screening Threshold Emission Rates

Parameter	Value	Risk Direction
Lake and Farm/Garden Distances, measured from the inside geographic centroid of the feature (km)	**0.5**	With increased distance from the source, chemical deposition typically is reduced and, consequently, exposures are reduced.
	5	
	10	
	20	
	40	

Notes: Bold font indicates the value is equal to the value used in Tier 1.

Exhibit 29 depicts the spatial layouts of each lake- and farm/garden-distance scenario in Tier 2 for a single octant.[17] The 0.5-km-distance scenario is the same layout as the Tier 1 scenario shown in Exhibit 11 and is not repeated in Exhibit 29. The runoff and erosion characteristics are unchanged from the Tier 1 screen.

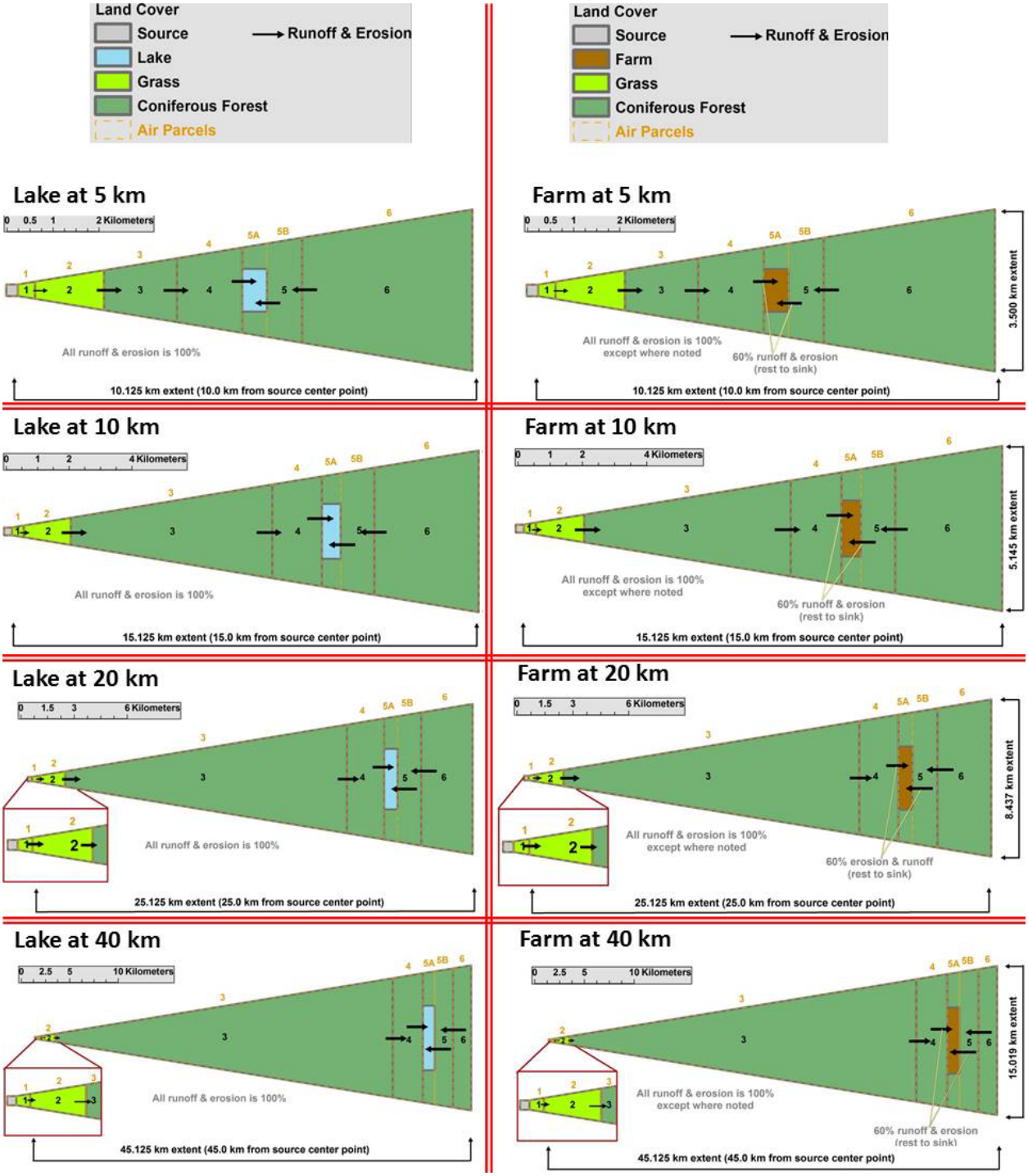
In resituating the lake and farm/garden at these alternative locations, we maintained ratios consistent with those included in the Tier 1 screening scenario for (1) lake or farm area to total land area in the modeled domain, (2) runoff watershed area to lake or farm area, and (3) erosion watershed area to lake or farm area. We used “thin” lake and farm shapes (i.e., downwind width much shorter than the cross-wind length) to minimize distance from the far end of the lake or farm to the facility, resulting in higher and more health protective media concentrations. Situating the lakes or farm/gardens farther from the stack required expansion of the modeled domain. For example, the modeling domain in the top parcel layouts in Exhibit 29

[16]Mass deposited at the outer edge of the watershed (50 km) is expected to result in a negligible increase in estimated exposure via the fisher or farmer scenarios. The TRIM.FaTE runs supporting Tier 2 indicate that chemical deposition rates at 43–45 km from the emission source (at parcel 6 in the Farm at 40 km layout shown in Exhibit 29) are between 1 and 3 orders of magnitude smaller than those at 0.5–2 km from the source (at parcel 2), depending on the chemical and meteorological parameters. Although additional chemical mass could be transported to the lake and farm through erosion and runoff, the amount of chemical deposited beyond 50 km from a facility is less per unit area and would runoff or erode over longer distances, further attenuating the mass that might reach a farm or lake. Wind speeds of 13 m/s (approximately 29 mph) or greater must be sustained for a full hour for the chemical plume to travel farther than 50 km. Wind speeds of that magnitude are unlikely to occur consistently for many days or weeks 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.

[17]The lake and farm surface areas also were changed for each new distance layout, which allowed for the simulations to maintain a constant ratio between watershed and erosion area compared with lake and farm areas.

extends 10 km from the middle of the source parcel, while the modeling domain in the bottom parcel layouts extend 45 km from the source (although the diagrams are the same size in Exhibit 29).

Exhibit 29. TRIM.FaTE Surface Layouts for the Tier 2 Multipathway Screen, Using Alternative Distances Between the Facility and the Fishable Lake or Farm/Garden (base layout is the same as Tier 1 shown in Exhibit 11 and not shown here)



Notes: The distance axes are longer for the farther locations of lake and farm/garden from the source (i.e., moving from the top to the bottom diagrams). Heavy, black arrows depict the direction of chemical runoff and erosion.

Maintaining the same overall ratio of land area to lake or farm area in each domain resulted in scenarios with surface areas for lakes and farms increasing with distance from the source. The changes in lake size between these configurations are not expected to have a substantial independent effect on exposure and risk because the effect of increased lake size (i.e., dilution of chemical due to greater volume) is offset by greater watershed area for total deposition and runoff. Furthermore, lake depth was not changed. The changes in farm size between these configurations also are not expected to have a substantial independent effect on exposure and risk because chemical concentrations in soil are estimated as mass per unit area (this also allows us to use the exposure media concentrations developed for the farmer scenario with the gardener scenarios, which have a smaller surface area than the farm). As noted above, we set up the configurations to ensure that the lakes and farms in the different scenarios received runoff and erosion from equivalent watersheds on a per-surface-area basis.

3.2.3 Gardener Exposure Scenario

The gardener scenario comprises the exposure pathways through which individuals might be exposed in an urban or non-farm rural setting. Notably, the gardener exposure scenario is analogous to the HHRAP "Resident" exposure scenario (U.S. EPA 2005a). Similar to the resident scenario in HHRAP, the gardener ingests a subset of the media that the subsistence farmer exposure scenario ingests, namely:

- Soil,
- Exposed fruits and vegetables,
- Protected fruits and vegetables,
- Root vegetables,
- Eggs, and
- Breastmilk (as an infant).

Exhibit 30 compares the ingested media for the gardener exposure scenario to those of the farmer exposure scenario.

Exhibit 30. Ingested Media for Farmer and Gardener Scenarios

Scenario	Soil	Protected Fruit	Exposed Fruit	Protected Vegetable	Exposed Vegetable	Root Vegetable	Dairy	Beef	Pork	Poultry	Eggs	Breast Milk
Farmer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Gardener	✓	✓	✓	✓	✓	✓					✓	✓

For the RTR inhalation risk assessment, receptor locations are designated as rural or urban, and the gardener in the multipathway screen is designated the same way. For a gardener in a rural environment, we use the same ingestion rates (IRs) as used for the farmer for the produce that the gardener ingests. As discussed above, this is a subset of the media that a farmer would ingest (see Exhibit 30). A reasonable assumption is that a gardener in a rural setting would be more likely to have sufficient land to support a garden large enough to provide for the assumed 90th percentile IRs and would tend to consume larger amounts of home-produced foods than would gardeners in urban settings. Gardeners in urban settings likely would grow produce on

smaller plots and, in general, would likely supplement homegrown produce with store-bought produce, particularly during the non-growing season (ingestion of produce that is not homegrown is not assessed in the screens). For gardeners in an urban setting, therefore, the mean instead of 90th percentile IR for homegrown produce from EPA's (2011) *Exposure Factors Handbook* is used. The IRs for the urban gardener generally are between one-third to one-half of those for the farmer and rural gardener, as shown in more detail in Attachment B. Soil ingestion for the urban and rural gardeners is the same high-end rate as for the farmer, and the farmer and gardener (both rural and urban) have higher soil IRs than the general population. A central-tendency soil IR could underestimate soil ingestion for gardeners.

To be health-protective, the gardener scenarios assume concentrations, and thus, the same transfers of chemical from adjacent modeling areas through runoff and erosion as the farming scenario. In a more refined site-specific assessment, an urban garden scenario might assume a raised garden bed or garden boxes that does not receive chemicals through runoff or erosion.

3.2.4 Development of Library of Tier 2 Screening Threshold Emission Rates, REFs, and Mixing Height Refinements

We conducted a large set of modeling runs based on unit emissions of 1 gram per day and taking into account: (1) wind speed, mixing height, and precipitation rate values shown in Exhibit 27; (2) lake and farm distances shown in Exhibit 28; and (3) spatial layouts shown in Exhibit 11 and Exhibit 29. These runs systematically varied each of these parameters so that all possible combinations were evaluated.[18] The resulting matrix of screening-level risk estimates represented each unique combination of PB-HAP and values for wind speed, mixing height, precipitation rate, and distance from the facility to a lake or farm. From these screening-level risk estimates, we calculated Tier 2 REFs and screening threshold emission rates for all the combinations stated above (note that for POMs and dioxins, screening threshold emission rates are only calculated for benzo[a]pyrene and 2,3,7,8-TCDD, respectively).

As in the Tier 1 screen, the Tier 2 screening threshold emission rate is defined as the emission rate that corresponds to a 1-in-one million excess lifetime cancer risk or an HQ of 1 for a given PB-HAP. As in Tier 1, for those chemicals that are not fully parameterized in TRIM.FaTE, the REFs in the Tier 2 screen reflect an individual POM or dioxin chemical's fate, transport, and toxicity relative to the index chemical for each group (BaP for POM and 2,3,7,8-TCDD for dioxin; see Section 2.2.4).

Mixing height has a direct effect on chemical concentrations, and therefore its exposure level. When a chemical is released to air, it mixes with air in the lower atmosphere (i.e., in the mixing layer). With the assumption of instantaneous and complete mixing (which is the assumption used in TRIM.FaTE), there is an inverse linear relationship between changes in mixing height and changes in chemical air concentrations. A lower mixing height (boundary) means that there is a smaller volume of air available for mixing, meaning less dilution and higher chemical concentrations within the mixing layer than when the mixing height is higher. At a given location, higher chemical air concentrations lead to higher deposition and higher chemical concentrations in environmental media, and ultimately higher exposure. Precipitation, on the other hand, affects chemical concentrations in two opposing processes: more precipitation results in more wet chemical deposition, but it also dilutes the deposited chemical in leachate and runoff. Wind speed influences air concentration with distance from an emission source—lower wind speeds result in higher chemical concentrations in air and more deposition closer to the source than

[18]There were 640 independent modeling runs per PB-HAP chemical (including each dioxin/furan congener).

farther away, while higher wind speeds result in relatively lower concentrations and deposition near the source.

Because of the direct and predictable effects of mixing height on exposure, and because the range of median mixing heights across the 824 meteorological stations is substantial (i.e., less than 200 m to more than 2,000 m), we used the matrix of Tier 2 screening threshold emission rates described above to further quantify the relationship between mixing height and exposure. The screening threshold emission rates decrease linearly with decreasing mixing height; put another way, SVs increase linearly with decreasing mixing height. The linear relationships are specific to each combination of PB-HAP, distance from facility to the lake or farm/garden, wind speed, and precipitation rate. Therefore, for each combination of those parameter values, we derived a linear regression to relate changes in mixing height (i.e., the four mixing height values used in the modeling) to changes in screening threshold emission rate. Using the regression coefficients, we are able to estimate the influence of mixing height on Tier 2 SV estimates with a continuous function based on reported mixing heights near a facility.

After developing the mixing height regression coefficients, we condensed the Tier 2 matrix into a Tier 2 library containing REFs, screening threshold emission rates, and mixing height regression coefficients for each unique combination of PB-HAP, wind speed, precipitation rate, and distance from the facility to a lake or farm/garden. With respect to mixing height, the screening threshold emission rates and REFs are derived using the mixing height value of 226 m (i.e., the Tier 1 mixing height) and are then adjusted using the actual mixing height near the facility being screened.[19]

Unlike Tier 1, the Tier 2 screen assesses potential risk from fish ingestion separately from homegrown produce, animal products, and soil ingestion; therefore, there is a distinct library of screening threshold emission rates, REFs, and mixing height regressions for each of the exposure scenarios (fisher, farmer, and rural and urban gardeners).

Section 3.3 discusses how the screening threshold emission rates, REFs, and regression coefficients discussed in this section are used to estimate potential multipathway risk.

3.3 Implementing the Tier 2 Multipathway Screen

To implement the Tier 2 multipathway screen, we developed a Microsoft® Access™ tool that is pre-loaded with the (1) U.S. lake location data; (2); U.S. meteorological database; and (3) libraries of Tier 2 screening threshold emission rates, REFs, and mixing height regression coefficients described above.

As noted in Section 3.2.2, the database of lakes used in the Tier 2 screen is available from ESRI® and based on USGS data. The database includes information on the location, surface area, use or type designation, and name (if available) of all lakes (including ponds and reservoirs) in the United States. To focus on lakes that can support harvest of upper-trophic-level fish, we excluded lakes used for disposal, evaporation, or treatment, and we included only lakes greater than 25 acres in area (see Section 3.3.1 below for more detail). We did not include

[19]The Tier 2 screening threshold emission rates are all based on a mixing height of 226 m. However, the SVs that are calculated from these screening threshold emission rates will be refined based on a regression equation that accounts for the actual mixing height around the facility. For example, if a facility has an SV of 3 assuming a mixing height of 226, and the mixing height refinement is a factor of 0.8 (based on the regression equation and a site specific median mixing height of 400 m), then the refined Tier 2 SV for this facility would be 2.4 (i.e., 3 × 0.8). This calculation is further described in Section 3.3.

lakes larger than 100,000 acres in area (Section 3.1.3). The database of lakes contains approximately 433,000 fishable lakes for evaluating Tier 2 impacts.

The Tier 2 screening tool identifies all qualifying lakes in the area surrounding a screened facility and determines their distances and directions with respect to the facility; each of these distance values are subsequently matched to the closest lake distance "bin" in the Tier 2 library (fish in lakes closer to the emission source generally accumulate more chemical). The user can vary the radial distance and area limits of qualifying lakes (defaults are set at 50 km and 25 to <100,000 acres, respectively), and the user can also review the nearby lakes and exclude ones that would not be used to harvest fish (e.g., based on names indicating industrial, waste, or treatment purposes). The tool records any excluded lakes to omit them from subsequent screens.

Unlike lake locations, farm and garden locations are not site-specific, so the tool calculates the Tier 2 farmer and gardener SVs at all distances available in the Tier 2 library and in all directions from the facility. SVs are calculated for both the rural and gardener scenarios and the appropriate scenario is selected based on whether the census block nearest to the facility is in an urbanized area based on population density.

Each facility being screened is then matched with the same surface meteorological station used in the RTR inhalation risk assessment (i.e., the closest station). This process currently utilizes over 800 meteorological stations nationwide.[20] From the selected meteorological station, the tool identifies the appropriate precipitation and wind speed bins. The tool matches the meteorological station's annual precipitation amount to the next higher precipitation amount in the Tier 2 library (higher precipitation rates generally lead to greater wet deposition resulting in increased chemical accumulation in fish and surface soil). The tool identifies the annual median wind speed blowing toward each lake or farm/garden location at the facility and matches it to the next lower wind speed in the Tier 2 library (lower wind speeds generally lead to greater near-field chemical accumulation in fish and surface soil).

Given the matching meteorological (wind speed and precipitation) and distance (for farms/gardens and lakes) values, the tool identifies the appropriate Tier 2 screening threshold emission rate and REF from the Tier 2 library for each emitted chemical. The annual median mixing height for the facility's matching meteorological station is then used with the mixing height regression coefficients from the Tier 2 library to account for the impact of mixing height using Equation 6:

$$RefMix_{T2} = (M \times S) + i \qquad \textbf{Eqn. 6}$$

where:

[20]The process of pairing dozens or hundreds of facilities with meteorological data has precedent. 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 for the 1996 NATA (U.S. EPA 2001b). In a separate 2009 report to the SAB on the RTR program, EPA described using 158 meteorological stations nationwide, with a standard practice of selecting the station closest to a facility unless the facility provides onsite meteorological data (U.S. 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 the approach for modeling large numbers of facilities, although it 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 (U.S. EPA 2001a; U.S. EPA 2010b).

$RefMix_{T2}$ = mixing height multiplier for Tier 2

i = intercept coefficient of the linear regression

M = median mixing height (in meters) associated with the facility

S = slope coefficient of the linear regression

After the appropriate Tier 2 screening threshold emission rate, REF, and mixing height refinement factor are identified, the final site-specific factor is considered: the frequency that winds blow toward an evaluated lake or hypothetical farm/garden location. In the Tier 2 modeling runs, as in the Tier 1 modeling runs, winds are modeled as blowing toward the lake and farm/garden 43 percent of the time (i.e., three days per week—an unusually consistent, but feasible, long-term wind pattern; e.g., similar to wind direction patterns in Yakima, Washington). The screening threshold emission rates in the Tier 2 library correspond to that direction frequency. Using the Tier 2 database of meteorological data, the Tier 2 screening tool accounts for the percentage of time that the wind actually blows in the direction of the lake or farm/garden being evaluated in the Tier 2 screen using Equation 7:

$$RefWD_{T2} = \frac{FreqWD_{T2}}{FreqWD_{T1}} \qquad \textbf{Eqn. 7}$$

where:

$RefWD_{T2}$ = Tier 2 wind direction multiplier

$FreqWD_{T2}$ = percent of time winds blow toward the Tier 2 lake or farm/garden

$FreqWD_{T1}$ = percent of time winds blow toward the Tier 1 lake and farm/garden (i.e., 43%).

Finally, for each chemical emitted by a facility and for each lake, farm, and garden, the tool calculates the Tier 2 SV for the facility's emissions using Equation 8:

$$SV_{T2} = \left(\frac{ER \times REF_{T2}}{Th_{T2}}\right) \times RefMix_{T2} \times RefWD_{T2} \qquad \textbf{Eqn. 8}$$

where:

SV_{T2} = Facility- and chemical-specific Tier 2 SV (i.e., ratio of facility emissions to threshold for adverse health effects for the chemical)

ER = Chemical-specific facility emission rate

REF_{T2} = Tier 2 REF (for individual dioxins or POM; = 1 for other chemicals)

Th_{T2} = Tier 2 screening threshold emission rate for the PB-HAP (arsenic, cadmium, mercury, 2,3,7,8-TCDD, or BaP) and the lake, farm, and garden.

As with the Tier 1 screen, the Tier 2 SVs for all emitted POM chemicals are summed to a total SV of POM as BaP-equivalents, and the Tier 2 SVs for all emitted dioxin/furan chemicals are summed to a total dioxin SV as 2,3,7,8-TCDD-equivalents.

At this stage of the Tier 2 screen, the Tier 2 fisher-scenario SVs reflect subsistence fishing at each individual lake, regardless of lake size (i.e., whether or not that harvest rate might overfish top trophic level fish in a lake). As discussed in Sections 3.3.1 and 3.3.2 below, we further refine

the Tier 2 fisher scenario to better reflect sustainable fish withdrawals. The Tier 2 farmer and gardener exposure scenarios assess exposure at each hypothetical farm and garden location, and the hypothetical farm and garden location with the largest SV for a facility and PB-HAP is identified.

3.3.1 Accounting for Sustainable Fishing

Early in the process of compiling the Tier 2 lake database, we encountered the question: "What size 'lake' is fishable for the purposes of this assessment?" The Tier 2 screen should focus on lakes large enough to support a fish harvest rate that would meet the high-end fish ingestion rates assumed for the exposure scenario (i.e., 373 g wet-weight fish fillet/day).

In the TRIM.FaTE model screening scenario, WCCs are modeled at the top of the water-column food chain (e.g., pickerel, pike, walleye, largemouth bass), with all of their diet consisting of smaller "prey" or "pan" fish in the water column (e.g., sunfish, crappie, perch). In the assumed *linear* water-column food chain for the screening scenario, those fish in turn consume smaller fish that are planktivorous (WCH; e.g., minnows, young-of-the-year fish). Thus, the WCCs can be called trophic level 4 (TL4) if the smallest fish are considered trophic level 2 (TL2). The BCs in TRIM.FaTE are modeled to represent an intermediate trophic level between 3 and 4 (i.e., TL3.5) in the benthic food *web*. Benthic carnivores (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, which consume benthic invertebrates only. Together, we refer to the WCC and BC fish compartments as piscivorous fish.

To identify sustainable fish harvest rates by lake size, we made the eight key assumptions listed below. Information and citations to peer-reviewed literature that support these assumptions are provided in Attachment E.

1. Ponds or lakes must exceed a certain size to sustain a population of WCC over the long term (i.e., smaller ponds/lakes might support only two or three trophic levels given limits on total lake productivity per unit area and the 80–90 percent loss of food energy per trophic transfer).
2. In lakes with stable fish communities including a reliable WCC fish population, piscivorous fish (i.e., WCC TL4 and BC TL3.5) might comprise approximately 20–22 percent of the total fish biomass (references in Attachment E).
3. Productivity in most lakes of small to moderate size depends substantially on the benthos, with benthic invertebrates consuming detritus derived from both in-lake algae and macrophytes and from plant litter eroded into the lake from terrestrial sources across the watershed. We expect more biomass in the BC than in the WCC compartment. Assuming 21 percent of the standing biomass of fish are piscivorous, BC fish might account for 17.5 percent of the total standing fish biomass, and WCC fish might account for 3.5 percent of the total fish biomass (Attachment E). The remaining 79 percent would include "pan" fish (e.g., sunfish, perch), minnows, young-of-the-year of piscivorous fish. This set of assumptions represents a "point estimate" of fish biomass distribution across different compartments.
4. Humans consume fish from the BC compartment and the WCC compartment, with a 50:50 split, reflecting fishing and consumption preferences rather than relative abundance of fish in the BC and WCC compartments. Depending on the chemical, bioaccumulation over 4.0 trophic transfers might result in higher concentrations in the WCC fish compartment than bioaccumulation over 3.5 trophic transfers in the BC fish compartment. On the other hand,

for chemicals that partition primarily to the sediment compartment, benthic invertebrates might accumulate more chemical, resulting in higher concentrations in the BC than the WCC compartment. Because we could not predict, a priori, which fish compartment, the BC or the WCC, would have higher chemical concentrations for any PB-HAPs, we assumed the 50:50 split in fish harvested from the WCC and BC compartments.

5. The total fish standing biomass is assumed to be 40 g wet weight/m^2, which might be relatively high for natural ponds and lakes across much of the United States; however, it is a mean value for reservoirs. Overestimates of lake productivity would bias results to be more health protective, because more fish could be harvested from contaminated lakes closer to a facility.
6. We assume that the minimum viable population (MVP) size for a single fish species is at least 50 adult fish for a local population to survive over several decades. Interbreeding populations of 500 or more adults (with 50:50 male:female ratio) should be sustainable without adverse effects from inbreeding. Actual MVP for a population genome depends on many factors and varies substantially across different species and landscapes. To model MVP for a given species and location, one should specify the timeframe of concern (e.g., 50 years, 100 years) and a target probability of local extirpation (e.g., less than 5 percent). Population modeling for individual species is beyond the scope of RTR screens; we therefore use the estimate of at least 50 breeding individuals to maintain a fish species in a lake.
7. Humans can harvest 10 percent of any single fish compartment without threatening the population due to overharvesting. Although sustainable harvest rates vary with species life history characteristics, for top carnivores, data suggest that 10 percent harvest rates should prevent overfishing (Attachment E).
8. 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 that must be harvested for human consumption of fillet only.

Using the above assumptions, we estimated fish-fillet ingestion rates as a function of total standing fish biomass and lake area. Because we assume a 50:50 harvest of BC and WCC fish, and because the standing biomass of WCC fish is approximately one fifth of the standing biomass of BC fish, we focus on lakes that can provide the MVP of 50 breeding individuals for the WCC fish compartment. Attachment E presents the calculations and steps required to estimate which combinations of lake size and productivity could sustain at least 50 individual WCC fish, and the human fish ingestion rates that could be supported for those combinations.

The grey shading in Exhibit 31 indicates combinations of lake size and lake productivity that would not support a MVP of 50 individual adult WCC fish. The white, or unshaded, cells in Exhibit 31 indicate combinations of lake area and productivity that could sustain the listed fish-ingestion rates for WCC plus BC fish over several decades, but might not be sufficient to prevent inbreeding depression. Finally, the yellow shading in Exhibit 31 indicates combinations of lake productivity and lake size that are likely to provide long-term sustainability of WCC fish in the lake.

Once we had established which cells of Exhibit 31 were in the grey, white, and yellow zones, we calculated the fish ingestion rates associated with each cell.

Exhibit 31. Estimated Maximum Fish Ingestion Rate (g/d) Associated with Sustainable Fishing[a]

Total Fish Biomass (g ww/m^2)[b]	Area 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

Note: Calculated using a series of basic assumptions and equations discussed in this section and in Attachment E.

[a]Dark gray shading indicates combinations of lake productivity and size that could support 50 or more adult WCC fish over a few decades, the minimum viable population size; yellow-shaded cells indicate a long-term self-sustaining population of WCC with at least 500 adult fish for one (or more) species is likely; no shading (white) indicates medium-term sustainability.

[b]Represents the total fish standing biomass. The biomass of WCC fish is 3.5% of the total. Reading from the table, at the assumed fish standing biomass of 40 g ww/m^2, 25 acres could support a water-column WCC fish population but would provide at most 26 grams of fillet (wet weight) per day for a single fisher over a full year (intersection of the vertical and horizontal red lines). A lake of 100 acres with 40 g ww/m^2 total fish standing biomass could provide as much as 102 g/d of fish fillet. Reading straight across the row at 40 g ww/m^2 total fish biomass, the WCC plus BC fish-fillet-ingestion rate associated with lakes of different sizes turned out to be 1 g ww/acre. Thus, as a rule of thumb, we estimated lake productivity in grams of fish fillet [WCC & BC] per person per day as equal to the lake surface area in acres.

At the assumed standing fish biomass of 40 g wet weight (ww)/m^2, a 25-acre lake is the smallest lake that might sustain a population of 50 or more WCC (smallest lake with unshaded cells). Therefore, 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 and Tier 3 screens. In addition, we did not consider lakes larger than 100,000 acres (Section 3.1.3).

As shown in Exhibit 31, the fish-ingestion rate associated with a 25-acre lake and the assumed fish biomass of 40 g ww/m^2 is 26 g/day, or approximately 1 gram fish/acre/day. Thus, a 25-acre lake cannot by itself support the adult human ingestion rate used in the multipathway screens (i.e., 373 g ww fillet per day) with a 50:50 mix of WCC and BC fish. However, a fisher could fish multiple lakes, totaling 373 acres, to achieve that ingestion rate. In Section 3.3.2 below, we discuss the refined-fisher scenario, whereby a fisher withdraws and consumes fish at an assumed sustainable rate of 1 gram fish/acre/day from as many acres of lake(s) as necessary to harvest 373 grams of fish (wet weight fillet) per day. The refined-fisher scenario also aggregates SVs at lakes impacted by emissions from more than one facility in the source category.

Lakes smaller than 25 acres could be stocked annually to support substantial fish withdrawals. However, we assume that when introduced to the lake, the stocked fish would be uncontaminated by the chemicals of interest. Moreover, the period over which accumulation of chemical from the lake could occur would be approximately three to six months (i.e., the fishing season) for the majority of the fish stocked as large juveniles or adults, instead of several years for fish hatched in or born into the lake. We believe that not taking stocked fish into consideration is a reasonable assumption.

We could have used other assumptions about human fishing behavior. For example, fishers could harvest BC and WCC in proportion to their relative abundance (i.e., 80:20); however, it is not clear which fish compartment might have higher chemical concentrations. Alternatively, fishers could consume "pan" fish like sunfish and small perch to meet their daily fish ingestion rates fishing smaller lakes than predicted in Exhibit 31. Pan fish, however, represent TL3 fish in the water column. Therefore, chemical concentrations in the tissues of pan fish would likely be lower than in the TL3.5 BC or the TL4 WCC fish compartments for mercury, cadmium, dioxins, and POM.

3.3.2 Refined-fisher Scenario

In the Tier 2 screen, the refined-fisher scenario is based on the idea that an adult fisher might fish from multiple lakes if the first fished lake is unable to provide an adequate catch to satisfy the assumed ingestion rate (i.e., 373 g ww-fish/day for adults). The scenario assumes that lake fish productivity supports a long-term sustainable harvest of no more than 1 gram of fish fillet (wet weight) of top trophic level fish per acre of lake (Attachment E). That means the fisher must harvest fish from 373 acres of lakes to fulfill the assumed ingestion rate, provided the assumptions in Section 3.3.1. Which lakes are fished, and in what order, must be methodically determined.

We determine the Tier 2 refined-fisher lake fishing order using estimates of chemical concentrations in fish in *each lake* within 50 km of a facility, and those concentrations include the contributions from source-category emissions from all facilities within 50 km of *that lake*. Thus, if a lake is 50 km or less from two facilities (e.g., Facility A and B) in the source category, two SV values are calculated for a given PB-HAP using Equation 8 (in Section 3.3): one SV_{T2} value corresponding to Facility A's emissions and another SV_{T2} value corresponding to Facility B's emissions. In this example, the two SV_{T2} values are summed into one aggregated SV_{T2}

value for the lake and PB-HAP. The aggregate SV_{T2} value accounts for emissions from both facilities.

In the refined-fisher scenario, a fisher travels to each relevant lake within 50 km of a facility (Section 3.2.2), in order of highest to lowest chemical concentration in fish (of a given PB-HAP), until the fisher catches fish from 373 acres of lake(s). Ordering of fished lakes can be different for different PB-HAPs because fate-and-transport characteristics vary by chemical. Thus, the most contaminated lake (of at least 25 acres) for one PB-HAP might differ from the most contaminated lake (of at least 25 acres) for another PB-HAP. In this situation, the order of lakes fished would be different for the two PB-HAPs. The final PB-HAP-specific Tier 2 SV for the fisher can be expressed as the sum of the SV from each lake that is fished (which is based on the amount of fish ingested from each lake multiplied by the PB-HAP concentration in fish).

If there are no lakes within 50 km of a facility, then there is no fisher scenario (the fisher SV would be 0). Otherwise, there are three possible lake fishing scenarios, discussed below: (1) the highest-concentration lake (for a given PB-HAP) within 50 km of the facility can provide 373 g/d fish (is 373 acres or larger, though we limit ingestion to 373 g/d); (2) the highest-concentration lakes within 50 km of the facility individually are smaller than 373 acres and unable to provide 373 g/d fish, but together can provide a total of 373 g/d; or (3) all lakes within 50 km cannot supply a total of 373 g fish/d.

1. If the first lake fished is 373 acres or larger, the fisher is assumed to catch 373 g ww-fish/day from that lake. The refined-fisher SV is equal to the value obtained from Equation 8, summed across all source-category facilities within 50 km of the lake.
2. If the first lake fished is smaller than 373 acres, then multiple lakes must be fished. If *n* lakes are fished, where the total surface area of lakes 1 to *n*-1 is less than 373 acres (and the total area of lakes 1 to *n* is 373 acres or more), the refined-fisher SV of each lake 1 to *n*-1 is calculated using Equation 9 below.

   For lakes 1 to *n*-1 which total less than 373 acres:

$$SV_{T2RefFish,\ Lake} = SV_{T2Fish,\ Lake} \times \left(\frac{A_{Lake}}{373\ acres}\right) \qquad \textbf{Eqn. 9}$$

   where:

   $SV_{T2RefFish,Lake}$ = lake's SV for the Tier 2 refined-fisher scenario;

   $SV_{T2Fish,Lake}$ = lake's Tier 2 SV from Equation 8, summed across all source-category facilities within 50 km of the lake; and

   A_{Lake} = lake's surface area (acres).

   Then, the refined fisher SV for lake *n* is calculated using Equation 10 below. As discussed in the preceding paragraphs, these SVs incorporate deposition from multiple source-category facilities.

   For lake *n*, where lakes 1 to *n* total 373 acres or more:

$$SV_{T2RefFish,\ Lake\ n} = SV_{T2Fish,\ Lake\ n} \times \left(\frac{373\ acres - \sum_{i=1}^{i=(n-1)}(A_{Lake\ i})}{373\ acres}\right) \qquad \textbf{Eqn. 10}$$

Finally, the cumulative Tier 2 SV for the refined fisher is calculated as shown in Equation 11:

$$SV_{T2RefFish,Total} = \sum (Eqn.\ 9) + Eqn.\ 10 \qquad \textbf{Eqn. 11}$$

or

$$SV_{T2RefFish,Total} = \sum_{i=1}^{i=(n-1)} \left(SV_{T2RefFish,\ Lake\ i}\right) + SV_{T2RefFish,\ Lake\ n}$$

3. If there are *n* total lakes in the modeling domain to assess, and their total surface area is smaller than 373 acres, then we use Equation 9 above to calculate the refined Tier 2 fisher SV for each lake, and then Equation 12 below calculates the final fisher SV for all fished lakes combined. As discussed in the preceding paragraphs, these SVs incorporate deposition from multiple facilities within a source category.

$$SV_{T2RefFish,Total} = \sum (Eq.\ 9) \qquad \textbf{Eqn. 12}$$

or

$$SV_{T2RefFish,Total} = \sum_{i=1}^{i=n} \left(SV_{T2RefFish\ ,\ Lake\ i}\right)$$

3.3.3 Considering Inhalation Risks at Hypothetical Garden Locations

To further prioritize the next steps in risk evaluations and risk management decisions, the screening tool incorporates the RTR total-cancer inhalation risk value at the closest residential receptor (according to the inhalation modeling) in each of the eight primary directions. Each inhalation-receptor location is matched to the closest hypothetical garden location, and then the garden total-cancer SV (i.e., the sum of the arsenic, POM, and dioxin SVs) is summed with the total-cancer inhalation risk (i.e., the sum of cancer risks from all emitted HAPs, normalized to a "1-in-one million" convention) and the location of the largest total cancer-risk is identified. The combination of inhalation risk and ingestion SV is used to better understand the potential total cancer risk that might exist for individuals living near a facility emitting PB-HAPs. That information guides selection of next steps in the risk assessment of the source category.

3.3.4 Outputs

The screening tool generates several output tables, including an intermediate table that provides information on each lake, farm, and garden, including the amount of fish ingested and SV associated with each lake.

Finally, the tool generates the final screening tables for each facility and PB-HAP group. Summary tables identify the number of facilities exceeding the Tier 2 screening threshold emission rate of each PB-HAP group (separately for the fisher, farmer, and gardener), and which facilities have the largest SVs. All intermediate and final results tables present the Tier 1 and Tier 2 SVs side-by-side for comparison. Exhibit 32 through Exhibit 34 provide screen shots of the primary tool output tables.

Facilities with PB-HAP emissions that do not exceed any Tier 2 screening threshold emission rate are assumed to pose risks below levels of concern and no additional multipathway assessment is required. Facilities having emissions that exceed any of the Tier 2 screening threshold emission rates could be assessed further with Tier 3.

Exhibit 32. Example of Source Category Summary Results Output from Tier 2 Tool

Src Cat Info				Tier 1			Num Facil SV ≥ 2								
							Fisher				Fisher				
Src Cat	PB-HAP Grp	Num Facil in Src Cat (Emitting Any HAP)	Num Facil Emitting this Grp	Num Facil SV ≥ 2	Max SV	Max Facil ID	With Agg Impacts	Without Agg Impacts	Farmer	Inh+Farmer	SV	Agg Impacts?	SV Before Agg Impacts (If Applicable)	Facil ID	SV
Src Cat A	Arsenic	91	90	55	1.E+01	96058	0	0	9	0	2.E-01	Y	3.E-02	12785	3.E+0
Src Cat A	Cadmium	91	90	0	4.E-01	88187	0	0	0	0	7.E-02	N		78624	2.E-02
Src Cat A	Dioxin	91	68	50	7.E+02	40172	45	14	30	0	1.E+02	N		89662	3.E+0
Src Cat A	Methyl Mercury (Hg2)	91	90	68	2.E+02	55584	52	24	0	0	4.E+01	Y	3.E+00	80221	9.E-02
Src Cat A	POM	91	0	0	0.E+00	30537	0	0	0	0	0.E+00	N		37979	0.E+0
Src Cat A	Total Cancer (Arsenic+POM+ Dioxin)	91	90	70	7.E+02	34211	45	19	36	36	1.E+02	N		49159	3.E+0
Src Cat B	Arsenic	91	90	84	3.E+01	75443	0	0	20	0	3.E-01	Y	2.E-01	38743	8.E+0
Src Cat B	Cadmium	91	90	0	1.E+00	66297	0	0	0	0	1.E-01	Y	7.E-02	19292	4.E-02
Src Cat B	Dioxin	91	68	68	7.E+02	51927	72	29	61	0	1.E+02	N		60856	3.E+0
Src Cat B	Methyl Mercury (Hg2)	91	90	70	5.E+02	68523	67	34	0	0	8.E+01	Y	3.E+01	11903	1.E-01
Src Cat B	POM	91	0	0	0.E+00	19060	0	0	0	0	0.E+00	N		48528	0.E+0
Src Cat B	Total Cancer (Arsenic+POM+ Dioxin)	91	90	89	7.E+02	63574	72	35	63	63	1.E+02	N		37307	3.E+0

Note: Only a portion of this table is shown due to space limitations; information not shown here includes: numbers of facilities with gardener SVs ≥ 2, numbers of facilities where sums of inhalation risk values with gardener SVs are ≥ 2, largest farmer and gardener SVs and their corresponding facility IDs, and largest sums of inhalation risk values with farmer/gardener SVs and their corresponding facility IDs. The facility IDs shown here are not real (they are only for illustration purposes). Red shading and font indicate where facilities did not screen out (i.e., the SV or sum of SV and inhalation risk rounded to 2 or higher). "Src Cat" = source category. "HAP" = hazardous air pollutant. "PB-HAP Grp" = persistent and bioaccumulative HAP group. "Num" = number. "Facil" = facility. "SV" = screening value (i.e., ratio of facility emission to screening threshold emission rate). "Max" = maximum. "Inh" = inhalation. "ID" = identifier. "Agg" = aggregate (as in emissions from multiple source category facilities impacting the feature of interest).

Exhibit 33. Example of Facility-level Results Output from Tier 2 Tool

Facil Info						Tier 1	Fisher			Farmer			Farmer + Inhalation				
Src Cat	Facil ID	Facil Lat	Facil Long	Facil Met WBAN	PB-HAP Gr	SV	SV	Agg Impacts?	SV Before Agg Impacts (If Applicable)	SV	Oct	Dist from Facil (km)	Total Value	Farmer Value	Inhalation Value	Oct	Inh Di Fa
Src Cat A	67248	34.3134	-70.7310	13876	Arsenic	5.E+00	7.E-02	Y	7.E-02	2.E+00	W	5.E-01					
Src Cat A	67248	34.3134	-70.7310	13876	Cadmium	2.E-01	2.E-02	Y	2.E-02	7.E-03	W	5.E-01					
Src Cat A	67248	34.3134	-70.7310	13876	Dioxin	1.E+02	2.E+01	N		6.E+00	W	5.E-01					
Src Cat A	67248	34.3134	-70.7310	13876	Methyl Mercury (Hg2)	2.E+00	4.E-01	Y	4.E-01	8.E-04	W	5.E-01					
Src Cat A	67248	34.3134	-70.7310	13876	POM	0.E+00	0.E+00	N		0.E+00	NW	4.E+01					
Src Cat A	67248	34.3134	-70.7310	13876	Total Cancer (Arsenic+POM +Dioxin)	2.E+02	2.E+01	Y	2.E+01	8.E+00	W	5.E-01	8.E+00	8.E+00	0.E+00	W	0.E+0
Src Cat A	41870	49.9141	-105.7870	93806	Arsenic	7.E-01	1.E-02	N		3.E-01	S	5.E-01					
Src Cat A	41870	49.9141	-105.7870	93806	Cadmium	1.E-02	2.E-03	N		7.E-04	S	5.E-01					
Src Cat A	41870	49.9141	-105.7870	93806	Dioxin	0.E+00	0.E+00	N		0.E+00	NW	4.E+01					
Src Cat A	41870	49.9141	-105.7870	93806	Methyl Mercury (Hg2)	6.E-04	1.E-04	N		3.E-07	S	5.E-01					
Src Cat A	41870	49.9141	-105.7870	93806	POM	0.E+00	0.E+00	N		0.E+00	NW	4.E+01					
Src Cat A	41870	49.9141	-105.7870	93806	Total Cancer	7.E-01	1.E-02	N		3.E-01	S	5.E-01	3.E-01	3.E-01	0.E+00	S	0.E+0

Note: Only a portion of this table is shown for space limitations; information not shown completely here includes: gardener SVs and sums of inhalation risk values with farmer/gardener SVs. The facility IDs, locations, and meteorology station assignments shown here are not real (they are only for illustration purposes). Red shading and font indicate where facilities did not screen out (i.e., the SV or sum of SV and inhalation risk rounded to 2 or higher). "Src Cat" = source category. "Facil" = facility. "ID" = identifier. "Lat" and "Long" = latitude and longitude. "Met WBAN" = Weather Bureau-Army-Navy identifier for the meteorology station. "HAP" = hazardous air pollutant. "PB-HAP Grp" = persistent and bioaccumulative HAP group. "SV" = screening value (i.e., ratio of facility emission to screening threshold emission rate). "Oct" = one of the eight primary directional octants. "Dist" = distance. "km" = kilometers. "Agg" = aggregate (as in emissions from multiple source category facilities impacting the feature of interest).

Exhibit 34. Example of the Refined-fisher Output for Facility and PB-HAP from Tier 2 Tool

Facil Info			Tier 1	Tier 2														
					Lake Info							Unrefined Fisher SV		Refined Fisher Assessment				
																SV Fisher		
Src Cat	Facil ID	PB-HAP Grp	SV	Oct	Nam	Object ID (USGS)	Area (acres)	Facility-Lake Dist (km)	Lat	Long	Agg Impacts?	Independent Facil	Agg Facil	Fisher Order 0 = fisher did not fish	Fisher Fraction Ingestion (based on lake area)	Independent Facil	Agg Facil
Src Cat A	89341	Arsenic	5.E+00	W	Lake A	278	37	12.8	28.4090	-90.2940	Y	8.E-02	9.E-02	1	0.10	8.E-03	9.E-03
Src Cat A	89341	Arsenic	5.E+00	SW	Lake C	845	974	12.9	28.4380	-90.8240	Y	7.E-02	7.E-02	2	0.90	6.E-02	6.E-02
Src Cat A	89341	Arsenic	5.E+00	SW	Lake W	454	59	10.8	28.6720	-90.6420	Y	7.E-02	7.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake I	260	54	10.0	28.0140	-90.7200	Y	7.E-02	7.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	S	Lake U	789	198	8.1	28.9810	-90.1110	Y	6.E-02	7.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	S	Lake E	660	40	8.9	28.3370	-90.7690	Y	6.E-02	7.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	NW	Lake Q	601	32	6.9	28.4590	-90.9130	Y	6.E-02	7.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SE	Lake B	113	40	9.1	28.1480	-90.3060	Y	4.E-02	5.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	S	Lake D	673	40	19.2	28.3470	-90.3000	Y	4.E-02	5.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	S	Lake F	119	30	11.4	28.7060	-90.4190	Y	4.E-02	5.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	W	Lake G	369	44	39.0	28.8280	-90.6500	N	4.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	E	Lake J	412	37	5.5	28.1330	-90.0920	Y	4.E-02	6.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake V	942	114	20.6	28.9080	-90.4110	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake M	894	94	22.7	28.5680	-90.6640	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake K	754	86	27.9	28.6740	-90.1760	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake S	425	84	32.1	28.1320	-90.8510	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake T	838	82	23.9	28.5560	-90.4330	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake H	756	74	38.6	28.9480	-90.3070	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake N	210	69	30.8	28.8000	-90.4880	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake O	515	32	39.1	28.8470	-90.9710	Y	3.E-02	5.E-02	0	0.00	0.E+00	0.E+00
Src Cat A	89341	Arsenic	5.E+00	SW	Lake Z	818	27	26.1	28.2140	-90.8050	Y	3.E-02	4.E-02	0	0.00	0.E+00	0.E+00

Note: The facility IDs and lake information shown here are not real (they are only for illustration purposes). "Src Cat" = source category. Red shading and font indicate where SVs rounded to 2 or higher. "Facil" = facility. "ID" = identifier. "HAP" = hazardous air pollutant. "PB-HAP Grp" = persistent and bioaccumulative HAP group. "SV" = screening value (i.e., ratio of facility emission to screening threshold emission rate). "Oct" = one of the eight primary directional octants. "USGS" = U.S. Geological Survey. "Dist" = distance. "km" = kilometers. "Lat" and "Long" = latitude and longitude. "Agg" = aggregate (as in emissions from multiple source category facilities impacting the feature of interest).

4. Tier 3 Screen

This section describes the methods and assumptions for the Tier 3 screen. We provide an overview of the approach (Section 4.1); description of the lake screen refinement (Section 4.2); evaluations of the farmer and gardener exposure scenarios (Sections 4.3 and 4.4); refinement of the plume rise evaluation (Section 4.5); and a final time-series assessment using hourly instead of annual average meteorological data (Section 4.6).

4.1 Overview of Approach

Tier 3 multipathway screens can be conducted on facilities that do not screen out in Tier 2. Tier 3 consists of five possible individual refinements (described in more detail below) that are based on additional site-specific data. These refinements are applied in sequence because all might not be needed; potential ingestion risk is evaluated at the end of each refinement. Because the Tier 3 screens introduce additional site-specificity to the screening scenario, it can require a higher level of effort than the Tier 2 screen, but still a much lower level of effort than required for a full site-specific assessment. One of the Tier 3 screens (i.e., the lake screen) potentially results in the rescreening of facilities' emissions using the Tier 2 methods described in Section 3 and using a revised lake dataset. The other screens each may result in a refinement of the Tier 2 screening value. The hourly time-series screen, if conducted, supplants the plume-rise screen because it calculates plume rise on an hourly basis.

4.2 Lake Screen

A Tier 3 lake evaluation is conducted if the Tier 2 screen for the fisher scenario indicates a potential for risk. During this evaluation, we examine: (1) whether or not a given lake used in the Tier 2 screen truly exists; (2) the intended purpose of the lake (e.g., recreation, industrial disposal); (3) lake accessibility; and (4) whether or not the lake is likely fishable. This evaluation is conducted because the USGS database of lakes and reservoirs used in the Tier 2 screen

does not indicate lake accessibility or which lakes are likely fishable. In addition, USGS 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.

Using aerial imagery and other data sources, non-fishable "lakes" are identified, removed from the Tier 3 screen, and removed from the RTR lake dataset. If one or more lakes are removed from a facility's screen, the facility's emissions are rescreened using the revised lake database and the Tier 2 methods described in Section 3. 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 screen 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 screen.

We use aerial and street-view imagery and internet searches to ascertain if an assessed lake actually exists and whether or not it is likely to be fished. The assessed lakes are those from which the fisher harvests fish according to the Tier 2 methods discussed in Section 3.3.1. Lakes that appear swampy or covered in algae or used for industrial or waste disposal/treatment purposes are not fishable. Lakes adjacent or connected to a river or saltwater body (estuaries and rivers) are likely to have high outflow with limited chemical retention.

Based on the evaluation described above, we remove from the RTR lake dataset any lakes that are unsuitable for the RTR fisher scenario. For example, the area outlined in blue in Exhibit 35 identifies an area that the USGS dataset originally identified as a lake. However, aerial imagery (current and historical) shows that it is mostly or entirely dried up and not suitable for fishing. The area outlined in blue in Exhibit 36 identifies a lake from the USGS dataset that originally qualified for Tier 2 screening based on that dataset; however, aerial imagery shows that it is directly adjacent to an industrial facility and likely used only for on-site industrial purposes. Both lakes would be permanently removed from the RTR lake dataset and not considered in future.

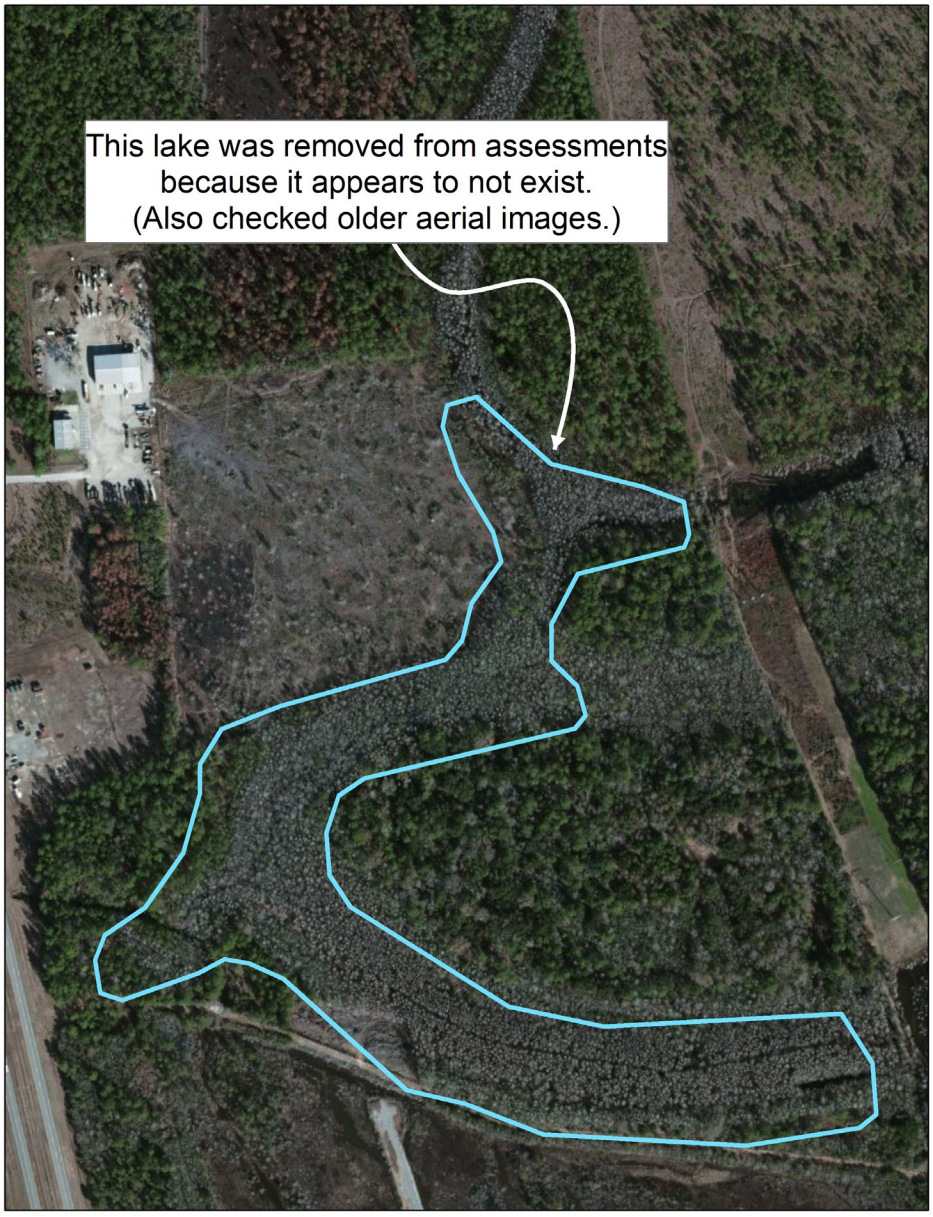
If we remove a lake during the Tier 3 screen, we often need to include an additional lake for fish harvest to reach 373 fishable acres. We assess the additional lake(s) using the same criteria and searches discussed in this section. After all lakes fished in the scenario (for the facilities not screening out in Tier 2) have been evaluated, we rerun the Tier 2 screen (using the tool discussed in Section 3) with the revised RTR lake dataset, producing revised screening results.

Lakes removed during this step of Tier 3 could affect screening results for other facilities in the source category. For example, if an assessed facility is within 100 km of another assessed facility, removing a lake might affect the screening results for both facilities. For this reason, we rerun the Tier 2 screen with the revised lake dataset for all facilities in the source category, including lakes contaminated by multiple facilities in the same source category. Screening results for the farmer and gardener scenarios are not affected by the lake screen.

4.3 Farmer Scenario Evaluation

In many settings, based on local land use, population density, and other factors, the existence of a full-scale farm capable of providing all of the ingested media that are assumed for the farmer scenario might be unrealistic. If the farmer exposure scenario does not screen out at Tier 2, additional information can be evaluated on the likelihood that full-scale farming operations exist within the modeling domain.

Exhibit 35. Example of Lake Removed from Screening—Likely Evaporated or Drained



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

Exhibit 36. Example of Lake Removed from Screening—Likely an Industrial Lake

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

If, after Tier 2, a farmer SV is above a level of concern, EPA will use census data, aerial imagery, and other available data to further assess the likelihood of subsistence farmer operations within 50 km of the facility. If, based on the additional analysis and review, it is determined that no subsistence farming operations are in the area, then the farmer scenario will no longer be used in Tier 3 and only the gardener SVs are reported. That is, EPA will assume that subsistence farming operations are not likely within 50 km of the facility, and only gardener SVs will be evaluated and reported. If information obtained suggests that subsistence farming operations likely exist, then in Tier 3, EPA will identify the farmer SV at the modeled location(s) that best matches the locational data obtained, and EPA will evaluate and report the largest of these SVs. Such location(s) may not be at the location of maximum SV as indicated in the Tier 2 screen. The gardener SVs will continue to be evaluated and reported, even if farmer results are used, because EPA considers the gardener scenario to be possible in all RTR evaluations.

4.4 Gardener Scenario Evaluation

Unlike the farmer exposure scenario, the gardener exposure scenario does not require a large geographic footprint (i.e., relatively small gardens could provide the fruits and vegetables to satisfy the gardener ingestion rates); this is especially true for the urban gardener scenario. Nonetheless, it does require that human receptors be present in the area.

If, after Tier 2, a gardener SV is above a level of concern, in Tier 3 EPA will evaluate whether there likely are residential areas near the location of the gardener SV. EPA will use information such as Census data, aerial imagery, and land-use data to determine whether people are likely to live near the SV location. If EPA determines that people likely live there, the Tier 2 gardener

SV is retained. If EPA determines people likely do not live there, then in Tier 3 EPA will report the next-highest gardener SV at a location where people likely reside.

4.5 Plume-rise Screen

If, after the lake screen, the Tier 3, an SV is still above a level of concern, the risk assessor may choose to conduct a plume-rise screen. Atmospheric conditions coupled with the physical parameters of the chemical release point can cause the chemical plume to rise substantially higher than the physical release height. Plume rise is not explicitly modeled by TRIM.FaTE but can substantially reduce ground-level chemical exposure if the plume frequently rises above the air mixing height. The plume-rise screen varies chemical release height over time to simulate the effect of 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 air mixing height for a given hour, then in the TRIM.FaTE modeling system there is no chemical deposition or exposure for that hour.

In TRIM.FaTE modeling, the chemical mass reaching 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). Depending on ambient conditions, the top of the air mixing layer can fall below the top of tall stacks 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 height. If this occurs across many hours, it will substantially reduce total PB-HAP exposure and reduce the screening value. The plume-rise refinement 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 value, thus lowering the screening value.

The Tier 3 plume-rise screen uses 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 use hourly meteorological data (e.g., air temperature and wind speed) from the closest weather station, 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 (needed to estimate the plume height at the estimated edge of the facility).

We use EPA guidance (U.S. EPA 2000) to calculate wind speed at the stack height. We use equations reproduced in Seinfeld and Pandis (1998) to calculate plume rise with the above data and the assumed average vertical gradients of temperature and potential temperature (a calculation that normalizes temperature measurements for differences in height and pressure) corresponding to the stability class (e.g., neutral stability, slight or extreme instability—atmospheric conditions that affect how an air parcel moves vertically).

For each relevant emission source, we compare estimates of the hourly effective release height (i.e., sum of actual release height and plume rise) to the hourly mixing height to determine the mass of chemical remaining in the mixing layer when winds in that layer blow toward the lake or farm/garden of interest. We compare the mass of chemical remaining in the mixing layer, summed across all sources at a given facility, to the total emitted mass of the chemical—this ratio is the plume-rise retention factor. The screening tool described in Section 3 multiplies that factor by the appropriate farmer, gardener, and fisher SVs following the Tier 3 analyses discussed above (Equation 13):

$$SV_{T3PR} = SV_X \times \left[\frac{Hrs(W \text{ and } E<M)}{Hrs(W)}\right] \qquad \textbf{Eqn. 13}$$

where:

SV_{T3PR} = SVs for the Tier 3 plume-rise screen;

SV_X = SVs either for the Tier 3 fisher scenario from the Tier 3 lake screen or the Tier 2 farmer/gardener scenario;

$Hrs(W \text{ and } E<M)$ = number of hours when winds are blowing toward the lake or farm/garden when the effective release height (physical stack height + plume-rise height) is less than the mixing height;

$Hrs(W)$ = number of hours when winds are blowing toward the lake or farm/garden of interest.

For the fisher scenario, after the SVs at each lake are adjusted based on plume rise, the screening tool reapplies the refined fisher screening calculation discussed in Section 3.3.1, but the order of fished lakes does not change.

For example, suppose two lakes are being assessed, having surface areas of 273 and 100 acres and having Tier 3 lake SVs for mercury of 5.7 and 3.0, respectively. Applying the refined-fisher scenario calculations (Section 3.3.1), the site-wide fisher-scenario SV for mercury is [5.7 × (273/373)] + [3.0 × (100/373)] = 5.0. Winds blow toward the first lake 1,800 hours per year, and during that time, the effective release height (physical stack height + plume-rise height) is below the mixing layer 1,000 hours; its plume-rise retention factor is 1,000/1,800=0.56. That means that 56 percent of the chemicals emitted remain in the mixing layer. Winds blow toward the second lake 500 hours per year, and during that time, the effective release height is below the mixing layer 400 hours per year; its plume-rise retention factor is 400/500 = 0.8. The Tier 3 plume-rise fisher-scenario SVs for mercury are 5.7 × 0.56 = 3.2 and 3.0 × 0.8 = 2.4. With the refined-fisher calculations, the site-wide fisher-scenario SV for mercury is [3.2 × (273/373)] + [2.4 × (100/373)] = 3.0.

4.6 Screen Using Hourly Time-series Meteorological Data and Effective Release Heights

If a Tier 3 plume-rise screen indicates potential ingestion risks remain, we refine the screen using hourly meteorological data from the closest weather station. Hourly meteorological data and estimates of plume rise are run through TRIM.FaTE and results compiled.[21] The use of time-series meteorological data, which capture hour-by-hour changes in each of the assessed meteorological parameters (instead of using the single annual average values as in the Tiers 1 and 2 screens), increases the accuracy of the assessment by accounting for potential correlations among meteorological parameter values over time.

This screen utilizes hourly effective release heights (computed in the plume-rise screen above) along with the hourly meteorological data associated with the facility instead of the 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 screen described above. These time-varying release height

[21]As discussed in Section 3, the Tier 2 multipathway screening results are based on typical meteorological conditions prevailing at the facility being screened. This is in contrast to the modeling with TRIM.FaTE for the Tier 3 screen which incorporates hour-by-hour site-specific meteorological data and plume-rise estimates in new modeling runs.

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 estimation, leads directly to a screening-level cancer risk or HQ (i.e., a revised screening value). For simplicity in the software implementation of the Tiers 2 and 3 screens, the result of this Tier 3 time-series screen is converted to a time-series refinement factor—the revised SV divided by the SV after the Tier 3 lake screen. This ratio can then be multiplied by the SV after the Tier 3 lake screen, yielding the revised SV accounting for the time-series screen.

For a Tier 3 time-series screen, we use the facility's emissions, a time series of hourly effective release heights, a time series of hourly meteorological data (i.e., wind speed and direction, mixing height, temperature, and precipitation), and the Tier 2 spatial scenario that best matches each lake fished by the simulated subsistence fisher (or the relevant farm/garden locations if the farmer or gardener scenario is of concern). The site-specific hourly data and Tier 2 spatial layout are input to TRIM.FaTE, which provides estimated PB-HAP concentrations in environmental media that subsequently are used to estimate exposures and risk. If multiple lakes are fished (to allow for the subsistence fish ingestion rate), the percent of daily-ingested fish caught at each lake is multiplied by the screening level risk or HQ value for that lake. The PB-HAP-specific results are summed across all lakes (i.e., the refined-fisher calculations discussed in Section 3.3.1 are applied to the modeling results, using the screening tool described in Section 3).

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Attachment A. TRIM.FaTE Inputs

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Exhibits

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 the meteorological and air parameter values, respectively, entered into the model.

Exhibit A-4 presents parameter values for soil and groundwater. Exhibit A-5 and Exhibit A-6 present runoff assumptions for the lake and farm scenarios, respectively; while Exhibit A-7 and Exhibit A-8 present parameter values for the universal soil loss equation (USLE) for calculating erosion for the lake and farm scenarios, respectively. Exhibit A-9 and Exhibit A-10 indicate the vegetation type assumed for each terrestrial parcel for the lake and farm scenarios, respectively, while Exhibit A-11 lists parameter values used terrestrial vegetation. Lake-parameter values for abiotic compartments are included in Exhibit A-12 for the surface water column and in Exhibit A-13 for the unconsolidated sediment layer (above the sediment sink). Parameter values for the biotic compartments in the lake (e.g., fish, invertebrates, algae) are included in Exhibit A-14.

Chemical-specific parameter values for the TRIM.FaTE scenarios (e.g., molecular weight, diffusion rate constants, Henry's law constant) are provided in Exhibit A-15 for arsenic, Exhibit A-16 for cadmium, Exhibit A-17 for mercury, Exhibit A-18 for POM, and Exhibit A-19 for dioxins. Chemical-specific parameter values for the TRIM.FaTE abiotic compartments (e.g., air, surface water, sediment, surface soil, root-zone soil) are presented in Exhibit A-20 for arsenic, Exhibit A-21 for cadmium, Exhibit A-22 for mercury, Exhibit A-23 for POM, and Exhibit A-24 for dioxins. Chemical-specific parameter values for the plant compartments (e.g., leaf, stem, root) are presented in Exhibit A-25 for arsenic, Exhibit A-26 for cadmium, Exhibit A-27 for mercury, Exhibit A-28 for POM, Exhibit A-29 for dioxins. Finally, chemical-specific parameter values for aquatic species are presented in Exhibit A-30 for arsenic, Exhibit A-31 for cadmium, Exhibit A-32 for mercury, Exhibit A-33 for POM, and Exhibit A-34 for dioxins.

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."

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

Parameter Name	Units	Value Used	Reference
Air temperature	degrees K	298	U.S. EPA 2005a.
Horizontal wind speed	m/sec	1.6 or varies	Tiers 1 and 2, and Tier 3 lake screen: The ~5th percentile of median annual wind speeds, partitioned by 8 wind directions, recorded at 824 MET stations across the United States in 2016. Tier 3 plume-rise and time-series screens: Varies by the hour; site-specific hourly meteorological data.
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 or varies	Tiers 1 and 2, and Tier 3 lake screen: "On" is defined as time during which wind is blowing across the source into the model domain. The weekly split was determined to be a health-protective setting by evaluating archived meteorology data (NCDC 1995). Tier 3 plume-rise and time-series screens: Varies by the hour; site-specific hourly meteorological data.
Rainfall rate	m^3[rain]/m^2 [surface area]-day	0.0041 or varies	Tiers 1 and 2, and Tier 3 lake screen: The ~95th percentile of the annual average precipitation for 824 MET stations across the United States was approximately 1.5 m/yr or 0.0041 m/day, based on 1981–2010 normals where available (812 MET stations) and based on 2016 values otherwise (11 MET stations). Tier 3 plume-rise and time-series screens: Varies by the hour; site-specific hourly meteorological data.
Mixing height (used to set air VE property named "top")	m	226 or varies	Tiers 1 and 2, and Tier 3 lake screen: The ~5th percentile of annual median mixing heights recorded at 824 MET stations across the United States in 2016. Tier 3 plume-rise and time-series screens: Varies by the hour; site-specific hourly meteorological data.
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	–	

Note: MET = meteorological.

Exhibit A-3. Air Parameter Values 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	U.S. EPA 1997.
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 Parameter Values for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Surface Soil Compartment Type			
Air content	m^3[gas]/m^3[compartment]	0.28[a]	McKone et al. 2001.
Average vertical velocity of water (percolation)	m^3[water]/m^2[surface soil]-day (or m/day)	8.08E−04	Assumed as 0.2 times average precipitation for New England in McKone et al. 2001.
Boundary layer thickness above surface soil	m	0.005	Thibodeaux 1996; McKone et al. 2001 (Table 3).
Density of soil solids (dry weight)	kg[solid]/m^3[solid]	2600	Default in McKone et al. 2001 (Table 3).
Thickness – untilled[b]	m	0.01	McKone et al. 2001 (p. 30).
Thickness – tilled[b]	m	0.20	U.S. EPA 2005a.
Erosion fraction	unitless	varies[c]	See Exhibit A-5 and Exhibit A-6.
Fraction of area available for erosion	m^2[area available]/m^2[total]	1	Area assumed rural.
Fraction of area available for runoff	m^2[area available]/m^2[total]	1	Area assumed rural.
Fraction of area available for vertical diffusion	m^2[area available]/m^2[total]	1	Area assumed rural.
Fraction sand	unitless	0.25	Assumption.
Organic carbon fraction	kg[organic carbon]/kg[solids wet wt]	0.008[a]	U.S. average in McKone et al. 2001 (Tables 16 and A-3).
pH	unitless	6.8	Assumption.
Runoff fraction	unitless	varies[c]	See Exhibit A-5 and Exhibit A-6
Total erosion rate	kg[soil]/m^2[surface soil]-day	varies[c]	See Exhibit A-7 and Exhibit A-8

Parameter Name	Units	Value Used	Reference
Total runoff rate	m^3[water]/m^2[surface soil]-day	1.62E−03[a]	Calculated using scenario-specific precipitation rate and assumptions associated with water balance.
Water content	volume[water]/volume[compartment]	0.19[a]	McKone et al. 2001 (Table 15).
Root Zone Soil Compartment Type			
Air content	m^3[gas]/m^3[compartment]	0.25[a]	McKone et al 2001 (Table 16).
Average vertical velocity of water (percolation)	m^3[water]/m^2[surface soil]-day (or m/day)	8.08E−04	Assumed as 0.2 times average precipitation for New England in McKone et al. 2001.
Density of soil solids (dry weight)	kg[solid]/m^3[solid]	2,600	McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.25	Assumption.
Thickness – untilled[b]	m	0.79	McKone et al. 2001 (Table 16, U.S. average).
Thickness – tilled[b]	m	0.6	Adjusted from McKone et al. 2001 (Table 16).
Organic carbon fraction	kg[organic carbon]/kg[solids wet wt]	0.008[a]	McKone et al. 2001 (Tables 16 and A-3, U.S. average).
pH	unitless	6.8 [a]	Assumption.
Water content	volume[water]/volume[compartment]	0.21[a]	McKone et al. 2001 (Table 16).
Vadose Zone Soil Compartment Type			
Air content	m^3[gas]/m^3[compartment]	0.22[a]	McKone et al. 2001 (Table 17).
Average vertical velocity of water (percolation)	m^3[water]/m^2[surface soil]-day (or m/day)	8.08E−04[a]	Assumed as 0.2 times average precipitation for New England in McKone et al. 2001.
Density of soil solids (dry weight)	kg[solid]/m^3[solid]	2,600	Default in McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.35	Assumption.
Thickness[b]	m	1.4	McKone et al. 2001 (Table 17).
Organic carbon fraction	kg[organic carbon]/kg[solids wet wt]	0.003[a]	McKone et al. 2001 (Tables 16 and A-3, U.S. average).
pH	unitless	6.8	Assumption.
Water content	m^3[liquid]/m^3[compartment]	0.21[a]	McKone et al. 2001 (Table 17, U.S. average).

Parameter Name	Units	Value Used	Reference
Groundwater Compartment Type			
Thickness[b]	m	3	McKone et al. 2001 (Table 3).
Fraction sand	unitless	0.4	Assumption.
Organic carbon fraction	kg[organic carbon]/kg[solids wet wt]	0.004	Assumption.
pH	unitless	6.8	Assumption.
Porosity	L[total pore space]/L [total compartment]	0.2	Default in McKone et al. 2001 (Table 3).
Density of solid material	kg[solid]/m^3[solid]	2,600	Default in McKone et al. 2001 (Table 3).

[a]Scenario-specific parameters.
[b]Set using the volume element properties file.
[c]See Exhibit A-5, Exhibit A-6, Exhibit A-7, and Exhibit A-8 for erosion/runoff fractions and total erosion rates.

Exhibit A-5. Runoff Assumptions for TRIM.FaTE Base Lake (L) Screening Scenario

Originating Compartment	Destination Compartment	Runoff/Erosion Fraction
SurfSoil_Source	Sink	1.0
	SurfSoil_Parcel1	0
SurfSoil_Parcel1	SurfSoil_Source	0
	Lake	1.0
SurfSoil_Parcel2N	Lake	1.0
	SurfSoil_Parcel3	0
SurfSoil_Parcel2S	Lake	1.0
	SurfSoil_Parcel3	0
Lake	SurfSoil_Parcel1	0
	SurfSoil_Parcel2N	0
	SurfSoil_Parcel2S	0
	Lake	1.0
	SurfSoil_Parcel3	0
SurfSoil_Parcel3	SurfSoil_Parcel2N	0
	SurfSoil_Parcel2S	0
	Lake	1.0
	SurfSoil_Parcel4	0
SurfSoil_Parcel4	SurfSoil_Parcel3	1.0

Exhibit A-6. Runoff Assumptions for TRIM.FaTE Base Farm (F) Screening Scenario

Originating Compartment	Destination Compartment	Runoff/Erosion Fraction
SurfSoil_Source	Sink	1.0
	SurfSoil_Parcel1	0
SurfSoil_Parcel1	Sink	0.4
	SurfSoil_Source	0
	SurfSoil_Farm	0.6
	SurfSoil_Parcel2	0
SurfSoil_Farm	Sink	1.0
	SurfSoil_Parcel1	0
	SurfSoil_Parcel2	0
SurfSoil_Parcel2	Sink	0.4
	SurfSoil_Parcel1	0
	SurfSoil_Farm	0.6
	SurfSoil_Parcel3	0
SurfSoil_Parcel3	SurfSoil_Parcel2	1.0
	SurfSoil_Parcel4	0
SurfSoil_Parcel4	SurfSoil_Parcel3	1.0
	SurfSoil_Parcel5	0
SurfSoil_Parcel5	SurfSoil_Parcel4	1.0

Exhibit A-7. USLE Erosion Parameter Values for the TRIM.FaTE Base Lake (L) 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]	$kg/m^2/d$
Source	62,500	300	0.39	1.5	untilled soil	0.2	1	35.1	0.02156	0.5281	0.01138
Parcel1	116,891	300	0.39	1.5	grass	0.1	1	17.55	0.01078	0.4884	0.005264
Parcel2N	232,594	300	0.39	1.5	grass	0.1	1	17.55	0.01078	0.4481	0.004830
Parcel2S	232,594	300	0.39	1.5	grass	0.1	1	17.55	0.01078	0.4481	0.0048301
Parcel3	4,082,258	300	0.39	1.5	coniferous forest	0.1	1	17.55	0.01078	0.2088	0.002251
Parcel4	13,386,064	300	0.39	1.5	coniferous forest	0.1	1	17.55	0.01078	0.1800	0.001940

[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-8. USLE Erosion Parameter Values for the TRIM.FaTE Base Farm (F) 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]	$kg/m^2/d$
Source	62,500	300	0.39	1.5	untilled soil	0.2	1	35.1	0.02156	0.5281	0.01138
Parcel1	116,891	300	0.39	1.5	grass	0.1	1	17.55	0.01078	0.4884	0.005264
Farm	40,633	300	0.39	1.5	tilled soil	0.2	1	35.1	0.02156	0.5573	0.01201
Parcel2	281,012	300	0.39	1.5	grass	0.1	1	17.55	0.01078	0.3960	0.004268
Parcel3	608,730	300	0.39	1.5	grass	0.1	1	17.55	0.01078	0.3595	0.003875
Parcel4	4,082,258	300	0.39	1.5	coniferous forest	0.1	1	17.55	0.01078	0.2088	0.002251
Parcel5	13,386,064	300	0.39	1.5	coniferous forest	0.1	1	17.55	0.01078	0.1800	0.001940

[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-9. Terrestrial Plant Placement for the TRIM.FaTE Base Lake (L) Screening Scenario

Surface Soil Volume Element	Surface Soil Depth (m)	Coniferous Forest	Grasses/ Herbs	None
Source	0.01 (untilled)			x
Parcel1	0.01		x	
Parcel2N	0.01		x	
Parcel2S	0.01		x	
Parcel3	0.01	x		
Parcel4	0.01	x		

Exhibit A-10. Terrestrial Plant Placement for the TRIM.FaTE Base Farm (F) Screening Scenario

Surface Soil Volume Element	Surface Soil Depth (m)	Coniferous Forest	Grasses/ Herbs	None
Source	0.01 (untilled soil)			x
Parcel1	0.01		x	
Farm	0.2 (tilled soil)			x
Parcel2	0.01		x	
Parcel3	0.01		x	
Parcel4	0.01	x		
Parcel5	0.01	x		

Exhibit A-11. Terrestrial Plant Parameter Values 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]	Growing season: for screening scenario, begins March 9 (set to 1) and ends November 7 (set to 0). Nationwide 80th percentile.
Average leaf area index	m^2[total leaf area]/ m^2[underlying soil area]	5	Representative value for conifers, N. Nikolov, Oak Ridge National Laboratory	5	Mid-range of 4–6 for old fields, R.J. Luxmoore, Oak Ridge National Laboratory.
Calculate wet deposition interception fraction (Boolean)	1 = yes, 0 = no	1	Selected setting.	1	Selected setting.
Correction exponent, octanol to lipid	unitless	0.76	From roots, Trapp 1995.	0.76	From roots, Trapp 1995.
Degree stomatal opening	unitless	1	Set to 1 for daytime (when stomata are open; stomatal diffusion is turned off at night using a different property, IsDay).	1	Set to 1 for daytime (stomatal diffusion is turned off at night using a different property, IsDay).
Density of wet leaf	kg[leaf wet wt]/m^3[leaf wet]	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, Müller and Pröhl 1993.	3.00E−04	1E−04 to 6E−04 for different crops and elements, Müller and Pröhl 1993.
Length of leaf	m	0.01	Professional judgment.	0.05	Professional judgment.
Lipid content	kg[lipid]/kg[leaf wet weight]	0.00224	European beech, Riederer 1995.	0.00224	European beech, Riederer 1995.
Litter fall rate	1/day	0.0021	Value assumes first-order relationship and that 99% of leaves fall in 6 years.	Seasonal[b]	Leaf fall: for screening scenario begins November 7 and ends December 6; rate = 0.15/day during this time (value assumes 99% of leaves fall in 30 days).

Parameter Name	Units	Coniferous[a]		Grass/Herb[a]	
		Value Used	Reference	Value Used	Reference
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	kg[water]/kg[leaf wet wt]	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[plant part wet wt]/ m^2[surface soil]	2	Calculated from leaf area index, leaf thickness (Simonich and Hites, 1994), density of wet foliage.	0.6	Calculated from leaf area index and Leith 1975a,b in Leith and Whitaker 1975.
Particle on Leaf Compartment Type					
Allow exchange	1 = yes, 0 = no	1	–	Seasonal[b]	See leaf compartment.
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]	See leaf compartment.
Correction exponent, octanol to lipid	unitless			0.76	Trapp 1995.
Lipid content of root	kg[lipid]/kg[root wet wt]			0.011	From bean root, Trapp 1995.
Water content of root	kg[water]/kg[root wet wt]			0.8	Professional judgment.
Wet density of root	kg[root wet wt]/m^3[root wet]			820	Soybean, Paterson et al. 1991.
Wet mass per soil area	kg[plant part wet wt]/m^2[surface soil]			1.4	Temperate grassland, Jackson et al. 1996.

Parameter Name	Units	Coniferous[a]		Grass/Herb[a]	
		Value Used	Reference	Value Used	Reference
Stem Compartment Type – Nonwoody Only					
Allow exchange	1 = yes, 0 = no			Seasonal[b]	See leaf compartment
Correction exponent, octanol to lipid	unitless			0.76	From roots, Trapp 1995; in Trapp and McFarlane, eds. 1995.
Density of phloem fluid	kg[phloem]/m^3 [phloem]			1,000	Professional judgment.
Density of xylem fluid	kg[xylem fluid]/m^3[xylem fluid]			900	Professional judgment.
Flow rate of transpired water per leaf area	m^3[water]/m^2 [stem]-day			0.0048	Crank et al. 1981, as cited by Paterson et al. 1991.
Fraction of transpiration flow rate that is phloem rate	unitless			0.05	Paterson et al. 1991.
Lipid content of stem	kg[lipid]/kg[stem wet wt]			0.00224	Leaves of European beech, Riederer 1995.
Water content of stem	kg[water]/kg [stem wet wt]			0.8	Paterson et al. 1991.
Wet density of stem	kg[stem wet wt]/ m^3[stem wet]			830	Professional judgment.
Wet mass per soil area	kg[plant part wet wt]/m^2[surface soil]			0.24	Calculated from leaf and root biomass density based on professional judgment.

[a]See Exhibit A-9 and Exhibit A-10 for assignment of plant types.
[b]Seasonal values; leaves must be present for exchanges with leaves.

Exhibit A-12. Surface Water Parameters for the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value Used	Reference
Algae carbon content (mass fraction; dry wt basis)	unitless	0.465	APHA 1995.
Algae density in water column	g[algae wet wt]/L[water]	0.0025[a]	Millard et al. 1996.
Algae growth rate	1/day	0.7	Hudson et al. 1994, in Watras and Huckabee, eds. 1994. Also cited in Mason et al. 1995b.
Algae radius	µm	2.5	Mason et al. 1995b.
Algae water content (mass 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[chloride/L[surface water]	8[a]	Kaushal et al. 2005.
Chlorophyll concentration	mg[chlorophyll]/L[surface water]	0.0029[a]	Nürnberg 1996.
Depth[b]	m	3.12[a]	WI DNR 2007– calculation based on relationship between drainage basin and lake area size.[b]
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[a]	Calculated based on pond dimensions and flow calculations.
Fraction sand	unitless	0.25	Assumption.
Organic carbon fraction in suspended sediments	kg[organic carbon]/kg[solids wet wt]	0.02[a]	Professional judgment.
pH	unitless	7.3[a]	Professional judgment.
Suspended sediment deposition velocity	m/day	2[a]	Assumption (in sediment balance calculations).
Total suspended sediment concentration	kg[sediment]/m^3[water column]	0.05[a]	Assumption (in sediment balance calculations).
Water temperature	degrees K	298[a]	U.S. EPA 2005a.

[a]Scenario-specific parameters, values provided are for RTR screens.
[b]Set using the volume element properties named “top” and “bottom.” If not set, depth computed via: d/(A*F), where d is the annual discharge (in m^3/year), A is the lake area (in m^2), and F is the flush rate per year.

Exhibit A-13. Sediment Parameter Values 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	kg[organic carbon]/kg[solids wet wt]	0.02[b]	McKone et al. 2001 (Table 3).
Porosity of the sediment zone	volume[total pore space]/volume[sediment compartment]	0.6	Assumption.
Solid material density in sediment	kg[sediment]/m^3[sediment]	2,600	McKone et al. 2001 (Table 3).
pH	unitless	7.3[b]	Assumption.
Sediment resuspension velocity	m/day	7.62E−05[b]	Calculated from sediment balance model.

[a]Unconsolidated sediment layer just below surface water column.
[b]Scenario-specific parameters; values provided are for Tier 1 screenings.

Exhibit A-14. Aquatic Animals Food Chain, Density, and Biomass for the TRIM.FaTE Screening Scenario

Aquatic Biota (Consuming Organism)	Fraction Diet[a]								Biomass (kg/m^2)[a]	Body Weight (kg)[b]	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	0.25	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.

[a]Scenario-specific parameters; values provided are for RTR screening.
[b]Assumption across all scenarios.

Exhibit A-15. Arsenic Chemical-Specific Parameter Values for the TRIM.FaTE Screening Scenario

Parameter Name[a]	Units	Value	Reference
CAS number[b]	–	7440-38-2	–
Diffusion coefficient in pure air	m^2[air]/day	0.92	U.S. EPA 1996 as cited in U.S. EPA 1999.
Diffusion coefficient in pure water	m^2[water]/day	1.07E−04	U.S. EPA 1996 as cited in U.S. EPA 1999.
Henry's Law constant	Pa-m^3/mol	1.00E−37	U.S. EPA 1999.
Melting point	degrees K	1093	U.S. EPA 2004 as cited in U.S. EPA 2005a.
Molecular weight	g/mol	77.922	NCBI 2017
Octanol-air partition coefficient (Koa)	m^3[air]/m^3[octanol]	–	–
Octanol-water partition coefficient (Kow)	L[water]/kg[octanol]	–	–

[a]All parameters in this table are TRIM.FaTE chemical properties.
[b]This CAS number applies to elemental As.

Exhibit A-16. Cadmium Chemical-Specific Parameter Values for the TRIM.FaTE Screening Scenario

Parameter Name[a]	Units	Value	Reference
CAS number[b]	–	7440-43-9	–
Diffusion coefficient in pure air	m^2[air]/day	0.71	U.S. EPA 1996 as in U.S. EPA 1999, Table A-2-35.
Diffusion coefficient in pure water	m^2[water]/day	8.16E−05	U.S. EPA 1996 as cited in U.S. EPA1999, Table A-2-35).
Henry's Law constant	Pa-m^3/mol	1.00E−37	U.S. EPA 1999 (Table A-2-35; assumed to be zero).
Melting point	degrees K	593.15	U.S. EPA 2004 as cited in U.S. EPA 2005a.
Molecular weight	g/mol	112.41	NCBI 2017 (rounded to five significant digits)
Octanol-air partition coefficient (Koa)	m^3[air]/m^3[octanol]	–	–
Octanol-water partition coefficient (Kow)	L[water]/kg[octanol]	–	–

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

Exhibit A-17. Mercury Chemical-Specific Parameter Values for the TRIM.FaTE Screening Scenario

Parameter Name[a]	Units	Value			Reference
		Hg(0)[b]	Hg(2)[b]	MHg[b]	
CAS number	unitless	7439-97-6	14302-87-5	22967-92-6	ChemFinder
Diffusion coefficient in pure air	m^2[air]/day	0.478	0.478	0.456	U.S. EPA 1997.
Diffusion coefficient in pure water	m^2[water]/day	5.54E−05	5.54E−05	5.28E−05	U.S. EPA 1997.
Henry's Law constant	Pa-m^3/mol	719	7.19E−05	0.0477	U.S. EPA 1997.
Melting point	degrees K	234[c]	5.50E+02[d]	443[e]	See endnotes.
Molecular weight[f]	g/mol	201	201	216	U.S. EPA 1997.
Octanol-water partition coefficient (Kow)	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	U.S. EPA 1997, 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.
[c]U.S. EPA (2004) as cited in U.S. EPA (2005a).
[d]SRC (2005) as cited in U.S. EPA (2005a).
[e]USDHHS (1992) as cited in CARB (1994).
[f]NCBI (2017), rounded to 3 significant figures.

Exhibit A-18. POM Chemical-Specific Parameter Values 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	0.00864	0.388	0.441	0.372	0.00864	0.19
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	0.203	18.5	12.7	1.22	0.074	0.0485	0.0278
Melting point	degrees K	307.6	395.5	366.4	364.8	433.5	452.1	441	545.5
Molecular weight	g/mol	142.2	256.34	154.21	152.2	228.29	252.31	252.31	276.33
Octanol-water partition coefficient (Kow)	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	0.00864	0.00864	0.00864	0.00864	0.00864	0.00864
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	0.043	0.53	0.0076	1.96	9.81	0.029
Melting point	degrees K	490	528.5	542.5	383.19	387.77	435
Molecular weight	g/mol	252.31	228.29	278.36	202.25	166.22	276.33
Octanol-water partition coefficient (Kow)	L[water]/L[octanol]	8.71E+05	5.37E+05	3.16E+06	1.45E+05	1.51E+04	5.25E+06

Parameter Name	Units	Reference
CAS number	unitless	Chemfinder database
Diffusion coefficient in pure air	m^2/day	U.S. EPA 2005a. Exceptions include U.S. EPA 1995a (7,12-dimethylbenz[a]anthracene) and U.S. EPA 2004 as cited in U.S. EPA 2005b (2-methylnapthalene, acenaphthylene, and benzo(ghi)perylene).
Diffusion coefficient in pure water	m^2/day	U.S. EPA 2005a. Exceptions include U.S. EPA 1995a (7,12-dimethylbenz[a]anthracene) and U.S. EPA 2004 as cited in U.S. EPA 2005b (2-methylnapthalene, acenaphthylene, and benzo[ghi]perylene).
Henry's Law constant	Pa-m^3/mol	All values cited in Mackay et al. 2006, with exception of 7,12-dimethylbenz[a]anthracene, which is from ToxNet HSDB, derived from Meylen 1991.[a] [Original studies, cited by Mackay et al. 2006 but not in the reference list for this attachment, include Bamford et al. 1999, Yaws et al. 1991, Staudinger and Roberts 2001, Altschuh et al. 1999, Hulscher et al. 1992, and Eastcott et al. 1988.]
Melting point	degrees K	Lide 2003 as cited in Mackay et al. 2006.
Molecular weight	g/mol	Mackay et al. 2006.
Octanol-water partition coefficient (Kow)	L[water]/L[octanol]	All values cited in Mackay et al. 2006. [Original studies, cited by Mackay et al. 2006 but not in the reference list for this attachment, include Hansch et al. 1995, Passivirta et al. 1999, and Sangster 1993.]

Exhibit A-19. Dioxin Chemical-Specific Parameter Values 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	0.68	0.19	1.28	1.43	1.42	1.08	1.449
Melting point	degrees K	598.7	532.2	537.7	509.7	495.2	547.2	499.2
Molecular weight	g/mol	460.76	443.76	425.31	409.31	409.31	390.87	374.87
Octanol-water partition coefficient (Kow)	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	1.115	0.26	0.507	1.115
Melting point	degrees K	558.7	505.7	516.7	520.7	513.7	499.2	512.7
Molecular weight	g/mol	390.87	374.87	390.87	374.87	356.42	340.42	374.87
Octanol-water partition coefficient (Kow)	L[water]/L[octanol]	1.62E+08	8.31E+07	1.62E+08	3.80E+07	1.86E+07	6.17E+06	8.31E+07

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	ChemFinder
Diffusion coefficient in pure air	m^2/day	0.192	0.899	0.203	U.S. EPA 2000b cited in U.S. EPA 2005a. Exception: U.S. EPA 2004 cited in U.S. EPA 2005a (for 2,3,7,8-TCDD and 2,3,7,8-TCDF).
Diffusion coefficient in pure water	m^2/day	6.91E−05	4.84E−05	5.19E−05	U.S. EPA 1995b cited in U.S. EPA 2005a. Exception: U.S. EPA 2004 cited in U.S. EPA 2005a (for 2,3,7,8-TCDD and 2,3,7,8-TCDF).
Henry's Law constant	Pa-m^3/mol	0.505	3.33	1.459	Mackay et al. 1992 cited in U.S. EPA 2000b. Exceptions: Sijm et al. 1989 cited in U.S. EPA 2000b (1,2,3,7,8-PeCDD); and U.S. EPA 2000b cited in U.S. EPA 2005a (for 1,2,3,6,7,8-HxCDD; 1,2,3,7,8,9-HxCDD; 1,2,3,4,7,8-HxCDF; 1,2,3,7,8,9-HxCDF; 2,3,4,6,7,8-HxCDF; OCDF; and 1,2,3,7,8 PeCDF).
Melting point	degrees K	469.4	578.7	500.7	Rordorf 1987 cited in U.S. EPA 2000b. Exception: Friesen et al. 1985 cited in U.S. EPA 2000b (for OCDD).
Molecular weight	g/mol	340.42	321.98	305.98	U.S. EPA 2000b cited in U.S. EPA 2005a.
Octanol-water partition coefficient (Kow)	L[water]/L[octanol]	3.16E+06	6.31E+06	1.26E+06	Mackay et al. 1992 cited in U.S. EPA 2000b. Exceptions: Passivirta et al. 1999 cited in Mackay et al. 2006 (1,2,3,7,8-PeCDD); U.S. EPA 2000a (for 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF and 2,3,4,6,7,8-HxCDF); Sijm et al. 1989 cited in U.S. EPA 2000b (for 1,2,3,7,8-PeCDF); and Broman et al. 1991 cited in Mackay 2006 (for 1,2,3,4,7,8,9-HpCDF).

Exhibit A-20. Arsenic Chemical-Specific Parameter Values for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Air Compartment Type			
Particle dry deposition velocity (vdep)	m/day	500	McKone et al. 2001.
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	Set to no.
Root Zone Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, else = yes	0	Set to no.
Vadose Zone Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, else = yes	0	Set to no.
Surface Water Compartment Type			
Ratio of concentration in water to concentration in algae to concentration dissolved in water	L[water]/g[algae wet wt]	0.155	Mean value from Table 5.5 of Crompton 1998.

Exhibit A-21. Cadmium Chemical-Specific Parameter Values for Abiotic Compartments in the TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Air Compartment Type			
Particle dry deposition velocity (vdep)	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	Set to no.
Root Zone Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, else = yes	0	Set to no.
Vadose Zone Soil Compartment Type			
Use input characteristic depth (Boolean)	0 = no, else = yes	0	Set to no.
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-22. Mercury Chemical-Specific Parameter Values 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 (vdep)	m/day	500	500	500	CalTOX value cited in McKone et al. 2001.
Demethylation rate	1/day	NA	NA	0	Assumption.
Methylation rate	1/day	NA	0	NA	Assumption.
Oxidation rate	1/day	0.00385	NA	NA	Low end of half-life range (6 months to 2 years) in U.S. EPA 1997.
Reduction rate	1/day	NA	0	NA	Assumption.
Washout ratio	m^3[air]/m^3[rain]	2E+5	2E+5	2E+5	Mackay et al. 1986.
Surface Soil Compartment Type					
Use input characteristic depth (Boolean)	0 = no, else = yes	0	0	0	Set to no.
Soil-water partition coefficient (Kd)	L[water]/kg[soil wet wt]	1,000	58,000	7,000	U.S. EPA 1997.
Vapor dry deposition velocity	m/day	50	2,500	NA	Hg(0) – from Lindberg et al. 1992; Hg(2) – estimate by EPA using the Industrial Source Complex (ISC) Model – [See Vol. III, App. A of the Mercury Study Report (U.S. EPA 1997)]; MHg not emitted from source.
Demethylation rate	1/day	NA	NA	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	NA	0.001	NA	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	NA	NA	Value assumed in U.S. EPA 1997.
Reduction rate	1/day	NA	1.25E−05	NA	Value used for untilled surface soil (2 cm), 10% moisture content, in U.S. EPA 1997; general range is 0.0013–0.0001/day × moisture_content for forested region (Lindberg 1996; Carpi and Lindberg 1997).

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	Set to no.
Soil-water partition coefficient (Kd)	L[water]/kg[soil wet wt]	1,000	58,000	7,000	U.S. EPA 1997.
Demethylation rate	1/day	NA	NA	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	NA	0.001	NA	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	NA	NA	Value assumed in U.S. EPA 1997.
Reduction rate	1/day	NA	3.25E−06	NA	Value used for tilled surface soil (20 cm), 10% moisture content, in U.S. EPA 1997 (Lindberg 1996; Carpi and Lindberg 1997).
Vadose Zone Soil Compartment Type					
Use input characteristic depth (Boolean)	0 = no, else = yes	0	0	0	Set to no.
Soil-water partition coefficient (Kd)	L[water]/kg[soil wet wt]	1,000	58,000	7,000	U.S. EPA 1997.
Demethylation rate	1/day	NA	NA	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	NA	0.001	NA	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	NA	NA	Value assumed in U.S. EPA 1997.

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Reduction rate	1/day	NA	3.25E−06	NA	Value used for tilled surface soil (20 cm), 10% moisture content, in U.S. EPA 1997 (Lindberg 1996; Carpi and Lindberg 1997).
Groundwater Compartment Type					
Soil-water partition coefficient	L[water]/kg[soil wet wt]	1,000	58,000	7,000	U.S. EPA 1997.
Demethylation rate	1/day	NA	NA	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	NA	0.001	NA	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	NA	NA	Small default nonzero value (0 assumed in U.S. EPA 1997).
Reduction rate	1/day	NA	3.25E−06	NA	Value used for tilled surface soil (20 cm), 10% moisture content, in U.S. EPA 1997 (Lindberg 1996; Carpi and Lindberg 1997).
Surface Water Compartment Type					
Algal surface area-specific uptake rate constant	nmol/[μm^2-day-nmol]	0	2.04E−10	3.60E−10	Assumes radius = 2.5 mm, Mason et al. 1995b, Mason et al. 1996; Hg(0) assumed same as Hg(2).
D_{ow} ("overall Kow")	L[water]/kg[octanol]	0	–[a]	–[b]	Mason et al. 1996.
Solids-water partition coefficient	L[water]/kg[solids wet wt]	1E+3	1E+5	1E+5	U.S. EPA 1997.
Vapor dry deposition velocity	m/day	NA	2,500	NA	U.S. EPA 1997 (Vol. III, App. A).
Demethylation rate	1/day	NA	NA	0.013	Average range of 1E−3 to 2.5E−2/day from Gilmour and Henry 1991.
Methylation rate	1/day	NA	0.001	NA	Value used in U.S. EPA 1997; range is 1E−4 to 3E−4/day (Gilmour and Henry 1991).
Oxidation rate	1/day	0	NA	NA	Assumption.

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Reduction rate	1/day	NA	0.0075	NA	Value used in U.S. EPA 1997; reported values range from less than 5E−3/day for depths greater than 17 m, up to 3.5/day (Xiao et al. 1995; Vandal et al. 1995; Mason et al. 1995a; Amyot et al. 1997).
Sediment Compartment Type					
Solids-water partition coefficient (Kd)	L[water]/kg[solids wet wt]	3,000	50,000	3,000	U.S. EPA 1997.
Demethylation rate	1/day	NA	NA	0.0501	Average range of 2E−4 to 1E−1/day from Gilmour and Henry 1991.
Methylation rate	1/day	NA	1.00E−04	NA	Value used in U.S. EPA 1997; range is 1E−5 to 1E−3/day, Gilmour and Henry 1991.
Oxidation rate	1/day	0	NA	NA	Assumption.
Reduction rate	1/day	NA	1.00E−06	NA	Inferred value based on presence of Hg(0) in sediment porewater (U.S. EPA 1997; Vandal et al. 1995).

Note: NA = not applicable.
[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-23. POM Chemical-Specific Parameter Values 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	m^3[air]/m^3[rain]	2E+5	2E+5	2E+5	2E+5	2E+5	2E+5	2E+5	2E+5	2E+5
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

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); U.S. EPA 1998 (7,12-dimethylbenz[a]anthracene, benzo[ghi]perylene, and fluoranthene)/average of range; HSDB 2001d (acenaphthene); HSDB 2001b (acenaphthylene); and Spero et al. 2000 (fluorene).
Washout ratio	m^3[air]/m^3[rain]	2E+5	2E+5	2E+5	2E+5	2E+5	Mackay et al. 1986 (for chemicals primarily or entirely in particle form).
Surface Soil Compartment Type							
User input characteristic depth (Boolean)	0 = No, Else = Yes	0	0	0	0	0	Set to no.
Half-life	day	1000	940	275	33	730	MacKay et al. 2000/average of range. Exceptions include ATSDR 2005 (2-methylnaphthalene = value recorded for napthalene); U.S. EPA 1998 (7,12-dimethylbenz[a]anthracene, benzo[ghi]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	Set to no.
Half-life	day	1000	940	275	33	730	Howard et al. 1991/upper bound measured or estimated value. Exceptions include ATSDR 2005 (2-methylnaphthalene = value recorded for napthalene); U.S. EPA 1998 (7,12-dimethylbenz[a]anthracene, benzo[ghi]perylene, and fluoranthene)/average of range; HSDB 2001d (acenaphthene); HSDB 2001b (acenaphthylene); and HSDB 2001e (fluorene).

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluor-ene	IcdP	
Vadose Zone Soil Compartment Type							
User input characteristic depth (Boolean)	0 = No, else = Yes	0	0	0	0	0	Assumption.
Half-life	day	2000	1880	550	66	1460	Howard et al. 1991/upper bound measured or estimated value. Exceptions include ATSDR 2005 (2-methylnaphthalene = value recorded for napthalene); U.S. EPA 1998 (7,12-dimethylbenz[a]anthracene, benzo[ghi]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 = value recorded for napthalene); U.S. EPA 1998 (7,12-dimethylbenz[a]anthracene, benzo[ghi]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							
Ratio of conc in algae to conc dissolved in water	(g[chem]/kg[algae])/ (g[chem]/L[water])	280	1388	67.4	5.8	1653	Calculated from Kow 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[ghi]perylene); Montgomery 2000 (fluoranthene); and Boyle 1985 (fluorene).

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluor-ene	IcdP	
Sediment Compartment Type							
Half-life	day	2290	2290	2290	2290	2290	Mackay et al. 1992/POM 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-24. 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
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])	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

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

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

Parameter Name	Reference
Air Compartment Type	
Deposition velocity	McKone et al. 2001.
Half-life	Atkinson 1996 as cited in U.S. EPA 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)	Set to no.
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	Set to no.
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)	Set to no.
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 Kow value using model from DelVento and Dachs 2002.
Half-life	Kim and O'Keefe 1998, as cited in U.S. EPA 2000b.
Sediment Compartment Type	
Half-life	Estimation based on Adriaens and Grbic-Galic 1992,1993 and Adriaens et al. 1995, as cited in U.S. EPA 2000b.

Exhibit A-25. Arsenic 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 (assume 1% of transfer factor from leaf particle to leaf).
Particle on Leaf Compartment Type			
Transfer factor to leaf	1/day	0.2	Assumption.
Root Compartment Type – Grasses and Herbs[a]			
Root-to-root soil partition – alpha of steady state	unitless	0.95	Selected value.
Root-to-root soil partition – partitioning coefficient	m^3[bulk root soil]/m^3[root]	0.05	Bergqvist 2013.
Root-to-root soil partition – time to reach alpha	day	10	Iriel 2015 (time to reach 95% of equilibrium).
Stem Compartment Type – Grasses and Herbs[a]			
Transpiration stream concentration factor (TSCF)	m^3[soil pore water]/m^3[xylem fluid]	0.24	Zhao 2008.

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

Exhibit A-26. 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 (assume 1% of transfer factor from leaf particle to leaf).
Particle on Leaf Compartment Type			
Transfer factor to leaf	1/day	0.2	Assumption.
Root Compartment Type – Grasses and Herbs[a]			
Root-to-root soil partition – alpha of steady state	unitless	0.95	Selected value.
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 (time to reach 95% of equilibrium).
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-27. Mercury Chemical-Specific Parameter Values for Plant Compartments in 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	NA	NA	0.03	Calculated from Bache et al. 1973.
Methylation rate	1/day	NA	0	NA	Assumed from Gay 1975, Bache et al. 1973.
Oxidation rate	1/day	1.0E+06	NA	NA	Assumed to be nearly instantaneous.
Reduction rate	1/day	NA	0	NA	Assumption.
Particle on Leaf Compartment Type					
Transfer factor to leaf	1/day	0.2	0.2	0.2	Assumption.
Demethylation rate	1/day	NA	NA	0	Assumption.
Methylation rate	1/day	NA	0	NA	Assumption.
Oxidation rate	1/day	0	NA	NA	Assumption.
Reduction rate	1/day	NA	0	NA	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(0) assumption; Hg(2) is geometric mean of values from Leonard et al. 1998, John 1972, and Hogg et al. 1978; MHg is based on Hogg et al. 1978.
t-alpha for root-root zone bulk soil	day	21	21	21	Assumption.
Demethylation rate	1/day	NA	NA	0	Assumption.
Methylation rate	1/day	NA	0	NA	Assumption.
Oxidation rate	1/day	0	NA	NA	Assumption.
Reduction rate	1/day	NA	0	NA	Assumption.

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
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 and Scots pine, Bishop et al. 1998.
Demethylation rate	1/day	NA	NA	0.03	Calculated from Bache et al. 1973.
Methylation rate	1/day	NA	0	NA	Assumption.
Oxidation rate	1/day	0	NA	NA	Assumption.
Reduction rate	1/day	NA	0	NA	Assumption.

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

Exhibit A-28. POM Chemical-Specific Parameter Values for Plant Compartments in 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	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
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	17.8
Root Compartment Type – Grasses and Herbs[a]										
Half-life	day	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6	34.6
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	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

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	3.5	3.5	3.5	3.5	3.5	Approximated from data reported by Edwards 1988 and from unpublished research (McKone 1997).
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	17.8	2.31	2.31	17.8	Calculated as 2 times the measured photolysis half-life from Mackay et al. 1992. Exceptions: value of 2.31 for BaP used for 2-methylnaphthalene, 7,12-dimethylbenz[a]anthracene, acenaphthene, acenaphthylene, BghiP, fluoranthene, and fluorene.
Root Compartment Type – Grasses and Herbs[a]							
Half-life	day	34.6	34.6	34.6	34.6	34.6	Approximated from data reported by Edwards 1988 (in Cooke and Dennis, eds.,1988); for bush beans in nutrient solution.
Root-soil-water interaction − alpha	unitless	0.95	0.95	0.95	0.95	0.95	Selected value.
Stem Compartment Type – Grasses and Herbs[a]							
Half-life	day	3.5	3.5	3.5	3.5	3.5	Approximated from data reported by Edwards 1988 (in Cooke and Dennis, eds.,1988); for bush beans in nutrient solution.

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

Exhibit A-29. Dioxin Chemical-Specific Parameter Values 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% of transfer factor to leaf; highly uncertain.
Half-life	day	70	Arjmand and Sandermann 1985, as cited in Komoba et al. 1995 (in Trapp and McFarlane, eds., 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 U.S. EPA 2000c (an estimate for mercury) and Trapp 1995; highly uncertain.
Half-life	day	4.4	McCrady and Maggard 1993; photodegradation; particles sorbed to grass foliage in sunlight; assumed 10% direct 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 (in Trapp and McFarlane, eds., 1995); soybean root cell culture metabolism test data for DDE.
Root-soil-water interaction – alpha	unitless	0.95	Selected value.
Stem Compartment Type – Grasses and Herbs[a]			
Half-life	day	70	Arjmand and Sandermann 1985, as cited in Komoba et al. 1995 (in Trapp and McFarlane, eds., 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-30. Arsenic Chemical-Specific Parameter Values for Aquatic Species in the RTR Screening Scenario[a]

Parameter Name	Units	Value	Reference
Benthic Invertebrate (BI) Compartment Type			
Biota – Sediment accumulation factor (BSAF)	kg[bulk dry sed]/kg[fish – benthic invertebrate wet wt]	8.5E–02	BJC 1998. Mean of as-sampled BSAF (0.329) and depurated BSAF (0.240), in units of kg[bulk dry sed]/kg[fish – benthic invertebrate dry wet], then multiplied by fraction dry weight (0.30).
Benthic Omnivore (BO) Compartment Type			
Biota – Sediment accumulation factor (BSAF)	kg[bulk dry sed]/kg[fish – benthic omnivore wet wt]	6.5E–04	Davis et al. 1996.
Benthic Carnivore (BC) Compartment Type			
Biota – Sediment accumulation factor (BSAF)	kg[bulk dry sed]/kg[fish – benthic carnivore wet wt]	6.5E–04	Davis et al. 1996.
Water-column Herbivore (WCH) Compartment Type			
Bioaccumulation factor (BAF)	L[water]/kg [fish – water-column herbivore wet wt]	71	U.S. EPA 2003b, Table 3.3, highest value for freshwater carp.
Water-column Omnivore (WCO) Compartment Type			
Bioaccumulation factor (BAF)	L[water]/kg [fish – water-column omnivore wet wt]	95	U.S. EPA 2003b, Tables 3.3 and 3.9, highest value for Trophic Level 3 fish, alewife.
Water-column Carnivore (WCC) Compartment Type			
Bioaccumulation factor (BAF)	L[water]/kg [fish – water-column carnivore wet wt]	46	U.S. EPA 2003b,Tables 3.4 and 3.9, highest value for Trophic Level 4, largemouth bass.

[a]Arsenic tends not to bioaccumulate from one trophic level to the next in freshwater ecosystems. Instead, concentrations in top predatory fish tend to be somewhat lower than concentrations in their prey (U.S. EPA 2003). As a result, the biokinetic model of food-web bioaccumulation simulated in TRIM.FaTE was not used for arsenic. Instead, biota-sediment accumulation factors (BSAF) and biota-water bioaccumulation factors (BAF) were sought for freshwater fish. Other investigators have reported different BAF values for arsenic in fish from specific studies than presented by EPA [e.g., Williams et al. (2006) reported the wet-weight BAF for alewife in the Upper Mystic Lake study by Chen and Folt (2000) was 46, not 95].

Exhibit A-31. Cadmium Chemical-Specific Parameter Values for Aquatic Species in TRIM.FaTE Screening Scenario

Parameter Name	Units	Value	Reference
Zooplankton Compartment Type			
Absorption rate constant	L[water]/kg[plankton 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	Selected value.
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[a]	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[a]	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.68E–03[b]	Computed based on empirical equation.
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[a]	Calculated based on body weight from regression in Hendriks and Heikens 2001.

Parameter Name	Units	Value	Reference
Elimination rate constant	unitless	1.73E–02	Assumption.
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[a]	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[a]	Calculated based on body weight from regression in Hendriks and Heikens 2001.
Elimination rate constant	unitless	1.73E–02	Assumption

[a]Formula used: 10**(−0.30*log10(compartment.BW)−0.09).

[b]Formula used: 10**(−0.25*log10(compartment.BW)−2.7).

Exhibit A-32. Mercury Chemical-Specific Parameter Values for Aquatic Species in TRIM.FaTE Screening Scenario

Parameter Name	Units	Value			Reference
		Hg(0)	Hg(2)	MHg	
Zooplankton Compartment Type					
Assimilation efficiency from algae	unitless	0.015	0.2	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	NA	0	NA	Assumption.
Oxidation rate	1/day	1.0E+06	NA	NA	Assumption.
Reduction rate	1/day	NA	0	NA	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[in-vertebrate wet wt]	0.0824	0.0824	5.04	Hg(0) value assumed based on Hg(2) value; Hg(2) and MHg from 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	NA	NA	0	Assumption.
Methylation rate	1/day	NA	0	NA	Assumption.
Oxidation rate	1/day	1.0E+06	NA	NA	Assumption.
Reduction rate	1/day	NA	0	NA	Assumption.
Water-column Herbivore Compartment Type					
Assimilation efficiency from plankton	unitless	0.06	0.06	0.5	Williams et al. 2010.

Note: NA = not applicable.
[a]Screening scenario includes: benthic omnivore, benthic carnivore, water-column herbivore, water-column omnivore, and water-column carnivore.

Exhibit A-33. POM Chemical-specific Parameter Values for Aquatic Species in 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[plank-ton wet wt]-day	790	42650	42230	42300	42650	42653	42650	42656	42652
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	170	2.03	148	123	2.07	1.389	2.12	0.33	1.48
Half-life	day	0.00779	17	0.00239	0.00239	1.28	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	2	2	2	2

Parameter Name	Units	Value					Reference
		Chr	DahA	Fluoran-thene	Fluorene	IcdP	
Zooplankton Compartment Type							
Absorption rate constant	L[water]/kg[fish wet wt]-day	42650	42656	142000	15000	42656	AQUAWEB-estimated based on Kow (Arnot et al. 2004). Exceptions: 2-methylnaphthalene, fluoranthene, and fluorene from Berrojalbiz et al. 2009.
Assimilation efficiency (AE) from algae	unitless	0.46	0.25	0.49	0.5	0.25	AQUAWEB-estimated based on Kow (Arnot et al. 2004). Exceptions: Value of 0.25, the maximum AE for copepods exposed to BaP (Wang and Wang 2006), is assumed for all higher molecular weight POM (i.e., 7,12-dimethylbenz[a]anthracene, BaA, BaP, BbF, BghiP, DahA, and IcdP).
Elimination rate constant	1/day	2.375	0.4331	8.678	81.87	0.269	AQUAWEB-estimated based on Kow (Arnot et al. 2004).
Half-life	day	0.495	17	0.00239	0.00025	17	McElroy 1990. Exceptions: 2-methylnaphthalene, fluoranthene, and fluorene from Berrojalbiz et al. 2009; BaA, BaP, and chrysene from Moermond et al. 2007.
Benthic Invertebrate Compartment Type							
Clearance constant	unitless	100.6	100.6	100.6	100.6	100.6	Stehly et al. 1990; estimated for mayfly, 120-day-old nymphs.
V_d (ratio of concentration in benthic invertebrates to concentration in pore water)	mL/g	7235	7235	7235	7235	7235	Stehly et al. 1990; estimated for mayfly, 120-day-old nymphs.
Half-life	day	0.495	17	0.722	0.722	17	Moermond et al. 2007.

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: Barber 2008 (for 2-methylnaphthalene and acenaphthene); Niimi and Palazzo 1986 (for acenaphthylene, fluoranthene, and fluorene).
Half-life	day	0.533	2	0.165	0.2	2	Moermond et al. 2007. Exceptions see note.[b]

[a]Screening scenario includes: benthic omnivore, benthic carnivore, water-column herbivore, water-column omnivore, and water-column carnivore.

[b]Moermond et al. (2007) calculated metabolic degradation rate constants for fluoranthene, chrysene, BaA, BeP, and BaP from experiments conducted on fish. Value of 0.2 days is assumed for the lower molecular weight POM based on the value for fluoranthene rounded to one significant digit. Value of 2 days is assumed for the higher molecular weight POM based on the value for BaP rounded to one significant digit.

Exhibit A-34. Dioxin Chemical-Specific Parameter Values for Aquatic Species in 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	L[water cleared]/kg[benthic invertebrate wet wt]-hr	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)	L[water]/kg[benthic invertebrate wet wt]	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
Fish 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

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	0.08192	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	L[water cleared]/kg[benthic invertebrate wet wt]-hr	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)	L[water]/kg[benthic invertebrate wet wt]	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

Parameter Name	Units	Reference
Zooplankton Compartment		
Absorption rate constant	L[water]/kg[fish wet wt]-day	Zhang et al. 2011, copepod k_u value.
Assimilation efficiency from algae	unitless	Morrison et al. 1999. Exceptions: Niimi and Oliver 1986 (for 1,2,3,4,6,7,8,9-OCDD, 1,2,3,4,6,7,8,9-OCDF); Berntssen et al. 2007 (for 1,2,3,4,6,7,8-HpCDD, 1,2,3,4,6,7,8-HpCDF); and value for 1,2,3,4,7,8,9-HpCDF set by 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., 0.2 interpolated from 0.3 and 0.1).
Elimination rate constant	1/day	AQUQWEB-estimated based on Kow (Arnot and Gobas 2004).
Half-life	day	Morrison et al. 1999, metabolic rates for invertebrates.
Benthic Invertebrate Compartment		
Clearance constant	L[water cleared] /kg[benthic invertebrate wet wt]-hr	Assumption.
Sediment partitioning partition coefficient	kg/kg	Rubinstein et al. 1990 (used TCDD data for sandworm) and U.S. EPA 1999.
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)	L[water]/kg[benthic invertebrate wet wt]	Assumption.
Half-life	day	Rubinstein et al. 1990, TCDD value for sandworm; same value assumed for all other congeners.
All Fish Compartments[a]		
Assimilation efficiency (AE) from food	unitless	Morrison et al. 1999. Exceptions: Niimi and Oliver 1986 (OCDD, OCDF); value for 1,2,3,4,7,8,9-HpCDF set by linear interpolation between values for

Parameter Name	Units	Reference
		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., 0.2 interpolated from 0.3 and 0.1); and two exceptions in notes b and c.
Chemical uptake rate via gill	L[water]/kg[fish wet wt]-day	Muir et al. 1985 (explicit or interpolated based on congener-specific differences in relative assimilation efficiencies from food). 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, representative of 2,3,7,8-substituted dioxins and furans fed to large salmon (calculated half-lives ranged from 36 to 99 days with no trend apparent with degree of chlorination).

[a]Screening scenario includes: benthic omnivore, benthic carnivore, water-column herbivore, water-column omnivore, and water-column carnivore.
[b]AE value of 0.21 from Berntssen et al. (2007) (for fish smaller than 1 kg body weight) used for water-column herbivore, water-column omnivore, and benthic omnivore. AE values of 0.13 used for the two carnivore fish compartments (2 kg body weight) based on van den Berg et al. (1984).
[c]AE value of 0.37 from van den Berg et al. (1984) (for smallest fish species) used for water-column herbivore. AE value of 0.31 used for remaining fish compartments based on Morrison et al. (1999).

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Attachment B. Multimedia Ingestion Risk Methodology Used for RTR Exposure and Risk Estimates

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Contents

Exhibits

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B.1 Introduction

B.1.1 Purpose and Overview

For persistent and bioaccumulative hazardous air pollutants (PB-HAPs), risks from direct inhalation of the chemical can be much less than risks from ingestion of the chemical in water, fish, and food products grown in an area of chemical deposition. For example, 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. This attachment provides a detailed description of the multimedia ingestion risk estimation methodology developed by EPA's Office of Air Quality Planning and Standards (OAQPS) for use in Risk and Technology Review (RTR) multimedia risk assessments.

The methodology described in this attachment uses equations, assumptions, and default parameter values previously published by EPA and approaches consistent with EPA guidance on human exposure and risk estimation. In particular, the methodology complies with EPA's latest guidelines for exposure and risk assessment, including *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (HHRAP; U.S. EPA 2005a); 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* (U.S. EPA 2005c,d,b, respectively); and its *Exposure Factors Handbook* (EFH; U.S. EPA 2008a, 2011a).

B.1.2 Organization of This Attachment

The RTR multimedia ingestion risk estimation methodology (hereafter referred to as "the methodology") is described in Sections B.2 through B.5 of this attachment. Section B.2 identifies the exposure pathways and receptors included in the scope of the methodology. Section B.3 describes the exposure algorithms used in the methodology, including how average daily doses (ADDs) are calculated. Section B.4 presents the toxicity reference values the methodology uses to calculate risks. Section B.5 describes the risk characterization algorithms. Section B.6 describes the data requirements of the methodology, and Section B.7 identifies default parameter assumptions EPA uses for RTR screening assessments. Section B.8 provides references.

Note that EPA used the default parameter values described in Section B.7 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. For some assessments, it may be appropriate to use values other than the defaults to better represent a specific exposure scenario. This attachment provides tables of alternate values for some parameter values and assumptions (e.g., exposure factors) from previously published EPA sources.

B.2 Methodology Overview

The RTR multimedia ingestion risk methodology provides screening-level estimates of exposures and risks associated with fishing activities and farming and gardening activities in the vicinity of a source of PB chemical emissions to air. The methodology can assess human exposures via ingestion pathways, including drinking water consumption, incidental soil ingestion, fish ingestion, and ingestion of 10 types of farm foods: exposed fruits, protected fruits, exposed vegetables, protected vegetables, root vegetables, beef, total dairy, pork, poultry, and

eggs. It also includes breast milk ingestion and risk estimates 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.

Sections B.2.1 and B.2.2 below summarize the ingestion exposure pathways and receptor age categories, respectively, included in the methodology.

B.2.1 Exposure Pathways

The methodology estimates the concentrations of chemicals in farm foods grown in an area of airborne chemical deposition using algorithms and parameter values provided in HHRAP (U.S. EPA 2005a). Ten categories of farm foods are examined: exposed fruit, protected fruit, exposed vegetables, protected vegetables, root vegetables, beef, total dairy, pork, poultry, and eggs. Exhibit B-1 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 estimated, as is the case for EPA’s RTR calculation of screening threshold emission rates for PB-HAPs (U.S. EPA 2008b).

Farm foods 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 (RCF) is applied. The algorithms used to estimate produce concentrations are presented in Section B.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. Diet options for farm animals include forage (plants grown on-site for 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.

Exhibit B-1. Transfer Pathways for Farm Foods

Farm Foods	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

Farm Foods	Chemical-transfer Pathways
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.

The algorithms in the methodology 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 B.3.1.2 of this attachment.

B.2.2 Receptor Groups

As noted in EPA risk assessment guidelines (U.S. EPA 2005b,c,d, 2008a), exposures of children are expected to differ from exposures of adults due to differences in body weights (BWs), ingestion rates (IRs), 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, U.S. 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 BWs, IRs, 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 (U.S. 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 IRs per unit BW, with the highest IRs occurring for the youngest, most rapidly growing, age groups.

For purposes of RTR assessments using this methodology, the selection of age categories is limited by the categories for which most of the farm food IRs have been calculated. In Chapter 13 of both its EFH (U.S. EPA 2011a) and its *Child-Specific Exposure Factors Handbook* (CSEFH; U.S. EPA 2008a), EPA summarized homegrown/raised food IRs 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 farm food IRs do not match precisely the groupings that EPA recommended in 2005 for Agency exposure assessments (U.S. 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* (NFCS; USDA 1992, 1993, 1994a) remains the most recent survey of IRs for homegrown 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 homegrown produce and animal products are the primary exposure pathways for which the multipathway risk methodology was developed, those are the age groupings used for all child parameter values used to estimate exposure and risk.

Thus, values for each exposure parameter were estimated for adults (20 up to 70 years of age) 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 B.5.1 and B.5.2 for descriptions of the risk characterization algorithms used to calculate cancer and noncancer 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 (U.S. 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 (U.S. 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 (U.S. EPA 2005c,d) also are included in the methodology:

- 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, the only PB-HAPs included in RTR assessments that have a mutagenic mode of carcinogenesis are the carcinogenic POMs. See Section B.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.

B.3 Exposure Algorithms

The exposure algorithms are described below in four sections. Section B.3.1 presents the algorithms used to estimate chemical concentrations in farm 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 B.3.2, and total chemical intake calculations are described in Section B.3.3. Finally, the sets of algorithms used to estimate chemical intake via consumption of breast milk by nursing infants are described in Section B.3.4. As noted previously, the exposure algorithms used in in this methodology are based on those presented in HHRAP (U.S. EPA 2005b). Any differences from HHRAP are explained in this section.

B.3.1 Farm Food Algorithms

The algorithms and parameters used to estimate chemical concentrations in produce and animal products are described in Sections B.3.1.1 and B.3.1.2, respectively. Discussions of the parameter value options and the values selected as defaults for RTR risk assessment are provided in Section B.6.2. The use of TRIM.FaTE to model chemical fate and transport in the environment prior to farm food calculations drives the most significant difference between the farm food 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 farm foods algorithms to calculate concentrations in those 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 farm foods algorithms to estimate food media concentrations.

B.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.

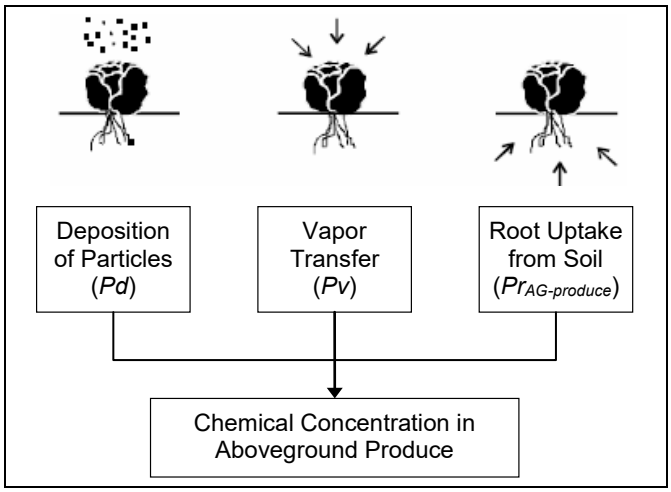
Exhibit B-2 lists the pathways by which chemicals are transferred to the produce categories. Note that for a general screening-level assessment, all of the pathways can be modeled, as was done for EPA’s calculation of Tier 1 screening threshold emission rates for PB-HAPs in its RTR assessments (U.S. EPA 2008b), and as described in the Technical Support Document. The two sections below (Aboveground Produce and Belowground Produce) describe the transfer pathways and algorithms for aboveground and belowground produce, respectively.

Exhibit B-2. Chemical-transfer Pathways for Produce

Farm Foods		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

Aboveground Produce

Exhibit B-3. Estimating Chemical Concentration in 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-3. 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 BCF ($Br_{AG\text{-}produce}$) 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 ($Cs_{root\text{-}zone\_produce}$).

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 BCF ($Br_{AG\text{-}produce\text{-}DW}$) 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

$$C_{AG-produce-DW(i)} = Pr_{AG-produce-DW(i)} + Pd_{(i)} + Pv_{(i)} \qquad \textbf{Eqn. B-1}$$

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 (Equation B-3)

$Pr_{AG\text{-}produce\text{-}DW(i)}$ = 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) (Equation B-2)

$Pv_{(i)}$ = 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-4)

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

$$Pr_{AG-produce-DW(i)} = Cs_{\text{root-zone\_produce}} \times Br_{AG-produce-DW(i)} \qquad \textbf{Eqn. B-2}$$

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

$$Pd_{(i)} = \frac{UCF \times \left(Drdp + (Fw \times Drwp)\right) \times Rp_{(i)} \times \left(1 - e^{(-kp(i) * Tp(i))}\right)}{Yp_{(i)} \times kp_{(i)}} \qquad \textbf{Eqn. B-3}$$

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

UCF = Units conversion factor of 1,000 mg/kg

$Drdp$ = 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.

The mulitpathway ingestion risk methodology uses 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 Equation B-3.

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

$$Pv_{(i)} = \frac{Ca \times Fv \times Bv_{AG(i)} \times VG_{AG(i)}}{\rho_a} \qquad \textbf{Eqn. B-4}$$

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 (µg/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. However, the multimedia ingestion risk methodology uses the average annual total air concentration of the chemical, *Ca*, for a specific location relative to the source in units of µg/m^3. 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 .

With the publication of HHRAP, EPA provided a companion database that includes default chemical-specific values for *Fv*, as well as certain other parameters.[22]

The calculations of chemical concentration in aboveground produce, ($C_{AG\text{-}produce\text{-}DW}$), shown in Equation B-1 above, are on a DW basis. The farm food IRs, on the other hand, are on a fresh- or wet-weight (WW) basis. Therefore the concentration in aboveground produce must be calculated on a WW basis, $C_{AG\text{-}produce\text{-}WW}$, using Equation B-5 and the moisture adjustment factor (*MAF*) of the farm food category.

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

$$C_{AG-produce-WW(i)} = C_{AG-produce-DW(i)} \times \left(\frac{(100 - MAF_{(i)})}{100} \right) \qquad \textbf{Eqn. B-5}$$

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)

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.

(a) 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 *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 WW 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.

[22]The HHRAP Companion Database is available at https://archive.epa.gov/epawaste/hazard/tsd/td/web/html/riskvol.html

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

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

Eqn. B-6

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)

*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 WW basis to its concentration in the soil pore water. *RCF*s 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 octanol-water partition coefficient (Kow) 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 calculated for many of the chemicals in HHRAP are included in the HHRAP Companion Database (including the values for POMs and dioxins).

(b) Inorganic and Ionic Organic Chemicals

For inorganic chemicals and ionized organic chemicals, it is not possible to predict *RCF* or *Kds* values from Kow. For inorganic chemicals, chemical-specific empirical values for the root/soil BCF must be used. The root/soil BCF, 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

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

Eqn. B-7

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

$$C_{BG-produce-WW} = C_{BG-produce-DW} \times \left(\frac{(100 - MAF_{BG})}{100} \right) \qquad \textbf{Eqn. B-8}$$

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)

B.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-4 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 (U.S. EPA 2008b).

The feed options for farm animals in the mulitpathway ingestion risk methodology 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-4, the algorithms 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-4. Chemical-transfer Pathways for Animal Products

Farm Foods		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. The multimedia ingestion risk methodology 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

$$C_{mammal(m)} = Ba_{(m)} \times MF \times \left(Soil_{Ch-Intake(m)} + \sum_{i=1}^{n} Plant_{Ch-Intake(i,m)} \right) \qquad \textbf{Eqn. B-9}$$

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

$$C_{poultry(m)} = Ba_{(m)} \times \left(Soil_{Ch-Intake(m)} + Plant_{Ch-Intake(i,m)}\right) \quad \textbf{Eqn. B-10}$$

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)

$Soil_{Ch-Intake(m)}$ = Incidental ingestion of chemical in surface soils by consumption of food on the ground (mg chemical/day) where *m* = poultry; see Equation B-11

$Plant_{Ch-Intake(i,m)}$ = 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

The incidental ingestion of the chemical in soils by livestock during grazing or consumption of feed placed on the ground ($Soil_{Ch-Intake(m)}$) is estimated using empirical soil IRs (*Qs*) and a soil bioavailability factor for livestock (*Bs*), as shown in Equation B-11. The default value for *Bs* 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. The surface soil concentration in Equation B-11, $Cs_{S-livestock}$, is for areas where livestock forage, which may be distinct from the surface soil concentration in areas where produce are grown and where humans might incidentally ingest soils (see Section B.6.1 of this attachment).

Equation B-11. Incidental Ingestion by Livestock of Chemical in Soil

$$Soil_{Ch-Intake(m)} = Qs \times Cs_{s-livestock} \times Bs \quad \textbf{Eqn. B-11}$$

where:

$Soil_{Ch-Intake(m)}$ = 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, on a dry-weight basis (DW), eaten by animal type *m* each day (kg soil DW/day)

$Cs_{s-livestock}$ = 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 IRs are on a DW basis; hence, no DW to WW conversion is needed.

Equation B-12. Ingestion by Livestock of Chemical in Feed

$$Plant_{Ch-Intake(i,m)} = F_{(i,m)} \times Qp_{(i,m)} \times C_{feed(i)} \qquad \textbf{Eqn. B-12}$$

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, on a dry-weight (DW) basis, 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)

$$C_{feed(i)} = Pr_{feed(i)} + Pd_{(i)} + Pv_{(i)} \qquad \textbf{Eqn. B-13}$$

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

The chemical concentration in animal feed due to root uptake from the soil is calculated with Equation B-14. The equation is the same as Equation B-2, except that a *Br* value appropriate to grasses is used and different soil concentrations could be used for the area used to grow animal

feed and the area used to grow produce for human consumption (see Section B.6.1 of this attachment). 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, soybeans) are protected from the air (i.e., by husks, pods).

Equation B-14. Chemical Concentration in Livestock Feed Due to Root Uptake

$$Pr_{feed(i)} = Cs_{root-zone\_feed(i)} \times Br_{feed(i)} \qquad \textbf{Eqn. B-14}$$

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

$Cs_{root-zone\_feed(i)}$ = 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 IRs for livestock are based on DW feed.

B.3.2 Chemical Intake Calculations for Adults and Non-infant Children

The multimedia ingestion risk methodology calculates human chemical intake rates from the ingestion of homegrown foods as *ADD*s normalized to BW for each age group, chemical, and food type separately. *ADD*s, calculated using Equation B-15, are expressed in milligrams of chemical per kilogram of receptor BW per day (mg/kg-day).

Equation B-15. Average Daily Dose for Specified Age Group and Food Type

$$ADD_{(y,i)} = \left(\frac{C_{(i)} \times IR_{(y,i)} \times FC_{(i)} \times ED_{(y)}}{BW_{(y)} \times AT_{(y)}} \right) \left(\frac{EF_{(y)}}{365 \text{ days}} \right) \qquad \textbf{Eqn. B-15}$$

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

$EF_{(y)}$ = Annual exposure frequency for age group *y* (days)

Equation B-15 accounts for 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 BW (U.S. EPA 2011a, 2003a). *ADD*s are calculated separately for each chemical, homegrown food type, and consumer age group.

ADD values, expressed as intakes, not absorbed doses, are appropriate for comparison with reference doses (RfDs) and for use with cancer slope factors (CSFs) to estimate risk, as discussed in Section B.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 B.3.4 of this attachment.

For screening-level assessments, all components of Equation B-15 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 accounted for). To calculate an $ADD_{(y,i)}$ from the contaminated area for food group *i* over an entire lifetime of exposure, age-group-specific IRs and BWs are used for the age groups described in Section B.2.2 of this attachment. The averaging time (AT) 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 B.3.2.1 through B.3.2.6 of this attachment. The algorithms for the breast milk ingestion pathway are described in Section B.3.4.

B.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

$$ADD_{Soil\,(y)} = \left(\frac{C_{Soil} \times IR_{Soil(y)} \times FC_{Soil} \times 0.001 \ \frac{mg}{\mu g}}{BW_{(y)}} \right) \left(\frac{EF}{365 \text{ days}} \right)$$

Eqn. B-16

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)

B.3.2.2 Chemical Intake from Fish Ingestion

The multimedia ingestion risk methodology includes ingestion of locally caught fish as a possible exposure pathway (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

$$ADD_{Fish(y)} = \left(1 - L1_{Fish}\right) \times \left(1 - L2_{Fish}\right) \times \frac{\left(C_{Fish} \times IR_{Fish(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times \ FC_{Fish} \right)}{BW_{(y)}} \times \left(\frac{EF}{365 \text{ days}} \right)$$

Eqn. B-17

Equation B-18. Consumption-weighted Chemical Concentration in Fish

$$C_{Fish} = (C_{FishTL3} \times F_{TL3}) + (C_{FishTL4} \times F_{TL4})$$

Eqn. B-18

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 (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 ingestion rates for homegrown food products, which are based on the products as brought into the home from the field (see Section B.6.3.3), the fish ingestion rates are on an "as consumed" basis (i.e., after preparation and cooking losses), and L1 and L2 therefore are set equal to zero. If an assessment will include local fish ingestion rates on an "as harvested" basis, L1 and L2 values also should be included as specified in Section B.6.4.3.

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; U.S. EPA 2011a) and included those losses in its HHRAP algorithms for chemical intake from fish ($L1_{Fish}$ and $L2_{Fish}$ in Equation B-17).

For arsenic, TRIM.FaTE-calculated water and sediment concentrations are multiplied by empirical bioaccumulation factors (BAFs) and biota-sediment accumulation factors (BSAFs) to estimate fish tissue concentrations in the water-column communities and benthic communities, respectively. (Fish tissue concentrations for other PB-HAPs are calculated in TRIM.FaTE's biokinetic food web model.) Estimation of water-column fish tissue concentration using the BAF approach requires, as an input, the concentration of dissolved chemical in surface water. Because TRIM.FaTE outputs the total water-column concentration (i.e., as both dissolved and suspended solids), this total water-column concentration is multiplied by the fraction of mass dissolved (which is available from TRIM.FaTE HTML outputs) to estimate the dissolved chemical concentration. This dissolved concentration is then multiplied by the empirical BAF to estimate water column fish concentrations. The BAF/BSAF approach to aquatic bioaccumulation could easily be extended to other inorganic chemicals included in an assessment. Equation B-19 presents the algorithm for estimating aquatic biota concentrations based on BAFs. Equation B-20 presents the algorithm for estimating aquatic biota concentrations based on BSAFs and is appropriate for sediment-dwelling fish and organisms.

Equation B-19. Concentrations in Aquatic Biota based on Empirical Bioaccumulation Factors

$$C_{Fish}=BAF \times C_{SurfaceWater} \times FMD \qquad \textbf{Eqn. B-19}$$

where:

C_{Fish} = Chemical concentration in whole fish on a wet-weight (WW) basis (mg/kg WW)

$C_{Surface\ Water}$ = Chemical concentration in surface water (mg/L)

BAF = Bioaccumulation Factor (L/kg WW fish)

FMD = Fraction mass of chemical dissolved in the water column (unitless)

Equation B-20. Concentrations in Aquatic Biota based on Empirical Biota-sediment Accumulation Factors

$$C_{Fish}=BSAF \times C_{Sediment} \qquad \textbf{Eqn. B-20}$$

where:

C_{Fish} = Chemical concentration in whole fish on a wet-weight (WW) basis (mg/kg WW)

$C_{Sediment}$ = Chemical concentration in sediment on a dry-weight (DW) basis (mg/kg DW)

$BSAF$ = Biota-sediment accumulation factor (kg DW sediment/kg WW fish)

B.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-21 and Equation B-22, respectively).

Equation B-21. Chemical Intake from Consumption of Exposed Fruits

$$ADD_{ExpFruit(y)} = \left(1 - L1_{ExpFruit}\right) \times \left(1 - L2_{ExpFruit}\right) \times \left(C_{ExpFruit} \times IR_{ExpFruit(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{ExpFruit} \right) \times \left(\frac{EF}{365\ \text{days}} \right) \qquad \textbf{Eqn. B-21}$$

Equation B-22. Chemical Intake from Consumption of Protected Fruits

$$ADD_{ProFruit(y)} = \left(1 - L1_{ProFruit}\right) \times \left(C_{ProFruit} \times IR_{ProFruit(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{ProFruit} \right) \times \left(\frac{EF}{365\ \text{days}} \right) \qquad \textbf{Eqn. B-22}$$

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 homegrown exposed fruits or protected fruits (depending on subscript) for age *y* (g WW/kg body weight-day)

Fruit IRs 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.

B.3.2.4 Chemical Intake from Vegetable Ingestion

The methodology includes three separate algorithms for homegrown vegetables adapted from EPA's HHRAP (U.S. 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-23, Equation B-24, and Equation B-25, respectively).

Equation B-23. Chemical Intake from Exposed Vegetables

$$ADD_{ExpVeg(y)} = \left(1 - L1_{ExpVeg}\right) \times \left(C_{ExpVeg} \times IR_{ExpVeg(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{ExpVeg} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \quad \textbf{Eqn. B-23}$$

Equation B-24. Chemical Intake from Protected Vegetables

$$ADD_{ProVeg(y)} = \left(1 - L1_{ProVeg}\right) \times \left(C_{ProVeg} \times IR_{ProVeg(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{ProVeg} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \quad \textbf{Eqn. B-24}$$

Equation B-25. Chemical Intake from Root Vegetables

$$ADD_{RootVeg(y)} = \left(1 - L1_{RootVeg}\right) \times \left(1 - L2_{RootVeg}\right) \times \left(C_{RootVeg} \times IR_{RootVeg(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{RootVeg} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \quad \textbf{Eqn. B-25}$$

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)

B.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-26 through Equation B-30 for homegrown beef, dairy (milk), pork, poultry, and eggs, respectively.

Equation B-26. Chemical Intake from Ingestion of Beef

$$ADD_{Beef(y)} = \left(1 - L1_{Beef}\right) \times \left(1 - L2_{Beef}\right) \times \left(C_{Beef} \times IR_{Beef(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Beef} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \quad \textbf{Eqn. B-26}$$

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-27. Chemical Intake from Dairy Ingestion

$$ADD_{Dairy(y)} = \left(C_{Dairy} \times IR_{Dairy(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Dairy} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \quad \textbf{Eqn. B-27}$$

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-28. Chemical Intake from Pork Ingestion

$$ADD_{Pork(y)} = (1 - L1_{Pork}) \times (1 - L2_{Pork}) \times \left(C_{Pork} \times IR_{Pork(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Pork} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \quad \textbf{Eqn. B-28}$$

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-29. Chemical Intake from Poultry Ingestion

$$ADD_{Poultry(y)} = (1 - L1_{Poultry}) \times (1 - L2_{Poultry}) \times \left(C_{Poultry} \times IR_{Poultry(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Poultry} \right) \times \left(\frac{EF}{365 \text{ days}} \right)$$

Eqn. B-29

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-30. Chemical Intake from Egg Ingestion

$$ADD_{Egg(y)} = \left(C_{Egg} \times IR_{Egg(y)} \times 0.001 \frac{\text{kg}}{\text{g}} \times FC_{Egg} \right) \times \left(\frac{EF}{365 \text{ days}} \right)$$

Eqn. B-30

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)

B.3.2.6 Chemical Intake from Drinking-water Ingestion

Assessments that evaluate chemical ingestion via drinking water use chemical concentration in g/L (equivalent to mg/mL), which could represent water from groundwater wells, community

water, nearby surface waters, or other source. For this exposure pathway, IRs are in units of mL/day (see Equation B-31).

Equation B-31. Chemical Intake from Drinking-water Ingestion

$$ADD_{DW(y)} = \left(\frac{C_{DW} \times IR_{DW(y)} \times FC_{DW}}{BW_{(y)}} \right) \times \left(\frac{EF}{365 \text{ days}} \right) \qquad \textbf{Eqn. B-31}$$

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)

B.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 homegrown 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-32 through Equation B-37, where *i* represents the i^{th} food type or ingestion medium and *n* equals the total number of food types or ingestion media.

Equation B-32. Total Average Daily Dose of Chemical for Infants less than One Year, from Ingestion of Breast Milk (mg/kg-day)

$$ADD_{(<1)} = ADD_{breastmilk}$$

Equation B-33. Total Average Daily Dose of Chemical from All Ingestion Sources for Children Ages 1 through 2 Years (mg/kg-day)

$$ADD_{(1-2)} = \sum_{i=1}^{n} ADD_{(1-2,i)}$$

Equation B-34. Total Average Daily Dose of Chemical from All Ingestion Sources for Children Ages 3 through 5 Years (mg/kg-day)

$$ADD_{(3-5)} = \sum_{i=1}^{n} ADD_{(3-5,i)}$$

Equation B-35. Total Average Daily Dose of Chemical from All Ingestion Sources for Children Ages 6 through 11 Years (mg/kg-day)

$$ADD_{(6-11)} = \sum_{i=1}^{n} ADD_{(6-11,i)}$$

Equation B-36. Total Average Daily Dose of Chemical from All Ingestion Sources for Children Ages 12 through 19 Years (mg/kg-day)

$$ADD_{(12-19)} = \sum_{i=1}^{n} ADD_{(12-19,i)}$$

Equation B-37. Total Average Daily Dose of Chemical from All Ingestion Sources for Adults Ages 20 up to 70 years (mg/kg-day)

$$ADD_{(adult)} = \sum_{i=1}^{n} ADD_{(adult,i)}$$

The lifetime average daily dose (*LADD*) is calculated as the time-weight average of the *ADD* values for each age group (Equation B-38).

Equation B-38. Lifetime Average Daily Dose

$$LADD = ADD_{(<1)}\left(\frac{1}{70}\right) + ADD_{(1\text{-}2)}\left(\frac{2}{70}\right) + ADD_{(3\text{-}5)}\left(\frac{3}{70}\right) + ADD_{(6\text{-}11)}\left(\frac{6}{70}\right) + ADD_{(12\text{-}19)}\left(\frac{8}{70}\right) + ADD_{(adult)}\left(\frac{50}{70}\right)$$

Eqn. B-38

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.

B.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 breast milk and absorption of the chemical. This exposure pathway is included in the multimedia ingestion risk methodology with adapted exposure algorithms and default assumptions from EPA's *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (U.S. 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.

B.3.4.1 Infant Average Daily Absorbed Dose

The ADD of chemical *absorbed* by the infant (DAI_{inf}) is estimated with Equation B-39. This basic exposure equation relies on the concentration of the chemical in the breast milk, the infant's breast-milk IR (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-39 is EPA's (U.S. EPA 1998) modification of an ADD 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 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-39 (and the equations that follow) that are not calculated from another equation, an EPA default value and options for other values for the infant breast-milk-exposure pathway are described in Section B.6.4 of this attachment.

Equation B-39. Average Daily Dose of Chemical to the Nursing Infant

$$DAI_{inf} = \frac{\left[\left(C_{milkfat} \times f_{mbm}\right) + \left(C_{aqueous} \times \left(1 - f_{mbm}\right)\right)\right] \times IR_{milk} \times AE_{inf} \times ED}{BW_{inf} \times AT} \qquad \textbf{Eqn. B-39}$$

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-40)

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-44)

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-39 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 B.3.4.2) and $C_{aqueous}$ (described in Section B.3.4.3).

B.3.4.2 Chemical Concentration in Breast-milk Fat

When developing the MPE (U.S. EPA 1998), EPA reviewed three first-order kinetics models for estimating chemical concentration in breast-milk fat. The model selected for use with the multimedia ingestion risk methodology is the model selected for MPE. The other two models were not selected for use 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 used in the multimedia ingestion risk methodology is a changing-concentration model that EPA adapted from a model by Sullivan *et al*. (1991). The model, shown in Equation B-40, 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-40 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 (U.S. EPA 2001a).

Equation B-40. Chemical Concentration in Breast-milk Fat

$$C_{milkfat} = \frac{DAI_{mat} \times f_f}{k_{elim} \times f_{fm}} \times \left[\frac{k_{elim}}{k_{fat\_elac}} + \frac{1}{k_{fat\_elac} \times t_{bf}} \left(1 - e^{-k_{elim} t_{pn}} - \frac{k_{elim}}{k_{fat\_elac}} \right) \left(1 - e^{-k_{fat\_elac} t_{bf}} \right) \right] \quad \textbf{Eqn. B-40}$$

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-41)

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 B.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-42)

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-43)

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-40 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 (ED), which are the chemicals of concern in the applications of this methodology 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 ED, an additional term is included in Equation B-40. 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-40, see Appendix B of MPE (U.S. EPA 1998).

To estimate an ADD *absorbed* by an infant's mother, or DAI_{mat}, the *ADD* (in mg/kg-day) for the chemical from all sources calculated for adults (ADD_{adult}), described in Section B.3.3 of this attachment, Equation B-37), 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-41. 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-41.

Equation B-41. Daily Maternal Absorbed Intake

$$DAI_{mat} = ADD_{(adult)} \times AE_{mat} \qquad \textbf{Eqn. B-41}$$

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) (see Section B.3.3 of this attachment, Equation B-37)

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 B.6.4 of this attachment)

Equation B-37, used to calculate $ADD_{(adult)}$, is based on many medium-specific IRs that are normalized to BW. The adult BWs to which the homegrown food IRs are normalized are the BWs of the consumers in the original USDA survey (see Section B.6.3.3 of this attachment), which included both males and females. An assumption in the breast-milk exposure pathway is that those IRs also are applicable to nursing mothers. The original data for IRs for soil, drinking water, and fish are on a per person basis for males and females combined. This methodology divides those chemical intakes by an adult BW for males and females combined (i.e., 71.4 kg mean value) to estimate the ADD normalized to BW from those sources. If the assessor finds that those exposure media contribute the majority of the chemical intake for the risk scenario under consideration, they may use alternative IRs for those media and alternative BWs for nursing women, as described in Section B.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 PB-HAPs, 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-42 is used to convert a measured half-life for elimination of a chemical for adults or non-lactating women to an elimination rate constant (U.S. EPA 1998). The equation can be used to estimate any kind of chemical loss rate constant from a measured chemical half-life.

Equation B-42. Biological Elimination Rate Constant for Chemicals for Non-lactating Women

$$k_{elim} = \frac{\ln 2}{h} \qquad \textbf{Eqn. B-42}$$

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-43 to estimate the total chemical elimination rate for lactating women, k_{fat_elac} (U.S. EPA 1998).

Equation B-43. Biological Elimination Rate Constant for Lipophilic Chemicals for Lactating Women

$$k_{fat\_elac} = k_{elim} + \frac{IR_{milk} \times f_f \times f_{mbm}}{f_{fm} \times BW_{mat}} \qquad \textbf{Eqn. B-43}$$

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-42)

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-43 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 BW (BW_{mat}), and the fraction of the mother's weight that is body fat (f_{fm}). In Equation B-43, the value for BW_{mat} should be specific to women of child-bearing age, as opposed to a BW value for both males and females that is used to estimate an adult ADD and the mother's absorbed daily intake in Equation B-41. BW values for the mother are described in Section B.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 (U.S. EPA 1998).

B.3.4.3 Chemical Concentration in Aqueous Phase of Breast Milk

When developing MPE (U.S. 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-44 (U.S. 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-44. Chemical Concentration in Aqueous Phase of Breast Milk

$$C_{aqueous} = \frac{DAI_{mat} \times f_{pl} \times Pc_{bm}}{k_{aq\_elac} \times f_{pm}} \qquad \textbf{Eqn. B-44}$$

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-41)

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-45)

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-46)

f_{pm} = Fraction of maternal weight that is blood plasma (unitless)

Equation B-44 is a steady-state concentration model that, like the Equation B-40 for $C_{milkfat}$, is dependent on the maternal absorbed daily intake (DAI_{mat}). In Equation B-44, 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 (MeHg), 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 (U.S. EPA 2001a). Due to this limitation, the model may over- or underestimate exposure to the infant.

Because Equation B-44 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-45, 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}; U.S. EPA 1998).

Equation B-45. Fraction of Total Chemical in Body in the Blood-plasma Compartment

$$f_{pl} = \frac{f_{bl} \times f_{bp}}{f_{bp} + Pc_{RBC}\left(1 - f_{bp}\right)} \qquad \textbf{Eqn. B-45}$$

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-44 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-42. 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-46. Biological Elimination Rate Constant for Hydrophilic Chemicals

$$k_{aq\_elac} = k_{elim} \qquad \textbf{Eqn. B-46}$$

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-42)

B.3.4.4 Alternative Model for Infant Intake of Methyl Mercury

EPA has not fully parameterized 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}). This parameter could be estimated using Equation B-45 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.

A literature search was conducted to identify existing physiologically based toxicokinetic (PBTK) models of lactational transfer of MeHg in humans. Most PBTK models 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).

Byczkowski and Lipscomb (2001) 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 (standard deviation) µg/kg-day and the average infant intake of MeHg to be 0.80 ± 0.38 µg/kg-day. Therefore, for purposes of this methodology, the DAI_{inf} of MeHg is estimated to be the same as the maternal intake per unit BW (Equation B-47).

Equation B-47. Infant Average Daily Absorbed Dose of Methyl Mercury

$$DAI_{inf\_MeHg} = DAI_{mat\_MeHg} \qquad \textbf{Eqn. B-47}$$

where:

DAI_{inf_MeHg} = Average daily dose of methyl mercury (MeHg) absorbed by infant from breast milk (mg/kg-day)

DAI_{mat_MeHg} = Average daily dose of MeHg absorbed by the mother, predominantly from fish (mg/kg-day)

B.4 Dose-response Values

The chemical dose-response values used with the multimedia ingestion risk methodology include ingestion carcinogenic potency slope factors (CSFs) and noncancer oral RfDs for chronic exposures. The dose-response values currently used for RTR assessments are shown in Exhibit B-5. OAQPS identified dose-response values for use in RTR 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-HAPs without OAQPS-identified dose-response values, alternative methods for deriving values were used (see Sections B.4.4 and B.4.5).

As provided in Exhibit B-5, TEFs from van den Berg et al. (2006) are used except for two congeners for which EPA's IRIS program has developed a CSF—1,2,3,6,7,8-hexachlorodibenzo-p-dioxin and 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin. Collectively across RTR assessments that EPA has conducted in recent years, these two congeners together constitute roughly 4 percent of total dioxin emissions from point sources. When the dioxin emissions are weighted by TEFs (to calculate TEQs), the two congeners constitute about 4 percent of the total dioxin TEQ emissions from point sources using TEF=0.1 from van den Berg et al. (2006) and about 2 percent using TEF=0.04 derived from the IRIS-based CSF. Therefore,

the impact of changing the TEFs of the two congeners is small. Moreover, as noted above, IRIS is the most preferred source for toxicity data.

Exhibit B-5. Oral Dose-response Values

Chemical	CAS No.	Cancer Slope Factor (CSF)[a]		Reference Dose (RfD)[a]	
		Value (mg/kg-day)$^{-1}$	Source	Value (mg/kg-day)	Source
Inorganics					
Arsenic	7440-38-2	1.5	IRIS (last updated 6/1/1995)	0.0003	IRIS (last updated 9/1/1991)
Cadmium compounds in food[b]	7440-43-9	not available		1.0E−03	IRIS (last updated 10/1/1989)
Mercury (elemental)	7439-97-6	not available		not available	
Mercuric chloride	7487-94-7	not available		3.0E−04	IRIS (last updated 5/1/1995)
Methyl mercury (MeHg)	22967-92-6	not available		1.0E−04	IRIS (last updated 7/27/2001)
Dioxins					
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	35822-46-9	1.5E+03	not available[c]	7.0E−08	not available[c]
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562-39-4	1.5E+03	not available[c]	7.0E−08	not available[c]
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	1.5E+03	not available[c]	7.0E−08	not available[c]
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	39227-28-6	1.5E+04	not available[c]	7.0E−09	not available[c]
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	1.5E+04	not available[c]	7.0E−09	not available[c]
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	6.2E+03	IRIS (last updated 3/31/1987)	1.8E−08	not available[c]
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	1.5E+04	not available[c]	7.0E−09	not available[c]
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	6.2E+03	IRIS (last updated 3/31/1987)	1.8E−08	not available[c]
1,2,3,7,8,9-Hexachlorodibenzofuran	72918-21-9	1.5E+04	not available[c]	7.0E−09	not available[c]
2,3,4,6,7,8-Hexachlorodibenzofuran	60851-34-5	1.5E+04	not available[c]	7.0E−09	not available[c]
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	3268-87-9	4.5E+01	not available[c]	2.3E−06	not available[c]
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	39001-02-0	4.5E+01	not available[c]	2.3E−06	not available[c]

Chemical	CAS No.	Cancer Slope Factor (CSF)[a]		Reference Dose (RfD)[a]	
		Value (mg/kg-day)$^{-1}$	Source	Value (mg/kg-day)	Source
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	1.5E+05	not available[c]	7.0E−10	not available[c]
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	4.5E+03	not available[c]	2.3E−08	not available[c]
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	4.5E+04	not available[c]	2.3E−09	not available[c]
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	1.5E+05	EPA ORD	7.0E−10	IRIS (last updated 2/17/2012)
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	1.5E+04	not available[c]	7.0E−09	not available[c]
Polycyclic Organic Matter (POM)					
1-Methylnaphthalene	90-12-0	5.0E−02	POM Group 72002[d]	7.0E−02	ATSDR (minimum risk level; last updated 8/2005)
2-Acetylaminofluorene	53-96-3	1.0E+00	POM Group 75002[d]	not available	
2-Methylnaphthalene	91-57-6	5.0E−02	POM Group 72002[d]	4.0E−3	IRIS (last updated 12/22/2003)
3-Methylcholanthrene	56-49-5	2.2E+01	CalEPA (last updated 2011)	not available	
7,12-Dimethylbenz[a]anthracene	57-97-6	2.5E+02	CalEPA (last updated 2011)	not available	
Acenaphthene	83-32-9	5.0E−02	POM Group 72002[d]	6.0E−02	IRIS (last updated 11/1/1990)
Acenaphthylene	208-96-8	5.0E−02	POM Group 72002[d]	not available	
Anthracene	120-12-7	0[e]	IRIS	3.0E−01	IRIS (last updated 9/1/1990)
Benz[a]anthracene	56-55-3	1.0E−01	IRIS CSF for BaP with EPA CPF	not available	
Benz[a]anthracene/Chrysene	NA	5.0E−02	POM Group 71002[d]	not available	
Benzo[a]pyrene	50-32-8	1.0E+00	IRIS (last updated 1/19/2017)	3.0E−04	IRIS (last updated 1/19/2017)
Benzo[a]fluoranthene	203-33-8	5.0E−02	POM Group 72002[d]	not available	
Benzo[b]fluoranthene	205-99-2	1.0E−01	IRIS CSF for BaP with EPA CPF	not available	

Chemical	CAS No.	Cancer Slope Factor (CSF)[a]		Reference Dose (RfD)[a]	
		Value (mg/kg-day)$^{-1}$	Source	Value (mg/kg-day)	Source
Benzo[b+k]fluoranthene	NA	1.0E−01	POM Group 76002[d]	not available	
Benzo[c]phenanthrene	195-19-7	5.0E−02	POM Group 72002[d]	not available	
Benzo[e]pyrene	192-97-2	5.0E−02	POM Group 72002[d]	not available	
Benzo[ghi]fluoranthene	203-12-3	5.0E−02	POM Group 72002[d]	not available	
Benzo[ghi]perylene	191-24-2	5.0E−02	POM Group 72002[d]	not available	
Benzo[j]fluoranthene	205-82-3	1.0E−01	IRIS CSF for BaP with California CPF	not available	
Benzo[k]fluoranthene	207-08-9	1.0E−02	IRIS CSF for BaP with EPA CPF	not available	
Benzofluoranthenes	56832-73-6	5.0E−02	POM Group 72002[d]	not available	
beta-Chloronaphthalene	91-58-7	5.0E−02	POM Group 72002[d]	8.0E−02	IRIS (last updated 11/1/1990)
Carbazole	86-74-8	2.0E−02	EPA ORD	not available	
Chrysene	218-01-9	1.0E−03	IRIS CSF for BaP with EPA CPF	not available	
Dibenzo[a,h]anthracene	53-70-3	1.0E+00	IRIS CSF for BaP with EPA CPF	not available	
Dibenzo[a,i]pyrene	189-55-9	1.0E+01	IRIS CSF for BaP with California CPF	not available	
Dibenzo[a,j]acridine	224-42-0	1.0E−01	IRIS CSF for BaP with California CPF	not available	
Fluoranthene	206-44-0	5.0E−02	POM Group 72002[d]	4.0E−02	IRIS (last updated 9/1/1990)
Fluorene	86-73-7	5.0E−02	POM Group 72002[d]	4.0E−02	IRIS (last updated 11/1/1990)
Indeno[1,2,3-c,d]pyrene	193-39-5	1.0E−01	IRIS CSF for BaP with EPA CPF	not available	

Chemical	CAS No.	Cancer Slope Factor (CSF)[a]		Reference Dose (RfD)[a]	
		Value (mg/kg-day)$^{-1}$	Source	Value (mg/kg-day)	Source
PAH, total	NA	5.0E−02	POM Group 71002[d]	not available	
Perylene	198-55-0	5.0E−02	POM Group 72002[d]	not available	
Phenanthrene	85-01-8	0[e]	IRIS	not available	
Polycyclic organic matter	NA	5.0E−02	POM Group 71002[d]	not available	
Pyrene	129-00-0	0[e]	IRIS	3.0E−02	IRIS (last updated 9/1/1990)
Retene	483-65-8	5.0E−02	POM Group 72002[d]	not available	

Abbreviations and data sources: NA = not applicable; CAS No. = Chemical Abstracts Service Registry Number, IRIS = Integrated Risk Information System (U.S. EPA 2017a), EPA ORD = EPA's Office of Research and Development (U.S. EPA 1997b), ATSDR = Agency for Toxic Substances and Disease Registry, CalEPA = California EPA (CalEPA 2019); CPF = cancer potency factor (EPA CPF = U.S. EPA 2015, California CPF [also called PEF] = CalEPA 2015), PAH = polycyclic aromatic hydrocarbon, BaP = benzo[a]pyrene.

Note: The "last updated" indicators refer to the date the agency posted the value.

[a]Values as of February 2021; 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 and/or RfDs for these congeners were derived as discussed in Section B.4.4 of this attachment.

[d]The method to assign oral cancer slope factors to POM without CSFs available from other EPA sources is the same as that used in the 1999 National Air Toxics Assessment [see: U.S. EPA (1999a)]. This method also is summarized in Section B.4.5 of this attachment.

[e]Weight of evidence evaluations indicated that the available data were adequate to determine that this chemical was not carcinogenic (U.S. EPA 2010).

B.4.1 Arsenic

EPA has developed a CSF of 1.5 per mg/kg-day for arsenic compounds based on data and analysis reported in IRIS. The data derived from 40,000 persons exposed to arsenic in drinking water and 7,500 relatively unexposed controls. A multistage model with time was used to predict dose-specific and age-specific skin cancer prevalence rates associated with ingestion of inorganic arsenic. IRIS also reports an RfD for arsenic; the RfD, however, was not considered because the use of the CSF is more health protective regardless of emission scenario.

B.4.2 Cadmium

EPA has developed two chronic RfDs for cadmium, 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 for RTR assessments is the higher RfD value for cadmium compounds in food (as described in Section B.3.2.6, 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 this methodology who assess exposures via drinking water would need to use the RfD for cadmium compounds in water (i.e., 5.0E−04 mg/kg-day).

B.4.3 Mercury

The RfD applies to the pregnant mother as well as young children. EPA has not specified the minimum ED at the RfD level of exposure that is appropriate to use in characterizing risk. For this methodology, EPA assumes 10 years for women of childbearing age and 1 year for infants. EPA notes that human exposures to MeHg are primarily through the consumption of fish and shellfish (U.S. 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 (U.S. EPA 2001b).

B.4.4 Dioxins

For chemicals for which the critical health effect is developmental, either *in utero* and/or during the first months or years of life, the ED and timing of exposure for comparison with the RfD (or comparable values) require special consideration. The most sensitive health endpoints for both mercury and dioxins (e.g., 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 ED 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 BW 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-Tetrachlorodibenzo-p-dioxin (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, the TEFs presented in Exhibit B-6 were used to derive the CSFs and RfDs (shown in Exhibit B-5) for dioxin congeners without available EPA dose-response values. These TEFs are from the World Health Organization (WHO) 2005 dioxin reevaluation (van den Berg et al. 2006), with the exception of 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin and 1,2,3,6,7,8-hexachlorodibenzo-p-dioxin—their CSFs are from IRIS, so their TEFs are calculated as the ratio of their CSFs to the CSF of 2,3,7,8-TCDD.

The TEF values from the WHO 2005 reevaluation are based on effects mediated by dioxins binding to the aryl hydrocarbon receptor (AhR) (van den Berg et al. 2006). Blocking AhR receptors contributes to several health effects in mammals, including impaired immune response, reproduction, development (e.g., cleft palate), and liver function and a variety of neoplastic lesions. Some in vitro studies of dioxin congeners compared with the same type of study with 2,3,7,8-TCDD (e.g., specific enzyme induction in mammalian tissue cultures) contribute to the weight of evidence used to estimate TEFs. The TEFs can therefore be multiplied by the CSF for 2,3,7,8-TCDD to estimate the CSF for other dioxins or the RfD for 2,3,7,8-TCDD can be divided by the TEF to estimate RfDs for the other dioxins.

As provided in Exhibit B-6, WHO TEFs from van den Berg et al. (2006) are used except for two congeners for which EPA's IRIS program has developed a CSF: 1,2,3,6,7,8-hexachlorodibenzo-p-dioxin and 1,2,3,7,8,9-hexachlorodibenzo-p-dioxin. Collectively across RTR assessments that EPA has conducted in recent years, these two congeners together constitute roughly 4 percent of total dioxin emissions from point sources. When the dioxin emissions are weighted by TEFs

(to calculate TEQs), the two congeners constitute about 4 percent of the total dioxin TEQ emissions from point sources using TEF=0.1 from van den Berg et al. (2006) and about 2 percent using TEF=0.04 derived from the IRIS-based CSF. Therefore, the impact of changing the TEFs of the two congeners is small.

Exhibit B-6. Toxic Equivalency Factors for Dioxin Congeners

Dioxin Congener	CAS No.	Toxic Equivalency Factor (TEF)
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	35822-46-9	0.01
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562-39-4	0.01
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	0.01
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	39227-28-6	0.1
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	0.1
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	0.04[a]
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	0.1
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	0.04[a]
1,2,3,7,8,9-Hexachlorodibenzofuran	72918-21-9	0.1
2,3,4,6,7,8-Hexachlorodibenzofuran	60851-34-5	0.1
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	3268-87-9	3E−04
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	39001-02-0	3E−04
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	1
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	0.03
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	0.3
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	1
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	0.1

Source: van den Berg et al. (2006), except as noted in footnote a, below.
Note: CAS No. = Chemical Abstracts Service Registry Number.
[a]For 1,2,3,7,8,9-HexCDD and 1,2,3,6,7,8-HexCDD, OAQPS identified an oral CSF from IRIS. For RTR multipathway assessments, EPA uses the TEF derived from this IRIS oral CSF (6200 per mg/kg-d, equaling a TEF of 0.04) rather than the van den Berg et al. (2006) TEF of 0.1.

B.4.5 Polycyclic Organic Matter

Dose-response values for some of the of polycyclic organic matter (POM) chemicals that are included in the screens 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 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. Exhibit B-7 presents each POM group (with all its member POM species reported in NEI, not just those currently evaluated in this assessment)

and the corresponding CSFs using this methodology. 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-7. Oral Dose-response Values for POM Groups

Individual POM Species or POM Group	CAS No.	Cancer Slope Factor[a,b] (mg/kg-day)$^{-1}$
POM Group 71002		
Benz[a]anthracene/Chrysene	NA	0.05
PAH, Total	NA	
Polycyclic organic matter	NA	
16-PAH	NA	
16-PAH–7-PAH	NA	
POM Group 72002		
Anthracene	120-12-7	0.05
Pyrene	129-00-0	
Benzo[ghi]perylene	191-24-2	
Benzo[e]pyrene	192-97-2	
Benzo[c]phenanthrene	195-19-7	
Perylene	198-55-0	
Benzo[g,h,i]fluoranthene	203-12-3	
Benzo[a]fluoranthene	203-33-8	
Fluoranthene	206-44-0	
Acenaphthylene	208-96-8	
1-Methylpyrene	2381-21-7	
12-Methylbenz[a]anthracene	2422-79-4	
Methylbenzopyrenes	NA	
Methylanthracene	26914-18-1	
Retene	483-65-8	
Benzofluoranthenes	56832-73-6	
9-Methylbenz[a]anthracene	NA	
1-Methylphenanthrene	832-69-9	
Acenaphthene	83-32-9	
Phenanthrene	85-01-8	
Fluorene	86-73-7	
1-Methylnaphthalene	90-12-0	
2-Methylnaphthalene	91-57-6	
beta-Chloronaphthalene	91-58-7	

Individual POM Species or POM Group	CAS No.	Cancer Slope Factor[a,b] (mg/kg-day)$^{-1}$
POM Group 73002		
7,12-Dimethylbenz[a]anthracene	57-97-6	100
POM Group 74002		
Dibenzo[a,i]pyrene	189-55-9	10
Dibenzo[a,h]pyrene	189-64-0	
3-Methylcholanthrene	56-49-5	
POM Group 75002		
Dibenzo[a,e]pyrene	192-65-4	1
Methylchrysene	NA	
5-Methylchrysene	3697-24-3	
Benzo[a]pyrene	**50-32-8**	
Dibenzo[a,h]anthracene	53-70-3	
2-Acetylaminofluorene	53-96-3	
POM Group 76002		
Benzo[b+k]fluoranthene	NA	0.1
Indeno[1,2,3-c,d]pyrene	193-39-5	
Benzo[j]fluoranthene	205-82-3	
Benzo[b]fluoranthene	205-99-2	
Dibenz[a,j]acridine	224-42-0	
Benz[a]anthracene	56-55-3	
POM Group 77002		
Benzo[k]fluoranthene	207-08-9	0.01
Chrysene	218-01-9	
Carbazole	86-74-8	
POM Group 78002		
7-PAH	NA	0.5

Notes: CAS No. = Chemical Abstracts Service Registry Number; NA = not applicable.
[a]These group CSFs are used only when OAQPS has not 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 (U.S. EPA 1999a). A complete description of the methodology is available at: http://archive.epa.gov/nata2002/web/pdf/pom_approach.pdf.

B.5 Risk Estimation

For 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 MOA at low doses is described in Section B.5.1 of this attachment. Risk characterization for chemicals likely to exhibit a threshold for response (e.g., noncancer hazards) is described in Section B.5.2.

B.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 MOA, the estimated *ELCR* is calculated as the product of the *LADD* and the *CSF*:

Equation B-48. Excess Lifetime Cancer Risk

$$ELCR = LADD \times CSF \qquad \textbf{Eqn. B-48}$$

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 B.3.3, 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 (U.S. EPA 2005b,c). Where data allow, EPA recommends development of lifestage-specific cancer potency *CSF*s. To date, EPA has developed a separate CSF for early lifestage exposure for only one chemical (i.e., 1,1,1-trichloroethane; U.S. EPA 2007a), 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 MOA for carcinogenesis for which EPA has adequate data to develop a reasonable quantitative default approach is mutagenesis (U.S. 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 (U.S. EPA 2005c). These conclusions are represented by *ADAF*s 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 homegrown food IRs in the multimedia ingestion risk methodology. As a consequence, *ADAF*s for the age groups 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.

Lifetime Cancer Risk: Chemicals with a Mutagenic MOA for Cancer

Equation B-49. Risk from Chemical Ingestion in First Year of Life (chemicals with a mutagenic mode of action)

$$Risk_{(<1)} = ADD_{(0-<1)} \times 10 \times CSF \times (1/70)$$

Equation B-50. Risk from Chemical Ingestion during Ages 1 through 2 Years (chemicals with a mutagenic mode of action)

$$Risk_{(1-2)} = ADD_{(1-2)} \times 6.5 \times CSF \times (2/70)$$

Equation B-51. Risk from Chemical Ingestion during Ages 3 through 5 Years (chemicals with a mutagenic mode of action)

$$Risk_{(3-5)} = ADD_{(3-5)} \times 3 \times CSF \times (3/70)$$

Equation B-52. Risk from Chemical Ingestion during Ages 6 through 11 Years (chemicals with a mutagenic mode of action)

$$Risk_{(6-11)} = ADD_{(6-11)} \times 3 \times CSF \times (6/70)$$

Equation B-53. Risk from Chemical Ingestion during Ages 12 through 19 Years (chemicals with a mutagenic mode of action)

$$Risk_{(12-19)} = ADD_{(12-19)} \times 2 \times CSF \times (8/70)$$

Equation B-54. Risk from Chemical Ingestion during Ages 20 up to 70 Years (chemicals with a mutagenic mode of action)

$$Risk_{(adult)} = ADD_{(adult)} \times 1 \times CSF \times (50/70)$$

Equation B-55. Total Extra Lifetime Cancer Risk (chemicals with a mutagenic mode of action)

$$ELCR = \sum_{i=1}^{n} Risk_{(i)}$$

Equation B-55 indicates that the total *ELCR* equals the sum of the age-group-specific risks estimated by Equation B-49 through Equation B-54,

where:

$ELCR$ = Total lifetime cancer risk (incremental or extra risk)

$ADD_{(<1)}$ = 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 up 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 i^{th} age group

n = Number of age groups (i.e., 6)

$(X/70)$ = Number of years in that age group (X) divided by a 70-year lifetime (weighting factor)

B.5.2 Noncancer Hazard Quotients

Noncancer risks are presented as hazard quotients (HQs), that is, the ratio of the estimated daily intake (i.e., ADD) to the RfD. If the HQ for a chemical is equal to or less than 1, EPA believes there is no appreciable risk that noncancer 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 an adverse health effect may occur.

B.5.2.1 Hazard Quotients for Chemicals with a Chronic RfD

For chemicals with a chronic *RfD*, *HQ*s are calculated for each age group separately using Equation B-56 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 BW (i.e., *ADD*) to the *RfD* for that chemical. *HQ*s are threshold effects and are not additive across age groups.

Equation B-56. Hazard Quotient for Chemicals with a Chronic RfD

$$HQ = \frac{ADD}{RfD} \qquad \textbf{Eqn. B-56}$$

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)

B.5.2.2 Hazard Quotients for Chemicals with an RfD Based on Developmental Effects

For chemicals for which the toxicity reference value is an RfD based on developmental effects, a shorter ED and AT may be required. For this type of chemical (e.g., MeHg, 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 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).

B.5.2.3 Hazard Index for Chemicals with Chronic RfDs

When conducting screening-level assessments for multiple chemicals, it can be informative to calculate a hazard index (*HI*) for toxicologically similar chemicals (U.S. EPA 2000). The *HI* is the sum of *HQ*s across chemicals (not age groups) as shown in Equation B-57. 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 MOA and target organ(s) for the chemicals with the highest *HQ*s to develop an appropriate approach to assessing their potential joint action.

Equation B-57. Hazard Index for Chemicals with Chronic RfDs

$$HI = HQ_1 + HQ_2 \ldots HQ_n \qquad \textbf{Eqn. B-57}$$

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" (U.S. 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 (U.S. 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 (U.S. EPA 2000).

Users of the multimedia ingestion risk methodology are responsible for determining how to interpret *HQ*s for multiple chemicals for each assessment.

B.6 Assessment Data and Parameter Values

This section describes the types of data and parameter values required for the multimedia ingestion risk methodology. Where applicable, default parameter values recommended by EPA are presented and discussed. In general, parameter values recommended by EPA were identified from HHRAP and EPA publications. For HHRAP parameters, including chemical-specific parameters, values were originally provided in the HHRAP Companion Database (U.S. EPA 2005a).

Required data for environmental media concentrations and air deposition rates, such as those predicted by (output of) TRIM.FaTE, are described in Section B.6.1 of this attachment. Values for farm food parameters for specific types of produce and animal products are discussed in Section B.6.2. Receptor characterization parameters are described in Section B.6.3, including age-group-specific parameter values for BW, water ingestion, and food ingestion by food type. Other exposure parameter values, such as exposure frequency and loss of chemical during food preparation and cooking, are discussed in Section B.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 data presented in this section were reviewed and used by EPA 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 section, are discussed in Section B.7.

B.6.1 Environmental Concentrations

As noted in Section B.2, the multimedia ingestion risk methodology is intended to estimate exposures and risks to farming, gardening, and fishing families from ingestion of contaminated media in an area of airborne chemical deposition.

Accordingly, the following values, specific to the air pollutant of concern, are required:

- 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) (only if drinking water exposure is assessed); 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 methodology as described in this attachment includes algorithms 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 B.3.2.6, drinking water exposure is not estimated 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.

For RTR assessments, EPA uses media concentrations output by TRIM.FaTE: EPA provides no default values for the data requirements listed above.

B.6.2 Farm Foods Parameter Values

Using the chemical information specified in Section B.6.1, above, chemical concentrations are calculated for 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.

B.6.2.1 List of Farm Foods Parameters

The multimedia ingestion risk methodology uses algorithms from HHRAP (U.S. EPA 2005a) to estimate chemical concentrations in the produce identified above, as described in Section B.3.2. Parameters 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 described in Exhibit B-8. As described in Section B.7, the default values recommended by EPA for RTR assessments are HHRAP-recommended parameter values, where available.

Exhibit B-8. 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	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

Parameter	Description	Units
$VG_{rootveg}$	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
$Ba_{(beef)}$	Chemical-specific biotransfer factor for chemical in diet of cow to chemical in beef	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: HHRAP (U.S. EPA 2005a).
Notes: DW = dry weight; WW = wet weight; FW = fresh weight (equivalent to WW).

B.6.2.2 Produce Parameter Values

Exhibit B-9 and Exhibit B-10 provide the default chemical-specific input values that EPA uses for RTR assessments. Exhibit B-11 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. Refer to HHRAP (U.S. EPA 2005a, Chapter 5 and associated appendices) for detailed descriptions of these parameters and documentation of input values; brief descriptions are provided below.

For **fraction of wet deposition** (***FW***; Exhibit B-9), 6E−01 is the value for cations and most organic chemicals. As described in HHRAP (U.S. EPA 2005a), Appendix B (Table B-3-7), EPA estimated this value (U.S. 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.

For nonionic organic chemicals, as described in HHRAP (U.S. EPA 2005a, Section 5), ***RCF*** (Exhibit B-9) is used to calculate the below-ground transfer of contaminants from soil to a root vegetable on a WW basis as shown in Equation B-6. In HHRAP for these nonionic organic chemicals, 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 (see equation A-2-14 of U.S. EPA 2005a). The RCF values as presented in HHRAP had been converted from wet-weight to dry-weight by dividing by a moisture adjustment factor of 0.13. For some chemicals, the Kow values differ between HHRAP and those used in TRIM.FaTE; to align with TRIM.FaTE Kow values, we recalculated the *RCF*s for nonionic organic chemicals using the regressions mentioned above and the TRIM.FaTE Kow values; we divided the regression output values by the same moisture adjustment factor of 0.13, which similarly resulted in RCF values on a DW basis. This moisture adjustment factor was reapplied when using the RCF to calculate the concentration of chemical in belowground produce on a wet-weight (WW) basis. All *RCF* values in Exhibit B-9 are in units of say L soil pore water/kg root DW. 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.

As discussed in HHRAP (U.S. EPA 2005a), Appendix A, the ***Kds*** (Exhibit B-9) 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 Section B 1.2.1.3 of U.S. EPA (1997c). *Kds* for cadmium compounds was calculated using the equation for cadmium presented in the abstract of U.S EPA (2005f). The *Kds* value for arsenic compounds was obtained from Table 3 of U.S. EPA (2005g). For all POM and dioxins, *Kds* was calculated by multiplying Koc times the screening scenario's fraction organic carbon content (0.008), as specified in Section A2-2.10 of U.S. EPA (2005b). Empirical information for Koc was available for acenaphthene, benz[a]anthracene, benzo[a]pyrene, dibenz[a,h]anthracene, fluoranthene, and fluorene in U.S. EPA (1996). For all other organic compounds, the Koc was calculated using the correlation equation A-2-7 presented in Section A2-2.9.2 of U.S. EPA (2005a).

As discussed in HHRAP (U.S. EPA 2005a), Appendix A (Section A2-2.12.4), the **chemical air-to-plant biotransfer factor** (***BvAG(i)***; Exhibit B-9) value for mercuric chloride was obtained from U.S. EPA (1997c). $Bv_{AG(i)}$ values for POM in HHRAP were calculated using the correlation equation (Equation A-2-19 in HHRAP Appendix A, Section A2-2.12) 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. However, the Bacci equation uses Kow and H (Henry's Law Constant), and for some chemicals the values of these parameters differ between HHRAP and those used in TRIM.FaTE; to align with TRIM.FaTE Kow and H values, we recalculated the $Bv_{AG(i)}$ values for POM using the Bacci equation, the TRIM.FaTE Kow and H values, and the ×100 reduction factor mentioned above. The values for dioxins in HHRAP were obtained from Lorber and Pinsky (2000). It is assumed that metals, with the exception of vapor-phase elemental mercury, do not transfer significantly from air into leaves. Speciation and fate and transport of mercury from emissions suggest that $Bv_{AG(i)}$ values for elemental and methyl mercury are likely to be zero (U.S. EPA 2005a).

Exhibit B-9. Chemical-specific Inputs for Produce Parameters

Chemical	Fraction of Wet Deposition (*Fw*) (unitless)	Root Concentration Factor (*RCF*) (belowground) (L soil pore water/kg root dry weight)	Soil-Water Partition Coefficient (*Kds*) (L/kg)	Chemical Air-to-Plant Biotransfer Factor ($Bv_{AG(i)}$) (unitless)
Inorganics				
Arsenic compounds	0.6	NA	2.5E+03	NA[a]
Cadmium compounds	0.6	NA	3.1E+02	NA[a]
Mercury (elemental)	0.6	NA	1.0E+03	0[b]
Mercuric chloride	0.6	NA	5.8E+04	1.8E+03
Methyl mercury	0.6	NA	7.0E+03	0[b]
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
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
POMs				
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
Benzo[b]fluoranthene	0.6	6.6E+03	3.8E+03	1.7E+05
Benzo[ghi]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

Chemical	Fraction of Wet Deposition (*Fw*) (unitless)	Root Concentration Factor (*RCF*) (belowground) (L soil pore water/kg root dry weight)	Soil-Water Partition Coefficient (*Kds*) (L/kg)	Chemical Air-to-Plant Biotransfer Factor ($Bv_{AG(i)}$) (unitless)
Dibenzo[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-c,d]pyrene	0.6	3.5E+04	3.2E+04	2.8E+06

Sources: HHRAP (U.S. EPA 2005a); Table 3 of U.S. EPA (2005g) for Kds of arsenic; equation for cadmium presented in the abstract of U.S EPA (2005f) for Kds of cadmium.

Note: NA = not applicable; CDD = chlorodibenzo-p-dioxin; CDF = chloridibenzofuran.

[a]It is assumed that metals, with the exception of vapor-phase elemental mercury, do not transfer significantly from air into leaves.

[b]Speciation and fate and transport of mercury from emissions suggest that $Bv_{AG(i)}$ values for elemental and methyl mercury are likely to be zero (U.S. EPA 2005a).

As discussed in HHRAP (U.S. EPA 2005a), Appendix A Section A2-2.12, the **plant-soil bioconcentration factor** (***$Br_{AG\text{-}produce\text{-}DW(i)}$***; Exhibit B-10) for aboveground produce, grain, silage, 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). However, those correlation equations (shown as A-2-17 and A-2-18 in the reference) use Kow (octanol-water partitioning coefficient), and for some chemicals, the Kow values differ between HHRAP and those used in TRIM.FaTE; to align with TRIM.FaTE Kow values, we recalculated the *Br* values for organics using the correlation equations mentioned above and the TRIM.FaTE Kow values. For cadmium and arsenic, *Br* values in HHRAP were derived from uptake slope factors provided in U.S. 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 in HHRAP for mercuric chloride and MeHg were calculated using methodology and data from Baes et al. (1984). *Br* forage values in HHRAP for mercuric chloride and MeHg (on a dry weight basis) were obtained from U.S. EPA (1997c), and *Br* forage and silage values for these chemicals are 0. The HHRAP methodology assumes that elemental mercury does not deposit onto soils; therefore, it is assumed there is no plant uptake through the soil. The $Br_{AG\text{-}produce\text{-}DW(i)}$ for root produce account for the uptake from soil. The *Br* root values in HHRAP for organics were calculated using the RCF divided by the Kds—we recalculated these values using the RCF and Kds values shown in Exhibit B-9. The *Br* root values in HHRAP for cadmium and arsenic were calculated from the same U.S. EPA (1992) upslope factor methodology noted above. The *Br* root values in HHRAP for mercuric chloride and MeHg were obtained from U.S. EPA (1997c).

As discussed in HHRAP (U.S. EPA 2005a), Section 5.3.3 and Appendix B, the **empirical correction factor for belowground produce** (***$VG_{rootveg}$;*** Exhibit B-10) reduces produce concentration. Because of the protective outer skin, size, and shape of bulky produce, transfer of lipophilic chemicals (i.e., log Kow 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 recommends using a $VG_{rootveg}$ value of 0.01 for PB-HAP with a log Kow greater than 4, and a value of 1.0 for PB-HAP with a log Kow less than 4, based on information

provided in U.S. EPA (1994b). We used the Kow values from TRIM.FaTE in applying these recommendations, to remain consistent with that model. In developing these values, U.S. 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).

As discussed in HHRAP (U.S. EPA 2005a), Sections 5.3.2.1 and 5.4.2.1, as well as Appendix B, the **empirical correction factor for aboveground produce** (***VG_{ag}***; Exhibit B-10) 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 Kow 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 recommends using a VG_{ag} value of 0.01 for PB-HAP with a log Kow greater than 4, and a value of 1.0 for PB-HAP with a log Kow less than 4, based on information provided in U.S. EPA (1994b). We used the Kow values from TRIM.FaTE in applying these recommendations, to remain consistent with that model. In developing these values, U.S. 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 U.S. (EPA 1994b). A VG_{ag} value for silage is not provided in U.S. (EPA 1994b); the VG_{ag} 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-10. Chemical-specific Inputs by Plant Type

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
Inorganics				
Arsenic compounds	Exposed Fruit	6.3E−03	–	1.0E+00
	Exposed Vegetables	6.3E−03	–	1.0E+00
	Forage	3.6E−02	–	1.0E+00
	Grain	4.0E−03	–	–
	Protected Fruit	6.3E−03	–	–
	Protected Vegetables	6.3E−03	–	–
	Root Vegetables	8.0E−03	1.0E+00	–
	Silage	3.6E−02	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
Cadmium compounds	Exposed Fruit	1.3E−01	–	1.0E+00
	Exposed Vegetables	1.3E−01	–	1.0E+00
	Forage	3.6E−01	–	1.0E+00
	Grain	6.2E−02	–	–
	Protected Fruit	1.3E−01	–	–
	Protected Vegetables	1.3E−01	–	–
	Root Vegetables	6.4E−02	1.0E+00	–
	Silage	3.6E−01	–	5.0E−01
Mercury (elemental)	Exposed Fruit	–	-	1.0E+00
	Exposed Vegetables	–	–	1.0E+00
	Forage	–	–	1.0E+00
	Grain	–	–	–
	Protected Fruit	–	–	–
	Protected Vegetables	–	–	–
	Root Vegetables	–	1.0E+00	–
	Silage	–	–	5.0E−01
Mercuric chloride	Exposed Fruit	1.5E−02	–	1.0E+00
	Exposed Vegetables	1.5E−02	–	1.0E+00
	Forage	0.0E+00	–	1.0E+00
	Grain	9.3E−03	–	–
	Protected Fruit	1.5E−02	–	–
	Protected Vegetables	1.5E−02	–	–
	Root Vegetables	3.6E−02	1.0E+00	–
	Silage	0.0E+00	–	5.0E−01
Methyl mercury	Exposed Fruit	2.9E−02	–	1.0E−02
	Exposed Vegetables	2.9E−02	–	1.0E−02
	Forage	0.0E+00	–	1.0E+00
	Grain	1.9E−02	–	–
	Protected Fruit	2.9E−02	–	–
	Protected Vegetables	2.9E−02	–	–
	Root Vegetables	9.9E−02	1.0E–02	–
	Silage	0.0E+00	–	5.0E–01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
PAHs				
2-Methylnaphthalene	Exposed Fruit	2.3E−01	–	1.0E+00
	Exposed Vegetables	2.3E−01	–	1.0E+00
	Forage	2.3E−01	–	1.0E+00
	Grain	2.3E−01	–	–
	Protected Fruit	2.3E−01	–	–
	Protected Vegetables	2.3E−01	–	–
	Root Vegetables	4.4E+00	1.0E+00	–
	Silage	2.3E−01	–	5.0E−01
7,12-Dimethylbenz[a]anthracene	Exposed Fruit	1.7E−02	–	1.0E−02
	Exposed Vegetables	1.7E−02	–	1.0E−02
	Forage	1.7E−02	–	1.0E+00
	Grain	1.7E−02	–	–
	Protected Fruit	1.7E−02	–	–
	Protected Vegetables	1.7E−02	–	–
	Root Vegetables	1.7E+00	1.0E−02	–
	Silage	1.7E−02	–	5.0E−01
Acenaphthene	Exposed Fruit	2.1E−01	–	1.0E+00
	Exposed Vegetables	2.1E−01	–	1.0E+00
	Forage	2.1E−01	–	1.0E+00
	Grain	2.1E−01	–	–
	Protected Fruit	2.1E−01	–	–
	Protected Vegetables	2.1E−01	–	–
	Root Vegetables	6.2E+00	1.0E+00	–
	Silage	2.1E−01	–	5.0E−01
Acenaphthylene	Exposed Fruit	1.9E−01	–	1.0E−02
	Exposed Vegetables	1.9E−01	–	1.0E−02
	Forage	1.9E−01	–	1.0E+00
	Grain	1.9E−01	–	–
	Protected Fruit	1.9E−01	–	–
	Protected Vegetables	1.9E−01	–	–
	Root Vegetables	4.1E+00	1.0E−02	–
	Silage	1.9E−01	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
Benz[a]anthracene	Exposed Fruit	1.7E−02	–	1.0E−02
	Exposed Vegetables	1.7E−02	–	1.0E−02
	Forage	1.7E−02	–	1.0E+00
	Grain	1.7E−02	–	–
	Protected Fruit	1.7E−02	–	–
	Protected Vegetables	1.7E−02	–	–
	Root Vegetables	2.3E+00	1.0E−02	–
	Silage	1.7E−02	–	5.0E−01
Benzo[a]pyrene	Exposed Fruit	1.4E−02	–	1.0E−02
	Exposed Vegetables	1.4E−02	–	1.0E−02
	Forage	1.4E−02	–	1.0E+00
	Grain	1.4E−02	–	–
	Protected Fruit	1.4E−02	–	–
	Protected Vegetables	1.4E−02	–	–
	Root Vegetables	1.2E+00	1.0E−02	–
	Silage	1.4E−02	–	5.0E−01
Benzo[b]fluoranthene	Exposed Fruit	1.8E−02	–	1.0E−02
	Exposed Vegetables	1.8E−02	–	1.0E−02
	Forage	1.8E−02	–	1.0E+00
	Grain	1.8E−02	–	–
	Protected Fruit	1.8E−02	–	–
	Protected Vegetables	1.8E−02	–	–
	Root Vegetables	1.7E+00	1.0E−02	–
	Silage	1.8E−02	–	5.0E−01
Benzo[ghi]perylene	Exposed Fruit	5.7E−03	–	1.0E−02
	Exposed Vegetables	5.7E−03	–	1.0E−02
	Forage	5.7E−03	–	1.0E+00
	Grain	5.7E−03	–	–
	Protected Fruit	5.7E−03	–	–
	Protected Vegetables	5.7E−03	–	–
	Root Vegetables	1.1E+00	1.0E−02	–
	Silage	5.7E−03	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
Benzo[k]fluoranthene	Exposed Fruit	1.4E−02	–	1.0E−02
	Exposed Vegetables	1.4E−02	–	1.0E−02
	Forage	1.4E−02	–	1.0E+00
	Grain	1.4E−02	–	–
	Protected Fruit	1.4E−02	–	–
	Protected Vegetables	1.4E−02	–	–
	Root Vegetables	1.6E+00	1.0E−02	–
	Silage	1.4E−02	–	5.0E−01
Chrysene	Exposed Fruit	1.9E−02	–	1.0E−02
	Exposed Vegetables	1.9E−02	–	1.0E−02
	Forage	1.9E−02	–	1.0E+00
	Grain	1.9E−02	–	–
	Protected Fruit	1.9E−02	–	–
	Protected Vegetables	1.9E−02	–	–
	Root Vegetables	1.7E+00	1.0E−02	–
	Silage	1.9E−02	–	5.0E−01
Dibenzo[a,h]anthracene	Exposed Fruit	6.8E−03	–	1.0E−02
	Exposed Vegetables	6.8E−03	–	1.0E−02
	Forage	6.8E−03	–	1.0E+00
	Grain	6.8E−03	–	–
	Protected Fruit	6.8E−03	–	–
	Protected Vegetables	6.8E−03	–	–
	Root Vegetables	1.6E+00	1.0E−02	–
	Silage	6.8E−03	–	5.0E−01
Fluoranthene	Exposed Fruit	4.0E−02	–	1.0E−02
	Exposed Vegetables	4.0E−02	–	1.0E−02
	Forage	4.0E−02	–	1.0E+00
	Grain	4.0E−02	–	–
	Protected Fruit	4.0E−02	–	–
	Protected Vegetables	4.0E−02	–	–
	Root Vegetables	5.6E+00	1.0E−02	–
	Silage	4.0E−02	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
Fluorene	Exposed Fruit	1.5E−01	–	1.0E−02
	Exposed Vegetables	1.5E−01	–	1.0E−02
	Forage	1.5E−01	–	1.0E+00
	Grain	1.5E−01	–	–
	Protected Fruit	1.5E−01	–	–
	Protected Vegetables	1.5E−01	–	–
	Root Vegetables	6.2E+00	1.0E−02	–
	Silage	1.5E−01	–	5.0E−01
Indeno[1,2,3-c,d]pyrene	Exposed Fruit	5.1E−03	–	1.0E−02
	Exposed Vegetables	5.1E−03	–	1.0E−02
	Forage	5.1E−03	–	1.0E+00
	Grain	5.1E−03	–	–
	Protected Fruit	5.1E−03	–	–
	Protected Vegetables	5.1E−03	–	–
	Root Vegetables	1.1E+00	1.0E−02	–
	Silage	5.1E−03	–	5.0E−01
Dioxins				
OctaCDD, 1,2,3,4,6,7,8,9-	Exposed Fruit	7.1E−04	–	1.0E−02
	Exposed Vegetables	7.1E−04	–	1.0E−02
	Forage	7.1E−04	–	1.0E+00
	Grain	7.1E−04	–	–
	Protected Fruit	7.1E−04	–	–
	Protected Vegetables	7.1E−04	–	–
	Root Vegetables	6.1E−01	1.0E−02	–
	Silage	7.1E−04	–	5.0E−01
OctaCDF, 1,2,3,4,6,7,8,9-	Exposed Fruit	9.2E−04	–	1.0E−02
	Exposed Vegetables	9.2E−04	–	1.0E−02
	Forage	9.2E−04	–	1.0E+00
	Grain	9.2E−04	–	–
	Protected Fruit	9.2E−04	–	–
	Protected Vegetables	9.2E−04	–	–
	Root Vegetables	6.8E−01	1.0E−02	–
	Silage	9.2E−04	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
HeptaCDD, 1,2,3,4,6,7,8-	Exposed Fruit	9.2E−04	–	1.0E−02
	Exposed Vegetables	9.2E−04	–	1.0E−02
	Forage	9.2E−04	–	1.0E+00
	Grain	9.2E−04	–	–
	Protected Fruit	9.2E−04	–	–
	Protected Vegetables	9.2E−04	–	–
	Root Vegetables	6.8E−01	1.0E−02	–
	Silage	9.2E−04	–	5.0E−01
HeptaCDF, 1,2,3,4,6,7,8-	Exposed Fruit	2.0E−03	–	1.0E−02
	Exposed Vegetables	2.0E−03	–	1.0E−02
	Forage	2.0E−03	–	1.0E+00
	Grain	2.0E−03	–	–
	Protected Fruit	2.0E−03	–	–
	Protected Vegetables	2.0E−03	–	–
	Root Vegetables	9.4E−01	1.0E−02	–
	Silage	2.0E−03	–	5.0E−01
HeptaCDF, 1,2,3,4,7,8,9-	Exposed Fruit	4.0E−03	–	1.0E−02
	Exposed Vegetables	4.0E−03	–	1.0E−02
	Forage	4.0E−03	–	1.0E+00
	Grain	4.0E−03	–	–
	Protected Fruit	4.0E−03	–	–
	Protected Vegetables	4.0E−03	–	–
	Root Vegetables	1.2E+00	1.0E−02	–
	Silage	4.0E−03	–	5.0E−01
HexaCDD, 1,2,3,4,7,8-	Exposed Fruit	1.2E−03	–	1.0E−02
	Exposed Vegetables	1.2E−03	–	1.0E−02
	Forage	1.2E−03	–	1.0E+00
	Grain	1.2E−03	–	–
	Protected Fruit	1.2E−03	–	–
	Protected Vegetables	1.2E−03	–	–
	Root Vegetables	7.6E−01	1.0E−02	–
	Silage	1.2E−03	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
HexaCDF, 1,2,3,4,7,8-	Exposed Fruit	3.5E−03	–	1.0E−02
	Exposed Vegetables	3.5E−03	–	1.0E−02
	Forage	3.5E−03	–	1.0E+00
	Grain	3.5E−03	–	–
	Protected Fruit	3.5E−03	–	–
	Protected Vegetables	3.5E−03	–	–
	Root Vegetables	1.2E+00	1.0E−02	–
	Silage	3.5E−03	–	5.0E−01
HexaCDD, 1,2,3,6,7,8-	Exposed Fruit	7.0E−04	–	1.0E−02
	Exposed Vegetables	7.0E−04	–	1.0E−02
	Forage	7.0E−04	–	1.0E+00
	Grain	7.0E−04	–	–
	Protected Fruit	7.0E−04	–	–
	Protected Vegetables	7.0E−04	–	–
	Root Vegetables	6.1E−01	1.0E−02	–
	Silage	7.0E−04	–	5.0E−01
HexaCDF, 1,2,3,6,7,8-	Exposed Fruit	1.0E−03	–	1.0E−02
	Exposed Vegetables	1.0E−03	–	1.0E−02
	Forage	1.0E−03	–	1.0E+00
	Grain	1.0E−03	–	–
	Protected Fruit	1.0E−03	–	–
	Protected Vegetables	1.0E−03	–	–
	Root Vegetables	7.1E−01	1.0E−02	–
	Silage	1.0E−03	–	5.0E−01
HexaCDD, 1,2,3,7,8,9-	Exposed Fruit	7.0E−04	–	1.0E−02
	Exposed Vegetables	7.0E−04	–	1.0E−02
	Forage	7.0E−04	–	1.0E+00
	Grain	7.0E−04	–	–
	Protected Fruit	7.0E−04	–	–
	Protected Vegetables	7.0E−04	–	–
	Root Vegetables	6.1E−01	1.0E−02	–
	Silage	7.0E−04	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
HexaCDF, 1,2,3,7,8,9-	Exposed Fruit	1.6E−03	–	1.0E−02
	Exposed Vegetables	1.6E−03	–	1.0E−02
	Forage	1.6E−03	–	1.0E+00
	Grain	1.6E−03	–	–
	Protected Fruit	1.6E−03	–	–
	Protected Vegetables	1.6E−03	–	–
	Root Vegetables	8.5E−01	1.0E−02	–
	Silage	1.6E−03	–	5.0E−01
HexaCDF, 2,3,4,6,7,8-	Exposed Fruit	1.0E−03	–	1.0E−02
	Exposed Vegetables	1.0E−03	–	1.0E−02
	Forage	1.0E−03	–	1.0E+00
	Grain	1.0E−03	–	–
	Protected Fruit	1.0E−03	–	–
	Protected Vegetables	1.0E−03	–	–
	Root Vegetables	7.1E−01	1.0E−02	–
	Silage	1.0E−03	–	5.0E−01
PentaCDD, 1,2,3,7,8-	Exposed Fruit	2.4E−03	–	1.0E−02
	Exposed Vegetables	2.4E−03	–	1.0E−02
	Forage	2.4E−03	–	1.0E+00
	Grain	2.4E−03	–	–
	Protected Fruit	2.4E−03	–	–
	Protected Vegetables	2.4E−03	–	–
	Root Vegetables	1.0E+00	1.0E−02	–
	Silage	2.4E−03	–	5.0E−01
PentaCDF, 1,2,3,7,8-	Exposed Fruit	4.6E−03	–	1.0E−02
	Exposed Vegetables	4.6E−03	–	1.0E−02
	Forage	4.6E−03	–	1.0E+00
	Grain	4.6E−03	–	–
	Protected Fruit	4.6E−03	–	–
	Protected Vegetables	4.6E−03	–	–
	Root Vegetables	1.3E+00	1.0E−02	–
	Silage	4.6E−03	–	5.0E−01

Compound Name	Plant Part	Plant-Soil Bio-Concentration Factor ($Br_{AG\text{-}produce\text{-}DW(i)}$) (unitless)	Empirical Correction Factor: Belowground Produce ($VG_{rootveg}$) (unitless)	Empirical Correction Factor: Aboveground Produce ($VG_{AG(i)}$) (unitless)
PentaCDF, 2,3,4,7,8-	Exposed Fruit	6.8E−03	–	1.0E−02
	Exposed Vegetables	6.8E−03	–	1.0E−02
	Forage	6.8E−03	–	1.0E+00
	Grain	6.8E−03	–	–
	Protected Fruit	6.8E−03	–	–
	Protected Vegetables	6.8E−03	–	–
	Root Vegetables	1.5E+00	1.0E−02	–
	Silage	6.8E−03	–	5.0E−01
TetraCDD, 2,3,7,8-	Exposed Fruit	4.5E−03	–	1.0E−02
	Exposed Vegetables	4.5E−03	–	1.0E−02
	Forage	4.5E−03	–	1.0E+00
	Grain	4.5E−03	–	–
	Protected Fruit	4.5E−03	–	–
	Protected Vegetables	4.5E−03	–	–
	Root Vegetables	1.3E+00	1.0E−02	–
	Silage	4.5E−03	–	5.0E−01
TetraCDF, 2,3,7,8-	Exposed Fruit	1.2E−02	–	1.0E−02
	Exposed Vegetables	1.2E−02	–	1.0E−02
	Forage	1.2E−02	–	1.0E+00
	Grain	1.2E−02	–	–
	Protected Fruit	1.2E−02	–	–
	Protected Vegetables	1.2E−02	–	–
	Root Vegetables	1.9E+00	1.0E−02	–
	Silage	1.2E−02	–	5.0E−01

Source: HHRAP (U.S. EPA 2005a).
Note: – = not applicable; CDD = chlorodibenzo-p-dioxin; CDF = chloridibenzofuran.

Baes *et al*. (1984) used an empirical relationship developed by Chamberlain (1970) to identify a correlation between initial **interception fraction** (***Rp***; Exhibit B-11) 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.

The **plant surface loss coefficient** (***kp***; Exhibit B-11) 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 U.S. EPA (1994a, 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 farm food media using the midpoint *kp* value of 18.

For **length of plant exposure to deposition** (***Tp***; Exhibit B-11), HHRAP (U.S. EPA 2005a) recommends using a value of about 0.16 years for aboveground produce and cattle silage. This is consistent with earlier reports by U.S. 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; and (2) 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.

Values for **yield or standing crop biomass** (***Yp***; Exhibit B-11) 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 i^{th} crop (kg DW) and A_{hi} = Area planted to i^{th} crop (m^2), 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/m^2 for silage was obtained from Shor *et al*. 1982.

The **plant tissue-specific *MAF*** (Exhibit B-11) converts dry-weight concentrations into WW concentrations (which are lower owing to the dilution by water compared with dry-weight concentrations). Values obtained from Section 10.3.2.1.4 of U.S. EPA (1999b), which references U.S. EPA (1997d).

Exhibit B-11. Non-chemical-specific Produce Inputs

Plant Part	Interception Fraction ($Rp_{(i)}$) (unitless)	Plant Surface Loss Coefficient ($kp_{(i)}$) (1/year)	Length of Plant Exposure to Deposition ($Tp_{(i)}$) (year)	Yield or Standing Crop Biomass ($Yp_{(i)}$) (kg/m^2)	Plant Tissue-specific Moisture Adjustment Factor ($MAF_{(i)}$) (percent)
Exposed Vegetables	0.982	18	0.164	5.66	92
Protected Fruit	NA	NA	NA	NA	90
Protected Vegetables	NA	NA	NA	NA	80
Forage (animal feed)	0.5	18	0.12	0.24	NA[a]

Plant Part	Interception Fraction ($Rp_{(i)}$) (unitless)	Plant Surface Loss Coefficient ($kp_{(i)}$) (1/year)	Length of Plant Exposure to Deposition ($Tp_{(i)}$) (year)	Yield or Standing Crop Biomass ($Yp_{(i)}$) (kg/m^2)	Plant Tissue-specific Moisture Adjustment Factor ($MAF_{(i)}$) (percent)
Exposed Fruit	0.053	18	0.164	0.25	85
Root Vegetables	NA	NA	NA	NA	87
Silage (animal feed)	0.46	18	0.16	0.8	NA[a]
Grain (animal feed)	NA	NA	NA	NA	NA[a]

Source: HHRAP (U.S. EPA 2005a).
Note: NA = not applicable.
[a]*MAF*s were not implemented for animal feed groups as the calculations for chemical concentration are based on dry weight not wet weight. Previous values used for these groups were 92, 92, and 90 respectively; however, 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.

B.6.2.3 Animal Product Parameter Values

The multimedia ingestion risk methodology requires chemical-specific inputs for many of the animal product algorithms. The relevant values are shown in Exhibit B-12 for the PB-HAP chemicals included in RTR multipathway assessments 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 IRs recommended in HHRAP for beef cattle, dairy cattle, swine, and chicken are provided in Exhibit B-13.

As discussed in HHRAP, Appendix A (Section A2-2.13) (U.S. EPA 2005a), **biotransfer factors** ($\boldsymbol{Ba_m}$; Exhibit B-12) for mercury compounds were obtained from U.S. EPA (1997c). 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. Also as discussed in HHRAP, Appendix A (Section A2-2.13), biotransfer factors for cadmium compounds were obtained from U.S. EPA (1995b), and those for arsenic were obtained from Baes et al. (1984) for beef and dairy. Biotransfer factors for arsenic into eggs, pork, and poultry were obtained from Appendix K of CalEPA (2012). HHRAP calculated biotransfer factors for dioxins and POM using a regression equation that accounted for Kow and then adjusted for fat content (Equation A-2-21 of HHRAP Appendix A, Section A2-2.13). However, for some chemicals, the Kow values differ between HHRAP and those used in TRIM.FaTE. To align with TRIM.FaTE Kow values, we recalculated the biotransfer factors for dioxins and POM using the regression mentioned above, the TRIM.FaTE Kow values, and the fat contents noted in HHRAP.

As discussed in HHRAP (U.S. EPA 2005a), U.S. EPA (1995c) recommends using an ***MF*** (Exhibit B-12) to account for metabolism by mammals of some chemicals, offsetting 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 (U.S. EPA 1995d). An *MF* of 0.01 is also used to calculate concentrations of POM in food products from mammalian species based on the work of Hofelt et al. (2001). This factor accounts for the P450-mediated metabolism of POM 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-12. Animal Product Chemical-specific Inputs

Compound Name	Biotransfer Factors (Ba_m) (day/kg fresh-weight tissue) and Metabolism Factors (*MF*) (unitless)						
	Mammal				Non-mammal		
	Beef (Ba_{beef})	Dairy (Ba_{dairy})	Pork (Ba_{pork})	*MF*	Eggs (Ba_{eggs})	Poultry ($Ba_{poultry}$)	*MF*
Inorganics							
Arsenic compounds	2.0E−03	6.0E−05	1.0E−02	1	7.0E−02	3.0E−02	NA
Cadmium compounds	1.2E−04	6.5E−06	1.9E−04	1	2.5E−03	1.1E−01	NA
Mercury (elemental)	0	0	0	1	0	0	NA
Mercuric chloride	1.1E−04	1.4E−06	3.4E−05	1	2.4E−02	2.4E−02	NA
Methyl mercury	1.2E−03	1.7E−05	5.1E−06	1	3.6E−03	3.6E−03	NA
Dioxins							
OctaCDD, 1,2,3,4,6,7,8,9-	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-	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-	8.8E−03	1.8E−03	1.1E−02	1	3.7E−03	6.5E−03	NA
HeptaCDF, 1,2,3,4,6,7,8-	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-	2.4E−02	5.1E−03	3.0E−02	1	1.0E−02	1.8E−02	NA
HexaCDD, 1,2,3,4,7,8-	1.1E−02	2.3E−03	1.3E−02	1	4.6E−03	8.1E−03	NA
HexaCDF, 1,2,3,4,7,8-	2.3E−02	4.8E−03	2.8E−02	1	9.6E−03	1.7E−02	NA
HexaCDD, 1,2,3,6,7,8-	6.8E−03	1.4E−03	8.2E−03	1	2.9E−03	5.0E−03	NA
HexaCDF, 1,2,3,6,7,8-	9.7E−03	2.0E−03	1.2E−02	1	4.1E−03	7.1E−03	NA
HexaCDD, 1,2,3,7,8,9 -	6.8E−03	1.4E−03	8.2E−03	1	2.9E−03	5.0E−03	NA
HexaCDF, 1,2,3,7,8,9-	1.4E−02	2.9E−03	1.7E−02	1	5.8E−03	1.0E−02	NA
HexaCDF, 2,3,4,6,7,8-	9.6E−03	2.0E−03	1.2E−02	1	4.1E−03	7.1E−03	NA
PentaCDD, 1,2,3,7,8-	1.8E−02	3.9E−03	2.2E−02	1	7.8E−03	1.4E−02	NA
PentaCDF, 1,2,3,7,8-	2.6E−02	5.5E−03	3.2E−02	1	1.1E−02	1.9E−02	NA
PentaCDF, 2,3,4,7,8-	3.1E−02	6.5E−03	3.8E−02	1	1.3E−02	2.3E−02	NA
TetraCDD, 2,3,7,8-	2.6E−02	5.5E−03	3.2E−02	1	1.1E−02	1.9E−02	NA
TetraCDF, 2,3,7,8-	3.6E−02	7.7E−03	4.4E−02	1	1.5E−02	2.7E−02	NA
POMs							
2-Methylnaphthalene	2.4E−02	5.0E−03	2.9E−02	0.01	1.0E−02	1.7E−02	NA
7,12-Dimethylbenz[a]anthracene	3.9E−02	8.3E−03	4.8E−02	0.01	1.7E−02	2.9E−02	NA
Acenaphthene	2.5E-02	5.2E−03	3.0E−02	0.01	1.0E−02	1.8E−02	NA
Acenaphthylene	2.6E−02	5.5E−03	3.1E−02	0.01	1.1E−02	1.9E−02	NA
Benz[a]anthracene	3.9E−02	8.3E−03	4.8E−02	0.01	1.7E−02	2.9E−02	NA
Benzo[a]pyrene	3.8E−02	8.0E−03	4.6E−02	0.01	1.6E−02	2.8E−02	NA
Benzo[b]fluoranthene	3.9E−02	8.3E−03	4.8E−02	0.01	1.7E−02	2.9E−02	NA
Benzo[ghi]perylene	2.9E−02	6.1E−03	3.5E−02	0.01	1.2E−02	2.1E−02	NA
Benzo[k]fluoranthene	3.8E−02	8.0E−03	4.6E−02	0.01	1.6E−02	2.8E−02	NA
Chrysene	4.0E−02	8.4E−03	4.8E−02	0.01	1.7E−02	2.9E−02	NA
Dibenzo[a,h]anthracene	3.1E−02	6.5E−03	3.8E−02	0.01	1.3E−02	2.3E−02	NA

Compound Name	Biotransfer Factors (Ba_m) (day/kg fresh-weight tissue) and Metabolism Factors (*MF*) (unitless)						
	Mammal				Non-mammal		
	Beef (Ba_{beef})	Dairy (Ba_{dairy})	Pork (Ba_{pork})	*MF*	Eggs (Ba_{eggs})	Poultry ($Ba_{poultry}$)	*MF*
Fluoranthene	4.0E−02	8.5E−03	4.9E−02	0.01	1.7E−02	3.0E−02	NA
Fluorene	2.9E−02	6.1E−03	3.5E−02	0.01	1.2E−02	2.1E−02	NA
Indeno[1,2,3-c,d]pyrene	2.7E−02	5.8E−03	3.3E−02	0.01	1.2E−02	2.0E−02	NA

Source: CalEPA (2012) for arsenic into pork, poultry, and eggs; HHRAP (U.S. EPA 2005a) for all other values.
Note: NA = not applicable; CDD = chlorodibenzo-p-dioxin; CDF = chloridibenzofuran.

NC DEHNR (1997) and U.S. EPA (1994b) recommended a **soil IR** (***Qs*$_{(m)}$**; Exhibit B-13) 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 BW. This results in a dry matter intake rate of 11.8 kg DW/day and a daily soil IR of about 0.5 kg/day. NC DEHNR (1997) and U.S. EPA (1994b) recommended a $Qs_{(m)}$ 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 BW. This resulted in a daily dry matter intake rate of 20 kg/day DW, and a daily soil IR of approximately 0.4 kg/day. Uncertainties associated with Qs include the lack of current empirical data to support soil IRs for dairy cattle and the assumption of uniform contamination of soil ingested by cattle. NC DEHNR (1997) recommended a $Qs_{(m)}$ for swine of 0.37, estimated by assuming a soil intake that is 8 percent of the plant IR of 4.3 kg DW/day. Uncertainties include the lack of current empirical data to support soil IRs and the assumption of uniform contamination of the soil ingested by swine. HHRAP 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 IRs for chicken and the assumption of uniform contamination of soil ingested by chicken.

The beef cattle **IRs of forage, silage, and grain** (***Qp*$_{(l,m)}$;** Exhibit B-13) 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 BW of 590 kg) and are supported by NC DEHNR (1997), U.S. 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 IRs for cattle. The dairy cattle *Qp* values are based on the total daily intake rate of about 20 kg DW/day (NAS 1987; U.S. 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. Swine are not grazing animals and are assumed not to eat forage (U.S. EPA 1998). U.S. EPA (1994b and 1998) and NC DEHNR (1997) recommended including only silage and grains in the diet of swine. EPA (1995c) recommended an IR of 4.7 kg DW/day for a swine, referencing NAS (1987). Assuming a diet of 70 percent grain and 30 percent silage (U.S. EPA 1990), HHRAP estimated *Qp* values 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. 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 IRs from site to site. In addition, assuming uniform contamination of plant materials consumed by chicken introduces some uncertainty.

Exhibit B-13. 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)[b]
Beef cattle	0.5	Silage	2.5
		Forage	8.8
		Grain	0.47
Dairy cattle	0.4	Silage	4.1
		Forage	13.2
		Grain	3.0
Swine	0.37	Silage	1.4
		Grain	3.3
Chicken (eggs)	0.022	Grain	0.2

Source: HHRAP (U.S. EPA 2005a) (Chapter 5).

B.6.3 Exposure Parameter Values for Adults and Non-infants

The exposure parameters included in the multimedia ingestion risk methodology and their default values are summarized in the following subsections. EPA selected the default values to result in a highly health-protective screening scenario. Also presented are alternatives to the default values (e.g., typically based on other percentiles from the distribution), which may be appropriate on a case-by-case basis. These parameter value options were primarily obtained or estimated from EPA's 2011 Exposure Factors Handbook (EFH) (U.S. EPA 2011a) and 2008 Child-specific EFH (CSEFH) (U.S. EPA 2008a). Where values were reported for age groupings other than those used in the methodology (see Section B.2.2), time-weighted average values were estimated for the methodology's age groups from the available data.

IRs for home-produced farm food items were identified for exposed fruit, protected fruit, exposed vegetables, protected vegetables, root vegetables, beef, total dairy, pork, poultry, and eggs. Those IRs are already normalized to BW (i.e., g_{ww}/kg-day) (U.S. EPA 2011a). The BW parameter values presented in Exhibit B-14, therefore, are not applied in the chemical intake (ADD) equations for these food types.

IRs also are identified for drinking water (mL/day), soil (mg/day), and fish (g/day). These IRs, however, are on a per-person basis (i.e., not normalized for BW). The BW parameter values presented in Exhibit B-14, therefore, are applied in the chemical intake (ADD) equations for these media.

B.6.3.1 Body Weights

BW options 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 screen, EPA uses the mean BW for each age group. The BW values are listed in Exhibit B-14.

Exhibit B-14. Mean and Percentile Estimates of Body Weight

Lifestage (years)	Duration (years)	Body Weight (kg)					
		Mean	5th	10th	50th	90th	95th
Adult 20 up to 70[a]	50	80.0	53.6	57.9	79.0	108	119
Child <1[b]	1	7.83	6.03	6.38	7.76	9.24	9.66
Child 1–2[c]	2	12.6	9.90	10.4	12.5	14.9	15.6
Child 3–5	3	18.6	13.5	14.4	17.8	23.6	26.2
Child 6–11[d]	6	36.0	22.1	24.0	33.5	51.2	58.6
Child 12–19[e]	8	64.2	41.1	44.6	60.9	88.5	98.4

Source, unless otherwise noted: Table 8-3 of U.S. EPA (2011a) (EFH), which derived the values from 1999–2006 *National Health and Nutrition Examination Survey* data. In some cases, as indicated in the footnotes below, the age groupings in the EFH differ from those shown in this table; in these cases, we used time-weighted averages of the values from the EFH. These time-weighted averages have uncertainties in cases where the EFH age groupings extend beyond the age group the data were used for (e.g., the estimation of BWs for Child 6–11 years was estimated using EFH age categories 6 to <11 and 11 to <16 years, as shown below). Original sample sizes are provided in the EFH table.

[a]The adult mean body weight (BW) represents the recommended value for adults from Table 8-1 of the EFH. The EFH defines adults as 21 years and older, while the methodology used here defines adults as 20 up to 70 years, which we estimate leads to minimal discrepancies (i.e., less than 1% BW). For the remaining percentiles for the adult, BW represents a time-weighted average of BWs for age categories 16 to <21, 21 to <30, 30 to <40, 40 to <50, 50 to <60, and 60 to <70 years (Table 8-3 of the EFH).

[b]For Child <1 year, each BW represents a time-weighted average of BWs for age groups birth to <1 month, 1 to <3 months, 3 to <6 months, and 6 to <12 months.

[c]For Child 1–2 years, each BW represents a time-weighted average of BWs for age groups 1 to <2 years and 2 to <3 years.

[d]For Child 6–11 years, each BW represents a time-weighted average of BWs for age groups 6 to <11 years and 11 to <16 years.

[e]For Child 12–19 years, each BW represents a time-weighted average BWs for age groups 11 to <16 years and 16 to <21 years.

B.6.3.2 Ingestion Rates for Water

Although exposure through ingestion of contaminated drinking water is not evaluated for RTR assessments (see Section 2.2 of the main document), the methodology allows for calculation of chemical ingestion via drinking water obtained from surface-water sources or from wells (i.e., from groundwater) in the contaminated area. The 2011 EFH-recommended values for drinking-water IRs for children are based on a study reported by Kahn and Stralka (2008). Table 3-33 of the EFH provides consumer-only estimates of community water IRs by age categories, based on EPA analysis of the 2003–2006 *National Health and Nutrition Examination Survey* (NHANES). 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. EPA concluded that some of these NHANES values were less statistically reliable due to small sample sizes, particularly for children under 3 years of age. Table 3-15 of the EFH provides consumer-only estimates of community water IRs by age category, based on the 1994–1996 and 1998 U.S. Department of Agriculture's (USDA's) *Continuing Survey of Food Intakes by Individuals* (CSFII) (USDA 2000), and also based on EPA (2004a) for adults 65 years and older. Although these Table 3-15 values are from an older survey relative to Table 3-33, the values for younger children were determined to be more statistically reliable in Table 3-15. The recommended values shown in Exhibit B-15 come from Table 3-15 for the Child <1 and Child 1–2 age groups, and Table 3-33 for the other age groups, with time-average weighting as needed to conform to the required age groups.

Exhibit B-15. Estimated Daily Consumer-only Mean and Percentile Water Ingestion Rates*

Lifestage (years)	Ingestion Rates, Community Water (mL/day)				
	Mean	50th	90th	95th	99th
Child <1[a]	504	482	969	1113	1440
Child 1–2[b]	332	255	687	903	1318
Child 3–5[c]	382	316	778	999	1592
Child 6–11[d]	532	417	1149	1499	2274
Child 12–19[e]	698	473	1641	2163	3467
Adult 20 up to 70[f]	1219	981	2534	3087	4567

*As discussed in Section 2.2 of the main document, chemical intake from water ingestion is not evaluated for RTR because it is assumed that individuals are unlikely to use untreated surface water for drinking (or other household water uses). Also, HHRAP recommends that exposure to groundwater not be evaluated because EPA found that groundwater is an insignificant exposure pathway for airborne combustion emissions

Source: 2011 EFH (U.S. EPA 2011a), Table 3-15 for Child <1 and Child 1–2 (based on Kahn and Stralka [2008] examination of the 1994–1996 and 1998 *Continuing Survey of Food Intakes by Individuals* [USDA 2000]), and Table 3-33 for all other ages (based on EPA analysis of the 2003–2006 *National Health and Nutrition Examination Survey*). For some of the age groupings presented, the values are based on the time-weighted average value for 2 or more age ranges from the source table, as indicated below. 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]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.

[b]Each IR represents a time-weighted average of ingestion rates for age groups 1 to <2 years and 2 to <3 years.

[c]Each IR represents the ingestion rate for age group 3 to <6 years.

[d]Each IR represents a time-weighted average of ingestion rates for age groups 6 to <11 years and 11 to <16 years. Note that estimated values include children older than 11 years, which contributes to uncertainty in the estimates for 6 to 11 years.

[e]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. 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.

[f]Each IR represents a time-weighted average of ingestion rates for age groups 18 to <21 years and ≥21 years. Note that estimated values include people ages 18–19 years, which contributes to uncertainty in the estimates for people 20 years and older.

B.6.3.3 Ingestion Rates for Local Food

Exhibit B-16 presents mean, median, 90th, 95th, and 99th percentile food-specific IRs for consumers-only of farm foods for adults and children. The mean and percentile values are from EPA's analysis of data from the USDA's 1987–1988 NFCS (USDA 1993), as presented in Chapter 13 of the Agency's 2011 EFH (i.e., Intake of Home-Produced Foods) (U.S. 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 IRs 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.

For the adult age group, data were compiled on food-specific IRs separately for two types of households as indicated in the "Response to Questionnaire" (U.S. EPA 2011a, Chapter 13): (1) households that farm (F) and (2) households that garden or raise animals (HG, for home gardener). This division reflects EPA's data analysis. EPA tabulated IRs for fruits and vegetables separately for F households and HG households. Similarly, EPA tabulated IRs for animals and animal products for F households and HG households. Thus, F households represent farmers who may both grow crops and raise animals and who are likely to consume more homegrown/raised foods than HG households. HG households represent the non-farming households that may consume lower amounts of homegrown or home-raised foods (i.e., HG encompasses both households that garden and households that raise animals). The food-

specific IRs are based on the amount of each food type that each household produced and brought into their homes for consumption and the number of persons consuming the food. EPA averaged the actual IRs for homegrown foods over the 1-week survey period.

For children, EPA estimated food-specific IRs for four age categories (U.S. 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-16. Summary of Age-group-specific Ingestion Rates for Farm Foods

Product	Child (age in years)					Adult (20 up to 70 years)
	<1	1–2	3–5	6–11	12–19	
Mean ingestion rates (g/kg-day)						
Beef	NA	4.14	4.00	3.77	1.72	1.93
Dairy	NA	91.64	50.91	27.36	13.63	2.96
Eggs	NA	2.46	1.42	0.86	0.58	0.61
Exposed Fruit	NA	6.14	2.60	2.52	1.33	1.19
Exposed Vegetable	NA	3.48	1.74	1.39	1.07	1.38
Pork	NA	2.23	2.15	1.50	1.28	1.10
Poultry	NA	3.57	3.35	2.14	1.50	1.37
Protected Fruit	NA	16.64	12.36	8.50	2.96	5.19
Protected Vegetable	NA	2.46	1.30	1.10	0.78	0.86
Root Vegetable	NA	2.52	1.28	1.32	0.94	1.03
Median ingestion rates (g/kg-day)						
Beef	NA	2.51	2.49	2.11	1.51	1.55
Dairy	NA	124.63	65.98	34.43	15.46	2.58
Eggs	NA	1.51	0.83	0.56	0.43	0.47
Exposed Fruit	NA	5.03	1.82	1.11	0.61	0.68
Exposed Vegetable	NA	1.89	1.16	0.64	0.66	0.81
Pork	NA	1.80	1.49	1.04	0.89	0.80
Poultry	NA	3.01	2.90	1.48	1.30	0.92
Protected Fruit	NA	7.59	5.94	3.63	1.23	2.08
Protected Vegetable	NA	1.94	1.04	0.79	0.58	0.56
Root Vegetable	NA	0.92	0.46	0.52	0.57	0.63
90th percentile ingestion rates (g/kg-day)						
Beef	NA	9.49	8.83	11.40	3.53	4.41
Dairy	NA	185.34	92.45	57.37	30.92	6.16
Eggs	NA	4.90	3.06	1.90	1.30	1.31
Exposed Fruit	NA	12.70	5.41	6.98	3.41	2.37
Exposed Vegetable	NA	10.70	3.47	3.22	2.35	3.09

Product	Child (age in years)					Adult (20 up to 70 years)
	<1	1–2	3–5	6–11	12–19	
Pork	NA	4.90	4.83	3.72	3.69	2.23
Poultry	NA	7.17	6.52	4.51	3.13	2.69
Protected Fruit	NA	44.80	32.00	23.31	7.44	15.14
Protected Vegetable	NA	3.88	2.51	2.14	1.85	1.81
Root Vegetable	NA	7.25	4.26	3.83	2.26	2.49
95th percentile ingestion rates (g/kg-day)						
Beef	NA	12.86	12.47	12.50	3.57	5.83
Dairy	NA	166.67	89.94	55.97	32.25	7.80
Eggs	NA	5.38	3.62	2.37	1.43	1.59
Exposed Fruit	NA	14.60	6.07	11.70	4.78	3.38
Exposed Vegetable	NA	11.90	6.29	5.47	3.78	4.46
Pork	NA	6.52	6.12	4.73	6.39	2.60
Poultry	NA	8.10	7.06	5.07	3.51	3.93
Protected Fruit	NA	48.28	35.11	26.86	11.40	19.16
Protected Vegetable	NA	9.42	5.10	3.12	2.20	2.83
Root Vegetable	NA	10.40	4.73	5.59	3.32	3.37
99th percentile ingestion rates (g/kg-day)						
Beef	NA	20.90	19.76	13.30	4.28	6.84
Dairy	NA	180.48	87.17	54.83	34.70	9.20
Eggs	NA	16.17	11.24	8.19	4.77	1.83
Exposed Fruit	NA	25.15	32.50	15.70	5.90	12.96
Exposed Vegetable	NA	12.10	7.36	13.30	5.67	8.42
Pork	NA	8.71	9.74	6.61	4.29	3.87
Poultry	NA	9.63	10.24	6.12	4.60	4.93
Protected Fruit	NA	109.30	71.20	58.17	19.10	34.42
Protected Vegetable	NA	9.42	5.31	5.40	2.69	5.56
Root Vegetable	NA	10.40	4.73	7.47	5.13	7.57

Notes: NA = not applicable; the 90th percentile values are the default ingestion rates for RTR screening assessments and chemical threshold calculations.

Sources: 2011 EFH (U.S. EPA 2011a). Tables 13-25 (dairy), 13-33 (beef), 13-40 (eggs), 13-51 (pork), 13-52 (poultry), 13-58 (exposed fruit), 13-59 (protected fruit), 13-60 (exposed vegetable), 13-61 (protected vegetable), and 13-62 (root vegetable). The primary source for values was the 1987–1988 *Nationwide Food Consumption Survey* (USDA 1993). For all but dairy, 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 the *Continuing Survey of Food Intakes by Individuals* (USDA 2000)—see Tables 3-23a (beef), 3-6a (eggs), 3-24a (pork), 3-25a (poultry), 3-14a (exposed fruit), 3-15a (protected fruit), 3-11a (exposed vegetable), 3-12a (protected vegetable), and 3-13a (root vegetable). For dairy, 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 Table 11-4 (based on the 2003–2006 National Health and Nutrition Examination Survey).

For some food types and age categories, there were insufficient data for EPA to provide consumer-only IRs (i.e., the dataset for the subpopulation consisted of fewer than 20

observations). The HHRAP methodology, Section 6.2.2.2 (U.S. EPA 2005a), recommends a method by which to calculate the "missing" age-specific consumer-only IRs, as explained below. Food-specific 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, 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 (U.S. 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 U.S. EPA 2003c)—IRPC_total.

The ratio of $IR_{PC,\ age\_group\_x}$ to IR_{PC_total} from the CSFII data shows the IR of a particular food type by a specific age group relative to the IR 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 IR of a particular food type by a specific age group (consumers only) relative to the IR 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-58 was used to calculate the "missing" age-specific consumer-only *IRs*:

Equation B-58. 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, as brought into the home, for the total *Nationwide Food Consumption 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 total CSFII survey population

In this discussion, *per capita* (as opposed to *consumer-only*) indicates the IRs 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 IRs 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 IR for a food type for a specific age group (consumers only) has the same shape as the distribution of the IR 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 IRs based on only a few respondents in the tails of the distributions. The default IRs for this methodology are the 90th percentiles, which are likely more reliable than the 95th or 99th percentile estimates in this particular calculation.

B.6.3.4 Ingestion Rates for Local Fish

Screening Scenario

The USDA's 1987–1988 NFCS (USDA 1993, 1994a), as presented in Chapter 13 of the Agency's 2011 EFH (i.e., Intake Rates for Various Home Produced Food Items) (U.S. EPA 2011a), includes IRs by age category for family-caught fish. There are several disadvantages, however, to using that data source to estimate fish IRs. First, due to inadequate sample sizes, EPA did not report fish IRs for children less than 6 years of age. Second, the NFCS data were collected more than three decades ago. Third, the reported fish IRs are for ages 6 to 11 and 12 to 19 and are based on 29 and 21 individuals in each age category, respectively (U.S. EPA 2011a, Table 13-20). Finally, the IRs 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 IR data, are very uncertain and are based on squid and a wide variety of freshwater, estuarine, and marine fish (U.S. 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, IRs that are reflective of subsistence fisher IRs are desired. Therefore, a more recent survey was sought that included larger sample sizes, data for children younger than six years, IRs for the parts of fish actually consumed, and IRs reflective of subsistence fishers.

Taking all of these issues into consideration, the selected default IR of fish for adults is 373 g/day, which is the estimated 99th percentile of fish IRs 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 IRs 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 IR for this group of subsistence fishers is not the highest fish IR available for use by EPA, 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 IR 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 childbearing age are located throughout the United States. Finally, using a high-end (subsistence) fish IR is consistent with section 112 of the CAA, which focuses on risks associated with maximally exposed individuals.

Because Burger (2002) did not estimate fish IRs for children, another data source was needed to develop IRs for the child age categories. The child IRs need to be consistent with the Burger

IR for adults, reflective of subsistence-fisher IRs, and based on adequate sample sizes. To satisfy these requirements, data on IRs for children from EPA's *Estimated Per Capita Fish Consumption in the United States* (U.S. EPA 2002) were selected for use. Specifically, the estimated 99th percentile of *as-prepared*, *consumer-only* IRs for finfish plus shellfish were selected (see Section 4.2.1.1, Table 5 of U.S. EPA 2002). The original data were collected as part of the 1994–1996 and 1998 CSFII (USDA 2000) and do not require additional consideration of cooking and preparation losses.

Because the child age categories used in the methodology differ from the CSFII age categories presented in U.S. EPA (2002), the CSFII data were adjusted. The CSFII data did not provide IRs for the 1–2-year age category. To estimate IRs for this age group, EPA used the IR for the 3–5-year age category, scaled downward by the ratio of the mean BW of the 1–2-year age category to the mean BW of the 3–5-year age category. Because the methodology 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-year age categories, time-weighted-average IRs were calculated based on the CSFII IRs. Exhibit B-17 provides the fish IRs used in the screen.

Exhibit B-17. Ingestion Rates for Fish, as used in the Screening Scenario

Fish Ingestion Rates (g/day)					
Infants <1 year	**Child 1–2 years**	**Child 3–5 years**	**Child 6–11 years**	**Child 12–19 years**	**Adult 20 up to 70 years**
NA	107.70[a]	158.99[b]	268.19[c]	331.01[c]	373[d]

Sources: Ages up through 19 years: U.S. EPA (2002) (Section 4.2.1.1 Tables 4 and 5 [freshwater/estuarine habitat]); ages 20 years and above: Burger (2002).
Note: NA = not applicable (it is assumed that children <1 year of age do not consume fish).
[a]A fish-ingestion rate for ages 1–2 years was not available. The value represents the consumer-only fish-ingestion rate for ages 3–5 years from U.S. EPA (2002), 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 3–5 years from U.S. EPA (2002).
[c]These values represent time-weighted-average consumer-only fish ingestion rates based on ingestion rates from U.S. EPA (2002).
[d]This value represents the 99th percentile ingestion rate of wild-caught fish for women, as reported by Burger (2002).

Alternative Values

EPA's 2002 analysis of freshwater and estuarine fish ingestion data from the CSFII for the years 1994-96 and 1998 was chosen to provide fish IR options by age category (U.S. EPA 2002). Although the fish consumption rates reported in the CSFII include all sources (commercial and self-caught), for purposes of screening-level assessments of risk, it was assumed that all freshwater and estuarine fish consumed are self-caught. The inclusion of commercially obtained and estuarine fish could overestimate IRs of locally caught freshwater fish for most populations in the United States; however, these IRs also could underestimate IRs of locally caught fish 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, assessors are encouraged to use more locally relevant data when available.

For children, EPA identified values for the mean and the 90th, 95th, and 99th percentile fish *per-capita* IRs (freshwater and estuarine fish only) based on EPA's analysis of 1994-96 and 1998 CSFII data (U.S. EPA 2002, 2008a). Those rates include individuals who eat fish and those who do not eat fish.

As shown in Table 10-7 of EPA's 2008 CSEFH (U.S. EPA 2008a), the 90th percentile per-capita IRs estimated from the two-day CSFII recall period are zero for some child age groups.

Although not presented in CSEFH Table 10-7, median IRs 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 IRs that are zero result from the short duration of the CSFII recall period (two days) compared with the AT 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 IRs, however, is not useful. As a result, an alternative method was used to estimate fish IRs for children and adults that could provide reasonable, non-zero values for all age groups and percentiles. The alternative, age-group-specific fish IRs were derived using values for each age group, *y*:

- Mean or other appropriate percentile consumer-only fish IRs for age group *y*, $IR_{CO,y}$, from EPA's Estimated Per Capita Fish Consumption in the United States (U.S. EPA 2002, Section 5.2.1.1, Table 5, for freshwater/estuarine habitat).[23]
- Fraction of the population consuming freshwater/estuarine fish, $F_{PC,y}$, 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 (U.S. EPA 2008a) and U.S. EPA (2002).

Equation B-59 was used to calculate the alternative, per-capita fish IRs by age group ($IR_{PC,y}$):

Equation B-59. 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) (U.S. 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) (U.S. EPA 2008a, 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 fish. Here, per-capita ingestions are recommended by the HHRAP methodology because no consumer-only percentile-specific intakes are provided for the different age groups.

[23]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.

The mean and percentile consumer-only fish IRs for children and adults and the fraction of the population consuming freshwater/estuarine fish used in calculating long-term per capita fish IRs by age group are presented in Exhibit B-18 and Exhibit B-19. The mean and percentile per-capita fish IRs estimated using the methodology are summarized in Exhibit B-20. The fish IRs provided in Exhibit B-20 are intended to represent the harvest and consumption of fish in surface waters in a hypothetical depositional area. For site-specific assessments, more localized survey data may be more appropriate to estimate fish IRs. 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 B-17, in developing the screening threshold emission rates, health-protective fish IRs for child and adult fish consumers that more closely represent exposures of a high-end recreational fisher were used.

As noted in Section B.6.4.3, if the fish IRs shown in Exhibit B-20 are replaced with fresh-weight as-caught values (e.g., values obtained from a local creel survey), the assessor 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 B.6.4.3.

Exhibit B-18. Daily Mean and Percentile *Consumer-only* Fish Ingestion Rates ($IR_{CO,y}$)

Lifestage (years)	Ingestion Rates, All Fish (g/day)				
	Mean	50th	90th	95th	99th
Child <1	NA	NA	NA	NA	NA
Child 1–2[a]	27.31	15.61	64.46	87.60	138.76*
Child 3–5[b]	40.31	23.04	95.16	129.31	204.84*
Child 6–11[c]	61.49	28.46	156.86*	247.69*	385.64*
Child 12–19[d]	79.07	43.18	181.40*	211.15*	423.38*
Adult 20 up to 70[e]	81.08	47.39	199.62*	278.91	505.65*

Sources: U.S. EPA (2002) (Section 5.2.1.1 Table 5 [freshwater/estuarine habitat]), 2008 CSEFH (U.S. EPA 2008a).

Notes: NA = not applicable (it is assumed that children <1 year of age do not consume fish). Per-capita fish-ingestion rates (IRs) for children by age group are available from Chapter 10 of the 2008 CSEFH (U.S. EPA 2008a); however, all 50th and some 90th percentile IRs are zero. Per-capita fish IRs were therefore estimated as described in Equation B-59 to provide reasonable, non-zero values for all age groups and percentiles.

*The sample size for this value does not meet minimum reporting requirements as described in U.S. EPA (2002). Owing to the small sample sizes, these upper-percentiles value are highly uncertain.

[a]A fish IR for ages 1–2 years was not available. The value represents the consumer-only fish IR for ages 3–5 years from U.S. EPA (2002), scaled down by the ratio of the mean Child 1–2 body weight to the mean Child 3–5 body weight.

[b]These values represent the consumer-only fish IR for ages 3–5 years from U.S. EPA (2002). Sample size = 442.

[c]These values represent the consumer-only fish IR for ages 6–10 years from U.S. EPA (2002). Sample size = 147.

[d]These values represent the time-weighted-average per-capita fish IR for ages 11–15 and 16–17 years from U.S. EPA (2002); the value may underestimate ingestion rate for ages 12–19 years. Sample size = 135.

[e]These values represent the consumer-only fish IR for individuals 18 years and older from U.S. EPA (2002). Sample size = 1,633.

Exhibit B-19. Fraction of Population Consuming Freshwater/Estuarine Fish on a Single Day ($F_{PC,y}$)

Lifestage (years)	Fraction Consuming Fish
Child 3–5	0.0503
Child 6–11	0.0440
Child 12–19	0.0493
Adult 20 up to 70	0.08509

Sources: U.S. EPA (2002) (Section 5.1.1.1 Table 4), 2008 CSEFH (U.S. EPA 2008a).
Note: Values were calculated using the sample size for consumers only of the age group 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. For the Child 12–19 lifestage, the calculation uses the sum of the ages 11–15 and 16–17. For the Adult lifestage, the calculation uses ages 18 and older.

Exhibit B-20. Long-term Mean and Percentile Per-capita Fish Ingestion Rates ($IR_{PC,y}$)

	Ingestion Rates, All Fish (g/day)				
Lifestage (years)	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 20 up to 70[e]	6.90	4.03	16.99	23.73	43.02

Sources: U.S. 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) × (fraction of population consuming fish for Child 3–5).
[b]Values were calculated as (consumer-only IR for Child 3–5) × (fraction of population consuming fish for Child 3–5).
[c]Values were calculated as (consumer-only IR for Child 6–11) × (fraction of population consuming fish for Child 6–11).
[d]Values were calculated as (consumer-only IR estimated for Child 12–19) × (fraction of population estimated to consume fish for Child 12–19).
[e]Values were calculated as (consumer-only IR for Adults) × (fraction of population consuming fish for Adults).

Exhibit B-21 provides mean and the 90th percentile fish IRs for recreational fishers, black and female recreational fishers, and fishers of Hispanic, Laotian, and Vietnamese descent. 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 (U.S. EPA 2011a). IRs for black and female recreational fishers are presented in Burger (2002). The fish IRs 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. They reported mean and 95th percentile IRs for each subpopulation. In part due to the low sample size in the Shilling study (n = 30–45), 95th percentile values were believed to be unrealistically high. The 90th percentile IR estimates presented in Exhibit B-21 for Hispanic, Laotian, and Vietnamese fishers were derived by EPA using information from Shilling *et al*. (2010) and U.S. EPA (2010).

Exhibit B-21. 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]
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]Source: 1997 EFH (U.S. EPA 1997a)
[b]Burger (2002) weights are "as consumed" for locally caught fish.
[c]Source: Shilling et al. (2010).

RTR multipathway assessments to date have used whole-fish concentrations estimated by TRIM.FaTE (or by application of BAF and BSAF values for arsenic). 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 fish fillets equal to 2.6 percent for TL3 and 3.0 percent for TL4 (Table 6-9 in U.S. EPA 2003b). If an assessor wishes to account for reduced chemical concentration in fillet compared with whole fish for lipophilic chemicals, they can use a "preparation" loss of chemical (see Section B.6.4).

For lipophilic chemicals (e.g., log Kow 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.

B.6.3.5 Soil Ingestion Rates

Adult gardeners and farmers may incidentally ingest soils from gardening activities and from soil particles that adhere to exposed fruits and exposed and belowground 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. Both adults and children also may incidentally ingest indoor dust. Exhibit B-22 includes soil and dust IR options by age group for these types of exposures. Exhibit B-22 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), nor does it include options for geophagy, or the intentional ingestion of earths, which is usually associated with cultural practices (i.e., on the order of 50,000 mg/day) (U.S. EPA 2008a, 2017b).

Data on soil and dust IRs are sparse; the soil and dust IRs listed in Exhibit B-22 are based on limited data. The studies evaluated by EPA for children generally focused on children between the ages of 1 and 6 years and were not specific to families that garden or farm. To be health-protective, the default IRs are the EFH General Population values for Soil + Dust (Table 5.1, U.S. EPA 2017b).

Applying the Soil + Dust IR for the general population better reflects the risk associated with chronic exposure than applying a daily-peak IR associated with soil pica or geophagy. EPA's soil pica and geophagy IRs are likely to represent acute, high-end soil-ingestion episodes or behaviors at an unknown point on the high end of the distribution of soil ingestion. Moreover, most of the key studies used to develop the soil IRs were tracer-element studies that might not represent long-term behavior. EPA's HHRAP (U.S. EPA 2005a) excluded soil pica, in part, because the behavior is "temporary."

Exhibit B-22. Daily Mean and Percentile Soil and Dust Ingestion Rates

Age Group (years)	Soil and Dust Ingestion Rate (mg/day)				
	Mean[a]	50th[a]	90th[b]	95th[b]	99th[b]
Child <1[c]	NA				
Child 1–2	90	90	200	200	200
Child 3–5	60	60	200	200	200
Child 6–11	60	60	200	200	200
Child 12–19	30	30	200[d]	200[d]	200[d]
Adult 20 up to 70	30	30	200[d]	200[d]	200[d]

NA = not applicable

Sources: 2017 EFH (U.S. EPA 2017b). Child 1–2 values here are taken from the Table 5-1 category of 1 to <2 years; Child 3–5 from the category of 2 to <6 years; Child 6–11 from the category of 6 to <12 years; Child 12–19 and Adult from the category of >=12.

[a]For mean and 50th percentile soil ingestion rates, value represents a "central tendency" estimate for soil + dust ingestion from EPA's 2017 EFH, Chapter 5, Table 5-1.

[b]Values are the recommended "upper percentile" estimate for soil + dust ingestion from EPA's 2017 EFH, Chapter 5, Table 5-1.

[c]Estimates for children <1 year in the 2017 EFH are not based on measured tracers and so are not included because of the high-level of uncertainty associated with these IRs. The EFH considered biokinetic modeling for 4 children <6 months and biokinetic modeling blood lead levels in 31 children 6 months to 1 year from one location near a lead smelting facility.

[d]Value represents "adults following a traditional rural or wilderness lifestyle", as described in footnote j to EPA's 2017 EFH, Chapter 5, Table 5-1. This value was selected to better represent potentially higher ingestion rates for the farmer and gardener scenarios.

B.6.3.6 Total Food Ingestion Rates

Although the multimedia ingestion risk methodology was developed to perform deterministic screening-level exposure and risk assessments, total food IRs could be included if the methodology is adapted for a probabilistic assessment. In particular, the total food IRs presented in Exhibit B-23 could be used to normalize or to truncate the sum of food-specific IRs to ensure reasonable values. This procedure is particularly important when chemical intake from multiple upper-percentile food IRs for different types of food are added together. Individuals representing the upper-percentile IR for one food category might not be the same individuals who reported high-percentile IRs for one or any of the other food categories.

Exhibit B-23. Daily Mean and Percentile Per Capita Total Food Intake

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

Lifestage (years)	Percent of Group Consuming Food	Mean	50th	90th	95th	99th
Adult 20 up to 70[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 20 up to 70[g]	100%	14.8	13.9	23.7	27.6	35.5

Sources: U.S. EPA (2005e), 2008 CSEFH (U.S. EPA 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.

[b]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 represent 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 the *Continuing Survey of Food Intakes by Individuals*.

[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 the *Continuing Survey of Food Intakes by Individuals*.

[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.

B.6.4 Other Exposure Factor Values

The other exposure parameters included in the algorithms are exposure frequency (Section B.6.4.1), fraction of the food type obtained from the contaminated area (Section B.6.4.2), and reduction in the weight of the food types during preparation and cooking (Section B.6.4.3). For the breast milk ingestion pathway, additional exposure parameters are included in the algorithms (Section B.6.5).

B.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. The default value for EF is 350 days/year for all exposure sources and all potential receptors. This assumption is consistent with the food IRs (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 an assessor wishes to evaluate daily intake rates based on shorter ATs, they can replace both the food-specific IRs and the EF for each homegrown food product. For example, they may 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 homegrown produce is seasonal.

B.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 assessment scenario.

For RTR screening assessments, the default FC is 1, assuming that households that farm, garden, or raise animals produce 100 percent of the food product consumed, and 100 percent of the fish consumed is home caught. The assessor can vary this default FC value for individual food products to tailor the assessment to a particular exposure scenario.

B.6.4.3 Preparation and Cooking Losses

Food preparation and cooking losses are included in the calculations of exposure to farm foods 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 IRs calculated from the USDA 1987–1988 NFCS (USDA 1993, 1994a) are based on the weight of homegrown 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: (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]). The methodology uses 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-24. 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 EFHs (U.S. EPA 1997a, 2011a).

Exhibit B-24. 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

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]
Poultry	0.32	0.295[h]
Fish[i]	0.0	0.0

Note: 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 of 1997 EFH: U.S. EPA (1997a)].

[d]This value represents an average of means for all exposed vegetables with available data (Table 13-7 of 1997 EFH). 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 of 1997 EFH).

[f]This value represents an average of means for all protected vegetables with available data (Table 13-7 of 1997 EFH). 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 of 1997 EFH). Root vegetables include beets, carrots, onions, and potatoes.

[h]This value represents an average of means for chicken and turkey (Table 13-5 of 1997 EFH).

[i]If the assessor 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 [Table 13-69 of 2011 EFH: U.S. 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 IRs is not the USDA's 1987–1988 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 are based on parts actually consumed, and so no loss processes for preparation are needed.

If the assessor uses fish IRs 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), they should also use non-zero values for the L1 and L2 parameters.

B.6.4.4 Food Preparation/Cooking Adjustment Factor 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 IRs 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, a food preparation/cooking adjustment factor (FPCAF) can be applied to the

concentration in uncooked fish to estimate a concentration in cooked fish. The following sections discuss FPCAFs for each of the four PB-HAPs.

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 (U.S. EPA 2011b), an FPCAF of 1.5 was used to adjust MeHg concentrations in consumed fish (i.e., a 50-percent 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).

Arsenic

Similar to mercury, arsenic 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 arsenic.

Cadmium

Similar to mercury and arsenic, 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.

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 pentachlorodibenzo-p-dioxin (PCDD) and pentachlorodibenzofuran (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 64–72 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.

Polycyclic Organic Matter

While it is reasonable to assume that there might be losses of lipophilic POM during the cooking process, there is insufficient information to distinguish what the net loss (or gain) during cooking might be because cooking can create POM 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 POM.

B.6.5 Breast-Milk Infant Exposure Pathway Parameter Values

Values used for parameters in the breast-milk exposure pathway algorithms (see Section B.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 are listed. For parameters for which algorithms calculate values, the appropriate equation is listed. Scenario- and receptor-specific parameters are discussed in Section B.6.5.1 and chemical-specific parameters are discussed in Section B.6.5.2.

B.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-25 lists the parameters and their default values. The text that follows describes the recommended value or alternative values for each exposure parameter needed 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 B.3.4 of this attachment.

Exhibit B-25. 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-38
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

Parameter	Description	Default Value
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

AT and *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 ADD equation.

Infant BW (BW_{inf}). The assessor selects a value for BW_{inf}, the time-weighted average BW of the infant over the 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 assessor should select the BW for an infant that is averaged from birth to the first birthday. Similarly, if an infant breast feeds for 6 months, the assessor should select the BW 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 BW is 7.8 kg, which is the time-weighted average for the mean infant BW between birth and the first birthday from EPA's 2008 CSEFH (U.S. EPA 2008a). Exhibit B-26 presents additional percentile values for the infant BW parameter that may be appropriate for some assessments.

Exhibit B-26. 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
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]Default value used for RTR assessments.

Maternal BW (BW_{mat}). This parameter represents the BW of the mother averaged over the entire duration of the mother's exposure to the chemical of concern. The maternal BW is needed to calculate the biological elimination constant for the lipophilic chemical in lactating women (k_{fat_elac}). The methodology assumes that the mother will be pregnant for 9 months (i.e., 0.75 year) and will be lactating for 1 year. The recommended default maternal BW 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 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 (U.S. EPA 2004a). Exhibit B-27 presents additional values for the maternal BW parameter which might be appropriate for some assessments. The BW_{mat} value is *not* the value that the methodology uses to estimate the mother's absorbed daily intake (DAI_{mat}). The daily IRs for homegrown/raised food products are for men and women combined, with the rates normalized to BW. The IRs for soil, water, and fish are not normalized to BW but are based on both men and women. For those IRs, the methodology uses an average BW value for males and females to estimate the ADD (intake) of the chemical in mg/kg-day. These values are subject to the assumption that the body-weight normalized IRs and resulting ADD values are applicable to nursing mothers.

Exhibit B-27. 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: U.S. EPA (2004a).
[a]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 (U.S. EPA 1998). Harrison (1967) and Ueland (1976) reported plasma volumes between 63–70 percent in postpartum women (U.S. EPA 1998). The default value of 65 percent (0.65) is the value recommended by EPA in its MPE (U.S. EPA 1998).

Fraction of mother's BW 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-40, 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 (U.S. 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 (U.S. 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) (U.S. EPA 1998). A fraction of 0.3 indicates that 30

percent of the mother's BW is fat, which is a health protective value (U.S. EPA 2001a). To establish a health protective screening scenario, a default value for f_{fm} of 0.30 is used.

Fraction of fat in mother's breast milk (f_{mbm}). The $C_{milkfat}$ model (Equation B-40) 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, U.S. EPA 2011a, Smith 1987, Sullivan et al. 1991). The default value for f_{mbm} of 0.04 (i.e., 4 percent) is the value EPA recommended for MPE (U.S. 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 BW and averaged about 45 mL/kg. Ueland (1976) observed that the average plasma volume of women 6 weeks postpartum was 45 mL/kg of BW. 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 (U.S. EPA 1998). The default value for f_{pm} therefore is 0.046.

Infant breast milk IR (IR_{milk}). Milk IRs 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 IRs for infants that nurse for six and for twelve months (U.S. 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 IRs from those (U.S. EPA 2011a). EPA estimated an upper-percentile (upper-bound) value as the mean plus two standard deviations. The IRs, measured volumetrically (mL/day), are converted 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 U.S. EPA 2011a). The resulting values are shown in the first two rows of Exhibit B-28. The screening-level default value of 980 mL/day is an upper-bound estimate based on a one-year nursing period.

Exhibit B-28. 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	U.S. EPA 2011a[b]
0 to <12 months	688	0.709	980[a]	1.01[a]	U.S. EPA 2011a[b]
0 to <1 month	510	0.525	950	0.979	U.S. EPA 2008a[c]
1 to <3 months	690	0.711	980	1.01	U.S. EPA 2008a[b]
3 to <6 months	770	0.793	1,000	1.03	U.S. EPA 2008a[b]
6 to <12 months	620	0.639	1,000	1.03	U.S. EPA 2008a[b]

[a]Default; [b]Based on review of multiple studies; [c]Based on a single study.

Exhibit B-28 also includes the recommended values for four non-overlapping age categories from the CSEFH (U.S. 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 IRs are very close to 1 liter per day at all stages of development in the first year.

Duration of breast feeding (t_{bf}). This parameter is equal to the infant's *ED* and the infant's *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) (U.S. 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 (U.S. EPA 2001a). Nonetheless, to establish a health protective screening scenario, the default value 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-40 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 ED (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-40 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-40 with the t_{pn} term (U.S. 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, the methodology uses an ED equal to the default half-life for dioxins, or 10 years. Only 3,285 days of that period are pre-natal (i.e., 3,650 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.

B.6.5.2 Chemical-Specific Parameter Values

The chemical-specific parameters in the breast-milk pathway are listed in Exhibit B-29. 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-29. 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

Parameter and Description		2,3,7,8-TCDD	MeHg
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 (U.S. 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-43	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-42.

Absorption efficiency of the chemical by the oral route of exposure for the infant (AE_{inf}). The models included in the methodology 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 (U.S. EPA 2001a). However, since the methodology assumes 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 (U.S. 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 (U.S. EPA 1998).

The default value for AE_{inf} for both MeHg and dioxin is 1.0. For ingested lipophilic chemicals, it is reasonable to assume that absorption will be high (U.S. EPA 2004b). 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 (U.S. EPA 2004b). MeHg also is well absorbed, with measured values as high as 95 percent, and so a value of 100 percent is used (U.S. 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, 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 BW. 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 (U.S. 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 MeHg has been identified from the literature at this time. A value can be calculated using Equation B-45. 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 (U.S. 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 default half-life for dioxins is set to 10 years or 3650 days.

The half-life for MeHg 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 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-45. 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, the methodology estimates k_{elim} from chemical half-life assuming first-order kinetics as shown in Equation B-42. 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, k_{fat_elac} for dioxins is calculated from Equation B-43. When the parameters in that equation use the default values for dioxins, the estimated value of k_{fat_elac}. is 0.0015 per day

Partition coefficient for chemical between maternal blood plasma and aqueous phase of breast milk (Pc_{bm}). The aqueous model, presented in Equation B-44, assumes that the concentrations

in the plasma and aqueous phase of breast milk are directly proportional (U.S. EPA 1998). Therefore, the default value for this parameter for MeHg 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 (U.S. EPA 1998). For MeHg, the methodology uses 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).

B.7 Summary of Default Exposure Parameter Values

The default parameter values used in the multimedia ingestion risk methodology 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. EPA used these default parameter values 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 for parameter values as described in Section B.6 of this attachment. This section summarizes the default parameter values used to calculate screening thresholds.

This section is organized to present the chemical- and scenario-specific parameters by data type. The screening-level analysis uses the following IRs for each ingestion scenario of interest and population-specific characteristic assumptions (presented in Section B.7.1), that are generally health protective in nature:

- Fisher Scenario: 99th percentile IRs for fish (presented in Section B.7.1.1)
- Farmer Scenario: 90th percentile IRs for soil, breast milk, and farm foods (presented in Section B.7.1.2)
- Gardener Scenario: Urban gardener uses mean IRs for fruits and vegetables and eggs and 90th percentile IRs for soil and breast milk. Rural gardener uses 90th percentile rates for fruits and vegetables, eggs, soil, and breast milk (presented in Section B.7.1.3).

Screening threshold emission rates were derived for five RTR chemical groups: arsenic compounds, cadmium compounds, MeHg, 2,3,7,8-TCDD, and benzo[a]pyrene. Section B.7.3 presents chemical-specific parameter inputs for these five chemicals. Finally, Section B.7.4 presents default parameter values for the nursing infant exposure scenario, which applied only to dioxin and MeHg as discussed in Section B.3.4.

B.7.1 Default Ingestion Rates

The screening-level (or default) values for IRs for soil, breast milk, and for each farm-food item are set to the 90th percentile or mean of the distribution of national data for that medium based on the exposure scenario of interest. In general, these values were obtained from the 2011 EFH or the 2008 CSEFH (see Exhibit B-16). Fish IRs also are available from these sources; however, as described in Section B.6.3.4, other sources were used to obtain fish IRs.

B.7.1.1 Fisher Ingestion Scenario

The adult fish IR was obtained from Burger (2002), a study that examined daily consumption of wild-caught fish for high-end recreationalists (white, black, 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-17 and discussed in Section B.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 B.6.3.4, the baseline fish IRs for the screening scenario are based on "as prepared" total freshwater/estuarine fish IRs 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 U.S. 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 IRs are available) do not all directly correspond to the age groups in the U.S. EPA (2002) report. As described in Section B.6.3.4, these adjustments convert the available age-specific data on fish IRs to the age-specific values needed for the methodology.

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. Estimated 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 IRs presented here are representative of the 99th percentile of the evaluated data set, the use of these values (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 IRs 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 IR 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 IR also is consistent with section 112 of the CAA, which focuses on risks associated with maximally exposed individuals.

B.7.1.2 Farmer Ingestion Scenario

The default parameter values assume that all food types are obtained from the area of chemical deposition specified by the assessment scenario (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-30 also includes a sum of the 90th percentile IRs for homegrown food categories and 99th percentile fish ingestion to show the implied total food IR associated with setting multiple food-type-specific IRs 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 IRs 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 IRs* from the USDA's 1994-96 and 1998 CSFII (USDA 2000) data sets, as analyzed by EPA (U.S. EPA 2005e). The total IR for the farming households (third row from bottom) accounts for the cooking losses typical of each food category to provide a better comparison with the 90th percentile individual total food IRs from CSFII (which are based on consumption of prepared foods). The final row of Exhibit B-30 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 with the methodology.

Exhibit B-30. 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 up to 70 yrs	
Farm Foods							
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
Total Food Ingestion Rates (for comparison only not, used in RTR screening; excludes soil and water)							
Total Food: Homegrown only[i]	NA	259	142	99	51	35.5	g/kg-day

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 up to 70 yrs	
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: U.S. EPA 2011a, 2008a, unless otherwise noted.

NA = not applicable.

[a]Primary source for values was the 1987–1988 *Nationwide Food Consumption Survey* (USDA 1993); compiled results are presented in Chapter 13 of the 2011 Exposure Factors Handbook (U.S. 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 the *Continuing Survey of Food Intakes by Individuals*.

[b]Primary source for values was the 1987–1988 *Nationwide Food Consumption Survey* (USDA 1993), compiled results are presented in Chapter 13 of the 2011 Exposure Factors Handbook (U.S. 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 a *National Health and Nutrition Examination Survey* 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 U.S. EPA (2002) report (value presented is rounded); for these children, the RTR age-group range matches the U.S. 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 U.S. 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 $(1-L_1) \times (1-L_2)$, where L_1 and L_2 are the loss rates from Exhibit B-24. The rows are then summed to get the total post-cooking ingestion rate.

[j]90th percentile total food intake rates from U.S. EPA (2008a, 2005e) based on *Continuing Survey of Food Intakes by Individuals* data 1994−96 and 1998; see Section B.6.3.6 of this document.

B.7.1.3 Gardener Ingestion Scenario

As discussed in Section 3.2.3, two potential gardener scenarios can be evaluated depending on the surrounding land use: a rural gardener and an urban gardener. Similar to the farmer ingestion scenario, 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); however, an urban gardener is expected to have a lower IR for home produced goods than a rural gardener. The rural gardener is assumed to have the same 90th percentile IR as the farmer for the produce consumed. Exhibit B-31 and Exhibit B-32 provide IRs for the rural gardener and urban gardener, respectively.

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 resident in an urban or rural setting.

Exhibit B-31. Ingestion Rates for Rural Gardeners

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 up to 70 yrs	
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
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
Eggs[a]	NA	4.90	3.06	1.90	1.30	1.31	g/kg-day
Other							
Soil	NA	200[b]	200[b]	201[c]	201[c]	201[c]	mg/day

Note: NA = not applicable.

[a]Primary source for values was the 1987–1988 *Nationwide Food Consumption Survey* (USDA 1993); compiled results are presented in Chapter 13 of the 2011 Exposure Factors Handbook (U.S. 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 the *Continuing Survey of Food Intakes by Individuals*. Ingestion rates presented are the 90th percentile values.

[b]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.

[c]These values are 90th percentile adult ingestion rates calculated in Stanek et al. (1997), and they are used to represent older children and adults.

Exhibit B-32. Ingestion Rates for Urban Gardeners

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 up to 70 yrs	
Exposed Fruit[a]	NA	6.14	2.60	2.52	1.33	1.19	g/kg-day
Exposed Vegetable[a]	NA	3.48	1.74	1.39	1.07	1.38	g/kg-day
Protected Fruit[a]	NA	16.6	12.4	8.50	2.96	5.19	g/kg-day
Protected Vegetable[a]	NA	2.46	1.30	1.10	0.78	0.86	g/kg-day
Root Vegetable[a]	NA	2.52	1.28	1.32	0.94	1.03	g/kg-day
Eggs[a]	NA	2.46	1.42	0.86	0.58	0.606	g/kg-day
Other							
Soil	NA	200[b]	200[b]	201[c]	201[c]	201[c]	mg/day

Note: NA = not applicable.

[a]Primary source for values was the 1987–1988 *Nationwide Food Consumption Survey* (USDA 1993); compiled results are presented in Chapter 13, Table 13-58 to Table 13-62, of the 2011 Exposure Factors Handbook (U.S. 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 the *Continuing Survey of Food Intakes by Individuals*. Ingestion rates presented are the mean values.

[b]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.

[c]These values are 90th percentile adult ingestion rates calculated in Stanek et al. (1997), and they are used to represent older children and adults.

B.7.2 Default Screening-Level Population-Specific Parameter Values

The screening-level values for BWs for the RTR screening threshold analysis, which serve as the default values, are mean values and are presented in Exhibit B-33. As stated in Section B.6.3.1 of this attachment, EPA recommends using the mean BW for each age group when using upper-percentile values for IRs. Use of the mean BWs introduces no bias toward over- or underestimating risk. The default ED for each age group also is presented in Exhibit B-33.

Exhibit B-33. Mean Body-weight Estimates[a]

Lifestage (years)	Duration (years)	Mean Body Weight (kg)
Adult[b] (20 up to 70)	50	80.0
Child <1[c]	1	7.83
Child 1-2[c]	2	12.6
Child 3-5[d]	3	18.6
Child 6-11[e]	6	36.0
Child 12-19[f]	8	64.2

[a]Sources: U.S. EPA (1997, 2008a).
[b]EPA-recommended value (U.S. 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 *National Health and Nutrition Examination Survey* IV data as presented by Portier et al. (2007).

B.7.3 Default Chemical-Specific Parameter Values for Screening Analysis

Exhibit B-34 presents chemical-specific parameter values for the screening-level analysis. Values for bioavailability when ingested in soil (*Bs*), mammalian *MF*s, correction factors for belowground produce ($VG_{rootveg}$), wet deposition fractions (*Fw*), air to plant transfer factors (Bv_{AG}), *RCF*s, and *Kds* are presented.

Only single estimates were developed for each of these parameters for HHRAP (U.S. 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-10, are *not* repeated here. Finally, Exhibit B-35 presents biotransfer factors for each of the chemicals and animal types for which screening threshold emissions were calculated.

Exhibit B-34. Chemical-Specific Parameter Values[a]

Parameter	Description	BaP	Cadmium	Mercuric chloride	Methyl mercury	2,3,7,8-TCDD	Arsenic	Units
Bs	Soil bioavailability factor for livestock	1	1	1	1	1	1	unitless
SoilAdjFactor	Soil bioavailability factor	1	1	1	1	1	0.6[b]	unitless
MF	Mammalian metabolism factor	0.01	1	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	1	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	0.6	unitless
BvAG	Air-to-plant biotransfer factor for aboveground produce for vapor-phase chemical in air	174,523	0	1,800	0	65,500	0	[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	0	L soil pore water/kg root WW
Kds	Chemical-specific soil/water partition coefficient	7,750	332	58,000	7,000	31,126	2,512	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 screen are provided here.

[b]From U.S. EPA (2012). Compilation and Review of Data on Relative Bioavailability of Arsenic in Soil. Relative bioavailability (RBA) of arsenic in soils compared with arsenate dissolved in water. Fewer than 5% of 103 estimates of RBA of arsenic exceeded 0.60 (in vivo studies of juvenile swine, n = 64; monkeys, n = 24; and mice, n = 15).

Exhibit B-35. Chemical and Animal-Type Specific Biotransfer Factor (Ba) Values[a]

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	2.6E−02	5.5E−03	3.2E−02	1.1E−02	1.9E−02
Arsenic	2.0E−03	6.0E−05	1.0E−02	7.0E−02	3.0E−02

[a]([mg chemical/kg WW tissue or dairy]/[mg chemical intake/day] = day/kg WW tissue or dairy).

B.7.4 Screening-Level Parameter Values for Nursing Infant Exposure

For dioxins, chemical intake via breast milk by nursing infants was estimated using the model presented in EPA's MPE (U.S. 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 B.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 (1–5 percent).
- The maternal chemical intake is estimated using upper-percentile IRs for the different homegrown foods (see discussion for Exhibit B-30); this assumption might overestimate total ingestion of homegrown foods by a factor of more than 2 (see Exhibit B-30).
- 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 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 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 ED for the mother equal to the assumed half-life for dioxins, 10 years, may underestimate the duration of exposure of the mother.

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Attachment C. Dermal Risk Screening

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Contents

Exhibits

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Non-inhalation exposure to PB-HAPs can occur by dermal contact with PB-HAP-contaminated soil and water. Although dermal absorption of chemicals that are originally airborne generally is considered a relatively minor pathway of exposure compared to other exposure pathways, in certain settings it can be significant (U.S. EPA 2006, Cal/EPA 2012). 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 compared with the ingestion pathway. In general, the RTR dermal assessment follows 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* (U.S. EPA 2004)

C.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 noncancer effects for the five PB-HAPs currently assessed in the multipathway screening evaluation for RTR: arsenic, cadmium, divalent mercury, 2,3,7,8-TCDD, and benzo[a]pyrene. EPA has not developed carcinogenic potency slope factors (CSFs) and noncancer 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 percent (i.e., less than 50 percent). Otherwise, a default value of complete (100 percent) oral absorption is assumed, and no adjustment is made (U.S. 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 arsenic, 2,3,7,8-TCDD, and all polycyclic aromatic hydrocarbons (PAHs) (which includes benzo[a]pyrene) are estimated to be greater than 50 percent based on data provided in RAGS Part E, Exhibit 4-1. Therefore, as shown in Exhibit C-1, no adjustments to the available oral toxicity values (RfD or CSF) were required for these chemicals. For cadmium and divalent mercury, adjustments were made based on absorption data provided in RAGS Part E, Exhibit 4-1. The absorbed RfDs for cadmium and divalent mercury, adjusted to account for GI absorption, also are provided 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}) $(mg/kg\text{-}day)^{-1}$	Absorbed Reference Dose (RfD_{ABS}) (mg/kg-day)
Arsenic	No adjustment required[a]	1.5E+00	3.0E−04
Cadmium Compounds	0.05	NA	2.5E−05[b]
Divalent Mercury	0.07	NA	2.1E−05[c]
2,3,7,8-TCDD	No adjustment Required[a]	1.5E+05	7.0E−10
Benzo[a]pyrene	No adjustment Required[a]	1.0E+00	3.0E−04

NA = Not applicable.
[a]According to RAGS Part E, Exhibit 4-1, GI absorption is expected to be greater than 50%.
[b]Cadmium RfD for water = 5.0E−4.
[c]Divalent mercury RfD for = 3.0E−4.

C.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 (Farm) 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.

C.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 noncancer 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)

C.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 (U.S. EPA 2004) and the Child-Specific Exposure Factors Handbook (CSEFH, U.S. 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.

C.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 up to 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 because 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.

C.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 up to 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 noncancer 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.		

C.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 Farm (tilled 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.

Exhibit C-4. Chemical-Specific Dermal Exposure Values for Water and Soil Contact

PB-HAP	Arsenic	Cadmium	Divalent Mercury	2,3,7,8-TCDD	BaP	Source
Chemical concentration in Water (Cw) (mg/cm^3)	4.19E−10	7.48E−09	3.85E−10	9.03E−18	1.01E−11	TRIM.FaTE modeled concentration in screening scenario lake
Chemical concentration in Soil (Cs) (mg/kg)	1.66E−02	1.57E-01	3.36E−02	7.41E−10	9.77E−04	TRIM.FaTE modeled concentration in surface soil in farm in screening scenario
Permeability coefficient in water (Kp) (cm/hour)	0.001	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	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	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)	0.03	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).

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.

C.3 Screening-Level Cancer Risks and Noncancer Hazard Quotients

Toxicity values were used in conjunction with exposure information to evaluate the potential for cancer risks and noncancer health hazards. Risk estimation methods are presented below.

C.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:

$$Dermal\ Cancer\ Risk = DAD \times CSF_{ABS} \qquad \textbf{Eqn. C-1}$$

where:

DAD = Dermal Absorbed Dose (mg/kg-day)

CSF_{ABS} = Absorbed cancer slope factor (mg/kg-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).

C.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:

$$Dermal\ HQ = DAD/RfD_{ABS} \qquad \textbf{Eqn. C-2}$$

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. Noncancer hazard is not additive *across* the age groups evaluated here.

C.4 Dermal Screening Results

Exhibit C-5 provides estimated dermal noncancer hazards by age group and Exhibit C-6 provides estimated lifetime cancer risks from dermal exposures. Risks and hazards are summed for exposure to both water and soil. Soil and water concentrations that resulted in the Tier 1 threshold emissions rates are used as the media concentrations; these concentrations resulted in cancer risks of 1E-6 or HQs of 1.0 for a combined farmer and fisher receptor. The highest HQ value for dermal exposures was 0.003, representing divalent mercury exposure for children aged 1 to 2. This is approximately 320 times less than the estimated ingestion HQs associated with the screening scenario (i.e., emissions of divalent mercury in the screening scenario resulted in an ingestion HQ of 1, based on the ingestion of methyl mercury). The highest estimated individual lifetime cancer risk associated with potential dermal exposures was 1.0E-8 for arsenic; this value is approximately 100 times smaller than the estimated Tier 1 ingestion risk (i.e., 1E-06). Exhibit C-7 provides the estimated magnitude of difference between the ingestion risks or HQs and those for dermal exposure for each of the five PB-HAPs. These were calculated as the ratio of the risk or HQ from exposure through ingestion to the risk or HQ from dermal exposures. Although As, BaP, and TCDD have RfDs, as noted in Exhibit C-1, their cancer exposure assessments are more of concern; therefore, only lifetime cancer risks and not HQs are presented in Exhibit C-6.

Exhibit C-5. Dermal Noncancer HQs – Summed for Water and Soil Exposures

PB-HAP	HQ Child 1	HQ Child 2	HQ Child 3	HQ Child 4	HQ Child 5	HQ Adult	Max HQ
Cd	0.0004	0.0004	0.0003	0.0002	0.0002	0.00009	**0.0004**
Hg^{2+}	0.003	0.003	0.002	0.002	0.001	0.0006	**0.003**

Exhibit C-6. Dermal Cancer Risks – Summed for Water and Soil Exposures

PB-HAP	Lifetime Risk
As	1.0E−08
BaP	8.4E−09
TCDD	8.7E−10

Exhibit C-7. Comparison of Ingestion Risk/HQ to Dermal Risk/HQ

PB-HAP	Magnitude of Difference
As	99
BaP	119
Cd	2,400
Hg^{2+}	319
TCDD	1,150

Based on these results and taking into consideration the extremely conservative nature of the dermal exposure calculations, EPA has determined 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.

C.5 References

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Attachment D. Summary of TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

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Exhibit D-1. TRIM.FaTE Parameters Considered for Inclusion in Tier 2 Assessment

Parameter	Mechanism of Potential Influence in TRIM		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**

Parameter	Mechanism of Potential Influence in TRIM		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 (POM, 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**
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**

Parameter	Mechanism of Potential Influence in TRIM		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**

Parameter	Mechanism of Potential Influence in TRIM		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**

Parameter	Mechanism of Potential Influence in TRIM		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**

Parameter	Mechanism of Potential Influence in TRIM		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**

Attachment E. Analysis of Lake Size and Sustainable Fish Population

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Contents

Exhibits

Acronyms

BC	benthic carnivore (fish, e.g., large catfish)
BI	benthic (sediment-dwelling) invertebrate
BO	benthic omnivore (fish, e.g., smaller bottom feeding fish)
CASM	Comprehensive Aquatic Systems Model
CPUE	catch per unit effort
DOC	dissolved organic carbon
EPA	U.S. Environmental Protection Agency
HAP	hazardous air pollutant
MEI	morphoedaphic index
MVP	minimum viable population (self-sustaining population over decades)
PB-HAP	persistent and bioaccumulative hazardous air pollutant
RTR	Risk and Technology Review
SD	standard deviation
TLn	trophic level n (e.g., TL1, TL2, TL2.5 … TL4.5)
TN	total nitrogen
TP	total phosphorus
WCC	water-column carnivore (fish, e.g., walleye, pike)
WCO	water-column omnivore (fish, e.g., yellow perch, sunfish)
WCH	water-column herbivore (fish, e.g., young-of-the-year fish, minnows)

As stated in Section 1.4.1.1 of the TSD, the tiered risk screen for Risk and Technology Review (RTR) persistent and bioaccumulative hazardous air pollutants (PB-HAPs) includes a subsistence fisher who consumes fish from one or more lakes near a facility. The fish at the top of the aquatic food web in a lake should have substantially higher tissue concentrations of PB-HAPs than concentrations in the water or sediments due to bioaccumulation of the PB-HAPs through the food web links. For the Tier 1 screening scenario, we include a single hypothetical lake near the facility. For Tiers 2 and 3, we include actual lakes near the facility. This attachment provides supporting information for Section 3.5.1 of the Technical Support Document (TSD)—Processing Lake Data for Tier 2 Screen. For the remainder of this attachment, the word "angler" is used to refer to the "human fisher" consuming fish at subsistence levels in order to distinguish it from the mammalian "fisher" (*Martes pennanti*), which is used in some ecological risk assessments.

E.1 Purpose

To develop the screening scenarios with an angler, we needed to address two questions:

1. How large does a lake need to be to provide a self-sustaining population(s) of top-trophic-level fish?
2. How much fish can be harvested sustainably from lakes of different sizes?

The assumed high-end fish ingestion rate for an adult angler is 373 grams fish fillet per day (see Section 1.4.1.2 of TSD). A health-protective assumption is that the angler consumes top-trophic-level fish (allows maximal bioaccumulation). Thus, we needed to estimate, in essence, the fish ingestion rates near trophic level 4 (TL4) supported by lakes of different sizes.

Addressing the first question ensured we did not model an angler harvesting more fish than a lake could provide (e.g., removing several pounds per day, 365 days per year, a rate at which the entire fish population would be fished out within weeks or months). The second question estimates how many lakes of what size(s) would be required to meet the angler's daily fish ingestion rate.

E.1.1 Methods – Literature Searches

ICF conducted two searches through online bibliographic databases for information on aquatic food webs and biomass distribution within those webs: one in 2005 and one in 2014. In 2005, using standard literature/citation databases (e.g., Elsevier BIOBASE, Enviroline), ICF's information specialist searched citations for articles published from 1975 to 2005. The following search terms and logical variations of these words were used:

- Aquatic, aquatic ecosystem, fish, fisheries, fisheries population
- Lake, river, reservoir, pond, stream (not marine or estuarine)
- Trophic, pyramid, food web, food chain, trophic community structure
- Biomass, bioaccumulation, biomagnification, accumulation

Fugacity, mass-balance, model

The results of this search yielded an initial list of more than 400 publication titles. These titles were reviewed to develop a list of about 100 articles for which abstracts were retrieved. The abstracts were reviewed and used to select 33 publications for retrieval and review. Some of these publications cited additional relevant literature that we retrieved for review. Where we

have used a secondary source to describe the findings of an original source, we cite both the primary and secondary sources.

We conducted a similar literature search in 2014 to identify relevant references published since 2005. We found an initial list of more than 200 publication titles that we reviewed. We retrieved more than 60 abstracts and selected 31 for retrieval. We reviewed those studies to supplement this documentation and to determine if any literature contradicted key assumptions we made in 2005. Where we have used a secondary source from our 2014 search to describe the findings of an original source, we provide both the original and secondary citations.

E.1.2 Methods – Food Web Simulated in TRIM.FaTE

The food web simulated in TRIM.FaTE is reproduced in Exhibit E-1. Values for attributes of each biotic compartment in the TRIM.FaTE-simulated lake are listed in Exhibit E-2. The total fish biomass per unit area simulated by TRIM.FaTE is 5.7 grams fish wet weight/square meter [g ww/m^2], which is typical of lakes in Maine and southern Ontario. The final two columns in Exhibit E-2 show fish biomass and numbers for purposes of evaluating fish harvesting by anglers. The total fish standing biomass is higher, 40 g ww/m^2, to be more representative of lakes across the United States as described in Section E.6. The lower fish biomasses were used for TRIM.FaTE so that the fish compartments did not sequester (remove) large quantities of chemical mass from the water column (and sediments).

With limited removal of chemical mass from water and sediments, the TRIM.FaTE simulation is more similar to other aquatic food-web models that assume bioaccumulation in fish and other biota does not change the concentrations of chemical in water or sediments [e.g., Arnot and Gobas (2004); U.S. EPA (2009) KABAM for predicting pesticide bioaccumulation potential in aquatic systems].

Exhibit E-1. Aquatic Food Web Simulated in TRIM.FaTE

Aquatic Biota Compartments (Consumer Groups)	Percentage of Consumer's Diet									Sum of % Total Diet
	Algae	Macrophytes	Zooplankton	Benthic Invertebrates	Water Column Herbivores (WCH)	Benthic Omnivore (BO)	Water Column Omnivore (WCO)	Benthic Carnivore (BC)	Water Column Carnivore (WCC)	
Zooplankton	100	0	0	0	0	0	0	0	0	100
Benthic Invertebrate (BI)	0	0	0	0	0	0	0	0	0	100
Water Column Herbivore (WCH)	0	0	100	0	0	0	0	0	0	100
Benthic Omnivore (BO)	0	0	0	100	0	0	0	0	0	100
Water Column Omnivore (WCO)	0	0	0	0	100	0	0	0	0	100
Benthic Carnivore (BC)	0	0	0	50	0	50	0	0	0	100
Water Column Carnivore (WCC)	0	0	0	0	0	0	100	0	0	100

Exhibit E-2. Distribution of Biomass in Aquatic Compartments

Organism	Weight Per Individual (kg)	Percent of Total Fish Biomass	For TRIM.FaTE		For Fish Harvesting	
			Biomass (g ww/m^2)	No. Fish Per Hectare	Biomass (g ww/m^2)	No. Fish Per Hectare
Macrophytes	NA	NA	500	NA	NA	NA
Zooplankton	5.70E-08	NA	6.4	NA	NA	NA
Benthic Invertebrate (BI)	2.55E-04	NA	20	NA	NA	NA
Water Column Herbivore (WCH)	0.025	35	2	800	14	5614
Benthic Omnivore (BO)	0.25	35	2	80	14	561
Water Column Omnivore (WCO)	0.25	8.8	0.5	20	3.5	140
Benthic Carnivore (BC)	2	17.5	1	5	7	35
Water Column Carnivore (WCC)	2	3.5	0.2	1	1.4	7
Total Biomass of All Fish	NA	100	5.7	NA	40	NA

Abbreviations: 1 hectare = 10,000 m^2; NA = not applicable; ww = wet weight.

Of the trophic compartments in Exhibit E-1, two compartments represent top-trophic-level fish: benthic carnivores (BC) and water-column carnivores (WCC). Benthic carnivores are relatively large (e.g., 2 kg) bottom-feeding fish (e.g., catfish, chub) that consume benthic invertebrates and small benthic fish. The BC compartment thus represents the top-trophic-level fish exposed via trophic transfers to chemicals from the sediment compartment. Water-column carnivores are relatively large (e.g., 2 kg) pelagic piscivores (e.g., walleye, lake trout, northern pike), or "game" fish, that feed primarily on smaller fish in the water column. The WCC thus represents the top-trophic-level fish exposed to chemicals dissolved in the water column or adsorbed to suspended sediment particles and algae.

As shown in Exhibit E-1, for the BC compartment, we assume a diet of 50-percent benthic invertebrates (TL2) and 50-percent smaller benthic fish (TL3) that feed on benthic invertebrates (TL2) that feed on detritus in sediments (TL1, not included in Exhibit E-1). That diet composition averages to TL2.5, which means that the BC compartment represents TL3.5. For the WCC compartment (TL4.5), our simplified food web assumes that 100 percent of the WCC diet consists of water column omnivores (WCO, TL3.5, e.g., "pan" fish such as bluegill, other sunfish, white perch). The diet of the WCO can include various types of prey, but for a simplified food web we assume the diet of WCO is 100-percent minnow-sized fish species and young-of-the-year fish (TL2.5) that feed on zooplankton (TL2) and algae (TL1—treated as a phase of the surface water column) in the water column. In reality, many fish species (e.g., rainbow trout) feed on smaller fish and on invertebrates in both the water column and at the sediment surface.

E.1.3 Organization of This Report

Given the necessity of answering the two questions posed in Section E.1 for purposes of RTR screening, we evaluated several factors and used several simplifying assumptions. For factors with high natural variability, and for which we could predict whether high-end or low-end values would increase the angler's exposure to PB-HAPs, we selected values that likely would increase the angler's risk. For factors with high natural variability for which we could not predict which end of the range might result in more or less risk, we selected data or made an informed assumption that we thought would represent a central tendency in conditions across the country. We emphasize, however, that lake productivity, fish predator-prey relationships, and species' population dynamics in lakes across the United States are highly variable.

The remainder of this attachment is organized in six sections:

E.2 Angler Behavior

Assumptions regarding angler behavior drove some of our data selections and assumptions used to answer our two questions.

E.2.1 Consumption of Top-trophic-level Fish

As stated in Section 3.3.1, Exhibit 31, of the TSD, the angler consumes only top-trophic-level fish. Although the angler might prefer to catch and consume the WCC (TL4.5) game fish species, individual fish in that group are the least abundant and account for the lowest group biomass of all the fish compartments (Exhibit E-2). Fish in the BC (TL3.5) compartment are more abundant and account for more biomass than the WCC compartment (Exhibit E-2) in most lakes of moderate size (as discussed in Section E.5, excludes Great Lakes).

We could not predict a priori whether chemical concentrations in the WCC or in the BC compartment would be higher for any given PB-HAP. Depending on chemical Kow (octanol-water partitioning coefficient) and Kd (soil/sediment-water partitioning coefficient), TRIM.FaTE might estimate higher or lower concentrations in the TL3.5 BC fish than in the TL4.5 WCC fish. Given that unknown, we assumed that the angler catches and consumes a 50:50 ratio of fish from the WCC and BC compartments.

E.2.2 Sustainable Fish Harvest Rates

The angler lives in the same location for 50 to 70 years. The lake(s) must support fish harvesting by the angler over that period. In other words, the lake should not be "fished out" by the harvest rate required to meet the angler's 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 sustainably for human consumption are difficult values to estimate.

Models to predict sustainable harvests of different fisheries are numerous and complex. Species-specific parameters 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. We discuss some of those issues later in Section E.3–Fish Populations, Section E.3.4–Sustainable Fish Harvest Rates. Angler behavior related to sustainable fishing is discussed below.

Angler fishing pressure is a product of the number of anglers fishing a lake and the time each angler is willing to spend per unit catch. In reality, those factors are not independent of fish abundance per unit area and total number of fish per lake. For purposes of the RTR assessment, however, we assume a single angler is fishing the lake(s) near a facility. We also assume that the angler harvests fish at a subsistence level. In Tier 1 of the human health risk assessment, we assume the single lake provides fish at that level. In Tiers 2 and 3 of the human health risk assessment, if the lake with the maximum chemical concentrations in fish is too small to provide a sustainable harvest at that level, the angler moves to the next lake with the next highest chemical concentrations, and so on, until the desired harvest is met.

Other influences of angler behavior on fish population density and abundance are not included in RTR assessment. For example, fishing “pressure” does not change the abundance of fish in the lake. In actual lakes, as fishing pressure increases, fish abundance generally decreases. For example, in Wolfe Lake in Alberta, Canada, overfishing of walleye has resulted in a decrease of catch-per-unit-effort or time (CPUE) from 0.25 fish/hour in the early 1980s to 0.02 fish/hr in the mid-1990s (Post et al. 2002). In 1969, catching a pike in Lake Kehiwin took approximately 2.5 hours, whereas in 1995 an estimated 25 hours was required (Post et al. 2002). Stocking lakes has been the solution to allow harvesting at levels well above what wild populations could sustain in many locations. For the RTR screen, interactions among angler effort, fish population size and biomass density, and fishing success are not considered. Instead, we assume certain constants for fish harvesting.

E.2.3 Other Assumptions about Angler Behavior

Another assumption about angler behavior is that anglers 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 using 0.30 for the consumable fraction of fish (U.S. EPA 1989). For this assessment, we assume that the edible fraction for top-trophic-level fish is 0.33 (i.e., some proportion of fish consumed are salmon-like). The edible fraction of 0.33 is used in the analyses in Section E.6 to estimate total fish biomass required to support specified human fish consumption rates.

A final assumption is that the angler consumes 373 g/day of fish fillet. The value is from Burger’s (2002) report on fish ingestion rates for avid sport fishers interviewed at the Palmetto Sportsmen’s Classic in South Carolina in March 1998. The ingestion rate of 373 g/person-day is the 99th percentile ingestion rate reported by 107 females. EPA used that value in its *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* (U.S. EPA 2011).

E.3 Fish Populations

Our initial question in Section E.1 was what is the minimum size of a lake that can support a self-sustaining population of top-trophic-level fish? As stated in Section E.2, the RTR screening scenario assumes that an angler consumes 373 g ww fish fillet/day (50:50 ratio of BC to WCC)

for 50 to 70 years without stocking to maintain the fish population. This section provides background information required for the lake size analyses in Section E.6.

First, some basic principles of fish biology are reviewed (Section E.3.1). Next, a brief overview of fish population modeling is presented (Section E.3.2). To support calculation of the minimum lake acreage required to support a self-sustaining WCC fish population, an assumption for the minimum viable population (MVP) size is presented (Section E.3.3.). Finally, a sustainable adult fish harvest rate is proposed (Section E.3.4).

E.3.1 Fish Biology

For persons familiar with human health risk assessment or assessment of risks to terrestrial populations of wildlife (e.g., birds, mammals), some important attributes of fish biology are worth stating.

Fish are cold-blooded (i.e., poikilothermic). Their internal body temperatures vary considerably, particularly with the temperature of ambient water in which they live. Few fish (e.g., open-ocean tuna) are sufficiently active swimmers to maintain a core temperature above ambient water. Nor do fish have significant control over absorption of heat from incident sunlight. Thus, fish growth and reproduction vary considerably with latitude and general climatic factors.

Fish are gape feeders. They consume their prey whole, and thus cannot eat fish larger than their “gape,” or mouth opening. This results in the typical aquatic “food chain” of smaller fish being consumed by larger fish, which are consumed by still larger fish. The top piscivorous fish (e.g., walleye, pike) in the water column also tend to have wider or longer gapes, or both, for a given body weight compared to lower trophic-level fish (e.g., perch, sunfish) with a smaller gape relative to their body size.

Fish continue to grow over their lifespan. In northern temperate (and southern temperate) regions like the United States, fish tend to reproduce seasonally (once per year). The fastest growth occurs during the summer months. For all fish species, body size increases with age. For the longer-lived species, growth continues over the lifespan, and the age at first reproduction might be delayed for several years. As growth continues after sexual maturity, larger females can produce more eggs than younger, smaller females.

Many attributes of fish populations are density dependent. Survivorship of young (“recruitment”) tends to decrease with increasing abundance of adults and other predatory fish species; conversely, higher mortality among adults can release the young and juveniles from predation and competition for food, allowing higher recruitment and growth rates. Individual fish growth rates depend on density to some extent; growth rates tend to decrease with increasing fish numerical and biomass density due to increasing competition for food.

Approximately 10 percent of energy is lost between tropic levels. Limits to surface water primary productivity and inputs of organic materials from terrestrial ecosystems limit the overall fish carrying capacity (K) of any given lake. Losses of energy from one trophic level of fish to the next tend to be on the order of 90 percent (85–95 percent) (UM 2016); loss of energy from one level to the next for warm blooded animals (birds and mammals) is even higher (95–99 percent) because of the energy spent in maintaining body temperature. Thus, ingestion of 10 grams of fish biomass by another fish usually leads to a 1-gram increase in body weight or in egg production in the consumer fish. Fish standing biomass, therefore, tends to decrease with increasing trophic level.

E.3.2 Fish Population Modeling

Population modeling often is used in predicting fisheries responses to management options, including sustainable rates of exploitation. A variety of types of population models have long been used in fisheries management (Vaughan et al. 1984): (1) surplus production models (Shaffer 1968); (2) yield models (Gulland 1969; Ricker 1975); (3) stock-recruitment models (Ricker 1975; DeAngelis and Christensen 1979); (4) Leslie Matrix models (Leslie 1945; Goodyear and Christensen 1984); and (5) bioenergetics models, which examine factors that affect growth of individual fish (Ursin 1967; Stewart 1980). Leslie matrix models have the advantage of incorporating age-specific survivorship, growth, age at sexual maturity, and fecundity rates for females of a population, which is important for longer-lived top-trophic-level fish.

Use of population models in the field of ecological risk assessment began in the 1990s, but it faces many challenges (Barnthouse et al. 2008). One particularly difficult characteristic of natural populations is variation in key life-history parameter values with changes in population density (i.e., density-dependent population regulation) and fish community structure. In general, some additional adult mortality (e.g., fish harvesting) can be compensated by increased growth rates and increased survival of the young to maturity. Estimating MVP and sustainable harvest rates, given density-dependent compensation in populations, is difficult. Density-dependent predator-prey interactions among fish species in the same lake compound the difficulty. For example, Post et al. (2002) found that in lakes with high walleye harvest rates, populations of cyprinids and other TL3 fish increased. The TL3 fish eventually outcompeted juvenile walleye for food, resulting in loss of walleye altogether (Post et al. 2002).

An example of the Leslie matrix-approach is the Purchase et al. (2005) study of harvest rates of walleye and lake trout compatible with sustained fishing of those species in Lake Erie and in the Upper Kesagami Lake in Ontario, Canada. Purchase and colleagues used a modified age-structured Leslie matrix model (Leslie 1945, Caswell 1989, Hayes 2000) to estimate population sustainability under different fishing pressures. The basic equation using the Leslie matrix can be specified by Equation E-1:

$$1 = \sum_{x=1}^{q} l_x \, m_x \, e^{-rx} \qquad \textbf{\textit{Eqn. E-1}}$$

where:

l_x = age-specific survival rates (per year)

m_x = age-specific fecundity (birth rates, per year)

r = Malthusian parameter (per capita population growth rate)

x = age (years)

q = lifespan (years)

With population- and species-specific life-history data, the maximum value of r (r_{max}) can be estimated. That value corresponds, in theory, with a sustainable harvest rate assuming relatively constant environmental conditions and density-independent values for the specified parameters. The realized value of r for a population must exceed zero for long-term existence.

Purchase et al. (2005) analyzed fisheries data for walleye and lake trout in the two lakes, using published data for age of maturity, relative fecundity, and natural mortality from previous studies

of the populations. The annual natural adult mortality rates ranged from 0.11 for walleye in Upper Kesagami to 0.35 for walleye in Lake Erie, while reports of early mortality (for eggs through year 1) ranged from 0.99985 for walleye to 0.9957 for lake trout. Purchase et al. (2005) found that estimates of r_{max} were sensitive to estimates of early mortality, adult mortality, and growth rates. Purchase et al. (2005) found larger differences in modeled population growth rates between two populations of the same species in two different lakes than between the two different species in the same lake. This level of site-specificity is inappropriate for a screening level, nationwide, risk assessment for thousands of facilities.

Post et al. (2008) demonstrated use of a fish production and harvest model [based on the Gordon-Schaefer model included in Clark (2006)], which also depends on the logistic population growth function. The model integrates the density dependence of birth and death rates into the single parameter, *r.* The value of *r* declines with increasing density, approach the carrying capacity of a lake, *K*, at a rate that is density-dependent. The productivity of an environment (and the abiotic characteristics) and species life histories determine *K*. This approach, however, requires knowledge of carrying capacity, which depends on overall lake productivity and size. We therefore moved on to other approaches to estimating MVP (Section E.3.3) and lake productivity (Section E.4).

E.3.3 General Estimates of MVP

The MVP, a concept used frequently in conservation biology for animals, is defined as the smallest population that will persist for a specified duration (e.g., 100, 250, 1,000 years) with a given probability (e.g., 95 percent). To estimate an MVP, one must specify a timeframe of interest and an “acceptable” probability of extinction within that period (e.g., Soulé 1987; Akçakaya et al. 1999).

MVP for any given species and location depends on many attributes of the species’ biology (e.g., body size, reproductive rate, home range size, habitat patches, connectivity between habitats, variability in environmental characteristics that impact fecundity and survival, probability of local catastrophes). At lower numbers of breeding individuals, the chance that a local population would go extinct because of random environmental and demographic events is higher (Menzie et al. 2008).

Many textbooks and advanced degrees are dedicated to applied ecology and population modeling to inform conservation or resource management efforts. Much of the initial work on MVP investigated the genetic minima required for short-term survival, continuing adaptation to environmental change, and ultimately, long-term evolution. Consequences of inbreeding have been considered the primary threat to short-term population survival, and genetic drift is 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 a minimum “effective” population size of about 50 is required for short-term survival (e.g., several generations, decades). Effective population sizes of approximately 500 are necessary to provide adequate genetic variation for continuing adaptation over the longer term (e.g., tens of generations, centuries for some animals) (Shaffer 1981, 1987; FAO/UNEP 1980).

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 Allendorf 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, random mating between individuals, and no overlap between

generations (see studies cited in NRC 1986). For animals with 50:50 sex ratios, the effective population size is close to the actual breeding adult population size (Ewens et al. 1987).

The Food and Agriculture Organization of the United Nations Environment Programme (FAO/UNEP 1980) pointed out that if a population is held in check at $N_e = 50$, it will lose about one-fourth of its genetic variation after 20 to 30 generations. Thus, to maintain a particular stock for longer than that, its N_e must be increased. As stated in the report, "a rough rule of thumb is that G is approximately equal to N_e, G being the number of generations the stock is likely to retain its fitness at a relatively high level" (FAO/UNEP 1980).

We therefore concluded that a minimum of 50 adult fish of one species in the WCC compartment would be needed for a population to be self-sustaining. Given the large number of factors that influence MVP, Ewens et al. (1987) cautioned against using a "rule of thumb" across circumstances.

E.3.4 Sustainable Fish Harvest Rates

In addition to identifying an MVP, we needed to estimate what additional adult mortality might be tolerated by a WCC population due to harvesting by the angler in the RTR screening scenario. This introduces additional density-dependent interactions between the angler and the fish population. From an evaluation of 3,500 rainbow trout populations in British Columbia, Post et al. (2008) concluded that fish population abundance depends on the relationship between fishing effort and fish CPUE for four reasons: (1) harvest equals fishing effort multiplied by catch rate; (2) catch rate correlates with fish abundance; (3) abundance depends on the outcome of the fish population interaction with harvesting; and (4) fishing effort is a function of fish abundance.

Modeling the relationships between angler and fish population would require site-specific data, which is not appropriate for a nationwide screening-level assessment. We therefore searched the literature to find estimates of fish harvest rates that are sufficiently conservative to be tolerated by most fish species.

Allen et al. (2009) used an age-structured model and existing fisheries data to evaluate sustainable recreational harvesting of Murray cod (*Maccullochella peelii peelii*), one of the world's largest freshwater fish in southeastern Australia. They concluded that fishing could be sustained if the exploitation rate is maintained under 0.15 (for the current regulation of 50 cm minimum length to take home) to prevent overfishing. At a higher exploitation rate of 0.30, the minimum fish length would need to be at least 70 cm to be sustainable (i.e., for adequate annual spawning).

Johnson (1980) found that an annual exploitation rate of 0.11 (11 percent) of anadromous arctic charr (*Salvelinus alpinus*) by Inuit in northern Canada led to a steady decline in the size of fish. Based on those data, VanGerwen-Toyne & Tallman (2010) recommended that to ensure sustainability, a harvest rate ≤0.05 per year was needed in this very cold environment (Roux et al. 2011).

In a survey of fish communities in 122 lakes in northern Europe, Håkanson and Boulion (2004) concluded that a typical loss from fishing by birds, mammals, and humans approximates 10 percent of the fish biomass in the prey fish compartment (TL3) and 10 percent of the biomass in the predator fish compartment (TL4).

For our lake size analysis, we assumed that anglers could harvest 10 percent of the biomass of pelagic WCC (TL4.5) adult fish each year without diminishing the WCC fish population size or annual productivity. This harvest rate is low enough to allow density-dependent increased survival and growth rates of young and juvenile fish to balance (compensate for) the additional adult mortality.

E.4 Lake Fish Productivity

The first question in Section E.1 is: How large does a lake need to be to provide a self-sustaining population(s) of top-trophic-level fish? To phrase the question in another way, what are the combinations of (a) minimum lake size and (b) fish productivity per unit area that could maintain an MVP of 50 adult breeding fish in the WCC compartment? This section focuses on (b) lake fish productivity per unit area.

We emphasize that lake productivity varies with surface area, depth, temperature, latitude, altitude, nutrient status, local hydrogeology, weather extremes, and other factors. Fish population sustainability also depends on lake primary productivity, inputs of organic materials from land, the relative abundance and diversity of invertebrates and other fish species and their feeding relationships, among other factors. Thus, no "single" answer to either question would be "representative" of lakes across the United States for a screening-level risk assessment.

Nonetheless, for the RTR screen, we established one (Tier 1) or possibly more lake(s) (Tiers 2 and 3) and estimated a WCC harvest in those lakes. As background, we first describe general lake characteristics (Section E.4.1). Empirical models of lake productivity as it relates to measurable lake attributes are presented next (Section E.4.2). Finally, some of the studies that measured fish productivity in specific locations are included to emphasize similarities and differences among lakes (Section E.4.3). All three subsections discuss total fish productivity; we conclude this section with our selection of one lake productivity estimate to use for the RTR screen. Fish productivity by trophic level is investigated in Section E.5.

E.4.1 Lake Characteristics

Exhibit E-3 provides one summary of physical and chemical characteristics of natural lakes in North America based on a sample of 72 lakes of at least 5 hectares in size, located from the Precambrian shield in Central Ontario through sedimentary basin lakes in the eastern United States (Nürnberg 1996). In this sample, lake surface area ranges over 5 orders of magnitude and the mean depth for each lake ranges from 1.8 to 200 m. Exhibit E-3 is not meant to summarize the characteristics of lakes across all regions of the United States.

Exhibit E-3. Characteristics of 72 Lakes in Eastern North America

Variable	Units	Median	Minimum	Maximum	n
Surface Area (A)	ha	64	5	8.2×10^6	72
	km^2	0.64	0.05	8.2×10^4	
	m^2	640,000	50,000	8.2×10^{10}	
Depth, mean (D)	m	7.6	1.8	200	72
D/A	m/km^2	8.0	0.14	48.1	72
Total Phosphorus (TP)	µg/L	8.1	3.3	107	72
Total Nitrogen (TN)	µg/L	324	149	1,000	63

Variable	Units	Median	Minimum	Maximum	n
TN/TP		34	11.6	79	63
Chlorophyll	µg/L	2.9	1.0	40	43
Dissolved Organic Carbon (DOC)	mg/L	3.5	1.5	12.0	62

Note: Lakes from central Ontario in the Precambrian shield, from southern Ontario and Quebec, and from the eastern United States in sedimentary basins. n = number of lakes.
Source: Nürnberg (1996).

Although the maximum total phosphorus (TP) concentration in Exhibit E-3 is 107 µg/L for this sample of lakes, TP concentrations in some lakes are much higher.

Some attributes of lakes vary by latitude. For example, lakes in the southeastern United States are considered monomictic, that is, they turn over[24] once per year in the autumn, whereas northeastern lakes also turn over in the spring when the winter ice cover melts (Osidele and Beck 2003). In addition, the longer growing season in the south promotes higher total phytoplankton and microbial production (and higher turnover rates), which can support higher total biomasses of both non-fish and fish trophic groups (Osidele and Beck 2003).

Lakes have been categorized from a biological perspective into three categories generally related to available nutrients and consequent primary productivity: oligotrophic, mesotrophic, and eutrophic (see text box below). Values for several chemical/physical characteristics of lakes that are associated with these categories have been quantified. For example, Exhibit E-4 presents one lake classification standard and associated values for TP, TN, chlorophyll, and water transparency associated with the three lake trophic categories in Canada (colder than most regions in the United States).

Exhibit E-4. One Trophic Classification Standard for Lakes

Trophic Status	Total Phosphorous (mg/m^3)	Total Nitrogen (mg/m^3)	Chlorophyll a (mg/m^3)	Transparency (m)
Oligotrophic	<15	<400	<3	>4.0
Mesotrophic	15–25	400–600	3–7	2.5–4.0
Eutrophic	>25	>600	>7	<2.5

Measurements are average, epilimnetic (layer of water above the thermocline), summer values, in Canadian lakes.
Source: Forsberg and Ryding (1980) as modified by Canfield et al. (1983).

[24]During summer, a thermocline generally develops as the surface layer of water warms, becomes less dense, and therefore floats above the bottom layer of colder water (in lakes deep enough to develop a thermocline). In the fall, the surface water layer cools, becomes similar in density to the bottom layer, and they can mix (turn over) with the nutrient-laden bottom waters mixing with the nutrient-depleted surface water. In northern freshwater lakes, ice cover keeps water at the surface colder than in the remainder of the lake; when the ice cover melts, the dense colder surface layer again mixes with the remaining lake waters. TRIM.FaTE does not simulate lake turnovers.

In most lakes, nitrogen concentrations are more than adequate to support maximal primary production; TP tends to be the limiting nutrient. Thus, the inorganic parameter most often related to lake trophic status is TP concentration. Definitions of TP concentration "cutoffs" between lake trophic categories vary slightly among investigators. Using data from several classification cutoffs reported by Nürnberg (1996), we summarize the definitions of trophic categories for lakes with respect to epilimnetic summer values for TP as:

- Oligotrophic: TP <10–15 µg/L
- Mesotrophic: TP 10–15 to 25–30 µg/L
- Eutrophic: TP 25–30 to 100 µg/L
- Hypertrophic: TP >100 µg/L

Lake Trophic Classification – Definitions

Oligotrophic: Waters lacking in plant nutrients and plants and generally rich in oxygen.

Mesotrophic: Stage between oligotrophic and eutrophic with respect to plant nutrients, plant productivity, and water oxygen content.

Eutrophic: Waters rich in mineral and organic nutrients that promote abundant plant life, particularly algae. As the plant material turns over and decays, dissolved oxygen can decline to levels that support few fish.

Shallow lakes with large stands of macrophytes can show different relationships between TP and phytoplankton, oxygen, and transparency because of the phosphorus tied up in the macrophytes (Canfield et al. 1983).

The biomass of fish (and the number of trophic levels supported) depends on lake size and the general productivity of a lake per unit area. Lake productivity depends on many factors, including latitude, seasonal temperatures, nutrients supporting algae, and inputs of organic materials (e.g., leaf litter) from terrestrial habitats and from emergent vegetation (allochthonous inputs). For example, in sub-catchments within a 275-hectare watershed in Ontario, Canada, Tanentzap et al. (2014) found that near-shore forested and wetland sub-catchment areas around Daisy Lake export more organic material to the lake than other sub-catchments. They estimated that at least 34 percent of yellow perch (*Perca flavescens*) biomass in the lake is supported by terrestrial primary production via organic inputs that enhance bacterial biomass that enhances biomass in larger zooplankton, which enhances production of young-of-the-year fish. In areas with high forest cover, they estimated that up to 66 percent of fish biomass was supported by organic loading from terrestrial primary production. TRIM.FaTE does not simulate export of organic materials from terrestrial parcels to the lake(s).

E.4.2 Predicted Lake Productivity – Nutrient Status and Fish Biomass

As stated above, climatic factors play a large role on a global or hemispheric scale, but at regional scales, many researchers have found "morphometric" (e.g., surface area, maximum depth, mean depth) and "edaphic" (e.g., nutrient content, dissolved oxygen, acidity) indicators for lakes correlate with overall fish productivity. Several versions of the morphoedaphic index (MEI) were developed starting in the 1960s and 1970s to combine lake morphology and nutrient status to estimate fish yields (Cote et al. 2011).

The literature on productivity and standing crop (biomass) of fish and other trophic groups in lakes is extensive and is not reviewed here. As stated in Section E.4.1, one physical/chemical attribute of lakes that provides high predictive power for biomass in aquatic ecosystems is the often-limiting nutrient TP. Other characteristics, such as total lake surface area, ratio of surface area to mean depth, dissolved organic carbon (DOC), macrophyte biomass, transparency, and an MEI based on several abiotic and biotic measures, have also been examined for their

predictive power. The simplest relationship with high predictive powers, however, relates total fish biomass to lake TP.

Peters (1986) evaluated empirical relationships between TP and biomass in various categories of organisms in lakes developed by other researchers (e.g., Bird and Kalff 1984; Hanson and Legget 1982; Pace 1986). Categories included bacteria, nanoplankton, "net" plankton, microzooplankton (e.g., rotifers and flagellated or ciliated protozoa), and macrozooplankton (e.g., *Daphnia*, copepods, amphipods, fish larvae). Peters converted all biomass to units of grams wet weight per square meter (g ww/m^2). Exhibit E-5 presents those models along with predictions of total biomass for each group for 5, 10, and 50 µg [TP]/L.

Relationships for bacteria and plankton were initially reported in biomass per unit volume. Peters (1986) converted them to biomass per unit area by assuming that bacteria and planktonic organisms occur only in the euphotic zone, the depth of which is given by Equation E-2 from Peters (1986):

$$Depth\_of\_Euphotic\_Zone\ (m) = 24 \times TP\ (mg/m^3)^{-0.28} \qquad \textbf{Eqn. E-2}$$

Note that this equation indicates that the more abundant plankton of more eutrophic lakes should be concentrated in a shallower euphotic zone (the depth of light penetration decreases with increasing concentrations of algae at the surface of more eutrophic lakes). Peters (1986) converted zooplankton dry weight to wet weight assuming a 1:10 ratio and converted bacterial cell counts to wet weight (ww) assuming 0.1 g ww per 10^{12} cells (Peters 1986).

Exhibit E-5. Predictions of Biomass (B) of Biotic Components of Lakes with Different Total Phosphorus (TP) Concentrations

Group	Equation	Biomass (B) (g wet weight/m^2)		
		TP = 5 µg/L	TP = 10 µg/L	TP = 50 µg/L
Bacteria	$B = 2.1 \times TP^{0.37}$	3.8	4.9	8.9
Nanoplankton	$B = 0.40 \times TP^{1.0}$	2.0	4.0	20
Net plankton	$B = 0.20 \times TP^{1.4}$	1.9	5.0	48
Microzooplankton	$B = 4.1 \times TP^{0.29}$	6.5	8.0	13
Macrozooplankton	$B = 4.6 \times TP^{0.37}$	8.3	11	20
Benthos	$B = 0.81 \times TP^{0.71}$	2.5	4.2	13
Fish	$B = 0.59 \times TP^{0.71}$	1.8	3.0	9.5

Source: Adapted from Peters (1986).

In a regression analysis of data on 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 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) evaluated data for 43 lakes ranging in surface area from 0.1 to 82,414 km^2 (10 ha to 8 million ha; 25 acres to 20 million acres), with TP concentrations of 8–540 µg/L and macrobenthos standing crop of 0.48–61.1 g/m^2, and located between 42° and 62° N latitude and 17° E to 117° W longitude. Based on a subset of 21 lakes sampled at the same time, the best univariate predictor of fish yield was TP; the regression correlation coefficient (r^2) was 0.84 (Equation E-3):

$$FY = 0.792 + 0.072\ (TP) \qquad \textbf{Eqn. E-3}$$

where:

FY = total fish yield (kg/hectare)

TP = total phosphorous (µg/L)

Logarithmic transformation did not improve the predictive power. All but five of the lakes had TP under 100 µg/L and fish yield of less than 1 g ww/m^2. At a 10-percent harvest rate, that would equal 10 g ww biomass/m^2.

Hanson and Legget (1982) also estimated the relationship between macrobenthos biomass and TP and fish standing crop from a sample of 18 to 20 lakes drawn from the same set of 43 lakes. The relationship between TP and total fish standing biomass is shown in Equation E-4 and between standing biomass of benthic invertebrates and fish biomass is shown in Equation E-5.

$$\log_{10}(FSB) = 0.708 \log_{10}(TP) + 0.774 \qquad (r^2 = 0.75,\ n = 18) \qquad \textbf{Eqn. E-4}$$

$$\log_{10}(FSB) = 5.692\ (M/z) + 28.7 \qquad (r^2 = 0.83,\ n = 20) \qquad \textbf{Eqn. E-5}$$

where:

FSB = total fish standing crop or biomass (kg/ha)

TP = total phosphorus (µg/L)

M/z = macrobenthos biomass (kg/ha) divided by mean lake depth (z) (meters)

Hanson and Leggett (1982) compared the predictions of Equation E-4 with Taylor's (1971) data on average TP and total fish biomass from five Tennessee Valley Authority reservoirs following rotenone poisoning. The comparison, presented in Exhibit E-6, produced a reasonable match.

Yurk and Ney (1989) examined the relationship between TP and standing stock of fish in 22 reservoirs in southern Appalachia sampled in 1973. The reservoirs ranged in surface area from 445 to 53,400 hectares, had TP concentrations ranging from 8 to 81 µg/L, with total fish biomass ranging from 3.4 to 232 g ww/m^2. Their logarithmic regression relating total fish standing crop or biomass (*FSB*) to *TP* is presented as Equation E-6.

$$log_{10}(FSB) = 1.07 + 1.14\ log_{10}(TP) \qquad (r^2 = 0.75,\ n = 22) \qquad \textbf{Eqn. E-6}$$

Predictions of total fish biomass from *TP* from the equation of Yurk and Ney (1989) are compared with the predictions from the equation of Hanson and Legget (1982) in Exhibit E-7. At intermediate TP concentrations, predictions of total fish biomass are similar between the two models.

Exhibit E-6. Reported Compared with Predicted Fish Biomass for Five Reservoirs

Reservoir	Average Total Phosphorus (µg/L)	Reported Fish Biomass (g ww/m^2)[a]	Predicted Fish Biomass (g ww/m^2)	Percent Predicted/Reported
Kentucky	270	28	26	92.5
Cherokee	160	23	19	83.9
Norris	20	15	11	73.3
Nottley	50	14.3	12.8	85.5
Douglas	110	12.5	16.4	131.2

[a]Total fish biomass following rotenone kill as reported by Taylor (1971).
Source: Hanson and Leggett (1982), Table 5; original units for biomass density = kg/hectare; changed to g wet weight biomass/m^2 by dividing by 10.

Exhibit E-7. Comparison of Predictions of Total Fish Biomass from Total Phosphorus (TP)

TP (µg/L)	Total Fish Biomass (g ww/m^2)	
	Hanson and Legget (1982)	Yurk and Ney (1989)
10	3.0	1.6
30	6.6	5.7
80	13.2	17.4
100	15.5	22.4
200	25.4	–
500	48.7	–

"–" indicates that TP is much higher than the TP range for data used to derive the model; thus, estimating fish biomass for those TP values with the Yurk and Ney (1989) model is not appropriate.

For a site-specific, refined risk assessment, one could use these regressions and measured TP concentrations in the lake(s) to predict total fish standing crop or biomass per unit area. For

Tiers 1 through 3 of the RTR screening risk assessment, however, we need to assume a single value for fish productivity per unit area where TP concentration is an unknown.

E.4.3 Measured Total Fish Standing Biomass

The empirical models provided in Section E.4.2 are based on lake data sets for which the original data are only partially published. In this section, we present some studies that measured total fish biomass in lakes of different sizes and from different climates. In reviewing studies of aquatic communities, we excluded data from the Great Lakes, because the size of those systems allows for substantially longer food chains and a more complete segregation between pelagic and benthic food webs than occurs in most freshwater ecosystems of North America. We also excluded lakes less than 5 hectares from our assessment, because they are unlikely to support stable fish communities and therefore generally are not evaluated for bioaccumulative chemicals.

In general, for small lakes in cold climates, relatively low fish productivity is likely. For example, Demers et al. (2001) found total fish standing biomass 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. Across 48 lakes in Newfoundland ranging in size from 3.56 hectares to 1,909 hectares, Cote et al. (2011) found that benthivorous salmonid biomass per unit area varied by more than an order of magnitude (minimum 0.045 g ww/m^2; maximum 1.0 g ww/m^2; mean: 0.40 g ww/m^2). Brook trout (*Salvelinus fontinalis*) biomass was almost 76 percent of total salmonids but varied by almost two orders of magnitude across lakes.

Brönmark and Weisner (1996) reported fish communities from 44 small ponds in southern Sweden (most were less than 5 hectares, or about 12 acres). All small ponds were dominated by periphyton (algae growing on rock surfaces), which was heavily grazed by freshwater snails. The TL3 fish consumed the snails. The piscivorous fish found in some ponds were all bottom feeders that ate both snails and small fish. Similarly, De Leeuw et al. (2003) found that most Scandinavian and Dutch lakes are dominated by benthivorous fish. The biomass and proportion of benthivores increased significantly with TP primarily due to increase of benthivorous bream (a species of sunfish/cyprinid) >25 cm in length.

The largest freshwater data set from more temperate climates of which we are aware is that of Leidy and Jenkins (1977). They analyzed 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 derived from data for 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 total fish biomass density was 41.3 (± 30.4 standard deviation) g ww/m^2 (Exhibit E-8).

Exhibit E-8. Total Fish Biomass in Reservoirs of the United States by Drainage Area

Drainage Area	Number of Reservoirs	Total Fish Biomass (g wet weight/m^2)	
		Mean	SD
Middle Atlantic	1	14.2	
Gulf and South Atlantic	9	18.3	6.2
Ohio Basin	13	26.4	16.3
Lower Mississippi	5	41.1	19.9

Drainage Area	Number of Reservoirs	Total Fish Biomass (g wet weight/m^2)	
		Mean	SD
Arkansas (Arkansas)	19	68.7	35.1
White (Arkansas)	6	33.4	8.4
Red (Arkansas)	6	30.9	24.6
Rio Grande and Gulf	1	28.3	
Missouri Basin	1	74.1	
All Reservoirs	61	41.3	30.4

Abbreviations: SD = standard deviation.
Source: Appendix B in Leidy and Jenkins (1977).

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 (Exhibit E-8). Thus, fish standing biomass per unit area in the reservoirs varied by more than three orders of magnitude.

The fish were sampled using rotenone poisoning of coves ranging in size from 1 to 5 acres after separating the coves from the reservoir using nets, similar to the method of Taylor (1971). To estimate the percentage of fish actually present that were recovered, marked fish were placed in the segregated coves prior to treatment with rotenone. In some cases, divers collected fish that did not float to the surface. All fish collected were identified to species and weighed. Most cove sampling was performed one time per year in August. Most reservoirs were sampled at least once for 2 or more years between 1952 and 1975, with some being sampled 10 to 20 years during that interval.

Leidy and Jenkins (1977) applied adjustment factors to correct for non-recovery bias (i.e., bottom fish that tend not to float to the surface; small fish that are not recovered) and habitat preference bias (i.e., fish that are more or less abundant in the coves compared with the open water). The combined adjustments for sampling bias ranged from a factor of 0.88 for sunfishes (cyprinids), which were over-represented by sampling in coves, to factors of 3.08 and 3.36 for catostomids and freshwater drum, respectively, which were estimated to be about 2.4 times more prevalent in the open water than in the coves. The use of adjustment factors for some species indicates the uncertainties in the data; however, unadjusted biomass estimates are very likely to be biased.

Exhibit E-9 summarizes the data on total fish biomass in reservoirs and lakes from the literature we reviewed. The table suggests that average fish biomass density for reservoirs, although quite variable, is generally higher than that for lakes. TP concentrations in the reservoirs might be higher on average than TP concentrations in the natural lakes; however, the data are insufficient to test that hypothesis for the studies reviewed. Reservoirs in general might support higher fish biomass densities for a given TP level than do natural lakes because of extensive littoral zones with macrophytes or high quantities of detritus to fuel the BI component of the aquatic food web.

Exhibit E-9. Total Fish Biomass Density in Reservoirs and Lakes from Different Studies

Water Body (Source)	N	Total Fish Biomass (g ww/m^2)				Mean TP (µg/L)
		Mean	Min	Max	Med.	
Reservoirs of the U.S. > 202 ha (a)	61	41.3	3.2	133	30.9	NR
Appalachian Reservoirs, U.S. (b)	22	64.2	3.4	232	55.0	32
DeGray Lake, Arkansas, U.S. (c)	1	7.5	–	–	–	NR
Ranger & Mouse Lakes, Ontario (d)	2	3.3	2.7	3.8	–	NR
Lakes in U.S. (e)	18	9.4	NR	NR	NR	NR

Abbreviations: NR = not reported; "–" indicates not relevant; TP = total phosphorus.
Sources: (a) Leidy and Jenkins (1977); (b) Yurk and Ney (1989); (c) Ploskey and Jenkins (1982); (d) Demers et al. (2001); (e) Randall et al. (1995) as reanalyzed by Nash et al. (1999).

To estimate 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 TP 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.

E.5 Proportion of Fish Biomass by Trophic Level

Much of the literature on fish communities comes from research on the effects of different trophic elements on aquatic food web structure and consequent productivity of fisheries. Several hypotheses have been developed over the years to explain relationships among trophic levels in lakes and rivers using fundamental ecological concepts.

E.5.1 Principles of Trophic Pyramids

As a "rule of thumb" in ecology, 10 percent 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) (UM 2016). With different species having different energy assimilation efficiencies, with fat providing approximately twice as many calories as muscle, and with smaller animal species generally having higher turnover rates than larger species, however, 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 TL4.5 fish).

Further complicating prediction of standing biomass at different trophic levels are the relationships among trophic groups. For example, a "classic" trophic cascade hypothesis associated with managing lakes for top-trophic-level fish predicts that increasing piscivore biomass in a lake will result in: (a) decreasing biomass of their prey, including planktivorous fish; (b) increasing biomass of zooplankton, and (c) decreasing biomass of phytoplankton (Carpenter et al. 1985; Carpenter and Kitchell 1996).

An alternative hypothesis about trophic structure is the "top-down/bottom-up" hypothesis, which predicts that the top-down effects of piscivores are strongest at the top of the food web, weakening in trophic groups closer to the primary producers, whereas the phytoplankton are most strongly influenced by nutrient availability (bottom-up). Drenner and Hambright (2002)

reported that as of 2002, over 1,900 reports had been published on the effects of fish in lakes. They reviewed 33 experiments and 6 surveys to test these hypotheses, of which only 17 did not include confounding factors. Of those, they concluded that 7 supported the trophic cascade hypothesis and 10 did not.

Drenner and Hambright (2002) found a general pattern of lower chlorophyll concentrations for given TP concentrations in systems containing piscivores (4-link systems) relative to systems with only planktivorous fish (3-link systems). The trophic cascade appears to work where herbivorous fish are dominated by small (vulnerable to predation) species rather than larger herbivores (e.g., shad, carp) that are not vulnerable to predation after reaching larger sizes.

Given the diversity of lake ecosystems and competing hypotheses for fish community structure by trophic level, we investigated two lines of evidence: models of fish biomass at different trophic levels (Section E.5.2) and measurements of fish biomass in different trophic groups (Section E.5.3). Bioenergetic simulation models of fish community structure are useful because a model can include several species, predator-prey relationships, and age/size classes at one time, using measured values to parameterize the model initially. Measurement of biomass at different trophic levels is difficult because different species and sizes of fish are best caught via different methods. Rotenone killing of all fish in a lake, which can yield the most accurate measurement, is feasible only in relatively small lakes or ponds and is wasteful.

E.5.2 Models of Fish Biomass in Different Trophic Groups

Of the recent models that simulate bioaccumulation of toxic chemicals in aquatic food webs identified in the literature search, the one that appeared most similar to the TRIM.FaTE approach in compartmentalizing the fish compartments of the food web is the Comprehensive Aquatic Systems Model (CASM, Version 2.0) developed for Quebec, Canada (DeAngelis et al. 1989). This detailed food-web model includes data sets that provide parameter values for four Canadian aquatic ecosystems: (1) northern lakes/reservoirs, (2) northern rivers, (3) southern lakes/reservoirs, and (4) southern rivers. Northern is defined as between 48° latitude and 55° latitude, and southern is defined as between 44° and 48° latitude. The parameterization of the model for “southern” locations would apply only to the more northern areas of the United States.

For each aquatic ecosystem, CASM includes three data sets derived from the primary literature: (1) data for the primary producer and consumer populations; (2) definitions of the grazing and predator-prey interactions (diet preferences and assimilation efficiencies); and (3) data on daily incident solar radiation, water temperature, and nutrient inputs. Using those three data sets, CASM can be used to estimate the baseline biomass values in 10 biotic compartments based on factors that affect primary productivity and trophic transfers.

Although CASM and its databases are not publicly available, Bartell et al. (1999) have published baseline biomass estimates in the open literature for a northern river and for a Florida lake. We totaled those biomass estimates for each compartment type and then determined the proportion of the total biomass represented in each compartment type, shown in Exhibit E-10 for the lake. The diets assigned to each species were not reported in the publications, so cannot be evaluated.

Exhibit E-10. Distribution of Standing Biomass Among Aquatic Compartments Simulated in the Comprehensive Aquatic Systems Model (CASM) for a Florida lake

Biotic Compartment	Total Biomass		Percent Biomass	
	g C/m^2	Percent	Animal	Fish
Phytoplankton	1.38	13	NA	NA
Periphyton	0.70	6	NA	NA
Macrophytes (e.g., *Elodea*, *Ceratophyllum*)	7.6	70	NA	NA
Zooplankton	0.07	1	0.06	NA
Benthic Invertebrates	0.44	4	0.39	NA
Pelagic Omnivore (e.g., shiners, sunfish)	0.263	2	0.23	0.42
Pelagic Piscivore (e.g., gar, pickerel)	0.059	1	0.05	0.10
Benthic Omnivore (e.g., bullhead, warmouth)	0.275	3	0.24	0.44
Benthic Piscivore (i.e., largemouth bass)	0.022	2	0.02	0.04

Note: We did not identify data for converting dry carbon to wet-weight biomass for the compartments listed.
Abbreviations: C = carbon, NA = not applicable.
Source: Bartell et al. (1999).

The lake clearly is dominated by macrophytes, including the invasive species from the aquarium trade, rooted or free-floating *Elodea* sp. and *Ceratophyllum* sp., which, unlike phytoplankton, grow in length without harvesting by most fish species (an exception is carp, which can consume both macrophytes). The macrophytes and plankton undoubtedly contribute to detritus in the benthos; however, Bartell et al. (1999) did not report the carbon content of detritus per unit area. The pelagic and benthic omnivores comprise 86 percent of the total fish biomass, while the pelagic and benthic carnivores comprise 14 percent of the total fish biomass. For a lake in Florida without large quantities of invasive macrophytes, the trophic pyramid might look substantially different.

Hossain et al. (2010) evaluated fish biomass and harvest rates for an oligotrophic lake (low productivity) in Southern Hokkaido, Japan (latitude 42°36´ N, longitude 140°51´ E). The lake is volcanic in origin, with surface area 70 km^2, maximum depth 179 m, and mean depth 116 m. A monomictic system, its annual average TP concentration is 3 µg/L and TN is 150 µg/L. Hossain et al. (2010) used the mass-balance modeling software Ecopath and Ecosim (EwE) (e.g., Christensen and Walters 2004, Christensen et al. 2005), built to simulate coastal fisheries, to investigate whether the level of fish harvests reported for the late 1990s (masu salmon harvest of 2.64 kg/km^2-year and sockeye salmon harvest of 24.45 kg/km^2-yr) are likely sustainable.

Exhibit E-11 lists the estimated biomass, trophic level, annual production/biomass ratio (except for detritus and organic matter), and the percentage of total fish biomass represented in each of their fish compartments. Values in Exhibit E-11 are in line with other estimates (see Exhibit E-1 and Section E.5.3): 5.8 percent of total fish biomass estimated at a trophic level higher than 4.0 (masu salmon, *Oncorhynchus masou*), 12 percent of adult sockeye salmon (*Oncorhynchus nerka*) estimated to be at TL3.75 in their model, and 81 percent of fish near TL3 (smelt, *Hypomesus transpacificus nipponensis*, and juvenile sockeye salmon). None of the fish groups are TL2; fish fry are probably represented in the zooplankton compartment. Difficulties interpreting these simulations, however, come from the continual stocking of salmon, fish harvesting above levels that might be sustainable for the sockeye salmon, the complex food web simulated, and migration of some of the fish into and from the lake (anadromous).

Exhibit E-11. Estimated Biomass by Aquatic Compartment in Lake Toya, Japan

Aquatic Compartment	Biomass (kg/km^2)	Biomass ($g\ ww/m^2$)	Trophic Level[a]	Production/ Biomass (kg/kg)	Percent Total Fish Biomass
Masu Salmon	22.7	0.023	4.12	0.54	5.8%
Adult Sockeye Salmon	45.5	0.046	3.75	0.33	12%
Juvenile Sockeye Salmon	14.1	0.014	3.16	1.72	4%
Japanese Smelt	303	0.30	3.17	1.24	77%
Other Fish	5.8	0.0058	3.07	1.50	1.5%
Shrimp	5.9	0.0059	2.27	1.83	NA
Amphipods	136	0.14	2.32	6.0	NA
Insects	110	0.11	2.11	4.2	NA
Zooplankton	162	0.16	2.05	33.5	NA
Phytoplankton	50.2	0.050	1	365	NA
Organic Materials	2000	2.0	1	NA	NA
Detritus	1000	1.0	1	NA	NA

Abbreviation: NA = not applicable.
[a]Trophic level estimated by Hossain et al. (2010) given the food web they characterized.
Source: Hossain et al. (2010).

Exhibit E-11 does illustrate well, however, the relatively low standing biomass of phytoplankton (0.050 g ww/m^2) compared with the other compartments but its very high annual productivity (365 g/g production/standing biomass) and turnover rates compared with other aquatic compartments. Zooplankton shows the next highest annual productivity rate (33.5 g/g), even though its standing biomass (0.16 g ww/m^2) is less than that of the smelt (0.3 g ww/m^2), which produce 1.24 g/g annually.

Rather than work further with fish biomass and production simulation models, which require substantial data and are not readily transparent, we investigated measurements of fish biomass in different trophic groups (see Section E.5.3).

E.5.3 Measured Biomass of Fish in Different Trophic Groups

A popular measure of fish productivity for game fish species across lakes is the angler effort required to catch each fish (or catch per unit effort, CPUE). The measure, used in numerous studies (e.g., Gorman et al. 2014; Quiros 1990), provides valuable information for commercial and recreational fisheries applications. It, however, does not provide information on the numeric "trophic pyramid" in lakes or the relative standing biomass of each trophic group needed for TRIM.FaTE modeling. Specifically, CPUE usually misses the smaller fish and untargeted species.

A key difficulty with sampling lakes for total standing fish biomass and for fish biomass at different trophic levels is capturing and measuring the fish in the first place (see Section E.4.3). Some lakes have been sampled by killing with rotenone all fish in a lake, which then can be collected and measured. This practice is feasible for relatively small lakes for which state fish and game officials might want to start the lake's trophic structure "over"; however, for larger lakes, it is both impractical and wasteful. Other approaches to making an inventory of fish standing stock include combinations of seine fishing, electroshocking, and other methods;

however, each includes some biases against certain species and age-classes that require "correction factors" (e.g., based on total kill inventory methods) or at least acknowledgment of the possible magnitude and direction of biases (Leidy and Jenkins 1977).

Leidy and Jenkins (1977) estimated the biomass of fish supported by various food compartments in the 61 reservoirs included in their survey (Exhibit E-12). Only reservoirs at least 500 acres (202 hectares) in size were included. They did not separate the piscivorous fish species (i.e., the biomass of fish supported by "Fish" in Exhibit E-12) by benthic or pelagic feeding habits. We pulled the data in Exhibit E-12 from Appendix G in Leidy and Jenkins (1977).

Exhibit E-12. Carrying Capacity, Biomass (g ww/m^2) of Fish Supported by Each Food Compartment Across 61 Reservoirs by Drainage Area

Drainage Area	Plants & Detritus	Benthic Inverts.	Zoo-plankton	Fish	Terrest. Inverts.	Total
Gulf and South Atlantic	5.12	3.77	0.55	2.77	0.45	12.67
Green and Cumberland Rivers and Dewey Reservoir	10.60	6.03	1.61	3.09	0.39	21.74
Lower Mississippi Valley	11.54	4.81	4.89	6.77	0.31	28.36
Blue Mountain, Nimrod, and Wister Reservoirs	22.64	8.53	16.03	9.26	0.33	56.72
Arkansas River Basin	25.78	9.63	6.50	7.79	0.44	50.10
Red River Basin	9.01	7.32	0.46	4.40	0.84	22.08
White River Basin	10.46	7.32	2.01	3.43	0.48	23.65
Average	13.59	6.77	4.58	5.36	0.46	30.76
Standard Deviation	7.59	2.05	5.53	2.57	0.18	16.27

Abbreviations: Terrest. Inverts. = terrestrial invertebrates, primarily insects that lay eggs at the water surface or that fall into the reservoir from emergent and terrestrial plants.
Source: Appendix G in Leidy and Jenkins (1977).

We calculated from Exhibit E-12 that, on average, 18 percent of the fish biomass across the 61 reservoirs they examined was piscivorous (minimum of 14 percent and maximum 24 percent, including both benthic and pelagic species; see bold values in Exhibit E-13).

Exhibit E-13. Proportion of Total Carrying Capacity, Proportion Fish Biomass Supported by each Food Compartment by Drainage Area

Drainage Area	Plants & Detritus	Benthic Inverts.	Zoo-plankton	Fish	Terrest. Inverts.	Total
Gulf and South Atlantic	0.40	0.30	0.04	0.22	0.04	1.00
Green and Cumberland Rivers and Dewey Reservoir	0.49	0.28	0.07	0.14	0.02	1.00
Lower Mississippi Valley	0.41	0.17	0.17	0.24	0.01	1.00
Blue Mountain, Nimrod, and Wister Reservoirs	0.40	0.15	0.28	0.16	0.01	1.00
Arkansas River Basin	0.51	0.19	0.13	0.16	0.01	1.00

Drainage Area	Plants & Detritus	Benthic Inverts.	Zoo-plankton	Fish	Terrest. Inverts.	Total
Red River Basin	0.41	0.33	0.02	0.20	0.04	1.00
White River Basin	0.44	0.31	0.08	0.15	0.02	1.00
Average	0.44	0.25	0.12	**0.18**	0.02	
Standard Deviation	0.05	0.07	0.09	0.04	0.01	
Minimum	0.40	0.15	0.02	**0.14**	0.01	
Maximum	0.51	0.33	0.28	**0.24**	0.04	
Median	0.41	0.28	0.08	0.16	0.02	

Source: Calculated from Exhibit E-12; data from Appendix G in Leidy and Jenkins (1977).

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 declined to less than 20 percent. The piscivores included both benthic and pelagic species. We note that most benthic piscivores also consume benthic macroinvertebrates.

Scharf (2008) evaluated the biomass of top predatory fish (TL4 to TL4.5, pike > 20 cm, pikeperch > 40 cm) in a large, deep stratifying reservoir in Germany (Exhibit E-14). Scharf found that over the 20 years of the reservoir's existence, the standing biomass of those fish never exceeded 10 percent of total fish biomass despite stocking and protection efforts. We assigned a TRIM.FaTE compartment (WCC, WCO, WCH, BC, BO) or combination of two compartments to describe the feeding habitat of each fish age/size-class and species and assigned a likely trophic level to each age/size-class based on our experience with estimating fish trophic levels (U.S. EPA 2000). Those compartments and trophic levels also are listed in Exhibit E-14. Our estimate is that the WCC compartment of fish at TL4.5 is 3.4 percent of the total fish biomass and that the combined WCC/BC TL3.5 (perch > 16 cm) is 17.6 percent of the total fish biomass.

Based on data from the reservoir over 20 years, Scharf (2008) concluded that introduction of pikeperch in 1988, which became self-reproducing, helped release perch from competition, which allowed perch to grow larger than >16 cm. At this size, they can consume other fish and become more abundant, accounting for 17.6 percent of the total fish biomass.

Exhibit E-14. Total Fish Biomass by Trophic Level in Wupper Reservoir, Germany

Fish Age-class and Species	Compartment Trophic Level[a]	Biomass Density		Individual Abundance	
		kg ww/ha	Percent	Individuals/ha	Percent
Total Fish Biomass	NA	93.6	100	4025	100
Piscivorous Fish Biomass (large pike, pikeperch, perch)	NA	25.7	27.5	NA	NA
Total Fish Biomass without YOY	NA	79.4	100	NA	NA
Piscivorous Fish Biomass	NA	25.7	32.4	NA	NA
Pike > 20 cm in length	WCC 4.5	0.5	**0.5**	1	0.02

Fish Age-class and Species	Compartment Trophic Level[a]	Biomass Density		Individual Abundance	
		kg ww/ha	Percent	Individuals/ha	Percent
Pikeperch YOY (<12 cm)	WCH 2.5	0.2	0.2	30	–
Pikeperch (12 to 40 cm)[b]	WCO 3.5	2.3	2.7	15.5	–
Pikeperch >40 cm	WCC 4.5	2.7	**2.9**	2.5	–
Perch YOY (<10 cm)	WCH 2	12.5	13.4	2.24	56
Perch 1-yr old (10 to <16 cm)	WCO 3	18.6	19.9	677	17
Perch older (>16 cm)	WCC/BC 3.5	16.5	17.6	90	2.2
Cyprinids YOY	WCH 2	1.7	1.8	374	9.3
Cyprinids 1-yr old	WCH 2.5	7	7.5	296	7.4
Cyprinids older (>16 cm)	WCO/BO 3	28.1	30	292	7.3
Eel (benthic carnivore)	BC 3.5	3.5	3.7	6	–
Total of Age Classes		94	100%	1834	100%
Water Column Carnivore (WCC)	4.5	3.2	3.4	NA	NA
Water Column Carnivore/Benthic Carnivore (WCC/BC) (except eels)	3.5	18.8	17.6	NA	NA
Water Column Omnivore (WCO/BO)	3.0	46.7	52.6	NA	NA
Water Column Herbivore (WCH)	2.0–2.5	21.4	22.9	NA	NA
Benthic Carnivore (BC) (eel)	3.5	3.5	3.7	NA	NA

Abbreviations: "–" not calculated in Scharf (2008) because body weight distribution across age classes uncertain; NA = not applicable (body size varies); YOY = young-of-year (from hatching to <1 yr).

[a]We assigned trophic levels to the group based on general feeding characteristics.

[b]Pikeperch 12 cm to <40 cm in length calculated from row for total pikeperch minus the smaller and larger pikeperch in Table 1 of Scharf (2008).

Source: Scharf (2008), Table 1.

We investigated other studies of fish biomass in lakes; however, most had limitations that meant we could not use them to estimate biomass distribution across fish trophic levels. Moreover, a disproportionate number of studies are for areas with colder climates than most of the continental United States, for which we expect total fish standing biomass to be less than the value of 5.7 g ww/m^2 used for the state of Maine. We list three examples below.

Post et al. (2008) estimated the carrying capacity of south-central British Columbia lakes to be 500 rainbow trout per hectare based on other studies. Individual trout body weight, however, was not reported.

Examining 78 lowland lakes in Germany, Emmrich et al. (2011) found that lake area is positively correlated with the number of fish size classes, with a wider range of fish body size, and with more of the larger sized fish in larger lakes. Raw data were not reported.

For 31 lakes in Newfoundland, Cote et al. (2011) reported a mean brook trout biomass of 0.474 g ww/m^2 (range 0.069–1.01 g ww/m^2) and a mean total salmonid biomass of 0.54 g ww/m^2 (range 0.113–1.01 g ww/m^2).

To summarize, several studies of fish biomass by trophic level indicate that top-trophic-level fish, combining pelagic and benthic carnivorous fish, might comprise approximately 20 percent of the standing fish biomass in many lakes. Ploskey and Jenkins (1982) estimated that piscivorous fish, both those that are generally free swimming or pelagic (e.g., pike, gar, walleye, TL4.5) and those that forage primarily in the benthos (e.g., various species of catfish, suckers, TL3.5) comprise 22 percent of the total fish biomass in DeGray Lake, Arkansas (averaged across several years). Using data from 122 lakes in Europe and North America, Håkanson and Boulion (2004) estimated 27 percent piscivorous fish biomass/total fish biomass for oligotrophic and mesotrophic lakes, declining to 20 percent in lakes with more than 100 µg/L TP. We interpret the data from Leidy and Jenkins (1977) as indicating 18 percent (range 14–24 percent) of the total standing fish biomass in reservoirs to be piscivorous fish (pelagic and benthic). Finally, Scharf (2008) provided data suggesting that 21 percent of the total standing fish biomass represented piscivores, with only 3.4 percent pelagic piscivores (WCC) at TL4.5.

E.5.4 Conclusion

Based on the studies listed above, we assume that 3.5 percent of fish standing biomass is in the WCC compartment for purposes of TRIM.FaTE modeling and for simulating angler harvest of WCC from lakes. The remaining distribution of biomass across biotic compartments in TRIM.FaTE, as presented in Exhibit E-2, also is consistent with the data presented here.

E.6 Derivation of Lake Sizes for Sustainable WCC Harvest

As stated in Section E.1, this attachment provides supporting information for Section 3.3.1 of the TSD—Accounting for Sustainable Fishing. To develop the screening scenarios with an angler, we needed to address two questions. Question 1—*How large does a lake need to be to provide a self-sustaining population(s) of top-trophic-level fish?*—is answered in Section E.6.1. Question 2—*How much fish can be harvested sustainably from lakes of different sizes?*—is answered in Section E.6.2.

E.6.1 Minimum Lake Size for Self-sustaining Population of WCC

As stated in Section E.3.3, we assume that at least 50 adult breeding WCC are needed for a self-sustaining population of WCC in an isolated lake. We derive the minimum lake size from two equations: Equations E-7 and E-8. The standing biomass of WCC in a lake is calculated using Equation E-7. The assumption that the WCC fish compartment represents approximately 3.5 percent of the total fish standing biomass was documented in Section E.5.

$$WCC\_SB = Total\_SB \times Fraction\_WCC \qquad \textbf{Eqn. E-7}$$

WCC_SB = Standing biomass of WCC fish (g ww/m^2)

Total_SB = Total standing biomass of all fish (g ww/m^2)

Fraction WCC = Fraction WCC fish biomass of total fish biomass (i.e., 0.035)

Using *WCC_SB* calculated from Equation E-7 and the size of the lake (*Lake_Size*), the total number of WCC fish supported in the lake is calculated using Equation E-8:

$$Number\_WCC = (Lake\_Size \times WCC\_SB \times CF_1)/BW_{WCC} \qquad \textbf{Eqn. E-8}$$

where:

Number_WCC = Total number of adult breeding WCC fish in lake

Lake_Size = Size of lake (acres)

WCC_SB = Standing biomass of WCC fish (g ww/m^2; from Equation E-7)

CF_1 = Unit conversion factor (4047 m^2/acre)

BW_{WCC} = Body weight of adult WCC fish (2000 g ww per individual; assumed)

Based on those two equations, we created a matrix that predicted the *Number_WCC* in a lake as a function of both fish biomass per unit area and the overall lake size in Exhibit E-15. The first vertical column presents the range of total fish biomass found by Leidy and Jenkins (1977) across 61 reservoirs in the United States. The interval between total fish biomass values from one row to the next is not monotonic; finer resolution is provided for the less productive lakes. The second vertical column in Exhibit E-15 presents the corresponding range of WCC biomass estimates assuming that WCC comprises 3.5 percent of the total fish biomass. The remaining columns in Exhibit E-15 present lakes of increasing size (from left to right). Again, the interval in lake size from one column to the next is not monotonic; finer resolution is presented for the smaller lakes. The numbers in each cell of Exhibit E-15 are the number of individual WCC fish predicted for each combination of total fish biomass and lake size.

In Exhibit E-15, all combinations of lake productivity and overall size that would *not* support a population of at least 50 WCC fish are shaded in gray. All combinations of lake productivity and size that might support 500 or more WCC fish, and therefore might be self-sustaining for a century or more, are highlighted in yellow. The unshaded cells represent the number of WCC between 50 and 500 individuals (2 kg each) that might be sustainable for an angler's lifetime.

Exhibit E-15. Number of WCC Adult Fish Supported by Lake Size (surface area in acres) and by Total Fish Biomass (TFB)

TFB	WCC	Number of Adult Water-column Carnivores (WCC) (by lake surface area from 1 to 250 acres)																						
(g ww/m^2)		1	2	3	4	5	7.5	10	15	25	35	40	50	60	70	80	90	100	125	150	175	200	225	250
2	0.070	0	0	0	1	1	1	1	2	4	5	6	7	8	10	11	13	14	18	21	25	28	32	35
3	0.105	0	0	1	1	1	2	2	3	5	7	8	11	13	15	17	19	21	27	32	37	42	48	53
4	0.140	0	1	1	1	1	2	3	4	7	10	11	14	17	20	23	25	28	35	42	50	57	64	71
5.7	0.200	0	1	1	2	2	3	4	6	10	14	16	20	24	28	32	36	40	50	61	71	81	91	101
10	0.350	1	1	2	3	4	5	7	11	18	25	28	35	42	50	57	64	71	89	106	124	142	159	177
15	0.525	1	2	3	4	5	8	11	16	27	37	42	53	64	74	85	96	106	133	159	186	212	239	266
20	0.700	1	3	4	6	7	11	14	21	35	50	57	71	85	99	113	127	142	177	212	248	283	319	354
30	1.05	2	4	6	8	11	16	21	32	53	74	85	106	127	149	170	191	212	266	319	372	425	478	531
35	1.225	2	5	7	10	12	19	25	37	62	87	99	124	149	174	198	223	248	310	372	434	496	558	620
40	1.40	3	6	8	11	14	21	28	42	71	99	113	142	170	198	227	255	283	354	425	496	567	637	708
50	1.75	4	7	11	14	18	27	35	53	89	124	142	177	212	248	283	319	354	443	531	620	708	797	885
60	2.10	4	8	13	17	21	32	42	64	106	149	170	212	255	297	340	382	425	531	637	744	850	956	1062
70	2.45	5	10	15	20	25	37	50	74	124	174	198	248	297	347	397	446	496	620	744	868	992	1115	1239
80	2.80	6	11	17	23	28	42	57	85	142	198	227	283	340	397	453	510	567	708	850	992	1133	1275	1416
90	3.15	6	13	19	25	32	48	64	96	159	223	255	319	382	446	510	574	637	797	956	1115	1275	1434	1594
100	3.50	7	14	21	28	35	53	71	106	177	248	283	354	425	496	567	637	708	885	1062	1239	1416	1594	1771
110	3.85	8	16	23	31	39	58	78	117	195	273	312	390	467	545	623	701	779	974	1169	1363	1558	1753	1948
120	4.20	8	17	25	34	42	64	85	127	212	297	340	425	510	595	680	765	850	1062	1275	1487	1700	1912	2125
130	4.55	9	18	28	37	46	69	92	138	230	322	368	460	552	644	737	829	921	1151	1381	1611	1841	2072	2302

Fish standing biomass for all fish (TFB) and for the WCC fish are provided in the first two columns. The TFB spans 2 to 130 acres in line with Leidy and Jenkins's (1977) estimates of total fish standing biomass per unit area across 61 reservoirs in the United States. The total standing biomass for WCC fish = TFB * 0.035.

Grey shaded area indicates that 50 or fewer WCC fish would be supported at the specified combination of lake size (acres) and TFB. Clear cells represent numbers of individual WCC fish that might be sustainable for an angler's lifetime of 50 to 70 years for lakes of different productivities and size. Yellow cells have populations of WCC that exceed 500, which might be self-sustaining for a century or more.

Note: Exhibit E-16 and Exhibit E-17 retain the same cell shading as Exhibit E-15, which presents the number of individual WCC that might be supported by the combinations of TFB and lake size. Each WCC fish weighs 2 kg.

Exhibit E-16. Total Standing Biomass of WCC Fish (kg) by Lake Size and Total Fish Biomass (TFB)

TFB	WCC	Total Standing Biomass of Water-column Carnivores (WCC) (kg) (by lake surface area from 1 to 250 acres)																						
(g ww/m^2)		1	2	3	4	5	7.5	10	15	25	35	40	50	60	70	80	90	100	125	150	175	200	225	250
2	0.070	0	1	1	1	1	2	3	4	7	10	11	14	17	20	23	25	28	35	42	50	57	64	71
3	0.105	0	1	1	2	2	3	4	6	11	15	17	21	25	30	34	38	42	53	64	74	85	96	106
4	0.140	1	1	2	2	3	4	6	8	14	20	23	28	34	40	45	51	57	71	85	99	113	127	142
5.7	0.200	1	2	2	3	4	6	8	12	20	28	32	40	48	57	65	73	81	101	121	141	161	182	202
10	0.350	1	3	4	6	7	11	14	21	35	50	57	71	85	99	113	127	142	177	212	248	283	319	354
15	0.525	2	4	6	8	11	16	21	32	53	74	85	106	127	149	170	191	212	266	319	372	425	478	531
20	0.700	3	6	8	11	14	21	28	42	71	99	113	142	170	198	227	255	283	354	425	496	567	637	708
30	1.050	4	8	13	17	21	32	42	64	106	149	170	212	255	297	340	382	425	531	637	744	850	956	1062
35	1.225	5	10	15	20	25	37	50	74	124	174	198	248	297	347	397	446	496	620	744	868	992	1115	1239
40	1.40	6	11	17	23	28	42	57	85	142	198	227	283	340	397	453	510	567	708	850	992	1133	1275	1416
50	1.75	7	14	21	28	35	53	71	106	177	248	283	354	425	496	567	637	708	885	1062	1239	1416	1594	1771
60	2.10	8	17	25	34	42	64	85	127	212	297	340	425	510	595	680	765	850	1062	1275	1487	1700	1912	2125
70	2.45	10	20	30	40	50	74	99	149	248	347	397	496	595	694	793	892	992	1239	1487	1735	1983	2231	2479
80	2.80	11	23	34	45	57	85	113	170	283	397	453	567	680	793	907	1020	1133	1416	1700	1983	2266	2550	2833
90	3.15	13	25	38	51	64	96	127	191	319	446	510	637	765	892	1020	1147	1275	1594	1912	2231	2550	2868	3187
100	3.50	14	28	42	57	71	106	142	212	354	496	567	708	850	992	1133	1275	1416	1771	2125	2479	2833	3187	3541
110	3.85	16	31	47	62	78	117	156	234	390	545	623	779	935	1091	1246	1402	1558	1948	2337	2727	3116	3506	3895
120	4.20	17	34	51	68	85	127	170	255	425	595	680	850	1020	1190	1360	1530	1700	2125	2550	2975	3399	3824	4249
130	4.55	18	37	55	74	92	138	184	276	460	644	737	921	1105	1289	1473	1657	1841	2302	2762	3222	3683	4143	4603

Note: Each WCC fish is assumed to weigh 2 kg. The total fish standing biomass used in TRIM.FaTE was 5.7 g ww/m^2 (see Exhibit E-2). Total fish standing biomass of 40 g ww/m^2 (red text) used to assess angler behavior is based on the mean fish standing biomass for 61 reservoirs of 41 g ww/m^2 (Leidy and Jenkins 1977). With a WCC proportion of the total fish biomass of 0.035, the assumed WCC standing fish biomass for the screen is 1.4 g ww/m^2. For example, a 25-acre pond (101,175 m^2) might support an annual average standing biomass of 142 kg WCC at a total fish biomass of 40 g ww/m^2.

E.6.2 Maximum Fish Ingestion Rate by Lake Size

The likely annual productivity of WCC fish (kg/year) in a lake is estimated using Equation E-9.

$$Productivity\_WCC = (Lake\_Size \times WCC\_SB \times CF_1)/CF_2 \qquad \textbf{Eqn. E-9}$$

where:

Productivity_WCC = Likely annual productivity of WCC fish (kg/year)
Lake_Size = Size of lake (acres)
WCC_SB = Standing biomass of WCC fish (g ww/m^2; from Equation E-7)
CF1 = Unit conversion factor 1 (4047 m^2/acre)
CF_2 = Unit conversion factor 2 (1000 g/kg)

The maximum daily fish ingestion rate (g/day) for fillet of WCC plus BC associated with sustainable fishing can be predicted using Equation E-10. The equation assumes the angler consumes 50 percent WCC and 50 percent BC, represented by the factor of 2 in Equation E-10:

$$Max\_IR_{(BC+WCC)} = 2 \times (Productivity\_WCC \times FF \times HF \times CF_1)/CF_2 \qquad \textbf{Eqn. E-10}$$

where:

$Max\_IR_{(BC+WCC)}$ = Predicted maximum sustainable ingestion rate for BC and WCC fish (g/day)
Productivity_WCC = Annual productivity of WCC fish in the lake (kg/year; from Equation E-9)
FF = Fillet fraction; represents the assumed edible portion of fish (0.33; unitless)
HF = Annual harvest fraction (0.10; unitless)
CF_2 = Unit conversion factor 2 (1000 g/kg)
CF_3 = Unit conversion factor 3 (365 days/year)

Exhibit E-17 lists the fish-fillet-ingestion rates that could be supported for each combination of lake productivity (standing fish biomass per unit area) and lake size. Exhibit E-17 is similar to Exhibit 26 in the TSD, except that a different series of lake sizes is presented in the columns. *At the assumed total fish standing biomass of 40 g ww/m^2, the ingestion rate of fish fillet (including both WCC and BC fish in a 50:50 ratio) supported by a lake is approximately 1 gram per day per acre. With this assumption, the angler needs to fish from at least 373 acres of lake to support a fish-fillet-ingestion rate of 373 g ww/day.*

Exhibit E-17. Estimated Maximum Fish-fillet-ingestion Rate (g/day) Associated with Sustainable Fishing of WCC by Lake Size and Total Standing Fish Biomass (TFB)

TFB	WCC	Maximum Fish-fillet-ingestion Rate (g/day) for a Diet of 50% BC Plus 50% WCC Fish (by lake surface area from 1 to 250 acres)																					
(g ww/m^2)		1	2	3	4	5	7.5	10	15	25	35	40	50	60	70	80	90	100	125	150	175	200	225	250
2	0.070	0	0	0	0	0	0	1	1	1	2	2	3	3	4	4	5	5	6	8	9	10	12	13
3	0.105	0	0	0	0	0	1	1	1	2	3	3	4	5	5	6	7	8	10	12	13	15	17	19
4	0.140	0	0	0	0	1	1	1	2	3	4	4	5	6	7	8	9	10	13	15	18	20	23	26
5.7	0.200	0	0	0	1	1	1	1	2	4	5	6	7	9	10	12	13	15	18	22	26	29	33	36
10	0.350	0	1	1	1	1	2	3	4	6	9	10	13	15	18	20	23	26	32	38	45	51	58	64
15	0.525	0	1	1	2	2	3	4	6	10	13	15	19	23	27	31	35	38	48	58	67	77	86	96
20	0.700	1	1	2	2	3	4	5	8	13	18	20	26	31	36	41	46	51	64	77	90	102	115	128
30	1.050	1	2	2	3	4	6	8	12	19	27	31	38	46	54	61	69	77	96	115	134	154	173	192
35	1.225	1	2	3	4	4	7	9	13	22	31	36	45	54	63	72	81	90	112	134	157	179	202	224
40	1.40	1	2	3	4	5	8	10	15	26	36	41	51	61	72	82	92	102	128	154	179	205	231	256
50	1.75	1	3	4	5	6	10	13	19	32	45	51	64	77	90	102	115	128	160	192	224	256	288	320
60	2.10	2	3	5	6	8	12	15	23	38	54	61	77	92	108	123	138	154	192	231	269	307	346	384
70	2.45	2	4	5	7	9	13	18	27	45	63	72	90	108	126	143	161	179	224	269	314	359	403	448
80	2.80	2	4	6	8	10	15	20	31	51	72	82	102	123	143	164	184	205	256	307	359	410	461	512
90	3.15	2	5	7	9	12	17	23	35	58	81	92	115	138	161	184	207	231	288	346	403	461	519	576
100	3.50	3	5	8	10	13	19	26	38	64	90	102	128	154	179	205	231	256	320	384	448	512	576	640
110	3.85	3	6	8	11	14	21	28	42	70	99	113	141	169	197	225	254	282	352	423	493	563	634	704
120	4.20	3	6	9	12	15	23	31	46	77	108	123	154	184	215	246	277	307	384	461	538	615	692	768
130	4.55	3	7	10	13	17	25	33	50	83	117	133	166	200	233	266	300	333	416	499	583	666	749	832

Note: We assume a 10% sustainable WCC fish harvest rate for the values in Exhibit E-13. Those values divided by 365 days/year = kg fish harvested/day. Multiplied by 0.33 edible fraction = kg fish fillet/day for one person. The BC fish are more abundant; therefore, if the angler can consume 0.013 kg WCC fish/day, the angler also can consume 0.013 kg BC fish/day. Thus, at a total fish standing biomass of 40 g ww/m^2, a 25-acre lake can support ingestion of 26 g total fish fillet/day (see Equations E-9 and E-10), or 1 g total fish fillet can be harvested per lake acre.

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Appendix 7 Protocol for Site-Specific Multipathway Risk Assessment

Protocol for Developing a TRIM.FaTE Model Scenario to Support a Site-specific Multipathway Risk Assessment in the RTR Program

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CONTENTS

TABLES

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1. Introduction

This document presents a protocol for developing TRIM.FaTE scenarios in support of site-specific multipathway risk assessments conducted within the Risk and Technology Review (RTR) program using the TRIM.FaTE environmental fate-and-transport model.

This section describes the regulatory context, intended purpose of the protocol, the scope and limitations of the protocol, and some caveats to its use. It also presents a road map to the content and structure of this document.

1.1 Regulatory Context and Approach to Risk Assessment for PB-HAPs

Section 112 of the Clean Air Act (CAA) directs the U.S. Environmental Protection Agency (EPA) to assess the risk remaining (residual risk) from emissions of hazardous air pollutants (HAPs) following the implementation of maximum achievable control technology (MACT) standards for emission sources. Such risk assessments for various emission source categories are a major component of EPA's RTR program.

To evaluate multipathway exposures and human health risks for RTR on a source category basis, EPA currently employs an iterative approach. The approach enables EPA to confidently screen out emissions of persistent and bioaccumulative HAPs (PB-HAPs) unlikely to pose health risks above levels of concern and to focus additional resources on sources of greater concern within the category.

Three models are used to estimate multipathway exposure and multipathway risk in the RTR program, as noted below.

- AERMOD is EPA's preferred near-field dispersion model for regulatory applications, and EPA uses it for RTR site-specific multipathway assessments to model the transport of pollutants in air and subsequent dry and wet deposition to soil, plant surfaces, and water.
- EPA uses the Fate, Transport, and Ecological Exposure module of EPA's Total Risk Integrated Methodology (TRIM.FaTE) to model the fate and transport of pollutants deposited to soil, plant surfaces, and water.
- EPA uses the RTR multimedia ingestion risk estimation methodology[1] to estimate transfer and uptake into the farm food chain and exposure to receptors consuming contaminated fish, farm foods, and soil. A subset of media-concentration estimates from AERMOD and TRIM.FaTE serve as inputs for estimating risk, which also depends on other exposure and biotransfer-related input parameters. (This document focuses on the TRIM.FaTE modeling with inputs from AERMOD).

The RTR approach to multipathway assessments is divided into four steps of increasing refinement, which are described below.

1. Tier 1 of the approach identifies facility-level emissions of PB-HAPs within a source category and compares them to the screening threshold emission rates.

2. Tier 2 uses the actual location of the facility emitting PB-HAPs to refine a subset of the assumptions associated with the modeled Tier 1 environmental scenario while maintaining the Tier 1 multipathway exposure-scenario assumptions.

3. Tier 3 uses Web searches on local lakes to determine their fishability and suitability for the approach, and it also uses facility stack parameters and local hourly meteorology to estimate the impacts on potential exposure from plume rise and hour-by-hour variations in meteorological conditions.

[1]The multimedia ingestion risk estimation methodology used for RTR risk assessments is discussed in detail in Attachment B of Appendix 6 to the Risk Report.

4. The final step, for facilities that cannot be screened out based on the Tiers 1–3 screens, is to conduct a more refined, site-specific multipathway risk assessment. A site-specific risk assessment (the subject of this Protocol document) is intended to 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. Site-specific risk assessments require more time and resources to complete than the screens. Unlike the screens, site-specific assessments utilize AERMOD to conduct air-dispersion and deposition modeling of chemical emissions, the results of which are input into TRIM.FaTE.

The methodology that EPA employs for the Tiers 1–3 screening is documented in *Technical Support Document for the TRIM-Based Multipathway Tiered Screening Methodology for RTR*, which is an appendix to the Risk Report.

1.2 Purpose of this Protocol

The site-specific protocol presented in this document is intended to serve as a guiding framework to set up and parameterize scenarios in TRIM.FaTE that support accurate and cost-effective site-specific risk assessments as part of the RTR framework.

The purpose of the protocol is to develop a standard set of guidelines and recommendations for conducting site-specific assessments, providing a streamlined and replicable framework for configuring and parameterizing the TRIM.FaTE model. The protocol aims to balance modeling accuracy with cost-effectiveness in implementation, and to facilitate consistency and transparency across diverse assessments. This protocol is also intended to function as part of the technical documentation for site-specific residual risk assessments by providing a clear and transparent description of the approach to parameterization and some of the relevant sources. Deviations from this protocol would need to be documented on a case-by-case basis.

1.3 Scope and Limitations

The site-specific protocol presented in this document focuses on the fundamental aspects of setting up a scenario in TRIM.FaTE from an RTR perspective. While the *TRIM.FaTE User's Guide* (U.S. EPA 2005) provides guidance on the mechanistic aspects of designing a simulation, the protocol focuses on identifying best practices that optimize model set-up efficiency while maintaining a high level of model precision in the RTR context. Chemical uptake into the farm food chain, average daily doses from ingestion of contaminated media, and subsequent health risks are calculated using the RTR multimedia ingestion risk estimation methodology and are not discussed here[1].

These best practices have been developed with a focus on the impact of alternative model-configuration and model-parameterization approaches on multipathway risk in the RTR process. Thus, if two alternative model-configuration approaches are estimated to have similar impacts on risk estimates in the RTR process, the protocol will recommend the less effort-intensive approach where appropriate. For instance, the protocol identifies only a limited set of TRIM.FaTE model properties as requiring site-specific parameterization, while proposing land-use-specific or nationally representative or health-protective values for others based on the finding that relatively few model parameters substantially influence risk in the RTR context.

However, the protocol is not driven exclusively by considerations of cost-effectiveness. In some instances, the protocol aims to provide superior methods of model configuration based on model accuracy and scientific considerations that were previously not clearly articulated in available TRIM.FaTE guidance and that have a focus on the RTR program.

This protocol is not step-by-step guide to running the model. It is not intended to serve as a substitute for the *TRIM.FaTE User's Guide* (U.S. EPA 2005) or the *TRIM.FaTE Technical Support Document* (U.S. EPA 2002), but it is recommended that the protocol be read in conjunction with those documents to provide a holistic perspective on how the model should be used in site-specific RTR applications.

1.4 Caveats

The findings and recommendations presented in this document are subject to the caveats given below.

- Some of the conclusions presented in this protocol are based on a combination of available empirical evidence, theoretical considerations, and expert judgment. A "brute-force" empirical approach to test an extensive range of scenarios and parameters was not feasible.
- For some model parameters, ICF relied on sensitivity analyses performed on previous configurations of the model. It is possible that the results of previous sensitivity analyses differ somewhat from the current Tier 1 screen model configuration.
- ICF did not test the sensitivity of model parameters in alternative model configurations.
- ICF did not research and identify land use-specific parameter values for soil properties values as part of this protocol, although it recommends their use.

Despite these limitations, the current recommendations are expected to meet the objectives of providing a cost-effective and accurate approach to site-specific multipathway risk assessment in the RTR program. However, users are encouraged to extend site-specific model design and parameterization beyond the levels proposed here as circumstances permit.

1.5 Protocol Road Map

This protocol contains

- best practices for TRIM.FaTE model configuration for use in site-specific RTR applications;
- documentation of the rationale for best-practice recommendations;
- nationally representative or health-protective model parameter values for site-specific applications of TRIM.FaTE; and
- documentation on using AERMOD deposition outputs in TRIM.FaTE.

These distinct elements are woven together in the structure noted below.

- Section 2 sets the context with a summary of TRIM.FaTE input files and their content.
- Section 3 discusses the model's meteorological data requirements, potential data sources, approaches to address missing data, data-processing requirements, and the issue of plume rise.
- Section 4 presents recommendations and rationale for best practices for designing air and surface parcels in TRIM.FaTE.
- Section 5 presents methodology for air-dispersion modeling in AERMOD and incorporation of deposition outputs into TRIM.FaTE.
- Section 6 presents recommendations and rationale for best practices for defining surface hydrology and erosion parameters required by TRIM.FaTE.
- Section 7 identifies parameters recommended for site-specific parameterization.
  - Section 7.5 identifies parameters recommended for land-use specific parameterization.
  - Section 7.6 identifies parameters recommended for national-default parameterization.
- Section 8 discusses potential future improvements and enhancements to the protocol.

2. A Brief Introduction to TRIM.FaTE Input Requirements

TRIM.FaTE is a spatially and temporally explicit multimedia environmental fate-and-transport model that estimates the concentrations of emitted chemicals in biotic and abiotic environmental media. The model uses a compartmental box-model approach to track the movement of chemicals in environmental media. The model is based on representing environmental media as compartments, moving chemical mass between interacting compartments consistent with a set of governing mathematical algorithms that describe physical and chemical processes in the environment, and assuming instantaneous mixing within each compartment.

2.1 TRIM.FaTE Input Files and Contents

TRIM.FaTE requires a variety of inputs from users to define the modeled environment and to quantify the various environmental mass-transfer processes. These inputs are provided to the model in the form of the files noted below.

- A "volume elements" file defines the spatial layout of the modeled domain in terms of three-dimensional abiotic compartments. Each volume element provides a frame of reference for one or more biotic compartments within it.
- A "compartments" file places biotic and abiotic compartments (modeling units containing chemical mass) within the volume elements.
- A "library" file contains all the model algorithms, properties, and emission-source information. Examples of the kinds of properties that are defined in the library file include
  - scenario characteristics (e.g., start/stop time, modeling time parameters, output options);
  - source characteristics (e.g., chemicals emitted, location, emission rate);
  - chemical-specific properties, including physiochemical (e.g., molecular weight, K_{ow}) and abiotic (e.g., degradation half-life);
  - nonchemical-specific characteristics of biota (e.g., body weight, food intake rate);
  - site-specific ecological setting data and characteristics of biota (e.g., type of species present, population and density information, food web relationships); and
  - abiotic environmental setting data such as abiotic media characteristics (e.g., air/water content of soil, pH of surface water, suspended sediment density), runoff/erosion fractions for adjacent surface soil compartments, and water flow between connected surface water compartments.
- A properties file typically contains: (i) simulation- and site-specific property values that are used to overwrite default library values, and (ii) the location of time-varying input files for parameters such as meteorological and vegetation parameters.

For RTR site-specific applications of TRIM.FaTE, EPA uses AERMOD to model the air dispersion of facility emissions and subsequent chemical deposition, rather than the simpler air-transport and deposition algorithms used in TRIM.FaTE (that is, TRIM.FaTE is run without a facility emission rate). The rationale for this is provided in Section 5.

The input files listed above must be developed using syntax that is consistent with TRIM.FaTE requirements. Further detail on the required syntax of the input files, and the process of setting up and running the model using these input files, is available in the *TRIM.FaTE User's Guide* (U.S. EPA, 2005). Supplemental input files are generated that set up AERMOD deposition rates as emission sources for TRIM.FaTE; further details on these input files can be found in Section 5 and Appendix B.

Much of the challenge in a site-specific TRIM.FaTE application lies in designing a spatial layout that is consistent with the nature of the governing algorithms and that reflects the environmental dynamics of the

modeled domain, researching and estimating numerous environmental properties that serve as inputs into the model, finding and preparing appropriate meteorological and climate-related data, and setting up the input files. The following sections discuss the optimal methods of performing these tasks from the perspective of a site-specific RTR application.

2.2 Recommended Sequence of Activities for TRIM.FaTE Set Up

The following sections of this document focus on various aspects of TRIM.FaTE set up as discrete elements in the model-configuration process. There are, however, interconnections between the research required to guide various components of the set-up process. Although there are no firm rules governing the order in which the model's input files must be developed, this protocol recommends the sequence of activities numbered below as a means to enhance efficiency and accuracy in the model-configuration process.

1. Perform qualitative spatial analyses of topography, aerial imagery, hydrography (boundaries of watersheds, flow lines), and land cover around the site. This will aid in identifying meteorology data, modeled lakes and farms or potential farmland, potential residences where home gardening might occur, and the shape of the model domain.

2. Identify meteorological data based on RTR considerations (e.g., what meteorology did the RTR inhalation risk assessment use for the site?), data availability, data quality, and the representativeness of the data and instrument siting with respect to the modeled facility. Create the meteorological file needed for modeling.

3. Identify lakes to model based on lakes evaluated in the Tier 2 screen, lake size, and a preliminary assessment of risk potential and data availability.

4. Identify farms or potential farmland and/or home gardens to model based on a preliminary assessment of risk potential and data availability.

5. Create the modeling spatial layout, including a receptor grid for AERMOD to calculate air concentrations and deposition rates.

6. Run AERMOD with chemical-specific properties and source characteristics to get receptor-specific air concentrations and deposition rates.

7. Estimate and define surface hydrology and erosion dynamics within the layout.

8. Gather data on site-specific properties per the protocol.

9. Generate TRIM.FaTE input files, including the supplemental files that set up surface-deposition rates transformed from AERMOD deposition outputs.

10. Run TRIM.FaTE.

3. Meteorological Data Development

RTR site-specific multipathway assessments use AERMOD to model the air dispersion and deposition to the ground of chemicals emitted by the facility (see Section 5), and then TRIM.FaTE models the re-suspension and re-deposition of chemical (which typically affects a small fraction of the chemical initially deposited) as well as the chemical transfer between terrestrial and aquatic media. Both models in general are highly sensitive to meteorological parameters such as wind speed, wind direction, mixing height, and rainfall rate, among others, and to the interactive effects between those parameters (see U.S. EPA 2009 for a sensitivity analysis for TRIM.FaTE). However, with this configuration of TRIM.FaTE using outputs of AERMOD, meteorological parameters have a greater impact on the results of AERMOD modeling (on the

air transport and initial deposition of facility emissions) than on TRIM.FaTE modeling (on chemical re-suspension and re-deposition, and transfer through compartments).

For these reasons, it is recommended that all meteorological parameters for AERMOD be site-specific at an hourly resolution (averaging to coarser time steps can obscure real trends in the data). For consistency, the TRIM.FaTE meteorological parameters should match those of AERMOD.

The development of meteorological data for the AERMOD modeling should follow established EPA guidance, and the selected surface and upper-air meteorological stations typically should match those used for the facility in the RTR inhalation assessment (which are typically the stations closest to the facility). This section discusses best practices in reformatting the data used in the AERMOD modeling for use in TRIM.FaTE.

TRIM.FaTE meteorology data must include the fields in Table 3-1. The TRIM.FaTE meteorology data file does not require hourly time steps (larger time steps will shorten model run time), although hourly data are used in site-specific assessments.

Table 3-1. Meteorological Parameters Required for Meteorology Input File for TRIM.FaTE

Parameter	Format	Units	Further Description and Notes
Date	M/D/YYYY	NA	NA
Hour	Numeric	NA	NA
Time Zone	e.g., “EST”	NA	NA
Horizontal Wind Speed	Numeric	m/s	NA
Wind Direction	Numeric degrees	degrees clockwise from north; blowing from	e.g., from north is 360 degrees; from east is 90 degrees; from south is 180 degrees; and so on. 0 degrees is reserved for calm winds (e.g., wind speed = 0 m/s), which cannot be used in TRIM.FaTE (minimum wind speed for TRIM.FaTE is 0.75 m/s).
Air Temperature	Numeric	K	NA
Mixing Height	Numeric	m	NA
Rain Rate	Numeric	m/day	NA
Cumulative Rain	Numeric	m	Total precipitation in a precipitation event. A multi-hour event will have equal cumulative rainfall values for each hour.
Is Day	Boolean (i.e., 1 or 0)	NA	Daytime (value of 1; after sunrise) or nighttime (value of 0; after sunset). Calculated using U.S. EPA’s SR-SS.exe program, available with TRIM.FaTE.

The AERMOD meteorology file produces two different calculations of mixing height—one based on convective turbulence, the other based on mechanically-generated turbulence. For use in TRIM.FaTE, these values should be condensed to one mixing height per hour: during convective conditions (when

sensible heat flux is positive) it should be the larger of the two values from the AERMOD meteorology file, and during all other times it should be the mechanical mixing height.

TRIM.FaTE requires that there be no missing data in its meteorology fields. U.S. EPA's recommended guidance for replacing missing meteorology data (U.S. EPA 1992) has a series of objective data replacement steps as a first pass, but those steps might not fill in all missing data. The guidance suggests some subjective procedures for filling in remaining missing data; however, these are manual steps and do not cover all possible cases of missing data (e.g., if more than a few contiguous hours of data are missing). A meteorologist or experienced air quality modeler should perform these subjective data-fill procedures. The user should expect that the quality of substituted values will be worse for longer contiguous periods of missing data versus only a few contiguous hours of missing data. However, as long as the amount of data originally missing is no more than 10 percent, and as long as the substituted values are not out of normal bounds, then substituted data will have only a small impact on modeling results—especially for RTR assessments where (1) AERMOD models primary air dispersion and deposition and (2) the desired TRIM.FaTE outputs are final accumulated media concentrations after several decades of modeling.

ICF developed a tool (AERMET2TRIM), based in Microsoft® Access™, that uses the meteorology file from the AERMOD modeling, fills in missing data in all meteorology fields needed by TRIM.FaTE (based on methods from U.S. EPA 1992), and reformats the data into the format required by TRIM.FaTE. Previous site-specific assessments conducted using TRIM.FaTE typically have used 50-year modeling periods, so the reformatting performed by AERMET2TRIM includes duplicating the one- or several-year meteorology file into a 50-year data period. For example, if the meteorology data represent years 2013–2016, that four-year period is repeated to create 50 years of data (e.g., 1990–2039).

If TRIM.FaTE time steps greater than 1 hour are desired (though not recommended), the user should aggregate the data to conform to the time step. Values of wind speed, air temperature, mixing height, and rain rates should be averaged. For wind direction, the hourly values of wind speed and wind direction should be used to calculate the vector components of the wind (u and v values), those vector components should be averaged, and the averaged vectors should be used to calculate the average wind direction. Calculate new cumulative rain values after averaging the rain rates. Use professional judgment to determine appropriate values for the "Is Day" parameter.

4. Air and Surface-parcel Design

4.1 The Role of Spatial Layouts in TRIM.FaTE

One of the primary inputs required by the TRIM.FaTE model is the specification of a spatial layout using Cartesian coordinates to define the vertices of surface and air parcels and volume elements. This information is input into the model via the "volume elements" input file. To construct the volume elements input file, users are required to divide the modeled domain into two-dimensional air parcels and surface parcels. Air parcels need not line up with surface parcels in all cases. Each parcel is also associated with a height, which may vary in time. The parcel coordinates and height are combined to define three-dimensional abiotic volume elements that contain biotic and abiotic compartments used to model the movement of chemical mass in TRIM.FaTE.

In a site-specific multipathway assessment, the spatial layout should capture the features of interest (farms, home gardens, and/or lakes) at the surface level and also specify how the overlying air domain is to be divided to produce accurate and informative estimates. Although the *TRIM.FaTE User's Guide* (U.S. EPA 2005) provides useful mechanistic guidelines and rules of thumb on the design of air and surface parcels, those recommendations are not specific to the RTR context and are not based on a multipathway risk perspective. The following guidelines, as noted in the introduction to this document, are intended to support site-specific multipathway risk assessments in the RTR program (utilizing AERMOD estimates of air dispersion and deposition of facility emissions) and should be considered in addition to the instructions and recommendations provided in the *TRIM.FaTE User's Guide* and *TRIM.FaTE Technical Support Document* (U.S. EPA 2002).

4.2 Recommended Best Practices for Air- and Surface-parcel Design

The following recommendations for air- and surface-parcel design are intended to maintain a high degree of modeling accuracy while reducing design effort and potentially optimizing computer run time. While these guidelines are intended to facilitate optimal parcel design, every scenario is unique and might require site-specific adjustments beyond the suggested approach provide here.

Step 1: Identify Features of Interest

Several steps are recommended for identifying features of interest, as described below.

- Use geospatial data (e.g., aerial imagery, data on watersheds and water bodies, and remotely-sensed land cover and crop growth) to identify features of potential interest from the RTR perspective, such as farms and lakes.
    - Geospatial data can include Google Earth (Google 2013), the National Hydrography Dataset (USGS 2013), the National Land Cover Database (MRLC 2013), and the Cropland Data Layer (USDA 2013).
- Use the guidance below to finalize the selection of lakes, gardens, and farms for modeling.
    - Features should be within 50 km of the emitting facility.
    - Prefer features closer to the emission source versus those farther away.
    - Prefer features that are frequently downwind from the emission source, if they exist, based on the meteorology data selected for modeling.
    - Prefer features that potentially receive elevated levels of chemical input via runoff and erosion from surrounding areas.
    - Prefer lakes for which preliminary research suggests good availability of modeling data (e.g., flush rates, depth, pH, total phosphorus levels, suspended sediment concentration).
    - Prefer the lake(s) selected in the Tier 2 and Tier 3 screens (all of which are between 25 and 100,000 acres in size).
    - Prefer features that are not very close to other features.
    - Hypothetical home gardens are most appropriately modeled at potential residential locations.

Draw a simplified surface-parcel polygon for each feature, reasonably capturing its true or intended surface area and location while minimizing unneeded complexity (complex feature boundaries will increase model run time while typically not improving modeling accuracy in a significant way).

Step 2: Identify Areas Potentially Impacting Features of Interest

Use geospatial data (elevation contours and watershed boundaries) to identify areas potentially providing non-negligible amounts of chemical runoff and erosion to the features of interest. These areas will include watersheds or sub-watersheds in which the features are located, as well as watersheds or sub-watersheds upslope from those features. These impacting areas should be within 50 km of the emitting facility.

Draw simplified surface-parcel polygons for these impacting areas. It is typically appropriate that they be delineated along watershed or sub-watershed boundaries, which the U.S. Geological Survey (USGS) or other agencies have estimated based on local elevation contours and water-body features that define the flow of rainfall and surface water across the local region. Because TRIM.FaTE requires that surface parcels be characterized based on land cover, it may also be appropriate to further subdivide the polygons based on primary land cover. These polygons should use appropriately simplified boundary definitions to minimize unneeded complexity.

Step 3: Draw Air Parcels

To improve the accuracy of TRIM.FaTE-modeled chemical re-suspension and re-deposition, it is recommended that the air parcels be co-located with surface parcels. This is chiefly important for the features of interest. If model run time is of concern, then air parcels away from the features of interest may be larger than the underlying surface parcels; professional judgment should be used in these cases, as fewer and larger air parcels will degrade the accuracy of calculations of re-suspension and re-deposition.

5. Air Modeling Using AERMOD

AERMOD (the AMS/EPA Regulatory Model) is the preferred model for near-field (less than 50 km) dispersion and it is used in RTR inhalation assessments. Its calculations of chemical air dispersion and deposition are more sophisticated than those of TRIM.FaTE; therefore, RTR site-specific multipathway assessments use AERMOD outputs as inputs into TRIM.FaTE.

5.1 Rationale for AERMOD Deposition Inputs

AERMOD uses a Gaussian plume approach based on a mathematical solution of the advection-dispersion equation with numerous meteorological, thermodynamic, and terrain considerations to calculate air concentrations. The model then calculates deposition using calculated or user-provided deposition velocities; calculated velocities are based on information about meteorological parameters, land cover, viscosities, resistances, particle sizes and densities (for particulate deposition), and pollutant-specific properties (for vapor deposition). It then computes deposition as the product of air concentration and deposition velocity. AERMOD assumes instantaneous steady-state concentrations and is not mass balanced.

The transfer factors in TRIM.FaTE are similar to the algorithms used by AERMOD for some types of deposition. TRIM.FaTE is a dynamic (non-steady-state), system-wide mass-balanced model. AERMOD and TRIM.FaTE are based on very different theoretical assumptions. Although the deposition factors translating air concentrations into deposition rates are approximately similar in some respects, the models are based on entirely different methods of computing air concentrations. Furthermore, in AERMOD, the user defines the particulate- and vapor-phase speciation in the emissions stream (and this distribution is assumed to remain constant during dispersion). By contrast, TRIM.FaTE phase speciation is computed within each air compartment based on chemical equilibration between the solid, aqueous, and air phases of the air compartments. Therefore, it is reasonable to conclude that overall net deposition is computed in very dissimilar ways by AERMOD and TRIM.FaTE.

The pseudo-source method, detailed in this section and Appendix B, combines air-deposition estimates from AERMOD with the surface modeling capabilities of TRIM.FaTE. The method introduces mass deposited from the air (based on AERMOD estimates) directly into the underlying soil, water, and vegetation compartments in the TRIM.FaTE model. Small amounts of chemical re-suspension from the surface, and subsequent re-deposition, are captured by the TRIM.FaTE algorithms; there is potentially a mass-imbalance issue with this approach, although it remains to be evaluated if it involves a significant loss of accuracy.

5.2 AERMOD Deposition Modeling

For the selected facilities of interest, AERMOD is used to estimate deposition rates for input into TRIM.FaTE. AERMOD modeling is completed using guidance from the Guideline on Air Quality Models, also published as Appendix W of 40 CFR Part 51, to determine model set up and application including

- four years of recent, representative meteorological data—the same surface meteorology data used to develop the meteorology file for TRIM.FaTE;
- local terrain elevations for sources and receptors;

- chemical properties and information collection request (ICR) emissions data specific to PB-HAPs of concern; and
- use of urban dispersion-modeling settings when appropriate.

5.2.1 AERMOD Receptor Grid

Deposition rates are calculated for a grid of receptors covering all surface parcels being utilized in TRIM.FaTE. The receptors may use uniform or non-uniform spacing between points. All TRIM.FaTE surface parcels should have at least one corresponding AERMOD receptor; parcels larger than about 1 acre should have at least two AERMOD receptors, and receptor spacing should not exceed 1,000 m.

5.3 Incorporating AERMOD Results into TRIM.FaTE

AERMOD produces deposition estimates for each receptor within a TRIM.FaTE surface compartment. AERMOD deposition rates are calculated on an hourly basis by the model, and then the model aggregates across the entire simulation period to produce a period-total deposition rate (g/m^2/period) for each modeled receptor. To aggregate these outputs for input to TRIM.FaTE, an average deposition rate for each TRIM.FaTE surface parcel is computed from the receptor estimates within each parcel. Area-weighted averages are used to ensure that varying receptor densities between and within parcels are properly accounted for. The units are converted to g/m^2/day for use in TRIM.FaTE (which assumes constant deposition with time).

In order to apply AERMOD average deposition rates directly to soil, plants, and surface water in TRIM.FaTE, several modifications to the model scenarios and libraries are required. A "pseudo-source" is created for each surface parcel to represent the deposition rate for the parcel as derived from AERMOD modeling, with an emission rate (in units g/day) equal to the product of the parcel surface area (m^2) and the spatially averaged deposition rate (g/m^2/day). Separate pseudo-sources are created for each deposition type: wet and dry, vapor-phase and particulate. In this way, the TRIM.FaTE processes of air transport and deposition are replaced by "emissions" directly into surface soil, plant, and surface water compartments. More details on how to input AERMOD deposition values in TRIM.FaTE can be found in Appendix B.

It should be noted that outputs from AERMOD also are used in the multimedia ingestion risk estimation methodology algorithms to estimate exposure and risk. Among other parameters, chemical air concentrations above features of interest and chemical-deposition rates to those features of interest are used. When site-specific RTR multipathway risk assessments use AERMOD for primary dispersion and deposition modeling, the values of air concentration and deposition in TRIM.FaTE reflect only the chemical re-suspended and re-deposited within TRIM.FaTE. Parcel-average AERMOD air concentrations must be calculated and included in estimating exposure and risk, and the parcel-average AERMOD deposition rates input to TRIM.FaTE must also be included in the equations used to estimate exposure and risk.

6. Surface Hydrology and Erosion Property Definitions

6.1 Surface-parcel Chemical Transfer Dynamics in TRIM.FaTE

The TRIM.FaTE model incorporates the ability to account for chemical transfers between adjacent surface parcels via runoff and erosion. The algorithms that model surface runoff and erosion in TRIM.FaTE simulate the advective chemical transfer dynamics between surface parcels without requiring spatial elevation information or land cover details as inputs. Instead, the algorithms depend on inputs explicitly specifying the destination of erosion and runoff from a specific parcel. In other words, for each surface parcel, users must specify the proportion of the erosion and runoff originating in that parcel that reaches specific adjacent parcels. These inputs are known as link properties in TRIM.FaTE and are typically specified in the TRIM.FaTE "properties" file discussed in Section 2. Users must also separately specify the average runoff and erosion rate for each surface parcel. These inputs are combined internally

with estimates of the chemical concentration in surface soil and soil water to estimate mass transfers that occur in conjunction with erosion and runoff processes.

The inter-parcel runoff and erosion parameter inputs in TRIM.FaTE are inherently site-specific because there is no logical default value for the percentage of runoff and erosion from one parcel that reaches an adjacent parcel. Simulations indicate that multipathway risk in the RTR process is sensitive to the choice of these values (refer to Appendix A). This section discusses options for parameterizing these inputs in site-specific TRIM.FaTE applications for RTR.

For users not having access to (or expertise in using) geographical information systems (GIS) software with features to quantitatively analyze surface hydrology and erosion, the recommended method of estimating parcel-to-parcel runoff/erosion fractions is summarized in Section 6.2. If sophisticated GIS software with features to analyze surface hydrology and erosion based on elevation is to be used, the recommended method is summarized in Section 6.3.

6.2 Estimating Runoff and Erosion Fractions without Sophisticated GIS Software

Without a license for sophisticated GIS software, the user can still obtain free GIS viewing tools that allow the user to display multiple layers of geospatial data and that have limited interaction with the data, including querying the data and measuring distances. With such viewing software, the method for estimating runoff/erosion fractions provided in Module 11 of the *TRIM.FaTE User's Guide* (U.S. EPA 2005) is appropriate. This method is summarized briefly here, with some additional tips not provided in the User's Guide.

Step 1: Assemble Hydrological and Elevation Data

The user should obtain geospatial data indicating boundaries of hydrological units relevant to the modeling domain. These hydrological data are available from the USGS National Hydrography Dataset (NHD; USGS 2013). These hydrography data should already have been obtained and used to inform the design of the modeling parcels. The NHD offers several levels of hydrological units, typically from regions (the most spatially coarse) to sub-watersheds (typically the highest spatial resolution). Considering that the typical site-specific TRIM.FaTE modeling domain has a radius less than 50 km and is divided into several surface parcels, watersheds or sub-watersheds will usually offer the most appropriate resolution for use in configuring parcels and estimating runoff/erosion fractions. The NHD also offers directional flow lines of streams, rivers, and other hydrographic features.

The user should also obtain elevation data for the modeling domain. High resolution data are available from the USGS National Elevation Dataset (NED; USGS 2006). These elevation data should already have been obtained and used to help construct the modeling parcels. The data with the highest spatial resolution are not necessary; 30-m resolution usually is appropriate.

Step 2: Relate Model Surface Parcels to Each Other and to Hydrological Units

The user should display the modeling surface parcels along with the appropriate hydrologic unit boundaries from the NHD. For each parcel ("sending parcel"), follow the steps below.

1. For each hydrologic unit that occupies at least part of the sending parcel, estimate (or calculate, if able) the ratio [surface area of the part of the hydrologic unit that is inside the sending parcel] to [surface area of the sending parcel].

2. Identify each neighboring parcel ("receiving parcel"), including sinks where appropriate for the sides of the sending parcel that lie along the outer boundary of the modeling.

3. For each hydrologic unit that occupies at least part of the sending parcel, estimate or calculate the length of each interface between the hydrologic unit and each receiving parcel (not discussed in the *TRIM.FaTE User's Guide*).

4. Estimate or calculate the fraction of the sending parcel's perimeter that interfaces with each receiving parcel (not discussed in the *TRIM.FaTE User's Guide*).

Step 3: Estimate Fraction of Runoff and Erosion

For each hydrologic unit that occupies at least part of a sending parcel, one should use NED elevation data and NHD flow lines to estimate the fraction of runoff that will flow from the hydrologic unit into each receiving parcel and, where appropriate, into sinks outside the modeling domain. A fraction might be 0 if the elevation and flow lines suggest that all water in the hydrologic unit flows away from a receiving parcel.

The *TRIM.FaTE User's Guide* (U.S. EPA 2005) Section A.5 discusses runoff/erosion fractions. Although not discussed there, the NHD flow lines can help estimate the relative distribution of runoff from a sending parcel to its receiving parcels, or from a hydrologic unit in the sending parcel to a receiving parcel. One can examine the flow lines along each sending-receiving boundary to get a sense how much of the boundary has flows from the sending area to the receiving area. This information can be combined with information on how much of the sending area's perimeter interfaces with the receiving area in question, aiding the user in developing runoff/erosion fractions.

As discussed in the *TRIM.FaTE User's Guide* Sections A.5 and A.6—separately for each hydrologic unit in a sending parcel, multiply [the fraction of sending parcel's area covered by the hydrologic unit] by [the runoff/erosion fraction from the hydrologic unit to the receiving parcel] for each of the sending parcel's receiving parcels. Then, for each of these receiving parcels, sum this product across the hydrologic units. This sum provides the final fraction of runoff/erosion from each sending parcel to each receiving parcel. For each sending parcel, the fractions will sum to 1 when sinks are included as appropriate.

Another option is to estimate the runoff and erosion fractions based on visual inspection. This approach does not explicitly relate the area of each hydrologic unit to each sending parcel. Therefore, it does not explicitly assume that water cannot cross the boundaries of hydrologic units. Like the methods described above, this option uses flow lines and the interfacial length between adjacent parcels. In this option, for each sending parcel, the user visually examines the NHD flow lines to see where (if at all) flow lines cross each interfacial boundary and into the receiving parcels. For each sending-receiving pair of parcels, the user should estimate (or measure, if possible) the length of the part of the interfacial boundary that has flow lines crossing into the receiving parcel. Then, divide that length by the total perimeter length of the sending parcel. This ratio provides the fraction of runoff/erosion from the sending parcel into the receiving parcel. Some professional judgment is required to subjectively adjust these fractions based on the relative magnitude of runoff across the various interfacial boundaries. These relative magnitudes can consider the overall terrain and flow patterns throughout the sending parcel (a flow into the receiving parcel with a relatively small fetch will likely carry less chemical into the receiving parcel than a flow with a relatively long fetch).

6.3 Estimating Runoff and Erosion Fractions with Sophisticated GIS Software

The method discussed in this section requires the use of ESRI® ArcGIS™ software. The software license must enable the "Spatial Analyst" extension.

In ArcGIS, select the "Flow Direction" tool of the "Spatial Analyst" extension. Given a raster elevation dataset (such as the NED), this tool will determine the flow direction of each raster cell to the steepest downhill neighboring raster cell. The output of this tool will be a raster, where the value of each raster cell will indicate the flow direction.

Then, select the "Flow Accumulation" tool of the "Spatial Analyst" extension. The input to the "Flow Accumulation" tool is the output of the "Flow Direction" tool described above. Separately for each input raster cell, the "Flow Accumulation" tool will follow the flow direction into the appropriate neighboring cell, and continue following the flow direction of that cell into a third cell, and so on, "connecting the dots" of the flow vectors until an endpoint is reached. This creates flow lines across the raster. Then, the tool

calculates the number of these flow lines that cross each raster cell. This is the "flow accumulation" number produced by this tool. The flow accumulation is unitless, as it does not represent an actual amount of water or chemical flowing from one place to another; the accumulation values should be viewed relative to each other.

For each sending parcel, the user would use the combination of flow-direction and flow-accumulation data from the above tools to calculate the total flow (unitless) from the sending parcel to each receiving parcel. The runoff/erosion fraction from the sending parcel into receiving parcel "A" would be the accumulated flow from the sending parcel to receiving parcel "A" divided by the total accumulated flow from the sending parcel to all its receiving parcels.

7. Developing Values of Compartment Properties

7.1 The Role of Properties in TRIM.FaTE

The TRIM.FaTE model is dependent on hundreds of user-specified properties that describe the biotic and abiotic environments being modeled. Properties in TRIM.FaTE can be broadly divided into the types listed below.

- Nonchemical-specific properties that define biotic compartments (e.g., biomass of game fish in a lake, the length of a leaf on a deciduous plant).
- Nonchemical-specific properties that define abiotic compartments (e.g., porosity of surface soil, the total suspended solids concentration in a lake).
- Chemical-specific properties (including system-wide chemical properties such as the Henry's Law constant, the octanol-water partition coefficient, and compartment-specific chemical properties such as reaction and degradation rate constants in various environmental media).
- Simulation-specific properties (e.g., model run time, model time step).

All user-defined (e.g., non-formula) properties in a TRIM.FaTE scenario can be assigned simulation- or site-specific values. In theory, the more properties that are assigned site-specific values, the more accurately the simulation will represent chemical fate and transport at that location. Following this logic, the user should try to find site-specific values for as many properties as possible. However, although each model property is potentially important in defining a particular environmental fate-and-transport process, it is apparent based on theoretical considerations and empirical evidence (analysis of model results and model evaluations) that there is a subset of model properties that more significantly influences the environmental concentrations that drive the risks of importance in the exposure scenarios evaluated in RTR assessments. The fact that some parameters are more influential on results is true for complex models in general. This is the focus of sensitivity analyses.

In previous site-specific risk assessments using TRIM.FaTE, which were conducted for RTR and in other regulatory applications, a substantial portion of the level of effort required to perform the assessments was directed toward site-specific property parameterization. One of the specific objectives of this protocol is to take advantage of the results of sensitivity analyses and model evaluations conducted of TRIM.FaTE. Based on these results, we have identified those compartment properties that are a high priority for site-specific parameterization, those that can be adequately represented by regional or land-use-specific default values, and those for which nationally representative or health-protective values are adequate. This classification scheme is intended to reduce the level of effort required to adequately parameterize site-specific multipathway assessments while maintaining a high level of accuracy in risk estimates for RTR.

7.2 Approach to Prioritizing Properties for Site-specific Parameterization

ICF relied on a combination of theoretical reasoning and empirical evidence to prioritize TRIM.FaTE properties for the purposes of this protocol. In this way, ICF was able to limit the need for "brute-force"

empirical evaluations (e.g., comprehensive sensitivity analyses that systematically vary all or most of the user-defined inputs, such as those conducted prior to the 2009 EPA Science Advisory Board review of RTR assessments (U.S. EPA 2009)) and additional resource-intensive literature searches. ICF's justification for determining that properties were ***not*** high priority was based on the three lines of evidence discussed below.

1. ICF followed a **"process"-based approach** to rule out a large subset of TRIM.FaTE properties from the need for site-specific parameterization. This approach was founded on the idea that the TRIM.FaTE model produces greater than necessary resolution (in terms of the number of concentrations that are calculated for different environmental media types) when viewed from the RTR perspective. The individual human multipathway exposure scenarios evaluated for RTR rely most directly on results from TRIM.FaTE for surface soil compartments at the location of a farm or garden and fish compartments in a lake of interest. All fate-and-transport processes—and the properties that exclusively define those processes—that do not strongly influence these concentrations can reasonably be ruled out from requiring site-specific parameterization. The implications of this approach will be discussed in greater detail below.

2. ICF also used practical considerations regarding **data availability** to rule out certain properties from site-specific parameterization. Over the course of numerous site-specific assessments and the parameterization of the screening scenarios, ICF has conducted literature searches on numerous TRIM.FaTE properties. ICF used the insight gained from these exercises to identify certain sets of parameters as being too data-scarce to parameterize on a site-specific basis at this time without expending a substantial amount of time and money (for possibly uncertain results).

3. **Physical constants and physicochemical properties** of the modeled PB-HAPs were also ruled out from site-specific parameterization based on their largely unchanging nature in the environment for the chemicals considered for RTR.

ICF evaluated the parameters not eliminated by the above considerations to determine which properties should be the focus of data collection efforts during site-specific TRIM.FaTE modeling for RTR. ICF conducted a limited number of evaluations and used the results of previous sensitivity analyses to decide which of these shortlisted parameters should be prioritized for site-specific parameterization, for land-use-based parameterization, or for regional parameterization.

Other scenario properties, such as emission period and the model's numerical integration time step, are typically not varied between site-specific assessments.

7.3 Elimination of Properties from Site-specific Parameterization

7.3.1 Process-based Elimination of Parameters

The operative principle in the process-based elimination of parameters is that fate-and-transport processes that do not substantially influence concentrations of interest from an RTR perspective are less important to parameterize. ICF used theoretical considerations based on the evaluation of the underlying TRIM.FaTE algorithms, combined with empirical evidence from TRIM.FaTE simulations, to identify the less important fate-and-transport processes and eliminate the need to parameterize those processes on a site-specific basis. The specific processes identified as being of less importance in the RTR context and the underlying justification for ruling them out from site-specific consideration are listed below:

- Chemical transported via water percolation through the sub-surface soil layers (not including surface soil) does not affect surface soil or lake water concentrations. Theoretical considerations suggest that chemical, once transported into the lower soil layers, will not substantially make its way back to the surface compartments of interest.

- Chemical transport via sub-surface soil diffusive processes, although having the potential to transfer mass upwards, is not sizeable in comparison to advective transfer processes. An evaluation of relative mass rate in the Tier 1 screen supports this assertion for all the chemicals evaluated.
- Chemical transport to the lake via horizontal groundwater flow and recharge is negligibly small compared to other advective chemical inputs into the lake. The relative mass rate for this process compared to other advective transfer processes carrying chemical into the lake in the Tier 1 screening scenario supports this assertion for all chemicals evaluated.

Because the RTR user has no intrinsic interest in the concentrations prevailing in the lower soil layers, all of the above processes have been ruled out from consideration for site-specific parameterization. As a consequence, it is possible to rule out all sub-surface soil compartment properties from requiring site-specific parameterization.

7.3.2 Data Availability-based Elimination of Parameters

Chemical-Specific Aquatic Biota Properties: The aquatic biota compartments in TRIM.FaTE—currently including benthic invertebrates and five types of fish—are characterized by several potentially site-specific properties that control algorithms influencing the uptake, degradation, and elimination of chemicals in the aquatic organisms. These chemical-specific properties include the absorption rates of chemical into each type of fish from surface water, elimination rates from fish digestive systems, degradation rates within the fish, and other parameters. In the course of parameterizing TRIM.FaTE for the screens and conducting extensive evaluations of parameter sensitivity, it has become apparent that only a limited number of studies are available for several of these properties for most combinations of chemicals and organisms.

Although these properties may potentially differ in alternative climates and conditions, it appears unlikely that additional literature searches and evaluations would yield better, more appropriate site-specific values than the current defaults. Until such time as more studies on these properties are available, practical considerations suggest that these chemical-specific aquatic biota properties be ruled out from site-specific parameterization.

Chemical-Specific Abiotic Compartment Properties: TRIM.FaTE algorithms model chemical reaction and degradation processes in several abiotic compartments (e.g., surface soil). These algorithms depend on chemical-specific parameters such as degradation rates (or half-lives), transformation rates, and other properties. Literature searches conducted during previous site-specific assessments in the RTR process and other regulatory applications using TRIM.FaTE have suggested that data are limited for these properties.

These chemical properties (with the exception of the oxidation, reduction, and methylation and demethylation rates influencing mercury) therefore are currently ruled out from site-specific consideration. The mercury transformation properties have been shown to be highly risk-influential as well as variable across different ecosystem types and conditions, and these properties are reserved for site- or land-use-specific parameterization in the future, subject to greater data availability and the results of additional evaluations.

7.3.3 Combination of Data- and Sensitivity-based Elimination of Parameters

Terrestrial Vegetation: The terrestrial vegetation compartments in TRIM.FaTE—currently including grass, coniferous forest, deciduous forest, wetland grass, and wetland forest—are not directly part of the RTR risk assessment calculations (chemical concentrations in these compartments are not used as inputs to the ingestion exposure estimation). However, these compartments act as sinks for chemicals and also transfer chemicals from air to soil via leaf litterfall. In this way, the choice of terrestrial vegetation influences surface soil concentrations and, ultimately, risk.

The terrestrial vegetation compartments depend on properties such as the lipid content of leaves, wet density of leaves, area indices of leaves, etc. Although it is possible that these properties differ on a site-specific basis—for instance, the characteristics of coniferous trees in Oregon are different from those of

coniferous trees in North Carolina—these differences are not expected to have a substantial influence on risk. ICF's simulations indicate that the impact on risk of alternative vegetation scenarios is limited after accounting for differences in erosion regimes specific to land-use type (see Appendix A). It is expected that site-specific differences within a single vegetation type would be even lower.

Literature searches during previous site-specific multipathway assessments in the RTR process have indicated that highly intensive literature search would be required to parameterize the full range of terrestrial vegetation parameters required by the TRIM.FaTE algorithms. Based on the limited risk impact of terrestrial vegetation properties, and limited data availability at the site-specific level, these properties are currently ruled out from site-specific parameterization.

7.3.4 Elimination of Physical and Chemical Characteristics

Algorithms in the TRIM.FaTE model frequently depend on physical and chemical parameters, such as the Henry's law constant and the octanol-water partition coefficient, to partition chemicals between phases within a compartment. These properties are, by their nature, relatively unchanging across most standard environmental conditions for the non-ionic organic compounds currently evaluated (dioxins/furans and polycyclic organic matter)[2]. These properties are thus ruled out from requiring site-specific parameterization for the time being.

7.4 Properties Recommended for Site-specific Parameterization

Following the elimination process described above, ICF identified a set of parameters for further evaluation based theoretical considerations as well as higher sensitivity potential displayed in previous sensitivity analyses (e.g., U.S. EPA 2009). To estimate the risk influence of these parameters, ICF performed a limited set of additional sensitivity analyses. The evaluated parameters are listed below, grouped by compartment type.

- Air: dust load, fraction of organic matter.
- Surface Soil: unit soil loss, inter-compartment drainage and erosion fractions, soil-particle density, soil-air fraction, soil organic content, soil pH, soil water content.
- Surface Water and Sediment: suspended solids concentration, bed-sediment density, suspended solids density, bed-sediment porosity.
- Aquatic Biota: biomass of various aquatic biota compartments.
- Terrestrial Vegetation: "Allow exchange" and "Litterfall" file inputs.

Unlike previous analyses, these sensitivity analyses were not based on fixed perturbations from the default values but instead used reasonable high and/or low bounds approximately corresponding to the range found in the environment. The impacts on risk were computed with respect to the Tier 1 screen results at equivalent emission rates. AERMOD was not incorporated into these runs.

ICF extended the scope of the current analyses by also using the results of TRIM.FaTE sensitivity analyses conducted in previous regulatory applications and pertaining to air, surface soil, and surface water and sediment. Although these analyses were performed on a different version of the Tier 1 screen setup, the results are considered informative.

The specific details of the analyses conducted as part of this protocol development are reported in Appendix A, while other supporting evidence has been drawn from previous reports (e.g., U.S. EPA 2009). Based on the results of these analyses, Table 7-1 contains TRIM.FaTE properties recommended for site-specific parameterization in the RTR process. These properties have been further classified as

[2] For mercury, some analogous properties, such as the partition coefficient for mercury in the aqueous phase, do vary according to pH; these relationships are incorporated into the model as formula properties.

high, medium, and low priority to facilitate an appropriate allocation of available resources in the parameterization process.

Table 7-1. TRIM.FaTE Properties Recommended for Site-specific Parameterization

Compartment	Property	Priority	Remark
Surface water	Depth	High	Having depth as well as flush rate helps serve as a check on surface hydrology assumptions.
	Flush rate	High	
	Suspended solids concentration	High	Attempt to find a column-averaged value.
	pH	Moderate	Important for metals.
	Algae density	Moderate	May be estimated from total phosphorus concentrations in the absence of measured values.
	Organic-carbon fraction	Moderate	Important for 2,3,7,8-tetrachlorodibenzo-p-dioxin (U.S. EPA 2009). Data availability may be limited.
	Water temperature	Moderate	Sensitive but unlikely to manifest wide range.
Aquatic biota	Biomass	Moderate	May be estimated from total phosphorus concentrations in absence of measured values.
Surface soil	pH	Moderate	Important for metals.
Terrestrial biota	“Allow Exchange” and “Litterfall” data files	Low	These files govern how long leaves remain open for stomatal exchange during different times of the year and also when the leaves fall off the trees onto the surface soil. Although the impact of these properties has not been empirically tested, theoretical considerations suggest they will have a low impact when estimating average annual risks.

In addition to these values, meteorology parameters, surface hydrology and erosion-related parameters, and the spatial layout are fundamentally site-specific elements of a TRIM.FaTE simulation, as noted in the previous sections.

7.5 Properties Recommended for Values Based on Land Use

In addition to the properties identified in Section 7.4 as desirable for site-specific parameterization, we identified properties that also influence risk substantially but for which the impacts on risk are expected to be largely captured by land-use-specific parameters. In other words, for these properties, accounting for variations that correspond to land use is expected to adequately account for any variation in these parameters (to the extent that they influence risk). Additional variation in parameter values resulting from site-specific variations within a particular land-use category is not expected to be significant. For example, differences in surface soil erosion (as expressed by the unit soil loss rate property in TRIM.FaTE) are expected to be larger between the average deciduous forest and the average parcel of tilled soil than between different types of deciduous forest or between different types of tilled soil. The use of land-use-specific values for such properties is expected, therefore, to adequately capture their impact on risk estimates in the RTR process.

The rationale for identifying properties as land-use-based in this protocol is a combination of risk sensitivity analysis (Appendix A and U.S. EPA 2009), professional judgment about the range exhibited in the environment, and expected data availability at the site-specific level. Table 7-2 lists the TRIM.FaTE parameters that are recommended for land-use-specific parameterization. These parameters are all related to the surface soil parcel and assume distinct values for each of the land-use types modeled in TRIM.FaTE. These land-use types currently include deciduous forest, coniferous forest, grass, agricultural soil, untilled soil, forested wetlands, and grassy wetlands. Land-use type is not an explicit input in TRIM.FaTE but is implicitly reflected in the TRIM.FaTE property values corresponding to each surface parcel.

Table 7-2. TRIM.FaTE Properties Recommended for Parameterization Based on Land Use

Property	Remark
Organic-carbon fraction	Fraction of dry-soil solids that is organic in origin.
Water content	The sum of the water and air content fractions of a soil determines its porosity.
Air content	
Particle density	Refers to the dry density of the average soil particle.
Rainfall/erosivity index	Universal Soil Loss Equation (USLE) properties used to compute each surface soil compartment's average erosion rate.
Soil-erodibility index	
Topographical (LS) factor	
Cover/management factor	
Supporting-practices factor	
Fraction of precipitation that evapotranspires	Water-balance-related property used to compute each surface soil compartment's average runoff rate.
Fraction of precipitation subject to overland runoff	

7.6 Properties Recommended for National Values

Nationally representative or health-protective values are recommended for all TRIM.FaTE properties that are not identified for site-specific or land-use-based parameterization in Sections 7.4 and 7.5 above. These properties are expected either to (1) not substantially influence risk in the RTR process, (2) not have adequate data to support site-specific parameterization, or (3) be relatively constant in the environment, as discussed in greater detail in the approach described earlier in Section 7. These properties have been previously characterized in the RTR Tier 1 and Tier 2 screening threshold derivation analyses by either nationally representative values or health-protective values. The same values are recommended for these properties in site-specific analyses. The national values are documented in the *Technical Support Document for the TRIM-Based Multipathway Tiered Screening Methodology for RTR*, which is an appendix to the Risk Report.

8. Potential Future Improvements

This protocol, documenting the current state of knowledge related to conducting site-specific environmental modeling in support of RTR multipathway risk assessments, could be enhanced in the future by documenting best practices and developing recommendations regarding the issues listed below (among others).

- Identification of land-use-specific parameters for the identified soil properties based on literature review.
- Application of enhanced technical approaches, such as the use of a sensitivity-score approach, to identify the most influential model properties.
- Additional sensitivity tests utilizing the combined AERMOD-TRIM.FaTE approach as well as the current TRIM.FaTE Master Library (now including arsenic) and screening configuration.
- Potential development of regional parameters for a subset of model properties based on the results of further sensitivity analysis and data-availability assessments.
- Greater use of graphics and figures to illustrate model set-up concepts.
- Enhanced technical editing to help the protocol be more self-explanatory and independent of other TRIM.FaTE support documents in its scope.
- Researching the potential for geographically variable biotransfer factors and other parameters used in estimating concentrations of ingested food products.
- Further research and development of GIS-based approaches to surface hydrology and erosion-property parameterization.

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Appendix A. Documentation of Empirical Analyses Used to Prioritize TRIM.FaTE Properties

A.1. Introduction

Several years ago, ICF performed a series of empirical analyses to prioritize TRIM.FaTE model properties for site-specific parameterization. These analyses were based on changing the value of one or more model properties relative to the Tier 1 screen and measuring the relative impact on risk. Unlike in a traditional sensitivity analysis, this analysis changed property values to approximate high- and low-end values within the environmental range of the property of interest, instead of using a fixed perturbation. The measured impacts on risk, the expected range in the environment, and data availability were considered in prioritizing model properties for site-specific parameterization, as discussed in Section 7. These model runs did not utilize AERMOD and did not include arsenic, which was added to RTR multipathway assessments in 2016. The TRIM.FaTE Master Library and Tier 1 configuration used in these empirical analyses may be different from the current Library and configuration.

Table A-1 summarizes the various empirical analyses that were conducted, the risk impact of the scenario modifications, and conclusions from the analyses.

Table A-1. Results and Conclusions from Empirical Analyses Used to Prioritize TRIM.FaTE Properties

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachloro dibenzo-p-dioxin	Benzo(a) pyrene	Cadmium	Methyl Mercury		
Tier 1 SS	Tier 1 Screening Scenario.	1.00	1.00	1.00	1.00	Designed to produce most conservative risk estimate.	All relative risks for modified scenarios are measured relative to the Tier 1 screening scenario.
WF1	Reduce watershed flows (erosion and runoff) to half screening scenario levels. Redirect remainder to sink. Maintain same flow directions as screening scenario.	0.56	0.69	0.21	0.38	Reducing the quantity of runoff and erosion reaching receiving compartments reduces chemical inputs into those compartments, including the lake, and reduces risk.	Surface hydrology and erosion flows (where and how much of the erosion and runoff from a compartment reaches) are potentially highly sensitive properties in the model (influencing risk by up to a factor of 10) and are recommended for site-specific parameterization.
WF2	Reduce watershed flows (erosion and runoff) to 1/10 screening scenario levels. Redirect remainder to sink. Maintain same flow directions as screening scenario.	0.34	0.68	0.11	0.25		
ER0	Switch off erosion.	0.39	1.02	1.10	0.43	Turning off erosion reduces chemical inputs into the lake and reduces chemical removal off the farm.	Although erosion is a relatively important process, its maximum impact on risk is less than a factor of 3, even when

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachlorodibenzo-p-dioxin	Benzo(a)pyrene	Cadmium	Methyl Mercury		
ER1	Double erosion rates.	1.09	0.99	0.86	0.86	Increasing erosion produces competing effects: while it increases chemical inputs into the lake, it also increases the burial rate of sediment and increases chemical removal from the farm.	accounting for variable runoff rates. A land-use-specific parameterization approach is recommended for the average erosion rates of surface soil compartments.
ER-RUN1	Double erosion and runoff rates (same flush rate; higher lake depth).	0.94	0.96	0.74	0.89	Increasing the runoff rate increases the input of soluble chemicals into the lake and decreases the removal of those chemicals from the farm.	
ER-RUN2	Double erosion and runoff rates (higher flush rate; same lake depth).	1.09	0.99	0.74	0.85	Increased runoff rates can be accommodated by means of increased lake depths or increased flush rates.	
RUN1	Switch off runoff; maintain flush rate and depth.	0.99	1.00	0.70	0.96	Nullifying chemical transfer through runoff reduces chemical input into the lake and reduces chemical removal from the farm.	Runoff rates have a limited impact on risk. A land-use-specific parameterization approach is recommended for average runoff rates from surface soil compartments.
RUN2	Implement cumulative runoff regime.	1.02	1.00	1.14	1.10	Assumes runoff from one compartment does not evaporate but contributes to runoff from the receiving compartment.	

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachlorodibenzo-p-dioxin	Benzo(a)pyrene	Cadmium	Methyl Mercury		
FR1	Double lake depth, half flush rate, same rainfall, and same runoff fraction.	0.71	0.96	1.00	1.15	Doubling depth reduces concentrations but halving the flush rate reduces chemical output from the lake.	Lake depth and flush rate have a modest impact on risk. However, knowledge of both these parameters can help guide the surface hydrology and erosion direction flows in the watershed which can more substantially influence risk. Site-specific parameterization is recommended for lake depth and flush rate.
FR2	Half lake depth, double flush rate, same rainfall, and same runoff fraction.	1.28	1.07	1.00	0.92	Halving depth increases concentrations but doubling the flush rate increases chemical output from the lake.	
FR3	Double depth, same flush rate, same rainfall, same runoff fraction (violate water balance in screening scenario).	0.69	0.96	0.58	1.02	Doubling depth reduces lake concentrations for most chemicals.	
FR4	Double flush rate, same depth, same rainfall, and same runoff fraction (violate water balance in screening scenario).	0.95	1.00	0.58	0.89	Doubling flush rate reduces lake concentrations.	
PERC1	Implement balanced percolation regime.	0.99	1.00	0.62	0.99	Assumes runoff from one compartment does not evaporate but percolates in the receiving compartment.	Percolation rate (the fraction of rainfall that is subject to percolation into the sub-surface) has a modest impact on risk. Land-use-based parameterization is recommended for this property.

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachloro dibenzo-p-dioxin	Benzo(a) pyrene	Cadmium	Methyl Mercury		
R1	Reduce rainfall down to 1/3rd SS value; same lake depth; runoff rates and flush rate down to 1/3rd.	0.64	0.59	0.92	0.58	Reducing rainfall reduces chemical washout from air.	This run, when combined with earlier runs focusing on the impacts of flush rate, suggests that the chemical washout impact of rainfall has more influence on risk than the impact of rainfall levels on hydrological properties like flush rate. This reinforces the argument for site-specific meteorological parameters.
V_C	Set all surface compartments except farm to coniferous forests.	0.79	0.75	0.40	0.87	The choice of vegetation in surface soil compartments impacts risk by absorbing chemicals from air and soil and then redepositing them onto the surface soil via litterfall.	Land-use type has a limited impact on risk. Based on these results, terrestrial vegetation parameters are recommended for land-use-specific parameterization. In interpreting these results, it is important to note that these runs have not been normalized for erosion rates. Therefore, the impacts on risk presented here are from a combination of impacts from differential erosion rates and vegetation types.
V_D	Set all surface compartments except farm to deciduous forests.	0.34	0.92	0.49	0.39		
V_G	Set all surface compartments except farm to grassland.	0.88	0.82	0.45	0.92		
V_U	Set all surface compartments except farm to untilled soil.	0.42	0.73	0.37	0.81		
V_WW	Set all surface compartments except farm to forested wetlands.	0.36	0.92	0.49	0.47		

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachloro dibenzo-p-dioxin	Benzo(a) pyrene	Cadmium	Methyl Mercury		
V_WG	Set all surface compartments except farm to grassy wetlands.	0.86	0.83	0.46	0.94		
BM1	Increase aquatic biomass uniformly by a factor of 10.	0.84	0.39	0.90	0.99	Increasing aquatic biomass reduces chemical concentration in biomass as the same amount of chemical is distributed in a higher amount of biomass.	Risk is sensitive to the aquatic biomass levels. These properties are therefore recommended for site-specific parameterization. In interpreting the results of these runs, it may be noted that all biomass levels were uniformly raised. In real applications, the biomass levels of the upper trophic levels may constitute a lower percentage of the total biomass as total biomass increases, suggesting slightly lower risk sensitivity than apparent here.
BM2	Increase aquatic biomass uniformly by a factor of 100.	0.35	0.32	0.29	0.79		
Air_DL1	Increase air dust load by a factor of 10.	2.34	2.31	0.50	0.98	Increasing the dust load in air increases	Although these runs indicate that air dust load

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachloro dibenzo-p-dioxin	Benzo(a) pyrene	Cadmium	Methyl Mercury		
Air_DL2	Increase air dust load by a factor of 100.	4.14	2.71	0.50	0.90	particulate deposition to the surface.	moderately influences risk, literature search indicated that the range manifested by this property is relatively small and the default value used is already in the high end of the observed range in the U.S. Therefore, this property is not recommended for site-specific parameterization.
Air_FOM1	Halve the fraction of organic matter in air solids.	0.87	0.66	0.50	1.00	The organic content of air solids can differentially influence chemical adherence to the solid phase.	Although these runs indicate that the fraction of organic matter in air solids moderately influences risk, literature search indicated that site-specific data may be difficult to obtain. This property is not recommended for site-specific parameterization.
Air_FOM2	Double the fraction of organic matter in air solids.	1.23	1.43	0.50	1.00		
Soil_Air	Double the soil-air content.	1.21	1.29	0.50	1.14	Increasing the soil-air fraction reduces soil solids, which distributes the same amount of chemical over a lower solids content, thereby increasing soil concentrations.	Although these runs indicate that air dust load moderately influences risk, literature search indicated that the range manifested by this property is relatively small and the default value used is already in the high end of the observed range in the U.S. Therefore, this property is not recommended for site-
Soil_FOC	Increase the soil organic fraction content by a factor of 10.	1.04	1.01	0.60	1.00	Increasing soil organic content increases chemical adherence to soil for some chemicals.	

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachlorodibenzo-p-dioxin	Benzo(a)pyrene	Cadmium	Methyl Mercury		
Soil_pH1	Set soil pH at 4.	1.00	1.00	0.39	1.00	Soil pH can influence chemical adherence to soil solids for some chemicals.	specific parameterization.
Soil_pH2	Set soil pH at 10.	1.00	1.00	0.66	1.00		
Soil_Rho	Set soil solids density at 1000 kg/m^3.	1.41	1.43	0.50	1.16	Decreasing soil particle density increases soil concentrations when normalized by soil weight.	
Soil_Water	Double the soil water content.	1.00	1.00	0.50	1.00	Increasing soil water content increases chemical removal by percolation for some chemicals.	
SusSed_TSS1	Increase lake suspended solids concentration by a factor of 2.	0.73	0.98	1.01	0.74	Increasing suspended solids in water causes more chemical to be deposited to sediment.	Suspended solids concentration in lakes has a moderate influence on risk. Due to the wide range potentially exhibited by this property, it has been recommended for site-specific parameterization.
SusSed_TSS2	Increase lake suspended solids concentration by a factor of 10.	0.33	0.98	0.46	0.38		
Sed_Bur	Halve sediment-burial rate; same erosion rate (violate solids balance in screening scenario).	1.11	1.00	1.12	1.31	Decreasing the burial rate reduces the removal of chemicals from the sediment layer.	Sediment properties have a moderate impact on risk, given the limited range of values assumed by them in the environment.

Scenario Name	Scenario Description (with respect to Tier 1 Screening Scenario)	Normalized Risk Relative to Tier 1 Screening Scenario				Risk Impact of Scenario Modification	Conclusions
		2,3,7,8-tetrachlorodibenzo-p-dioxin	Benzo(a) pyrene	Cadmium	Methyl Mercury		
Sed_Rho	Decrease bed-sediment-particle density to 1000 kg/m^3.	1.36	1.00	0.63	2.74	The lower the sediment-particle density, the lower the volumetric re-suspension rate from sediment and the higher the volumetric burial rate.	
Sed_Por	Halve sediment-bed porosity.	0.85	1.00	0.42	0.78	The lower the sediment porosity, the lower the volumetric re-suspension rate from sediment and the lower the volumetric burial rate.	

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Appendix B. AERMOD-to-TRIM.FaTE Input Requirements

As mentioned in Section 5.3, following the pseudo-source methodology of incorporation AERMOD deposition outputs into TRIM.FaTE, pseudo-sources are assigned to placeholder volume elements and linked to transfer mass to the appropriate surface compartments. For water parcels, the entire mass is transferred to the surface water compartment. For land parcels, algorithms apportioning mass between surface soil and leaves were derived from the existing FaTE algorithms for air-soil and air-plant transfers. The mass-transfer rates were time-varying because they rely on factors such as hours of daylight and fraction leaf coverage. The placeholder volume elements are designed to prevent transfer to any compartment other than those prescribed, and each contains only one pseudo-source. These four pseudo-sources (representing dry/wet and vapor/particle deposition) for each parcel, along with the corresponding placeholder compartments, links, and algorithms, are set up in the input files described in Table B-1.

Table B-1. Supplemental Files to Parameterize AERMOD Outputs for TRIM.FaTE

File Description	Contents	Purpose
Pseudo-source deposition-rate properties	Assigns surface-deposition rates ($g/m^2/day$) to each of the placeholder volume elements (dry particle, dry vapor, wet particle, and wet vapor deposition as needed) for each surface parcel and chemical.	This file serves as TRIM.FaTE input file to parameterize the surface-deposition rates for the subsequent fate-and-transport modeling.
Pseudo-source volume elements	Coordinates specifying the spatial dimensions of the placeholder volume elements for each surface parcel.	This file serves as a TRIM.FaTE input file to supplement the defined spatial layout of the modeled domain to include pseudo-source compartments.
Pseudo-source library	Defines supplemental compartment types, property types, and algorithms used in linking placeholder volume elements to targeted surface compartments. This file also includes the definitions and locations of pseudo-sources with emission-rate formulas accounting for parcel surface area.	This file serves as a TRIM.FaTE input file to define additional properties, compartments, and algorithms to initialize the pseudo-source methodology. This file must be manually imported through the TRIM.FaTE graphical interface and saved as a library.
Pseudo-source link properties	Defines the actual links that connect the placeholder elements to their surface targets. This includes determining which water, soil, and/or plant compartments are present on the surface of each parcel.	This file serves as a TRIM.FaTE input file to define links between different compartments, specifically to initiate mass transfer from pseudo-source to compartments on the surface of each parcel.

Appendix 8

Dose-Response Values Used in the RTR Risk Assessments

Appendix 8. Dose-Response Values Used in the RTR Risk Assessments

The dose-response values presented in Table 1 (chronic) and Table 2 (acute) are values used in the Risk and Technology Review program as of June 2018. In some cases, a value in Table 1 or 2 may reflect an update made after a source category-specific risk assessment was conducted. The values used in this risk assessment are presented in Table 3.1-1 in the body of the report.

Definition for Chronic Values

URE (unit risk estimate) = the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent over a lifetime at a concentration of 1 $\mu g/m^3$ in air.
RfC (reference concentration) = an estimate of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful noncancer health effects during a lifetime.
Cancer Slope Factor = an upper-bound estimate of the increased cancer risk from a lifetime oral exposure to an agent.
RfD (reference dose) = an estimate of a continuous oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of harmful noncancer health effects during a lifetime.

Sources:
IRIS = EPA Integrated Risk Information System
ATSDR = US Agency for Toxic Substances Disease Registry
CAL = California EPA Office of Environmental Human Health Assessment
HEAST = EPA Health Effects Assessment Tables
EPA OAQPS = EPA Office of Air Quality Planning and Standards
EPA ORD = EPA Office of Research & Development

Definition of Acute Values

AEGL-1 (acute exposure guideline level 1) = the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
AEGL-2 (acute exposure guideline level 2) = the airborne concentration (expressed as ppm or mg/m3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
ERPG-1 (emergency response planning guideline 1) = the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient health effects or without perceiving a clearly defined objectionable odor.
ERPG-2 (emergency response planning guideline 2) = the maximum airborne concentration below which nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious adverse health effects or symptoms that could impair an individual's ability to take protective action.
REL (reference exposure level) = the concentration level at or below which no adverse health effects are anticipated for a specified exposure duration. RELs are based on the most sensitive, relevant, adverse health effect reported in the medical and toxicological literature and are designed to protect the most sensitive individuals in the population by the inclusion of margins of safety.

Sources:
National Advisory Committee on Acute Exposure Guideline Level for Hazardous Substances, reviewed and published by the National Research Council - AEGL
American Industrial Hygiene Association – ERPG
California EPA Office of Environmental Human Health Assessment - REL

Table 1. Chronic Cancer and Noncancer Inhalation and Oral Dose-Response Values and the Source of Those Values

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Sourc	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
1,1,1-Trichloroethane	71-55-6			5	IRIS		
1,1,2-Trichloroethane	79-00-5	0.000016	IRIS				
Hexachlorocyclohexanes							
alpha-Hexachlorocyclohexane (a- HCH)	319-84-6	0.0018	IRIS				
beta-Hexachlorocyclohexane (b- HCH)	319-85-7	0.00053	IRIS				
Lindane (gamma-HCH)	58-89-9	0.00031	CAL				
technical Hexachlorocyclohexane (HCH)	608-73-1	0.00051	IRIS				
1,2,4-Trichlorobenzene	120-82-1			0.2			
1,2-Dibromo-3-chloropropane	96-12-8	0.002	CAL	0.0002	IRIS		
1,2-Diphenylhydrazine	122-66-7	0.00022	IRIS				
1,2-Epoxybutane	106-88-7			0.02	IRIS		
1,3-Butadiene	106-99-0	0.00003	IRIS	0.002	IRIS		
1,3-Dichloropropene	542-75-6	0.000004	IRIS	0.02	IRIS		
1,3-Propane sultone	1120-71-4	0.00069	CAL				
p-Dichlorobenzene	106-46-7	0.000011	CAL	0.06	ATSDR		
p-Dimethylaminoazobenzene	60-11-7	0.0013	CAL				
1,4-Dioxane	123-91-1	0.000005	IRIS	0.03	IRIS		
2,4,6-Trichlorophenol	88-06-2	0.0000031	IRIS				
2,4-Dinitrotoluene	121-14-2	0.000089	CAL				
2,4-Toluene diamine	95-80-7	0.0011	CAL				
2,4/2,6-Toluene diisocyanate mixture (TDI)	26471-62-5	0.000011	CAL	0.00007	IRIS		
2,4-Toluene diisocyanate	584-84-9	0.000011	CAL	0.00007	IRIS		
2-Chloroacetophenone	532-27-4			0.00003	IRIS		
2-Nitropropane	79-46-9	0.0000056	EPA OAQPS	0.02	IRIS		
3,3'-Dichlorobenzidine	91-94-1	0.00034	CAL				
4,4'-Methylene bis(2-chloroaniline)	101-14-4	0.00043	CAL				
4,4'-Methylenedianiline	101-77-9	0.00046	CAL	0.02	CAL		
Methylene diphenyl diisocyanate	101-68-8			0.0006	IRIS		
Acetaldehyde	75-07-0	0.0000022	IRIS	0.009	IRIS		
Acetamide	60-35-5	0.00002	CAL				
Acetonitrile	75-05-8			0.06	IRIS		
Acrolein	107-02-8			0.00035	CAL		
Acrylamide	79-06-1	0.00016	IRIS	0.006	IRIS		
Acrylic acid	79-10-7			0.001	IRIS		
Acrylonitrile	107-13-1	0.000068	IRIS	0.002	IRIS		
Allyl chloride	107-05-1	0.000006	CAL	0.001	IRIS		
Aniline	62-53-3	0.0000016	CAL	0.001	IRIS		
Antimony Compounds							
Antimony compounds	7440-36-0			0.0002	IRIS		
Antimony oxide	1327-33-9			0.0002	IRIS		
Antimony pentafluoride	7783-70-2			0.0002	IRIS		
Antimony pentoxide	1314-60-9			0.0002	IRIS		
Antimony potassium tartrate	304-61-0			0.0002	IRIS		
Antimony tetroxide	1332-81-6			0.0002	IRIS		
Antimony trihydride	7803-52-3			0.0002	IRIS		
Antimony trioxide	1309-64-4			0.0002	IRIS		

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Sourc	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
Arsenic Compounds							
Arsenic acid	7778-39-4	0.0043	IRIS	0.000015	CAL		
Arsenic as lead arsenate	7784-40-9	0.0043	IRIS	0.000015	CAL		
Arsenic chloride	7784-34-1	0.0043	IRIS	0.000015	CAL		
Arsenic compounds	7440-38-2	0.0043	IRIS	0.000015	CAL	1.5	
Arsenic pentoxide	1303-28-2	0.0043	IRIS	0.000015	CAL		
Arsenic trioxide	1327-53-3	0.0043	IRIS	0.000015	CAL		
Arsine	7784-42-1			0.00005	IRIS		
Benzene	71-43-2	0.0000078[d]	IRIS	0.03	IRIS		
Benzidine	92-87-5	0.1072	IRIS				
Benzyl chloride	100-44-7	0.000049	CAL				
Beryllium Compounds							
Beryllium chloride	7787-47-5	0.0024	IRIS	0.00002	IRIS		
Beryllium compounds	7440-41-7	0.0024	IRIS	0.00002	IRIS		
Beryllium fluoride	7787-49-7	0.0024	IRIS	0.00002	IRIS		
Beryllium nitrate	13597-99-4	0.0024	IRIS	0.00002	IRIS		
Beryllium oxide	1304-56-9	0.0024	IRIS	0.00002	IRIS		
Bis(2-ethylhexyl) phthalate	117-81-7	0.0000024	CAL				
Bis(chloromethyl)ether	542-88-1	0.062	IRIS				
Bromoform	75-25-2	0.0000011	IRIS				
Cadmium Compounds							
Cadmium acetate	543-90-8	0.0018	IRIS	0.00001	ATSDR		
Cadmium compounds	7440-43-9	0.0018	IRIS	0.00001	ATSDR		0.001
Cadmium as cadmium cyanamide	20654-10-8	0.0018	IRIS	0.00001	ATSDR		
Cadmium nitrate	10325-94-7	0.0018	IRIS	0.00001	ATSDR		
Cadmium oxide	1306-19-0	0.0018	IRIS	0.00001	ATSDR		
Cadmium stearate	2223-93-0	0.0018	IRIS	0.00001	ATSDR		
Carbon disulfide	75-15-0			0.7	IRIS		
Carbon tetrachloride	56-23-5	0.000006	IRIS	0.1	IRIS		
Carbonyl sulfide	463-58-1			0.163[f]	EPA ORD		
Chlordane	57-74-9	0.0001	IRIS	0.0007	IRIS		
Chlorine	7782-50-5			0.00015	ATSDR		
Chlorobenzene	108-90-7			1	CAL		
Chlorobenzilate	510-15-6	0.000078	HEAST				
Chloroform	67-66-3			0.098	ATSDR		
Chloroprene	126-99-8	0.00048	IRIS	0.02	IRIS		
Chromium Compounds							
Ammonium chromate	7788-98-9	0.012	IRIS	0.0001	IRIS		
Ammonium dichromate	7789-09-5	0.012	IRIS	0.0001	IRIS		
Barium chromate	10294-40-3	0.012	IRIS	0.0001	IRIS		
Calcium chromate	13765-19-0	0.012	IRIS	0.0001	IRIS		
Chromic acid (VI)	7738-94-5	0.012	IRIS	0.0001	IRIS		
Chromic sulfuric acid	13530-68-2	0.012	IRIS	0.0001	IRIS		
Chromium (VI) as lead chromate	7758-97-6	0.012	IRIS	0.0001	IRIS		
Chromium (VI) as lead chromate oxide	18454-12-1	0.012	IRIS	0.0001	IRIS		
Chromium (VI) compounds	18540-29-9	0.012	IRIS	0.0001	IRIS		
Chromium (VI) trioxide, chromic acid mist	11115-74-5	0.012	IRIS	0.000008	IRIS		
Chromium compounds	7440-47-3	0.012	IRIS	0.0001	IRIS		
Chromium dioxide	12018-01-8	0.012	IRIS	0.0001	IRIS		
Potassium chromate	7789-00-6	0.012	IRIS	0.0001	IRIS		
Potassium dichromate	7778-50-9	0.012	IRIS	0.0001	IRIS		
Sodium chromate	7775-11-3	0.012	IRIS	0.0001	IRIS		
Sodium dichromate	10588-01-9	0.012	IRIS	0.0001	IRIS		

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Source	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
Strontium chromate	7789-06-2	0.012	IRIS	0.0001	IRIS		
Zinc chromate	13530-65-9	0.012	IRIS	0.0001	IRIS		
Zinc potassium chromate	11103-86-9	0.012	IRIS	0.0001	IRIS		
Cobalt Compounds							
Cobalt aluminate	1345-16-0			0.0001	ATSDR		
Cobalt bromide	7789-43-7			0.0001	ATSDR		
Cobalt carbonate	513-79-1			0.0001	ATSDR		
Cobalt carbonyl	10210-68-1			0.0001	ATSDR		
Cobalt chloride	7646-79-9			0.0001	ATSDR		
Cobalt compounds	7440-48-4	g		0.0001	ATSDR		
Cobalt hydrocarbonyl	16842-03-8			0.0001	ATSDR		
Cobalt naphtha	61789-51-3			0.0001	ATSDR		
Cobalt nitrate	Co Nitrate			0.0001	ATSDR		
Cobalt oxide	1307-96-6			0.0001	ATSDR		
Cobalt oxide (II, III)	1308-06-1			0.0001	ATSDR		
Hexanoic acid, 2-ethyl-, cobalt (2+) salt	136-52-7			0.0001	ATSDR		
Coke Oven Emissions							
Benzene soluble organics (BSO)	141	0.00099	IRIS				
Coke oven emissions	8007-45-2	0.00099	IRIS				
Methylene chloride soluble organics (MCSO)	142	0.00099	IRIS				
Cresols							
Cresols (mixed)	1319-77-3			0.6	CAL		
m-Cresol (3-methylphenol)	108-39-4			0.6	CAL		
o-Cresol	95-48-7			0.6	CAL		
p-Cresol (4-methy phenol)	106-44-5			0.6	CAL		
Cumene	98-82-8			0.4	IRIS		
Cyanide Compounds							
Acetone cyanohydrin	75-86-5			0.01	HEAST		
Barium cyanide	542-62-1			0.0008	IRIS		
Calcium cyanamide	156-62-7			0.0008	IRIS		
Calcium cyanide	592-01-8			0.0008	IRIS		
Copper cyanide	544-92-3			0.0008	IRIS		
Cyanazine	21725-46-2			0.0008	IRIS		
Cyanide as Cadmium cyanamide	20654-10-8			0.0008	IRIS		
Cyanide compounds	57-12-5			0.0008	IRIS		
Cyanogen	460-19-5			0.0008	IRIS		
Cyanogen bromide	506-68-3			0.0008	IRIS		
Cyanogen chloride	506-77-4			0.0008	IRIS		
Cyanogen iodide	506-78-5			0.0008	IRIS		
Cyanophos	2636-26-2			0.0008	IRIS		
Cyanuric fluoride	675-14-9			0.0008	IRIS		
Ethylene cyanohydrin	109-78-4			0.0008	IRIS		
Hydrogen cyanide	74-90-8			0.0008	IRIS		
Isopropyl cyanide	78-82-0			0.0008	IRIS		
Potassium cyanide	151-50-8			0.0008	IRIS		
Potassium silver cyanide	506-61-6			0.0008	IRIS		
Potassium thiocyanate	333-20-0			0.0008	IRIS		
Silver cyanide	506-64-9			0.0008	IRIS		
Sodium cyanide	143-33-9			0.0008	IRIS		
Thiocyanate	Thiocyanate			0.0008	IRIS		
Thiocyanic acid	21564-17-0			0.0008	IRIS		
Zinc cyanide	557-21-1			0.0008	IRIS		
Dichloroethyl ether	111-44-4	0.00033	IRIS				
Dichlorvos	62-73-7			0.0005	IRIS		
Diesel engine emissions	Diesel emis			0.005	IRIS		

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Source	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
Diethanolamine	111-42-2			0.003	CAL		
Dimethyl formamide	68-12-2			0.03	CAL		
Dioxins and Furans							
1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	3268-87-9	0.0099	EPA ORD	0.00013	CAL	45	
1,2,3,4,6,7,8,9-Octachlorodibenzofuran	39001-02-0	0.0099	EPA ORD	0.00013	CAL	45	
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	35822-46-9	0.33	EPA ORD	0.000004	CAL	1500	
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562-39-4	0.33	EPA ORD	0.000004	CAL	1500	
1,2,3,4,7,8,9-Heptachlorodibenzofuran	55673-89-7	0.33	EPA ORD	0.000004	CAL	1500	
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	39227-28-6	3.3	EPA ORD	0.0000004	CAL	15000	
1,2,3,4,7,8-Hexachlorodibenzofuran	70648-26-9	3.3	EPA ORD	0.0000004	CAL	15000	
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	57653-85-7	3.3	EPA ORD	0.0000004	CAL	6200	
1,2,3,6,7,8-Hexachlorodibenzofuran	57117-44-9	3.3	EPA ORD	0.0000004	CAL	15000	
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	3.3	EPA ORD	0.0000004	CAL	6200	
1,2,3,7,8,9-Hexachlorodibenzofuran	72918-21-9	3.3	EPA ORD	0.0000004	CAL	15000	
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	40321-76-4	33	EPA ORD	0.00000004	CAL	150000	
1,2,3,7,8-Pentachlorodibenzofuran	57117-41-6	0.99	EPA ORD	0.0000013	CAL	4500	
2,3,4,6,7,8-Hexachlorodibenzofuran	60851-34-5	3.3	EPA ORD	0.0000004	CAL	15000	
2,3,4,7,8-Pentachlorodibenzofuran	57117-31-4	9.9	EPA ORD	0.00000013	CAL	45000	
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	33	EPA ORD	0.00000004	CAL	150000	
2,3,7,8-Tetrachlorodibenzofuran	51207-31-9	3.3	EPA ORD	0.0000004	CAL	15000	
Hexachlorodibenzo-p-dioxin	34465-46-8	3.3	EPA ORD	0.0000004	CAL	15000	
Epichlorohydrin	106-89-8	0.0000012	IRIS	0.001	IRIS		
Ethyl benzene	100-41-4	0.0000025	CAL	0.3	ATSDR		
Ethyl carbamate	51-79-6	0.000464	CAL				
Ethyl chloride	75-00-3			10	IRIS		
Ethylene dibromide	106-93-4	0.0006	IRIS	0.009	IRIS		
Ethylene dichloride	107-06-2	0.000026	IRIS	2.4	ATSDR		
Ethylene glycol	107-21-1			0.4	CAL		
Ethylene oxide	75-21-8	0.005	IRIS	0.03	CAL		
Ethylene thiourea	96-45-7	0.000013	CAL				
Ethylidene dichloride	75-34-3	0.0000016	CAL	0.5	HEAST		
Formaldehyde	50-00-0	0.000013	IRIS	0.0098	ATSDR		
Glycol ethers							
1,2-Dimethoxyethane	110-71-4			0.02	IRIS		
2-Butoxyethyl acetate	112-07-2			0.02	IRIS		
2-(Hexyloxy)ethanol	112-25-4			0.02	IRIS		
2-Propoxyethyl acetate	20706-25-6			0.02	IRIS		
Butyl carbitol acetate	124-17-4			0.02	IRIS		
Carbitol acetate	112-15-2			0.02	IRIS		
Diethylene glycol diethyl ether	112-36-7			0.02	IRIS		
Diethylene glycol dimethyl ether	111-96-6			0.02	IRIS		

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Source	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
Diethylene glycol ethyl methyl ether	1002-67-1			0.02	IRIS		
Diethylene glycol monobutyl ether	112-34-5			0.02	HEAST		
Diethylene glycol monoethyl ether	111-90-0			0.02	IRIS		
Diethylene glycol monomethyl ether	111-77-3			0.02	IRIS		
Ethoxytriglycol	112-50-5			0.02	IRIS		
Ethylene glycol diethyl ether	629-14-1			0.02	IRIS		
Ethylene glycol ethyl ether	110-80-5			0.2	IRIS		
Ethylene glycol ethyl ether acetate	111-15-9			0.3	CAL		
Ethylene glycol methyl ether	109-86-4			0.02	IRIS		
Ethylene glycol methyl ether acetate	110-49-6			0.09	CAL		
Ethylene glycol mono-sec-butyl ether	7795-91-7			0.02	IRIS		
Glycol ethers	171			0.02	IRIS		
Methoxytriglycol	112-35-6			0.02	IRIS		
Methyl Cellosolve Acrylate	3121-61-7			0.02	IRIS		
N-Hexyl carbitol	112-59-4			0.02	IRIS		
Phenyl cellosolve	122-99-6			0.02	IRIS		
Propyl cellosolve	2807-30-9			0.02	IRIS		
Triethylene glycol dimethyl ether	112-49-2			0.02	IRIS		
Triethylene glycol monohexyl ether	25961-89-1			0.02	IRIS		
Triglycol monobutyl ether	143-22-6			0.02	IRIS		
Heptachlor	76-44-8	0.0013	IRIS				
Hexachlorobenzene	118-74-1	0.00046	IRIS				
Hexachlorobutadiene	87-68-3	0.000022	IRIS				
Hexachlorocyclopentadiene	77-47-4			0.0002	IRIS		
Hexachloroethane	67-72-1			0.03	IRIS		
Hexamethylene-1,6-diisocyanate	822-06-0			0.00001	IRIS		
n-Hexane	110-54-3			0.7	IRIS		
Hydrazine	302-01-2	0.0049	IRIS	0.0002	CAL		
Hydrochloric acid	7647-01-0			0.02	IRIS		
Hydrofluoric acid	7664-39-3			0.014	CAL		
Isophorone	78-59-1			2	CAL		
Lead Compounds[e]							
Lead (II) oxide	1317-36-8			0.00015	EPA OAQPS		
Lead acetate	301-04-2			0.00015	EPA OAQPS		
Lead as lead arsenate	7784-40-9			0.00015	EPA OAQPS		
Lead as lead chromate	7758-97-6			0.00015	EPA OAQPS		
Lead as lead chromate oxide	18454-12-1			0.00015	EPA OAQPS		
Lead chloride	7758-95-4			0.00015	EPA OAQPS		
Lead compounds	7439-92-1			0.00015	EPA OAQPS		
Lead compounds (other than inorganic)	603			0.00015	EPA OAQPS		
Lead dioxide	1309-60-0			0.00015	EPA OAQPS		
Lead nitrate	10099-74-8			0.00015	EPA OAQPS		

		Inhalation				Oral (ingestion)[a]	
Pollutant	**CAS No.**	**URE 1/(ug/m³)**	**URE Source**	**RfC (mg/m³)**	**RfC Source**	**Cancer Slope Factor (1/(mg/kg/d))**	**RfD (mg/kg/d)**
Lead subacetate	1335-32-6			0.00015	EPA OAQPS		
Lead sulfate	7446-14-2			0.00015	EPA OAQPS		
Tetraethyl lead	78-00-2			0.00015	EPA OAQPS		
Tetramethyl lead	75-74-1			0.00015	EPA OAQPS		
Maleic anhydride	108-31-6			0.0007	CAL		
Manganese Compounds							
Manganese chloride	2145-07-6			0.0003	ATSDR		
Manganese compounds	7439-96-5			0.0003	ATSDR		
Manganese dioxide	1313-13-9			0.0003	ATSDR		
Manganese nitrate	10377-66-9			0.0003	ATSDR		
Manganese oxide	1317-35-7			0.0003	ATSDR		
Manganese sulfate	7785-87-7			0.0003	ATSDR		
Manganese tetroxide	1317-35-7			0.0003	ATSDR		
Manganese tricarbonyl (eta.5-2,4-cyclopentadien-1-yl)-	12079-65-1			0.0003	ATSDR		
Manganese trioxide	1317-34-6			0.0003	ATSDR		
Mercury compounds							
Gaseous divalent mercury	201			0.0003	IRIS		0.0001
Mercuric acetate	1600-27-7			0.0003	IRIS		0.0001
Mercuric chloride	7487-94-7			0.0003	IRIS		0.0001
Mercuric nitrate	10045-64-0			0.0003	IRIS		0.0001
Mercuric oxide	21908-53-2			0.0003	IRIS		0.0001
Mercury (elemental)	7439-97-6			0.0003	IRIS		c
Mercury (organic)	22967-92-6			0.0003	IRIS		c
Mercury compounds	HGCMPDS			0.0003	IRIS		c*
Methoxyethylmercuric acetate	151-38-2			0.0003	IRIS		0.0001
Methyl mercury	22967-92-6			0.0003	IRIS		c
Methylmercuric dicyanamide	502-39-6			0.0003	IRIS		0.0001
Particulate divalent mercury	202			0.0003	IRIS		0.0001
Phenylmercuric acetate	62-38-4			0.0003	IRIS		0.0001
Methanol	67-56-1			20	IRIS		
Methyl bromide	74-83-9			0.005	IRIS		
Methyl chloride	74-87-3			0.09	IRIS		
Methyl isobutyl ketone	108-10-1			3	IRIS		
Methyl isocyanate	624-83-9			0.001	CAL		
Methyl methacrylate	80-62-6			0.7	IRIS		
Methyl tert-butyl ether	1634-04-4	0.00000026	CAL	3	IRIS		
Methylene chloride	75-09-2	0.000000016	IRIS	0.6	IRIS		
Naphthalene	91-20-3	0.000034	CAL	0.003	IRIS		
Nickel compounds							
Nickel (II) sulfate hexahydrate	10101-97-0	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel acetate	373-02-4	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel carbonyl	13463-39-3	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel chloride	7718-54-9	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel compounds	7440-02-0	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel nitrate	13138-45-9	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel oxide	1313-99-1	0.00048	EPA OAQPS	0.00002	CAL		

		Inhalation				Oral (ingestion)[a]	
Pollutant	**CAS No.**	**URE 1/(ug/m³)**	**URE Source**	**RfC (mg/m³)**	**RfC Source**	**Cancer Slope Factor (1/(mg/kg/d))**	**RfD (mg/kg/d)**
Nickel refinery dust	NI_DUST	0.00024	IRIS				
Nickel subsulfide	12035-72-2	0.00048	IRIS	0.00009	ATSDR		
Nickel sulfamate	13770-89-3	0.00048	EPA OAQPS	0.00009	ATSDR		
Nickel sulfate	7786-81-4	0.00048	EPA OAQPS	0.00009	ATSDR		
Nitrobenzene	98-95-3	0.00004	IRIS	0.009	IRIS		
Nitrosodimethylamine	62-75-9	0.022	IRIS				
N-Nitrosomorpholine	59-89-2	0.0019	CAL				
o-Toluidine	95-53-4	0.000051	CAL				
Pentachlorophenol	87-86-5	0.0000051	CAL				
Phenol	108-95-2			0.2	CAL		
Phosgene	75-44-5			0.0003	IRIS		
Phosphine	7803-51-2			0.0003	IRIS		
Phthalic anhydride	85-44-9			0.02	CAL		
Polychlorinated Biphenyls							
Aroclor 1016	12674-11-2	0.0001	IRIS				
Aroclor 1221	11104-28-2	0.0001	IRIS				
Aroclor 1242	53469-21-9	0.0001	IRIS				
Aroclor 1248	12672-29-6	0.0001	IRIS				
Aroclor 1254	11097-69-1	0.0001	IRIS				
Aroclor 1260	11096-82-5	0.0001	IRIS				
Polychlorinated biphenyls	1336-36-3	0.0001	IRIS				
2-Chlorobiphyenyl	15999-91-1	0.0001	IRIS				
2,4,4'-Trichlorobiphenyl (PCB-28)	7012-37-5	0.0001	IRIS				
4,4'-Dichlorobiphenyl (PCB-15)	2050-68-2	0.0001	IRIS				
Decachlorobiphenyl (PCB-209)	2051-60-7	0.0001	IRIS				
Heptachlorobiphenyl	28655-71-2	0.0001	IRIS				
Hexachlorobiphenyl	26601-64-9	0.0001	IRIS				
Pentachlorobiphenyl	25429-29-2	0.0001	IRIS				
Tetrachlorobiphenyl	26914-33-0	0.0001	IRIS				
Polycyclic Organic Matter							
POM 71002		0.000048	CAL				
16-PAH	40	0.000048	CAL				
PAH, total	234	0.000048	CAL			0.05	
Polycyclic organic matter	246	0.000048	CAL			0.05	
POM 72002		0.000048	CAL				
1-Methylnaphthalene	90-12-0	0.000048	CAL			0.05	
1-Methylphenanthrene	832-69-9	0.000048	CAL				
2-Methylphenanthrene	2531-84-2	0.000048	CAL				
1-Methylpyrene	2381-21-7	0.000048	CAL				
2-Methylnaphthalene	91-57-6	0.000048	CAL			0.05	
2-Naphthylamine	91-59-8	0.000048	CAL				
12-Methylbenz(a)anthracene	2422-79-9	0.000048	CAL				
beta-Chloronaphthalene	91-58-7	0.000048	CAL			0.05	
Acenaphthene	83-32-9	0.000048	CAL			0.05	
Acenaphthylene	208-96-8	0.000048	CAL			0.05	
Anthracene	120-12-7	b	IRIS				
Benzo(a)fluoranthene	203-33-8	0.000048	CAL			0.05	
Benzo(g,h,i)fluoranthene	203-12-3	0.000048	CAL			0.05	
Benzo(c)phenanthrene	195-19-7	0.000048	CAL			0.05	
Benzo(e)pyrene	192-97-2	0.000048	CAL			0.05	
Benzofluoranthenes	56832-73-6	0.000048	CAL			0.05	
Benzo(ghi)perylene	191-24-2	0.000048	CAL			0.05	
Coal tar	8007-45-2	0.00099	CAL				
Coronene	191-07-1	0.000048	CAL				
Extractable organic matter (EOM)	284	0.000048	CAL				
Fluoranthene	206-44-0	0.000048	CAL			0.05	
Fluorene	86-73-7	0.000048	CAL			0.05	

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Source	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
Indene	95-13-6	0.000048	CAL				
Methylanthracene	26914-18-1	0.000048	CAL				
9-Methylanthracene	779-02-2	0.000048	CAL				
Methylbenzopyrene	65357-69-9	0.000048	CAL				
Octabromodiphenyl ether	32536-52-0	0.000048	CAL				
Perylene	198-55-0	0.000048	CAL			0.05	
Phenanthrene	85-01-8	b	IRIS				
Pyrene	129-00-0	b	IRIS				
POM 73002		0.096	CAL				
7,12-Dimethylbenz[a]anthracene	57-97-6	0.1136	CAL			250	
POM 74002		0.0096	CAL				
1,6-Dinitropyrene	42397-64-8	0.0096	CAL				
3-Methylcholanthrene	56-49-5	0.01008	CAL			22	
6-Nitrochrysene	7496-02-8	0.0096	CAL				
Dibenzo[a,h]pyrene	189-64-0	0.0096	CAL				
Dibenzo[a,i]pyrene	189-55-9	0.0096	CAL			10	
Dibenzo[a,l]pyrene	191-30-0	0.0096	CAL				
POM 75002		0.00096	CAL				
1,8-Dinitropyrene	42397-65-9	0.00096	CAL				
2-Acetylaminofluorene	53-96-3	0.00208	CAL			1	
Methylchrysene	41637-90-5	0.00096	CAL				
5-Methylchrysene	3697-24-3	0.00096	CAL				
7H-Dibenzo[c,g]carbazole	194-59-2	0.00096	CAL				
Benzo[a]pyrene	50-32-8	0.00096	EPA			1	
Dibenzo[a,e]pyrene	192-65-4	0.00096	CAL				
Dibenzo[a,h]anthracene	53-70-3	0.00096	EPA			1	
Polycyclic aromatic hydrocarbon as B(a)P TEQ		0.00096	CAL				
POM 76002		0.000096	CAL				
1-Nitropyrene	5522-43-0	0.000096	CAL				
4-Nitropyrene	57835-92-4	0.000096	CAL				
5-Nitroacenaphthene	602-87-9	0.0000592	CAL				
Benz[a]anthracene	56-55-3	0.000096	EPA			0.1	
Benzo[b]fluoranthene	205-99-2	0.000096	EPA			0.1	
Benzo[b+k]fluoranthene	102	0.000096	CAL			0.1	
Benzo[j]fluoranthene	205-82-3	0.000096	CAL			0.1	
Dibenz[a,h]acridine	226-36-8	0.000096	CAL				
Dibenz[a,j]acridine	224-42-0	0.000096	CAL			0.1	
Indeno[1,2,3-c,d]pyrene	193-39-5	0.000096	EPA			0.1	
POM 77002		0.0000096	CAL				
Benzo[k]fluoranthene	207-08-9	0.0000096	EPA			0.01	
2-Aminoanthraquinone	117-79-3	0.000015	CAL				
2-Nitrofluorene	607-57-8	0.0000096	CAL				
Carbazole	86-74-8	0.0000096	CAL			0.02	
Chrysene	218-01-9	0.00000096	EPA			0.001	
POM 78002		0.000176	CAL				
7-PAH	75	0.000176	CAL			0.05	
Propionaldehyde	123-38-6			0.008	IRIS		
Propylene dichloride	78-87-5			0.004	IRIS		
Propylene oxide	75-56-9	0.0000037	IRIS	0.03	IRIS		
Radionuclides							
Uranium, insoluble	7440-61-1			0.0008	ATSDR		
Uranium (IV) dioxide	1344-57-6			0.0008	ATSDR		
Uranium compounds	7440-61-1			0.0008	ATSDR		
Uranium hexafluoride	7783-81-5			0.00004	ATSDR		
Uranium oxide	1344-59-8			0.0008	ATSDR		
Uranium, soluble	UranSol			0.00004	ATSDR		

		Inhalation				Oral (ingestion)[a]	
Pollutant	CAS No.	URE 1/(ug/m^3)	URE Source	RfC (mg/m^3)	RfC Source	Cancer Slope Factor (1/(mg/kg/d))	RfD (mg/kg/d)
Uranyl acetate dihydrate	541-09-3			0.00004	ATSDR		
Uranyl nitrate hexahydrate	13520-83-7			0.00004	ATSDR		
Selenium Compounds							
Hydrogen selenide	7783-07-5						
Potassium selenate	7790-59-2			0.02	CAL		
Selenious acid	7783-00-8			0.02	CAL		
Selenium compounds	7782-49-2			0.02	CAL		
Selenium dioxide	7446-08-4			0.02	CAL		
Selenium disulfide	7488-56-4			0.02	CAL		
Selenium hexafluoride	7783-79-1			0.02	CAL		
Selenium oxide	12640-89-0			0.02	CAL		
Selenium oxychloride	7791-23-3			0.02	CAL		
Selenium sulfide	7446-34-6			0.02	CAL		
Selenourea	630-10-4			0.02	CAL		
Sodium selenate	13410-01-0			0.02	CAL		
Sodium selenite	10102-18-8			0.02	CAL		
Styrene	100-42-5			1	IRIS		
Styrene oxide	96-09-3						
Tetrachloroethene	127-18-4	0.00000026	IRIS	0.04	IRIS		
Titanium tetrachloride	7550-45-0			0.0001	ATSDR		
Toluene	108-88-3			5	IRIS		
Toxaphene	8001-35-2	0.00032	IRIS				
Trichloroethylene	79-01-6	0.0000048	IRIS	0.002	IRIS		
Triethylamine	121-44-8			0.007	IRIS		
Vinyl acetate	108-05-4			0.2	IRIS		
Vinyl bromide	593-60-2	0.000032	HEAST	0.003	IRIS		
Vinyl chloride	75-01-4	0.0000088	IRIS	0.1	IRIS		
Vinylidene chloride	75-35-4			0.2	IRIS		
Xylenes							
m-Xylene	108-38-3			0.1	IRIS		
o-Xylene	95-47-6			0.1	IRIS		
p-Xylene	106-42-3			0.1	IRIS		
Xylenes (mixed)	1330-20-7			0.1	IRIS		

Notes:

[a] Benchmark values are provided only for those PB-HAPs for which multipathway risk is assessed (via TRIM). There may be other PB-HAPs in this table, even though no benchmark is presented.

[b] IRIS has determined this POM to be not carcinogenic.

[c] The predominant form of mercury assessed in our multipathway risk screening is methyl mercury, which is a transformation product of divalent mercury and accumulates in fish. While elemental mercury emissions can convert to divalent mercury in the atmosphere, such transformations generally occur beyond the 50 km modeling domain around the emissions sources in our assessment. *Emissions reported as "mercury compounds" is speciated into elemental, particulate divalent, and gaseous divalent and modeled accordingly in the multipathway screening assessment.

[d] The EPA IRIS assessment for benzene provides a range of plausible UREs. This assessment used the highest value in that range, 7.8E-06 µg/m3. The low end of the range is 2.2E-06 µg/m3.

[e] There is no reference concentration for lead. In considering noncancer hazards for lead in this assessment, we compared rolling three-month average exposure estimates to the National Ambient Air Quality Standard (NAAQS) for lead (0.15 µg/m3). The primary (health-based) standard is a maximum or not-to-be-exceeded, rolling three-month average, measured as total suspended particles (TSP). The secondary (welfare-based) standard is identical to the primary standard.

[f] A chronic screening level of 0.163 mg/m3 was developed for carbonyl sulfide by EPA ORD from a No Observed Adverse Effects Level of 200 ppm based on brain lesions and neurophysiological alterations in rodents.

[g] Based on examination of California EPA's cancer inhalation unit risk factor for cobalt compounds, and taking into account aspects of the methodology used in the derivation of the value, we have decided not to use this value to support EPA's risk and technology review rules.

Table 2. Acute Dose-Response Values

Pollutant	CAS No.	AEGL-1 (1-hr) (mg/m^3)	AEGL-2 (1-hr) (mg/m^3)	ERPG-1 (mg/m^3)	ERPG-2 (mg/m^3)	MRL (mg/m^3)	REL (1-hr) (mg/m^3)
1,1,1-Trichloroethane	71-55-6	1300	3300	1900	3800	11	68
1,1,2-Trichloroethane	79-00-5					0.16	
1,1-Dimethylhydrazine	57-14-7		7.4				
1,2-Epoxybutane	106-88-7	210	410				
1,2-Propyleneimine	75-55-8		28				
1,3-Butadiene	106-99-0	1500	12000	22	1100		[a]
1,4-Dichlorobenzene	106-46-7					12	
1,4-Dioxane	123-91-1	61	1200			7.2	3
2,4/2,6-Toluene diisocyanate mixture	26471-62-5	0.14	0.59	0.071	1.1	0.000071	0.002
2,4-Toluene diisocyanate	584-84-9	0.14	0.59	0.071	1.1	0.000071	0.002
Methylene diphenyl diisocyanate	101-68-8				5		0.012
Acetaldehyde	75-07-0	81	490	18	360		0.47
Acetonitrile	75-05-8	22	84				
Acrolein	107-02-8	0.069	0.23	0.11	0.34	0.0069	0.0025
Acrylic acid	79-10-7	4.4	140	2.9	150		6
Acrylonitrile	107-13-1		3.7	22	76	0.22	
Allyl chloride	107-05-1	8.8	170	9.4	130		
Aniline	62-53-3	30	46				
Antimony Compounds							
Antimony compounds	7440-36-0					0.001	
Antimony oxide	1327-33-9					0.001	
Antimony pentafluoride	7783-70-2					0.001	
Antimony pentoxide	1314-60-9					0.001	
Antimony potassium tartrate	304-61-0					0.001	
Antimony tetroxide	1332-81-6					0.001	
Antimony trihydride	7803-52-3		7.7		2.6	0.001	
Antimony trioxide	1309-64-4					0.001	
Arsenic Compounds							
Arsenic acid	7778-39-4						0.0002
Arsenic as lead arsenate	7784-40-9						0.0002
Arsenic chloride	7784-34-1						0.0002
Arsenic compounds	7440-38-2						0.0002
Arsenic pentoxide	1303-28-2						0.0002
Arsenic trioxide	1327-53-3		3.0				0.0002
Arsine	7784-42-1		0.54		1.6		0.0002
Benzene	71-43-2	170	2600	160	480	0.029	[b]
Benzyl chloride	100-44-7			5.2	52		0.24
Beryllium Compounds							
Beryllium compounds	7440-41-7				0.025		
Biphenyl	92-52-4		61				
Bis(chloromethyl)ether	542-88-1		0.21		0.47		
Cadmium compounds	7440-43-9	0.1	0.76			0.00003	
Carbon disulfide	75-15-0	40	500	3.1	160		6.2
Carbon tetrachloride	56-23-5		82	130	630		1.9
Carbonyl sulfide	463-58-1		140				a
Chlorine	7782-50-5	1.5	5.8	2.9	8.7	0.17	0.21
Chloroacetic acid	79-11-8		26				
Chlorobenzene	108-90-7	46	690				
Chloroform	67-66-3		310		240	0.49	0.15
Chloromethyl methyl ether	107-30-2		1.6		3.3		
Cobalt Compounds							
Cobalt hydrocarbonyl	16842-03-8				0.9		
Cumene	98-82-8	250	1500				

Pollutant	CAS No.	AEGL-1 (1-hr) (mg/m^3)	AEGL-2 (1-hr) (mg/m^3)	ERPG-1 (mg/m^3)	ERPG-2 (mg/m^3)	MRL (mg/m^3)	REL (1-hr) (mg/m^3)
Cyanide Compounds							
Acetone cyanohydrin	75-86-5	7	25				
Calcium cyanide	592-01-8	3.8	13				
Cyanogen	460-19-5	4.3	18				
Cyanogen chloride	506-77-4				0.13		
Hydrogen cyanide	74-90-8	2.2	7.8		11		0.34
Isopropyl cyanide	78-82-0		5.7		85		
Potassium cyanide	151-50-8	5.3	19				
Sodium cyanide	143-33-9	4.0	14				
Dichlorvos	62-73-7	0.99	5.1			0.018	
Dimethyl formamide	68-12-2		270	6	300		
Dimethyl sulfate	77-78-1	0.12	0.62				
Epichlorohydrin	106-89-8	6.4	91	19	76		1.3
Ethyl acrylate	140-88-5	34	150	0.041	120		
Ethyl benzene	100-41-4	140	4800			22	
Ethyl chloride	75-00-3					40	
Ethylene dibromide	106-93-4	130	180				
Ethylene dichloride	107-06-2			200	810		
Ethylene glycol	107-21-1					2	
Ethylene imine (aziridine)	151-56-4		8.1				
Ethylene oxide	75-21-8		81		90	0.72	
Formaldehyde	50-00-0	1.1	17	1.2	12	0.049	0.055
Glycol ethers							
1,2-Dimethoxyethane	110-71-4						0.093
2-Butoxyethyl acetate	112-07-2						0.093
2-(Hexyloxy)ethanol	112-25-4						0.093
2-Propoxyoethyl acetate	20706-25-6						0.093
Butyl carbitol acetate	124-17-4						0.093
Carbitol acetate	112-15-2						0.093
Diethylene glycol diethyl ether	112-36-7						0.093
Diethylene glycol dimethyl ether	111-96-6						0.093
Diethylene glycol ethyl methyl ether	1002-67-1						0.093
Diethylene glycol monobutyl ether	112-34-5						0.093
Diethylene glycol monoethyl ether	111-90-0						0.093
Diethylene glycol monomethyl ether	111-77-3						0.093
Ethoxytriglycol	112-50-5						0.093
Ethylene glycol diethyl ether	629-14-1						0.093
Ethylene glycol ethyl ether	110-80-5						0.37
Ethylene glycol ethyl ether acetate	111-15-9						0.14
Ethylene glycol methyl ether	109-86-4						0.093
Ethylene glycol methyl ether acetate	110-49-6						0.093
Ethylene glycol mono-sec-butyl	7795-91-7						0.093
Glycol ethers	171						0.093
Methoxytriglycol	112-35-6						0.093
Methyl cellosolve acrylate	3121-61-7						0.093
N-Hexyl carbitol	112-59-4						0.093
Phenyl cellosolve	122-99-6						0.093
Propyl cellosolve	2807-30-9						0.093
Triethylene glycol dimethyl ether	112-49-2						0.093
Triethylene glycol monohexyl ether	25961-89-1						0.093
Triglycol monobutyl ether	143-22-6						0.093
Hexachlorobutadiene	87-68-3			11	32		
Hexachloroethane	67-72-1					58	
Hexamethylene-1,6-diisocyanate	822-06-0						[a]
n-Hexane	110-54-3		10000				
Hydrazine	302-01-2	0.13	17	0.66	6.6		

Hydrochloric acid	7647-01-0	2.7	33	4.5	30		2.1
Pollutant	**CAS No.**	**AEGL-1 (1-hr) (mg/m^3)**	**AEGL-2 (1-hr) (mg/m^3)**	**ERPG-1 (mg/m^3)**	**ERPG-2 (mg/m^3)**	**MRL (mg/m^3)**	**REL (1-hr) (mg/m^3)**
Hydrofluoric acid	7664-39-3	0.82	20	1.6	16	0.016	0.24
Maleic anhydride	108-31-6			0.8	20		
Mercury compounds							
Mercury (elemental)	7439-97-6		1.7		2		0.0006
Methanol	67-56-1	690	2700	260	1300		28
Methyl bromide	74-83-9		820		190	0.19	3.9
Methyl chloride	74-87-3		1900	310	2100	1	
Methyl hydrazine	60-34-4		1.7				
Methyl iodide	74-88-4	130	480	150	290		
Methyl isocyanate	624-83-9		0.16	0.058	0.58		
Methyl methacrylate	80-62-6	70	490				
Methyl tert-butyl ether	1634-04-4	180	2100	180	3600	7.2	
Methylene chloride	75-09-2	690	1900	1000	2600	2.1	14
Nickel compounds							[c]
Nickel carbonyl	13463-39-3		0.25				
Parathion	56-38-2		1.5				
Phenol	108-95-2	58	89	38	190		5.8
Phosgene	75-44-5		1.2		2.0		0.004
Phosphine	7803-51-2		2.8		0.7		
Phosphorus	7723-14-0	3.7	11				
Propionaldehyde	123-38-6	110	620				
Propylene dichloride	78-87-5					0.092	
Propylene oxide	75-56-9	170	690	120	590		3.1
Radionuclides							
Uranium (IV) dioxide	1344-57-6				10		
Uranium hexafluoride	7783-81-5	3.6	9.6	5	15		
Uranium oxide	1344-59-8				10		
Selenium Compounds							
Hydrogen selenide	7783-07-5		0.36		0.66		0.005
Selenium hexafluoride	7783-79-1	0.42	0.69				
Styrene	100-42-5	85	550	210	1100	21	21
Tetrachloroethene	127-18-4	240	1600	680	1400	0.041	20
Titanium tetrachloride	7550-45-0		7.8	5	20		
Toluene	108-88-3	250	2100	190	1100	7.5	[a]
Trichloroethylene	79-01-6	700	2400	540	2700		
Triethylamine	121-44-8						2.8
Vinyl acetate	108-05-4	24	130	18	260		
Vinyl chloride	75-01-4	640	3100	1300	13000	1.3	180
Vinylidene chloride	75-35-4				2000		
Xylenes							
m-Xylene	108-38-3						22
o-Xylene	95-47-6						22
p-Xylene	106-42-3						22
xylenes (mixed)	1330-20-7	560	4000			8.7	22

8/2021

Notes:

[a] Based on examination of California EPA's acute (1-hour) REL for this pollutant and considering aspects of the methodology used in the derivation of the value, we have decided not to use this value to support EPA's risk and technology review rules.

[b] Based on examination of California EPA's acute (1-hour) REL for benzene and considering aspects of the methodology used in the derivation of the value and how this assessment stands in comparison to the ATSDR toxicological assessment, we have decided not to use this value to support EPA's risk and technology review rules.

[c] Based on an in-depth examination of the available acute value for nickel [California EPA's acute (1-hour) REL], we have concluded that this value is not appropriate to use to support EPA's risk and technology review rules. This conclusion considers: the effect on which the acute REL is based; aspects of the methodology used in its derivation; and how this assessment stands in comparison to the ATSDR toxicological assessment, which considered the broader nickel health effects database. (79 FR 60247-8; October 6, 2014)

Appendix 9

Technical Support Document for Environmental Risk Screening Assessment

Technical Support Document for the Environmental Risk Screen for RTR

July 2017

Prepared For:

U.S. Environmental Protection Agency
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CONTENTS

FIGURES

TABLES

ACRONYMS/ABBREVIATIONS

AERMOD	American Meteorological Society/EPA Regulatory Model
AWQB	ambient water quality benchmarks
AWQC	ambient water quality criteria
BaP	benzo[a]pyrene
BM	benchmark
BW	body weight
CAA	Clean Air Act
DOE	Department of Energy
EcoEEF	ecological exposure equivalency factor
Eco-SSL	ecological soil screening level (Superfund)
EcoTEF	ecological toxic equivalency factor
EEF	exposure equivalency factor
EPA	Environmental Protection Agency
GEAE	generic ecological assessment endpoints
GLWQI	Great Lakes Water Quality Initiative
HAP	hazardous air pollutant
HCl	hydrogen chloride
HEM	Human Exposure Model
HF	hydrogen fluoride
LOAEL	lowest observed adverse effect level
LOEL	lowest observed effect level
MACT	maximum achievable control technology
NAAQS	national ambient air quality standards
NAWQC-ALC	national ambient water quality criteria–aquatic life criteria
NEL	no effect level
NOAEL	no observed adverse effect level
OAQPS	Office of Air Quality Planning and Standards (U.S. EPA)
ORNL	Oak Ridge National Laboratory
OSWER	Office of Solid Waste and Emergency Response (U.S. EPA) (currently Office of Land and Emergency Management
PAH	polycyclic aromatic hydrocarbon
PB-HAP	persistent and bioaccumulative HAP
PEL	probable effect level
POM	polycyclic organic matter
RAIS	Risk Assessment Information System (ORNL)
RTR	Risk and Technology Review
SAB	Science Advisory Board
SEB	soil ecotoxicity benchmark
SQB	sediment quality benchmark
SV	screening value
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin, termed “dioxin” in this report
TCE	trichloroethylene
TEF	toxic equivalency factor
TEL	threshold effect level
TRIM.FaTE	TRIM’s Fate, Transport, and Ecological Exposure module
TRV	toxicity reference value
UF	uncertainty factor

1 Overview

The environmental risk screen was developed to examine the potential for "adverse environmental effects" as required under Section 112(f)(2)(A) of the Clean Air Act (CAA). Section 112(a)(7) of the CAA defines an "adverse environmental effect" as:

> *"any significant and widespread adverse effect, which may reasonably be anticipated, to wildlife, aquatic life, or other natural resources, including adverse impacts on populations of endangered or threatened species or significant degradation of environmental quality over broad areas."*

The environmental risk screen was developed as a systematic, scientifically defensible, and efficient approach that the U.S Environmental Protection Agency (EPA) can use to screen for potential adverse environmental effects associated with emissions of hazardous air pollutants (HAPs) from facilities in Risk and Technology Review (RTR) source categories. The environmental risk screen is designed so it can be used effectively for large source categories, some with more than one thousand facilities, and for facilities located in any part of the United States.

The screen can be run quickly and with minimal additional data gathering by drawing on existing data, models, and modeling results, including those developed for the human health multipathway risk screen. The environmental risk screen uses the same TRIM.FaTE (Total Risk Integrated Methodology's Fate, Transport, and Ecological Exposure module) multipathway modeling and American Meteorological Society/EPA Regulatory Model (AERMOD) air dispersion modeling used for the human health risk assessment. In addition, the environmental risk screen applies ecological assessment endpoints and ecological health benchmarks to the same tiered screen design used for the human multipathway screen.

The environmental risk screen was developed to ensure consistency with the following EPA guidance and peer-review comments:

- EPA's *1998 Guidelines for Ecological Risk Assessment* (U.S. EPA 1998)

- EPA's Scientific Advisory Board Comments (U.S. EPA SAB 2010) on the Portland Cement manufacturing case study and the Petroleum Refining case study provided to the panel for review of RTR methods (U.S. EPA 2009)
- Participant comments and feedback provided to EPA during the Office of Air Quality Planning and Standards (OAQPS) Workshop on Ecological Risk Assessment of Air Toxics, June 2006 (ICF 2006).

Below, we summarize the design and key features of the environmental risk screen. In Section 2, we present the environmental risk screen conceptual model, the HAPs included in the screen, and the endpoints for which environmental risk are screened. Section 3 presents the approach used to identify ecological benchmarks for each HAP for each assessment endpoint. Section 4 describes the methods used to estimate HAP exposures in the environment. This section also describes how we used the benchmarks identified in Section 3 to calculate "screening threshold emission rates" and how we compared those thresholds to exposure estimates to screen for adverse environmental effects. Section 5 presents the outputs and analyses of the risk screening results.

2 Key Components of the Environmental Risk Screen

2.1 ENVIRONMENTAL HAPS

When considering which HAPs should be included in the environmental risk screen, we narrowed the list of 189 HAPs to the 31 environmental HAPs suggested in EPA's 2006 Ecological Risk Workshop. The workshop participants developed a list of 31 suggested environmental HAPs by starting with the 14 PB-HAPs identified for the RTR program (See the second column of Table 2-1) and then adding the following 17 pollutants for the reasons indicted below (OAQPS Workshop on Ecological Risk Assessment of Air Toxics June of 2006; ICF 2006):

- Hydrogen chloride (HCl), hydrogen fluoride (HF), and trichloroethylene (TCE) – toxicity to plants
- Hexachlorobutadiene and pentachlorophenol – toxicity to plants and aquatic species
- Phthalates – dibutyl phthalate, dimethyl phthalate, and bis-(2-ethylhexyl) phthalate (DEHP) – endocrine disruptors

- HAP metal compounds – antimony compounds, arsenic compounds, beryllium compounds, chromium compounds, cobalt compounds, manganese compounds, nickel compounds, and selenium compounds – persistence
- Cyanide compounds – highly toxic.

We evaluated the 31 suggested environmental HAPs for inclusion in the environmental screen based on the criteria shown in Table 2-1:

- Persistence and bioaccumulation potential
- Inclusion in the TRIM.FaTE multipathway model
- Magnitude of emissions
- Relative environmental toxicity – based on toxicity to wildlife, soil communities, and aquatic biota.

Table 2-1. Summary of HAPs Considered for Inclusion in Environmental Risk Screen

Pollutant	*RTR PB-HAP*	In Multi-pathway Model	2005 NEI Point Source Emissions (TPY)	Environmental Criteria			Included/Excluded – Rationale
				Wildlife NOAEL for Mink (mg/kg/d)[a]	Soil Screening BM (mg/kg)[b]	Water Quality Criteria (µg/L)[c]	
Antimony compounds			54	0.052	0.142[d]	80[d]	**Excluded** – persistent, but not bioaccumulative.
Arsenic compounds		X	181	0.052	100	150	**Included** – persistent but not bioaccumulative; low toxicity to aquatic biota and soil communities; but high relative wildlife toxicity.
Beryllium compounds			12	0.51	1.06[d]	3.6[d]	**Excluded** – persistent, but not bioaccumulative.
Bis-(2-ethylhexyl) phthalate (DEHP)			266	7.6	0.925[d]	0.3[d]	**Excluded** – not bioaccumulative; low relative wildlife toxicity.
Cadmium compounds	X	X	34	0.742	20	0.25	**Included** – PB-HAP in multipathway model; moderate wildlife and aquatic toxicity.
Chlordane	X		0.01	14	0.22[d]	0.0043	**Excluded** – PB-HAP, but very low emissions.
Chlorinated dibenzodioxins and furans (2,3,7,8-TCDD)	X	X	NA	0.0000008	1.2E-06[e]	1.0E-05[e]	**Included** – PB-HAP in multipathway model, high relative toxicity.
Chromium compounds			4,025	2.52 (Cr6) 2,105 (Cr3)	10	11 (Cr6) 74 (Cr3)	**Excluded** – persistent, but not bioaccumulative; low relative wildlife and water toxicity.
Cobalt compounds			77	7.33[g]	0.14[d]	24[d]	**Excluded** – persistent, but not bioaccumulative.
Cyanide compounds			290	49.7	1.33[d]	5.2	**Excluded** – not PB-HAP.
DDE dichlorodiphenyldichloroethylene	X		0.005	0.62	0.596[d]	4.5E-9[d]	**Excluded** – PB-HAP, but very low emissions.
Dibutyl phthalate			89	229	0.15[d]	9.7[d]	**Excluded** – not PB-HAP, low relative wildlife toxicity.
Dimethyl phthalate			248	NA	734[d]	330[e]	**Excluded** – not PB-HAP; low relative toxicity.
Heptachlor	X		0.002	0.1	0.0060[d]	0.0038	**Excluded** – very low emissions.
Hexachlorobenzene	X		0.61	0.08[i]	0.20[d]	0.0003[d]	**Excluded** – PB-HAP, but low emissions.
Hexachlorobutadiene			0.77	NA	0.040[d]	0.053[d]	**Excluded** – not PB-HAP, low emissions.
Hexachlorocyclohexane (all isomers)	X		0.01	NA	NA	NA	**Excluded** – PB-HAP, but low emissions, no BM.
Hydrogen chloride			396,069	NA	NA	NA	**Included** – high vapor emissions and high toxicity to terrestrial plants.

Pollutant	*RTR PB-HAP*	In Multi-pathway Model	2005 NEI Point Source Emissions (TPY)	Environmental Criteria			Included/Excluded – Rationale
				Wildlife NOAEL for Mink (mg/kg/d)[a]	Soil Screening BM (mg/kg)[b]	Water Quality Criteria (µg/L)[c]	
Hydrogen fluoride			60,238	NA	NA	NA	**Included** – high vapor emissions and high toxicity to terrestrial plants.
Lead compounds	X		307	6.15	900	2.5	**Included** – PB-HAP, Secondary NAAQS Standard.
Manganese compounds			1,386	68	100	120[h]	**Excluded** – persistent, but not bioaccumulative; low relative toxicity.
Mercury compounds	X	X	33	1.0	30	0.77	**Included** – PB-HAP, in multipathway model; methylmercury highly bioaccumulative and toxic.
Methoxychlor	X		0.001	3.1	NA	0.03	**Excluded** – PB-HAP, but very low emissions.
Nickel compounds			566	30.77	90	52	**Excluded** – persistent, but not bioaccumulative; low relative toxicity.
Pentachlorophenol			3	0.185	400	15	**Excluded** – not PB-HAP, low emissions.
Polychlorinated biphenyls	X		0.6	0.14[j]	0.000332[d]	0.014	**Excluded** – PB-HAP, but low emissions.
Polycyclic organic matter (BaP)	X	X	181	0.42	1.52[d]	0.014[g]	**Included** – PB-HAP, in multipathway model, and high relative toxicity.
Selenium compounds			496	0.154	100	5	**Excluded** – not PB-HAP; low relative toxicity.
Toxaphene	X		0.003	6.2	0.119[d]	0.0002	**Excluded** – very low emissions.
Trichloroethylene			4,291	0.291	12.4[d]	47[d]	**Excluded** – not PB-HAP; low relative toxicity.
Trifluralin	X		1	NA	NA	0.2[h]	**Excluded** – PB-HAP, but low relative toxicity to wildlife and no BM for soils.

Acronyms and abbreviations: BaP – benzoapyrene; BM – benchmark, NA – Not Available; NAAQS – National Ambient Air Quality Standards; PB-HAP – persistent bioaccumulative hazardous air pollutant, NEI = National Emissions Inventory, TPY = short tons per a year

[a]Sample et al. (1996). U.S. Department of Energy. ES/ER/TM-86/R3.

[b]Efroymson et al. (1997a,b). U.S. Department of Energy. ES/ER/TM-126/R2.

[c]U.S. EPA (2016b) National Aquatic Life Criteria Table. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

[d]U.S. EPA (2003a) Region 5 "RCRA [Resource Conservation and Recovery Act] Ecological Screening Levels" for soil and water.

[e]U.S. EPA Region 6 recommends using Texas Natural Resource Conservation Commission values (TNRCC 2001).

[f]U.S. EPA (2005c) "Ecological Soil Screening Levels for Cobalt, Interim Final" OSWER Directive 9285.7-67

[g]Suter and Tsao (1996). U.S. Department of Energy. ES/ER/TM-96/R2.

[h]U.S. EPA (2006). Region 3 Biological Technical Assistance Group (BTAG) Freshwater Sediment Screening Benchmarks.

The far right column of Table 2-1 shows the rationale for each HAP's inclusion or exclusion from the current environmental HAP risk screen. The following eight environmental HAPs are included in the environmental risk screen:

- Six persistent and potentially bioaccumulative HAPs:
  - arsenic
  - cadmium
  - dioxins/furans
  - polycyclic organic matter
  - mercury (both inorganic mercury and methyl mercury)
  - lead
- Two acid gases:
  - hydrogen chloride
  - hydrogen fluoride.

HAPs that persist in the environment and bioaccumulate through food chains are of particular environmental concern. They can accumulate in soils and sediments, with subsequent releases to pore water and surface waters where they can be taken up by plants or by animals (e.g., small fish) near the base of food webs, with possible further concentration by animals at higher trophic levels. Table 2-1 shows that cadmium, dioxins/furans, mercury, and POM all have relatively high environmental toxicity values (i.e., threshold-for-effect benchmarks are relatively low). Lead was included in the screen because it is a PB-HAP and because we can use the secondary lead National Ambient Air Quality Standards (NAAQS) as a reasonable measure for determining whether an adverse environmental effect occurs. According to the 2011 National Air Toxics Assessment of stationary sources, the six PB-HAPs we include in the screening analysis (arsenic, cadmium, mercury, lead, dioxins, POM) account for 99.9 percent of national emissions of PB-HAPs (the 14 in the RTR list cited above plus arsenic).

The acid gases HCl and HF were included due to their well-documented potential to cause direct damage to terrestrial plant foliage. In addition, when HF concentrations are above those at which plant damage is first seen, HF can cause fluorosis in livestock feeding on exposed forage. According to the 2005 National Emissions Inventory, HCl and HF account for about 99 percent (on a mass basis) of national acid gas emissions from stationary sources. We acknowledge that

other HAPs beyond the eight discussed above might have potential to cause adverse environmental effects. Therefore, EPA might add other HAPs to its environmental risk screen in the future, as risk assessment methods and resources allow.

2.2 ASSESSMENT ENDPOINTS

For the RTR environmental risk screen, we use conventional generic ecological assessment endpoints (GEAEs) (U.S. EPA 2003b, 2016b; Suter et al. 2004). EPA's 1998 *Guidelines for Ecological Risk Assessment* defines an ecological assessment endpoint as "an explicit expression of the environmental value to be protected and is defined operationally as an ecological entity (e.g., individual organisms, specified populations of species, biological communities or assemblages, and ecosystems) and its attributes (e.g., frequency of mortality, average fecundity, species abundance, community diversity)" (U.S. EPA 1998). Although EPA developed GEAEs to improve the scientific basis for ecological risk management decisions at EPA, GEAEs are used frequently for ecological risk assessments conducted outside the Agency.

For the RTR assessment, all emissions of HAPs are to the air from point sources (i.e., facilities) in the evaluated source categories. Consequently, all environmental media can be exposed to the HAPs. For the ecological HAPs that partition primarily to air (e.g., HCl, HF), we evaluate risks to the environment from direct contact with the airborne HAPs. For HAPs that can deposit on and partition to ground-level environmental media, and from there partition to other media and accumulate along biological food chains (i.e., PB-HAPs), we evaluate multimedia risks to the environment.

In the environmental risk screen, we evaluate the following four exposure media: terrestrial soils, surface water bodies, fish consumed by wildlife, and air. Within these four exposure media, we evaluate the nine GEAEs shown in Table 2-2. The GEAEs reflect the overall "health" of aquatic and terrestrial ecosystems and any important biota or community types that could be exposed in those ecosystems. For PB-HAPs, the generic set of receptors includes both community-level and population-level endpoints. For acid gases, the receptors are terrestrial plant communities. Selection of species for the population-level assessments for PB-HAPs was based on those organisms likely to be the most highly exposed due to bioaccumulation of the PB-HAP through

aquatic and terrestrial food chains. Exposure scenarios assumed for all GEAEs are chronic. For each GEAE listed in Table 2-2, we identified ecotoxicity benchmarks as discussed in Section 3.

Table 2-2. Generic Ecological Assessment Endpoints Used in the Environmental Risk Screen

Exposure Media	No.	Assessment Endpoint	Entities	Relevant Attributes	Benchmark[a]
Terrestrial Soils	1	Maintain structure/function of soil invertebrate communities (e.g., for nutrient recycling, soil aeration)	Assemblages of earthworms, insect grubs, nematodes	Species abundance and diversity; species composition; and survival and reproduction of those species' populations	Soil ecotoxicity benchmark (SEB): Invertebrates
	2	Maintain structure/function of terrestrial plant communities (e.g., for food and habitat for wildlife)	Assemblages of plant species: trees, herbs, grasses	Species abundance and diversity; survival, growth, and productivity of those species	SEB: Plants
	3	Maintain local bird populations that feed on soil invertebrates	Woodcock, robins, thrashers	Individual survival, growth, reproduction and development; area contaminated	SEB: Birds
	4	Maintain local mammal populations that feed on soil invertebrates	Shrews, moles, voles	Individual survival, growth, reproduction and development; area contaminated	SEB: Mammals
Surface Water Bodies	5	Maintain benthic community structure/function (sediment-dwelling organisms)	Assemblages of aquatic insects, amphipods, isopods, crayfish	Species abundance and diversity; survival, growth, development, and reproduction of those species	Sediment quality benchmark (SQB)
	6	Maintain aquatic community structure/function (water-column community to support fisheries)	Assemblages of fish and invertebrates in water column	Species abundance and diversity; survival, growth, development, and reproduction of those species	Ambient water quality benchmark (AWQB)
Fish (consumed by wildlife)	7	Maintain local populations of birds that feed on fish and other aquatic prey	Common merganser, belted kingfisher, herons, gulls, loons	Individual survival, growth and development, reproduction; area contaminated	Wildlife Toxicity Reference Value (TRV)
	8	Maintain local populations of mammals that feed on fish and other aquatic prey	Mink, otter, raccoon	Survival, growth and development, reproduction at the individual level; proportion habitat contaminated	Wildlife TRV
Air	9	Maintain community structure/ function of plants with foliage exposed to HAPs in air (e.g., food and habitat for wildlife)	Trees, shrubs, herbs, grasses, crops	Abundance; productivity	Air ecotoxicity benchmark: Plants

[a]A soil ecotoxicity benchmark (SEB) is a generic term used here to indicate any type of soil benchmark for ecological risk assessment. A sediment quality benchmark (SQB) also is a generic term, as is the term ambient water quality benchmark (AWQB). Different agencies, states, and offices have named and defined their own particular SEBs, SQBs, and AWQBs in different ways.

As mentioned above, the GEAEs used in the environmental risk screen include both population-level and community-level endpoints. Column 3 ("Assessment Endpoint") of Table 2-2 indicates whether an endpoint is population based or community based.

An assessment *population* is a group of organisms belonging to the same species that occupy the area defined as relevant to the ecological risk assessment (U.S. EPA 2003b). For the RTR risk screen, that area is defined as the modeling domain surrounding each facility. Endpoints 3, 4, 7, and 8 in Table 2-2 represent population-based GEAEs. Specifically, these population endpoints include bird and mammal populations that feed on soil invertebrates and aquatic prey (e.g., fish). Impairment of individual growth, development, reproduction, or survival could reduce population size and productivity and increase the probability of local extirpation if the impairment occurs in a significant proportion of the exposed or local population.

An assessment *community* is a multispecies group of organisms occupying the area defined as relevant to the assessment (U.S. EPA 2003b). For the RTR risk screen, that area is defined as the modeling domain surrounding each facility. Endpoints 1, 2, 5, 6, and 9 in Table 2-2 represent community-based GEAEs. Specifically, these community endpoints include the following communities: soil invertebrate, terrestrial plant, benthic, and aquatic.

2.3 ENVIRONMENTAL RISK SCREENING APPROACH

EPA conducts the environmental risk screen if any facilities in the source category emit any of the eight environmental HAPs. Specifically, if one or more of the eight environmental HAPs are emitted by at least one facility in the source category, the Agency conducts the environmental risk screen. Because of the unique properties and environmental effects of the HAPs, the environmental risk screen differs for three groups of the eight environmental HAPs:

- PB-HAPs – arsenic, cadmium, mercury, POM, and dioxin/furans
- Lead
- Acid gases – HCl and HF.

An overview of the environmental risk screen for each group is provided below.

2.3.1 PB-HAPs

For the five PB-HAPs—arsenic, cadmium, mercury, POM, and dioxins/furans—the environmental risk screen consists of three tiers (Figure 2-1). The tiered design used for the environmental risk screen is the same as that used for the human multipathway screen described Appendix 6 of the Risk Report.[1] Each tier uses a different conceptual model for the spatial relationship of the facility to surface waters and terrestrial environments, and each tier uses different parameter inputs. All three tiers of the environmental risk screen for PB-HAPs use the same assessment endpoint benchmarks (see Section 2.2).

The first tier of the screen is based on a hypothetical facility for which the surrounding environment was designed to encompass a health-protective environmental layout that would maximize PB-HAP concentrations in fish and in terrestrial environments in the immediate vicinity of a facility. This conceptual model is the same as used for the Tier 1 human health screen.

Section 4 provides further description of the conceptual model as applied in the environmental risk screen. TRIM.FaTE simulations were used to back-calculate Tier 1 screening threshold emission rates that correspond to the assessment endpoint benchmarks for each PB-HAP. In other words, each Tier 1 screening threshold emission rate represents the emission rate in tons per year that results in media concentrations at the hypothetical facility that equal the relevant ecological benchmarks.[2]

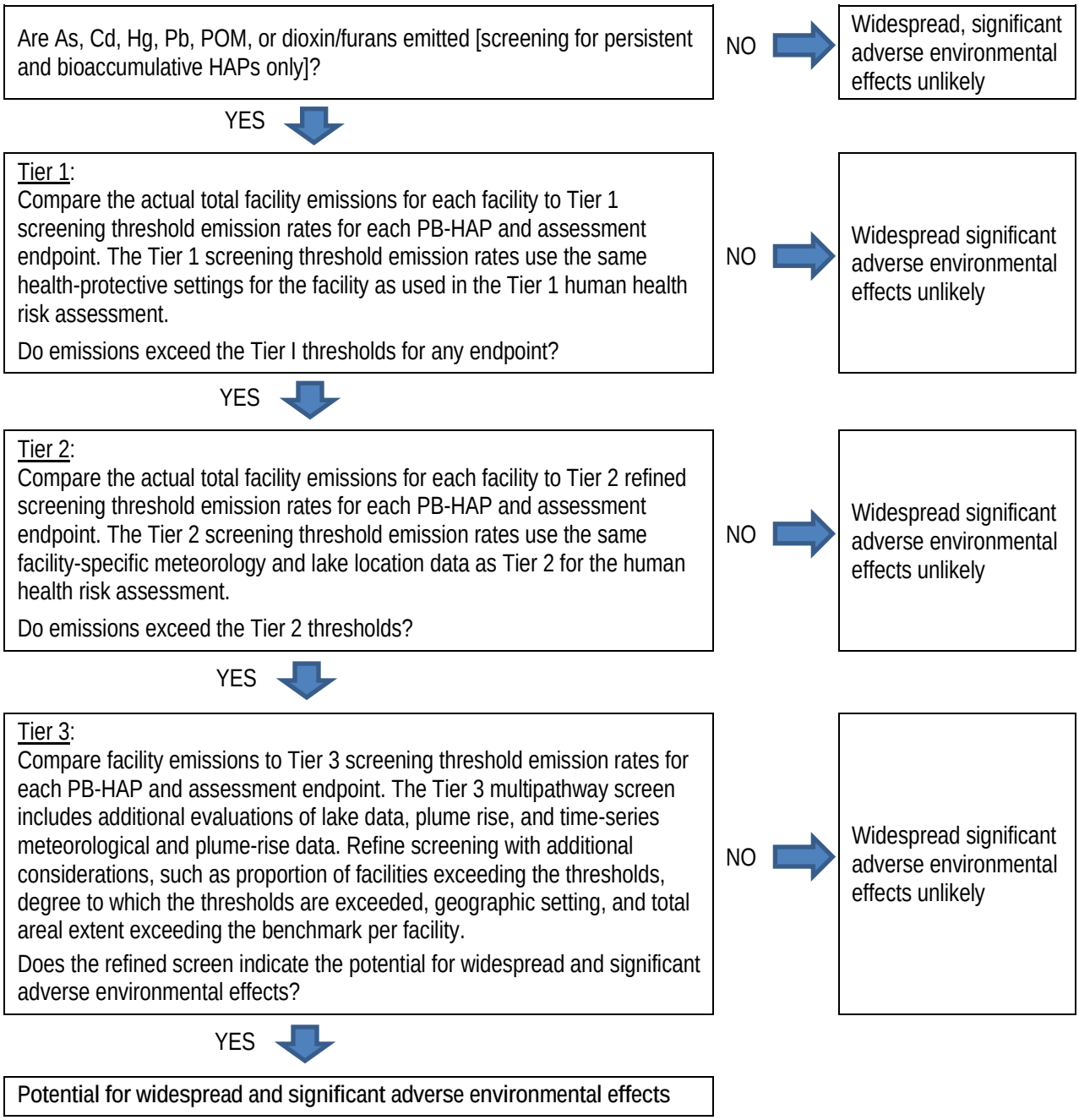
The Tier 1 environmental risk screen is performed by comparing the reported emission rate for each facility in tons per year to the Tier 1 screening threshold emission rate in tons per year for each PB-HAP, GEAE, and effect level if more than one is identified. If none of the emissions from a facility exceed these chemical-specific Tier 1 screening threshold emission rates, the facility "screens out" and therefore is not evaluated further under the environmental risk screen.

[1] Appendix 6 to the Risk Report is the *Technical Support Document for the TRIM-Based Multipathway Tiered Screening Methodology for RTR*.

[2] See Section 3, Effects Assessment, for discussion of the ecological benchmarks and wildlife toxicity reference values used for all three tiers of the environmental assessment.

If emissions from a facility exceed any of the Tier 1 screening threshold emission rates, the facility could be further evaluated in Tier 2.

Figure 2-1. Overview of the Environmental Risk Screen for PB-HAPs



In Tier 2 of the environmental risk screen, the screening threshold emission rates are refined to account for facility-specific meteorology and the actual location of lakes near facilities that did not pass the Tier 1 screen. If emissions from a facility do not exceed the Tier 2 screening

threshold emission rates, the facility "screens out" and is not evaluated further under the environmental risk screen. If emissions from a facility exceed the Tier 2 screening threshold emission rates, the facility could be further evaluated in Tier 3.

In Tier 3 of the environmental risk screen, the screening threshold emission rates are refined to account for lake data and time-series meteorological and plume-rise data (see Section 4 of Appendix 6 of the Risk Report for more information on the Tier 3 methods). If emissions from a facility do not exceed the Tier 3 screening threshold emission rates, the facility "screens out" and is not evaluated further. If emissions from a facility exceed the Tier 3 screening threshold emission rates, the facility could be further evaluated to consider the degree to which the screening threshold emission rates are exceeded, which endpoints and effect levels are exceeded, the geographic setting, and the total area exceeding the screening threshold emission rates. If, after additional refinement, the facility still exceeds the screening threshold emission rates, the facility might cause adverse environmental effects.

As with the multipathway human health risk assessment, a site-specific assessment could be conducted if the Tier 3 screening results indicate a potential for adverse environmental effects. The site-specific assessment uses model parameter values and scenario designs intended to better represent the modeled facility—aspects such as local terrain (influencing runoff and erosion patterns), watersheds, actual lake boundaries and water retention rates, soil types, and land cover. Site-specific assessments are not presented in this report.

2.3.2 Lead

The environmental risk screen for lead consists of one tier. For lead compounds, we currently do not have the ability to calculate concentrations in soils, surface waters, and sediments using the TRIM.FaTE model. Therefore, to evaluate the potential for adverse environmental effects from lead compounds, we compare the Human Exposure Model (HEM)/AERMOD-modeled air concentrations of lead for each facility in the source category to the level of the secondary

NAAQS for lead.[3] We consider values below the level of the secondary lead NAAQS to be unlikely to cause adverse environmental effects.[4]

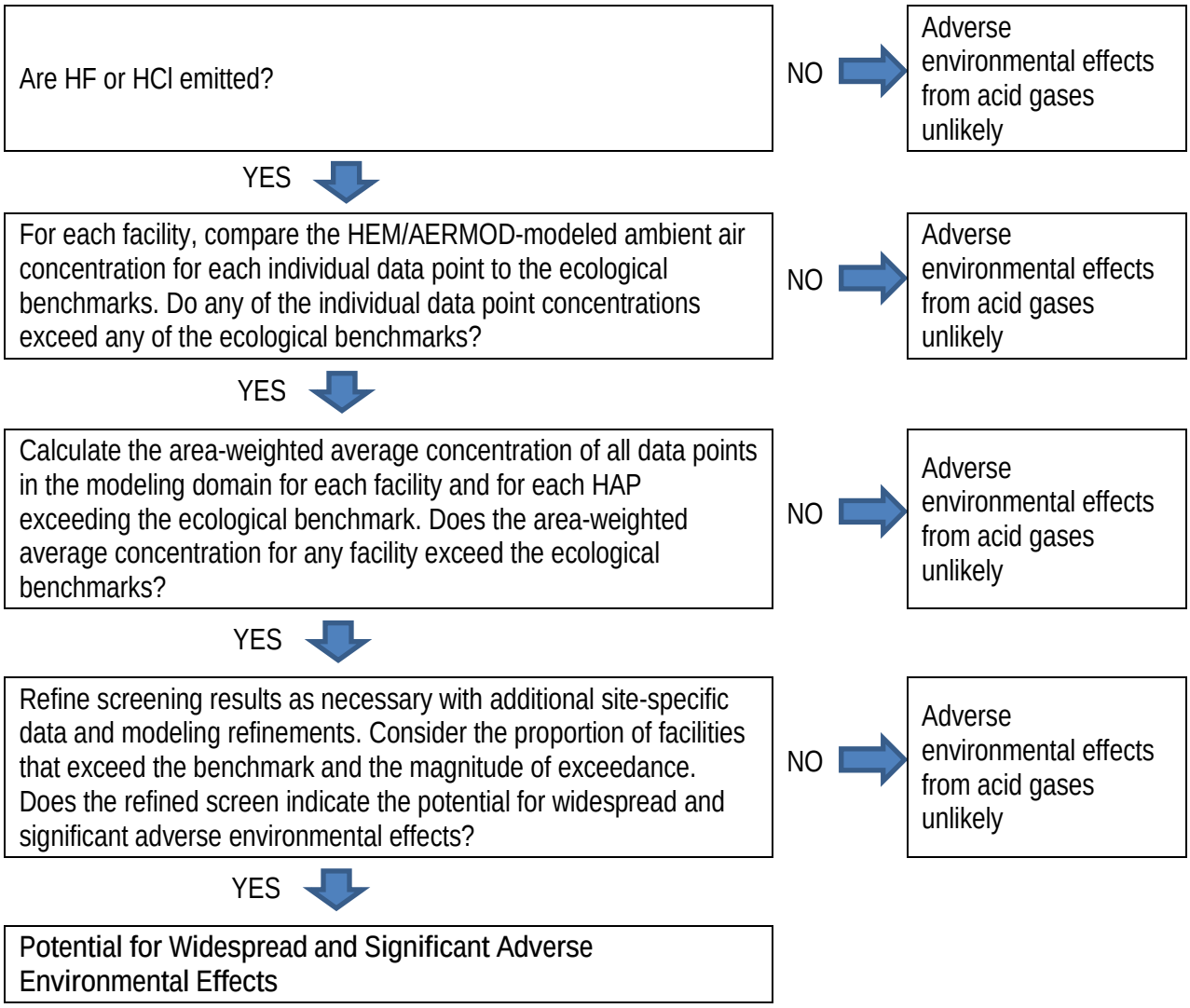
2.3.3 Acid Gases

For HF and HCl, the environmental risk screen evaluates potential phytotoxicity (i.e., poisonous to plants) and reduced productivity of plants due to chronic exposure. For each acid gas, the environmental risk screen compares the HEM/AERMOD-modeled ambient air concentrations in the modeling domain around each facility to ecological benchmarks (Figure 2-2). If the average concentration of a given HAP in the modeling domain around a facility exceeds the ecological benchmark, the facility does not pass the screen and, therefore, might cause adverse environmental effects.

[3] The secondary lead NAAQS is a reasonable measure of determining whether an adverse environmental effect exists because it was established considering "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

[4] On October 18, 2016, EPA issued its final decision to retain the 2008 NAAQS for lead (U.S. EPA 2016a).

Figure 2-2. Overview of the Environmental Risk Screen for Acid Gases



3 Effects Assessment

To assess effects, we identified appropriate ecological benchmarks to compare to exposure concentrations. As indicated in Section 2.2, we searched for available ecological benchmarks for each assessment endpoint listed in Table 2-2. Specifically, we sought benchmarks for chronic exposure to each HAP included in the environmental risk screen, except for lead, which was screened using the secondary NAAQS.

Ecological benchmarks represent a level of exposure to a chemical in the environment that has been linked to a particular environmental effect level (e.g., a no-effect level or a threshold effect level) through scientific study. The three general metrics for ecological benchmarks are listed below.

- **Dose-based –** Dose-based benchmarks are expressed as a dose of chemical ingested per day per kg of animal body weight, typically mg/kg-day, which has been linked to a particular effect level. This type of benchmark usually is used when evaluating risks to wildlife via ingestion pathways. TRVs for terrestrial animals (e.g., wildlife) are an example of a dose-based benchmark.
- **Concentration-based –** Concentration-based benchmarks are expressed as the concentration of a chemical in an environmental medium (e.g., µg of HAP per liter of water) that has been linked to a particular environmental effect level. Concentration-based benchmarks usually are used when evaluating risks to receptors that have direct contact with the contaminated medium (e.g., fish in water, plant roots in soil, plant foliage in air).
- **Tissue-based –** Tissue-based benchmarks are expressed in units of the amount of chemical per mass of tissue in the exposed receptor (e.g., mg of cadmium per kg of tissue). This type of benchmark can be used to assess almost any type of consumer animal (e.g., fish, benthic invertebrates, birds, mammals).

To evaluate risk in the RTR program, we use reported emissions data that include the mass of HAPs emitted from each facility in the source category being examined. The emissions data are used as inputs to the TRIM.FaTE multipathway model to estimate HAP concentrations in soil, surface water bodies, and fish, and using the HEM/AERMOD model to estimate HAP concentrations in air. These estimates are best suited to the use of dose-based or concentration-based benchmarks. Tissue-based benchmarks have little utility for the RTR program because site-specific data for the concentrations of HAPs in animal tissues (e.g., liver, kidney) are not available. Therefore, the identification of benchmarks for the environmental risk screen focused entirely on dose-based and concentration-based benchmarks.

Based on a review of available ecological benchmarks, where possible, we identified existing ecological benchmarks at three generic effect levels:

- **Probable effect level (PEL):** The level above which adverse effects at both population and community levels are expected to occur frequently. In general, local extirpation or absence of populations of key community species is likely, compromising community structure and function.
- **Threshold effect level (TEL):** The level at which some adverse effects might occur in a minority fraction (e.g., up to 20 percent) of the exposed proportion of a specified population (e.g., mink, merganser) or at which few species (e.g., 5 percent aquatic animal species) might be lost from a community. Losses are not expected to influence either population survival over its range at the county or state level or the overall structure and function of the community near the facility. To screen risks to wildlife populations, we use lowest-observed-adverse-effect levels (LOAELs) from scientific toxicity tests that assess survival, growth, reproduction, and development to calculate assessment population benchmarks from the same taxonomic class that represents TELs. LOAELs are the lowest test exposure level at which statistically significant adverse effects on survival, growth, reproduction, or development occurred in the test organisms of the toxicity study considered key.[5]
- **No effect level (NEL):** The highest exposure level at which no biologically significant increases occur in the frequency or severity of (1) adverse effects on community structure or (2) adverse effects on assessment populations. To screen risks to wildlife populations, we use no-observed-adverse-effect levels (NOAELs) from a key toxicity test[6] that assessed growth, reproduction, or survival species from the same taxonomic class to calculate assessment population benchmarks that represent NELs.[7]

We identified preferred benchmark sources to allow selection of benchmarks for each environmental HAP for each ecological assessment endpoint. In general, we used EPA sources at a programmatic level (e.g., Office of Water, Superfund Program), if available. If not, we used

[5]Many ecological risk assessors use the geometric mean of the LOAEL and NOAEL to represent a "threshold" acceptable exposure level. For the RTR assessment, we use the LOAEL to represent a threshold for potential "significant" (biologically) adverse effect in keeping with Section 112(a)(7) of the CAA.

[6]A key toxicity test is one selected from the set of adequately conducted and documented tests to represent a sensitive species and sensitive endpoint, given the experimental data set as a whole.

[7]No-effect-level benchmarks are generally used to assess risks to threatened and endangered species (e.g., U.S. EPA 2004), although additional "safety" factors might be applied to account for species-to-species variation in chemical sensitivity and for extrapolation from laboratory to field conditions.

EPA benchmarks used in regional programs (e.g., region-specific Superfund). If benchmarks were not available at a programmatic or regional level, we used benchmarks developed by other federal agencies (e.g., National Oceanic and Atmospheric Administration), state agencies, or Canada. Section 3.1.2 discusses the preferred benchmark sources in detail.

Benchmarks for all effect levels are not available for all combinations of environmental HAPs and assessment endpoints. In cases where benchmarks representing multiple effect levels, as defined above, were available for a particular environmental HAP and assessment endpoint, we used all three available effect levels. We believe this best informs conclusions regarding whether ecological risks exist and, if so, whether the risks could be considered significant and widespread. Probable-effect-level benchmarks generally are not available except for benthic community sediment benchmarks for some chemicals.

We have organized the remainder of this section into two sections: Section 3.1 – Benchmarks for PB-HAPs and Section 3.2 – Benchmarks for Acid Gases. Attachment A contains additional discussion about the ecological benchmarks, wildlife toxicity reference values, and toxic equivalency factors (TEFs). Attachment A also includes additional tables and citations to those presented in this section.

3.1 BENCHMARKS FOR PB-HAPS

This section identifies ecological toxicity (ecotoxicity) benchmarks, expressed as concentrations of chemicals in environmental exposure media, for the five PB-HAPs included in the environmental risk screen (Note, lead is the sixth PB-HAP. It is screened using the secondary NAAQS level for lead). It also includes TRVs for wildlife. The PB-HAPs included in the ecological effects assessment (i.e., benchmark assessment) are mercury (as methyl mercury or inorganic divalent mercury), cadmium, POM, arsenic, and dioxins/furans. We evaluated POM and dioxins/furans by relating each compound to an "index" compound within the group. Specifically, we identified both toxicity benchmarks for the "index" chemicals (i.e., benzo[a]pyrene, or BaP, and 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD) and TEFs for the remaining chemicals in each category relative to the appropriate index chemical.

3.1.1 Types of Benchmarks for PB-HAPs

In this section, we define the benchmarks selected for the combinations of assessment populations and communities and exposure media listed in Table 2-2 (Section 2.2), focusing on PB-HAPs. We also briefly reiterate the three generic effect levels for which we sought benchmarks.

3.1.1.1 Surface Soil Benchmarks

Across the Agency, up to two distinct types of soil communities and two groups of wildlife species have been used to derive soil ecotoxicity benchmarks (SEBs): (1) invertebrate community, (2) plant community, (3) birds that feed on soil invertebrates, and (4) mammals that feed on soil invertebrates. The latter two assessment endpoints are included specifically for PB-HAPs because the soil invertebrates might bioaccumulate these chemicals, resulting in higher exposures for the ground-feeding birds and mammals compared with chemicals that do not bioaccumulate.

SEBs are expressed as milligrams (mg) or micrograms (µg) of chemical per kilogram (kg) dry soil. To screen a location for possible risks to one or more of the soil assessment endpoints, estimates of surface soil contamination of PB-HAPs are compared with available corresponding benchmark values. TRIM.FaTE estimates concentrations for surface soil compartments at several successive distances from the source up to 10 kilometers (km). The TRIM.FaTE estimate of surface soil compartment chemical mass per unit volume is converted to a dry weight soil concentration by multiplying the volume of the compartment by the fraction of the volume that is in solid phase (0.57) and dividing the volume of the compartment by the mass-density of soil particles (2.6 kg/L soil).

For SEBs for avian or mammalian wildlife that EPA already has calculated for the Superfund or Resource Conservation and Recovery Act programs, we accepted the SEB as is. Implicit in the SEB is the TRV for the bird or mammal used by the office to back-calculate the SEB.[8]

[8]EPA "back-calculates" an SEB for a ground-feeding bird (e.g., woodcock) or mammal (e.g., shrew) as a concentration of chemical in soil that would result in the bird or mammal ingesting an amount of chemical equal to its TRV in mg/kg-day. A chemical-specific bioaccumulation factor relates the concentration in the food (e.g., earthworms) to the concentration in the soil. For PB-HAPs, the SEBs are lowest for wildlife species that ingest soil

For its derivation of ecological soil screening levels (Eco-SSLs), EPA's Superfund Office uses both bounded and unbounded NOAELs to establish a TRV for birds and for mammals based on the geometric mean of NOAELs across different toxicity tests for growth and reproductive effects for each taxon (U.S. EPA 2003c). The method also uses bounded LOAELs to check the final geometric mean NOAEL for plausibility. The geometric mean calculation gives equal weight to each result from multiple studies of the same endpoint (e.g., clutch size) for the same species (e.g., chicken) as for single studies of a different endpoint (e.g., weight gain by chicks) with a different species (e.g., mallard). We therefore conclude that the final geometric mean NOAEL does not account for interspecies variation in sensitivity (i.e., NOAEL is biased toward the species tested most often) and does not necessarily correspond to the most sensitive effect (i.e., NOAELs are averaged across growth and reproduction endpoints even if reproduction is the most sensitive endpoint).

3.1.1.2 Surface Water Body Benchmarks

Some EPA programs and regions (e.g., Superfund, Office of Water, Office of Pesticide Programs, various EPA Regions) also have developed aquatic benchmarks for two environmental "compartments" of aquatic ecosystems that might be in disequilibrium with each other: benthic sediments and the water column. Thus, benchmarks have been derived for aquatic communities in both compartments: the benthic community and the water-column community (Endpoints 5 and 6, respectively, in Table 2-2). The benthic community consists primarily of macroinvertebrates in contact with the sediments that consume detritus or graze on algae (e.g., amphipods, annelid worms, snails, aquatic larval stages of many insect species), but also can include filter feeders (e.g., mussels), predatory invertebrates (e.g., dragonfly nymphs), and invertebrate scavengers (e.g., crayfish). Benthic organisms are exposed through direct contact with contaminants in sediments and sediment pore water and by consumption of contaminated detritus/prey in the sediments. Benchmarks for the benthic community generally are called sediment quality benchmarks (SQB) and usually are expressed in units of mg chemical per

invertebrates (e.g., earthworms); other chemicals might be accumulated more by plants than by soil invertebrates. To calculate an SEB, EPA uses species-specific values for wildlife body weight, diet, food ingestion rate, and incidental soil ingestion as described in its guidance (U.S. EPA 2003c).

kilogram (kg) dry-weight sediment (Jones et al. 1997). Some SQBs are normalized to the total organic carbon content of the sediments (Jones et al. 1997).

The "aquatic" biota in the water-column compartment include plankton (i.e., microscopic algal cells and zooplankton such as water fleas and copepods) and free-swimming fish and some larger invertebrates (e.g., shrimp-like crustaceans). The water-column organisms are exposed by direct contact with the water (and water through their gills for respiration) and by ingestion of chemicals in their food. The food of free-swimming animals can be obtained from the water-column, the benthos, or both, depending on species of consumer. For that reason, the two compartments are not strictly separable when considering aquatic food webs. EPA Office of Water benchmarks for the water-column community of organisms generally are called ambient water quality benchmarks (AWQB) or criteria (AWQC) for the protection of aquatic life and are expressed as water concentrations in micrograms per liter of water.

3.1.1.3 Benchmarks for Wildlife that Feed on Contaminated Fish

For bioaccumulative chemicals, animals that feed at the top of food webs (i.e., top predators) are likely to experience the highest exposures of animal species in geographic area/ecosystem. For chemicals that bioaccumulate through aquatic food chains, the top predators in many geographic areas are wildlife that feed on aquatic prey. Thus, for PB-HAPs, EPA usually assesses risks to fish-eating (i.e., piscivorous) birds and mammals when evaluating ecological risks (e.g., see Great Lakes Water Quality Initiative, U.S. EPA 1995b).

EPA selected the American merganser (*Mergus merganser americana*), a bird of intermediate body size that regularly consumes relatively larger fish (up to 36 cm, Mallory and Mertz 1999), to represent highly exposed piscivorous birds. Many species of birds are piscivorous (Table 2-2, Endpoint 7). The belted kingfisher often is evaluated in ecological risk assessments; however, the maximum size of fish (and hence the top trophic level of fish they can consume) that belted kingfishers can consume is relatively small (generally no larger than 18 cm, Salyer and Lagler 1946).

EPA selected mink for screening of piscivorous mammals. Few mammals (see Table 2-2, Endpoint 8) are piscivores. Both river otters and mink commonly are assessed for risks from persistent and bioaccumulative chemicals (e.g., DDT [dichlorodiphenyltrichloroethane], DDE

[dichlorodiphenyldichloroethylene], PCBs [polychlorinated biphenyls], and other chemicals released directly to surface waters). Mink in some locations consume fish almost exclusively, and their smaller body size (i.e., 0.68–1.4 kg) compared with otters (i.e., 4.5–11 kg) (Burt and Grossenheider 1980) means that mink have a higher metabolic rate and so consume more fish per unit body weight than do otters. Both species consume primarily trophic level 3 fish (i.e., minnows, shiners, small trout, perch), although river otters capture larger fish on occasion. In addition, mink tend to be more abundant than otters and have smaller home ranges (U.S. EPA 1993a,b).

Note that geographic range was not a criterion that distinguished one species from another for the options listed above. The overall range of belted kingfishers and the common merganser spans North America from coast to coast, although the summer breeding ranges generally are more northerly while the overwintering ranges are more southerly. Similarly, the overall range of mink and river otters spans North America from coast to coast.

To assess risks to piscivorous wildlife from consuming contaminated fish for the environmental risk screen, we calculated TRVs, expressed as a dose, to compare with the total chemical intake of each wildlife species from its aquatic prey. To estimate exposures as total chemical intake, we used the Tier 1 (or Tier 2) screening TRIM.FaTE scenario to estimate the concentration of chemicals in the aquatic biota (compartments) included. Species-specific data for the mink and common merganser were used to estimate their food ingestion rates and the proportion of their diets likely obtained from each biotic compartment. For the latter, literature on the size of fish captured was consulted for both mink and merganser.

3.1.2 Preferred Sources for PB-HAP Benchmark Values

Available community-level benchmarks for sediments, surface waters, and soils were identified using the Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS) (http://rais.ornl.gov/). The Department of Energy (DOE) maintains the ORNL RAIS database for use in its risk assessments at hazardous waste sites. RAIS identifies virtually all toxicity reference values and benchmarks developed to date by federal and some state agencies in the United States and by other countries (e.g., Canada) for human health and ecological risk assessment. RAIS therefore allows quick identification of available ecotoxicity benchmarks.

RAIS includes all screening-level ecological benchmarks available from Suter and Tsao (1996; benchmarks developed at ORNL for use at DOE Superfund sites), which was a key source of benchmarks for the Coke Oven MACT (maximum achievable control technology) Residual Risk Assessment (U.S. EPA 2003d). RAIS also includes the other sources of benchmarks used in that assessment (e.g., U.S. EPA National Ambient Water Quality Criteria, EPA Region 4 values, National Oceanic and Atmospheric Administration benchmarks, Florida Department of Environmental Protection benchmarks).

We established a hierarchy of preferred benchmark sources to allow selection of benchmarks for chemicals and environmental media for which numerous benchmarks are listed in RAIS. In general, EPA benchmarks used at a programmatic level (e.g., Office of Water, Superfund Program) are preferred, if available. If not, EPA Regional benchmarks as used in regional programs (e.g., Superfund) are used, if available. If benchmarks are not available from EPA at a regional level, we consider the benchmarks developed by other agencies (e.g., DOE), by states, or by Canada.

In all cases, we reviewed available benchmarks to find one to represent each of the three levels of effect specified above (i.e., NEL, TEL, PEL). For some media/chemical combinations, we could identify benchmarks for all three effect levels, but for most, we could not. In several cases, only a single benchmark was available, generally a threshold for effects.

3.1.2.1 Soil Ecotoxicity Benchmarks (SEB)

For soils, EPA's national Superfund Program Eco-Soil Screening Levels (Eco-SSLs, U.S. EPA 2005a) were selected, if available, as the SEBs for the RTR environmental risk screen. These Superfund Eco-SSLs (from EPA's Office of Solid Waste and Emergency Response, OSWER [currently Office of Land and Emergency Management) are the only peer-reviewed and EPA-vetted ecological toxicity screening benchmarks for soils established for use by the Agency nationwide. For chemicals for which no Eco-SSLs were available, EPA Regional sources of soil ecotoxicity benchmarks (SEBs) were reviewed (e.g., Regions 4, 5, and 6). The general methods for deriving those benchmarks can differ from the methods EPA used to derive Eco-SSLs.

For some chemicals, the Regions use SEBs developed by other agencies such as DOE or by a state within the region. If not specified in published information, we assumed that whichever

group of organisms was most sensitive to the chemical in soil (e.g., earthworms, insect larvae, plant roots, ground-feeding wildlife consuming soil invertebrates, and in some cases herbivorous animals consuming plants grown in the contaminated soil) was likely to have been the basis for the criterion. If an EPA Region and another non-EPA agency use the same numeric benchmark, all sources that designated that value are acknowledged in the tables presenting the RTR ecotoxicity benchmarks. Finally, if the only source providing a screening-level benchmark for soils was not an EPA office or Region (e.g., DOE, Environment Canada, or a state), that value is used.

3.1.2.2 Aquatic Sediment Quality Benchmarks

For the benthic community residing in and on the sediments of a water body, the preferred benchmarks were the national-level sediment quality criteria published by EPA's Office of Water (U.S. EPA 1993a, 2001b, 2003e, 2008), if they were available or readily usable.

If national sediment quality benchmarks were not available from EPA's Office of Water, we selected sediment benchmarks from those available from EPA's Superfund Program and Regions 4 and 5, as available. If EPA-vetted sediment benchmarks were not available, other benchmarks were used (e.g., from the State of Florida, ORNL, and MacDonald et al. [2000]).

3.1.2.3 Ambient Water-Column Benchmarks

For organisms that live primarily in the water-column of aquatic ecosystems, EPA's National Ambient Water Quality Criteria, Aquatic Life Criteria (NAWQC-ALC) were used, as available (Stephan et al. 1985, U.S. EPA 2002). According to Suter and Tsao (1996), the *acute* NAWQC-ALC are considered "upper" screening levels in EPA's Superfund program—which we interpret to mean *probable effect levels* if associated with continuous long-term (chronic) exposures. The *chronic* NAWQC-ALC are considered "lower" screening-level benchmarks in EPA's Superfund program (Suter and Tsao 1996). Given the methods by which both acute and chronic NAWQC-ALC are derived, we interpret the chronic NAWQC-ALC to represent a threshold for adverse effects in aquatic communities (water-column compartment) rather than a no-effect level. At the NAWQC-ALC, 5 percent of species typical of the ecosystem might be lost; however, substantial changes in aquatic community structure and function are not expected because of functional redundancies among species in aquatic communities.

For chemicals for which NAWQC-ALC and Tier II secondary values were not available, we turned to benchmarks developed by EPA Regions 4, 5, or 6.

3.1.2.4 Avian and Mammalian Toxicity Reference Values

To assess risks to piscivorous (i.e., fish-eating) wildlife, one must identify a TRV for the wildlife species, expressed as an oral dose, and estimate dietary exposure via the chemical in prey (i.e., in fish and invertebrates consumed). The estimated total chemical intake via all types of prey in the diet, expressed as mg[chemical]/kg[wildlife body weight]/day (mg[chem]/kg bw-day), then can be compared with the TRV (expressed in the same units). An emission rate, back-calculated to match the TRV, then is used to screen facilities in Tiers 1, 2, and 3 environmental risk screens.

Two types of avian and mammalian TRVs were included in the environmental risk screen. The first type of TRV is incorporated into the EPA OSWER derivation of the Eco-SSLs intended to protect wildlife that feed on soil invertebrates (see Section 3.1.1). We indirectly use those TRVs by using the Eco-SSLs as soil benchmarks. We calculated separate TRVs to use for wildlife that consume fish using an approach similar to that developed for the EPA Great Lakes Water Quality Initiative (GLWQI, U.S. EPA 1995b). Those calculations are presented in Attachment A, Section A.3.

EPA OSWER developed TRVs for the EcoSSLs using an approach unique to those benchmarks. The EcoSSL TRVs are based on NOAELs, and they are calculated as the geometric mean of all NOAELs from adequately performed and reported studies for growth and for reproductive effects across all species of birds (or mammals). Thus, even unbounded NOAELs, which might be well below an effect level (because no effect level was identified), are included in calculating the geometric mean. That method of calculating a wildlife TRV has some limitations, as discussed by several investigators (e.g., Allard et al. 2010; Mayfield and Fairbrother 2013; Sample et al. 2014a,b).

For purposes of the RTR assessment of fish-eating wildlife, we prefer the GLWQI approach to developing a TRV for wildlife (U.S. EPA 1995b), which is to select a key study that represents a sensitive species and endpoint from among the available, adequately conducted and reported, studies. Moreover, we prefer to scale doses between experimental animals and wildlife species

based on relative body weight (U.S. EPA 2011). The derivation of TRVs for PB-HAPs for piscivorous wildlife are presented in Attachment A, Section A.3.1.

For the GLWQI approach, the available toxicity data are examined to determine the magnitude of uncertainty factors (UFs) that might be needed for three types of data gaps: to estimate a NOAEL from a LOAEL, to extrapolate from subchronic to chronic exposure, or to account for differences in sensitivity of test species. For most chemicals (including PB-HAPs, particularly dioxins and POM), only a few species of birds (e.g., quail, mallard, chicken, pheasant) and a few species of mammals (e.g., mice, rats, hamster, mink) have been tested sufficiently to provide both a LOAEL and a NOAEL for effects resulting from chronic exposures. Uncertainty factors can range from 1 to 10 for each type of uncertainty listed above, depending on the apparent magnitude of the data gap. A joint uncertainty value (the product of all three types of UF) exceeding 100 indicates that a TRV cannot be derived (U.S. EPA 1995b). Typically, a value of 1, 3, or 10 (not values in between) is used for each UF. The appropriate UFs are applied as divisors of the original toxicity value (e.g., LOAEL).

To estimate TRVs for piscivorous wildlife, we used the LOAELs and NOAELs from a single key study (most sensitive effect and species). If only an unbounded LOAEL were available (no NOAEL), the LOAEL could be divided by a factor of 10 to extrapolate to a NOAEL or an EPA-derived UF could be applied. The subchronic-to-chronic uncertainty factor was not applied, because all TRVs calculated for the PB-HAPs are based on chronic or gestational exposures. Neither was an interspecies UF used, except for the case of methyl mercury, for which EPA had already published a joint LOAEL-to-NOAEL and an interspecies UF for birds (Attachment A, Section A.3.2). For the other PB-HAPs, doses were scaled between a test species and the assessment species based on relative body weight to the ¾ power (U.S. EPA 2011).

3.1.3 Selected PB-HAP Benchmarks

Table 3-1 shows the ecological benchmarks used in the environmental risk screen for each PB-HAP and assessment endpoint. A discussion of the TEFs used to adjust each POM chemical relative to BaP and to adjust each dioxin congener relative to TCDD is presented in Attachment A, Section A.4.

3.2 BENCHMARKS FOR ACID GASES

3.2.1 Hydrogen Chloride

For HCl, EPA identified chronic benchmark concentrations as described in Appendix K to EPA's (2009) *Risk and Technology Review (RTR) Risk Assessment Methodologies: For Review by the EPA's Science Advisory Board. Case Studies – MACT I Petroleum Refining Sources, Portland Cement Manufacturing*. Substantial data were available for short-term exposures of plants to HCl; however, data to relate chronic exposures of plants to adverse effects on growth and productivity were lacking.

The chronic benchmark for HCl was based on a lowest-observed-effect level (LOEL) from a short-term exposure (20 minutes) that related HCl concentration to "changes" in the leaves of 7 of 8 plant species as reported by Lerman et al. (1976). The benchmark was the lowest exposure concentration at which effects of any type were observed (visible injury to some proportion of leaves). Haber's law (see Attachment A, Section A.2.3.2) was used to extrapolate the 1.5-mg/m^3 LOEL concentration after 20 minutes of exposure to a 0.5-mg/m^3 concentration expected to produce the same effect after 1 hour. To extrapolate from a 1-hr estimated LOEL to a chronic benchmark, they divided by a factor of 10 to yield 0.050 mg/m^3 or 50 µg/m^3.

We recognize that the uncertainty associated with extrapolating from a 20-minute exposure with minimally defined visual effects on foliage to a chronic exposure scenario with plant productivity as the assessment endpoint is very high. Thus, 50 µg/m^3 cannot be assumed to represent a benchmark with a known effect level for chronic exposures. EPA does consider the benchmark, however, to likely represent a NEL for exposures of plants to HCl.

Table 3-1. Ecological Benchmarks Used in the Environmental Risk Screen for each PB-HAP and Assessment Endpoint

Eco-HAP	Assessment Endpoint	Benchmark Effects Level	Benchmark Value	Benchmark Source
Cadmium	Fish-eating birds feeding from lake	NOAEL–common merganser	0.7 (mg/kg BW/day)	CA DTSC HERD 2009
		LOAEL–common merganser	1 (mg/kg BW/day)	
	Fish-eating mammals feeding from lake	NOAEL–mink	0.742 (mg/kg BW/day)	Sample et al. 1996 from Sutou et al. 1980
		LOAEL–mink	7.42 (mg/kg BW/day)	
Cadmium	Lake benthic sediment community	No-effect level	0.33 (mg/kg dry sediment)	CCME 1999a
		Threshold level	1.2 (mg/kg dry sediment)	U.S. EPA 1996a
		Probable-effect level	3.5 (mg/kg dry sediment)	CCME 1999a

Eco-HAP	Assessment Endpoint	Benchmark Effects Level	Benchmark Value	Benchmark Source
Cadmium	Surface soil – birds and mammals that consume soil invertebrates; soil plant and invertebrate communities	Threshold–shrew	0.36 (mg/kg dry soil)	U.S. EPA 2005d, OSWER Eco-SSLs
		Threshold–woodcock	0.77 (mg/kg dry soil)	
		Threshold–plant community	32 (mg/kg dry soil)	
		Threshold–invert. community	140 (mg/kg dry soil)	
Cadmium	Water-column community	Threshold level (chronic)	0.72 (µg/L)	U.S. EPA 2001b, revised 2016b
		Frank-effect level (acute)	1.8 (µg/L)	
Arsenic	Fish-eating birds feeding from lake	NOAEL–common merganser	0.15 (mg/kg BW/day)	Sample et al. 1996 from Camardese et al. 1990
		LOAEL–common merganser	1.5 (mg/kg BW/day)	
Arsenic	Fish-eating mammals feeding from lake	NOAEL–mink	0.052 (mg/kg BW/day)	Sample et al. 1996 from Schroeder and Mitchener 1971
		LOAEL–mink	0.52 (mg/kg BW/day)	
Arsenic	Lake benthic sediment community	Threshold level	8.2 (mg/kg dry sediment)	U.S. EPA 1996a
		Probable-effect level	33 (mg/kg dry sediment)	U.S. EPA 1996b
Arsenic	Surface soil – birds and mammals that consume soil invertebrates; soil plant community	Threshold–shrew	46 (mg/kg dry soil)	U.S. EPA 2005b, OSWER Eco-SSLs
		Threshold–woodcock	43 (mg/kg dry soil)	
		Threshold–plant community	18 (mg/kg dry soil)	
Arsenic	Water-column community	Threshold level (chronic)	150 (µg/L)	U.S. EPA 1995a OW
		Frank-effect level (acute)	340 (µg/L)	
2,3,7,8-TCDD	Fish-eating birds feeding from lake	NOAEL–common merganser	0.0000014 (mg/kg BW/day)	U.S. EPA 1995b, GLWQI, from Nosek et al. 1992a,b
		LOAEL–common merganser	0.000014 (mg/kg BW/day)	
2,3,7,8-TCDD	Fish-eating mammals feeding from lake	NOAEL–mink	0.000000771 (mg/kg BW/day)	U.S. EPA 1995b, GLWQI, from Murray et al. 1979
		LOAEL–mink	0.00000771 (mg/kg BW/day)	
2,3,7,8-TCDD	Lake benthic sediment community	Threshold level	0.00000116 (mg/kg dry sediment)	Average of U.S. EPA 2001a, 2003a, 2006 (Regions 3, 4, and 5)
2,3,7,8-TCDD	Surface soil – mammals that consume soil invertebrates	Threshold – shrew	0.0000002 (mg/kg dry soil)	U.S. EPA 2003a, Region 5
2,3,7,8-TCDD	Water-column community	Threshold level (chronic)	0.000012 (µg/L)	U.S. EPA 2001a, Region 4
		Frank-effect level (acute)	0.1 (µg/L)	
Mercuric chloride	Lake benthic sediment community	Threshold level	0.16 (mg/kg dry sediment)	Average of 8*
		Probable-effect level	0.84 (mg/kg dry sediment)	Average of 4**
Mercuric chloride	Surface soil plant and invertebrate communities	Threshold–plant community	0.3 (mg/kg dry soil)	U.S. EPA Region 6 cites Efroymson et al. 1997a
		Threshold–invert. community	0.1 (mg/kg dry soil)	U.S. EPA 2015, Region 4
Mercuric chloride	Water-column community	Threshold level (chronic)	0.77 (µg/L)	U.S. EPA 1993c, 1995a, 2015, OW
		Frank-effect level (acute)	1.4 (µg/L)	
Mercury (methyl)	Fish-eating birds feeding from lake	NOAEL–common merganser	0.013 (mg/kg BW/day)	U.S. EPA 1995b from Heinz 1974, 1975, 1976a,b, 1979
		LOAEL–common merganser	0.078 (mg/kg BW/day)	

Eco-HAP	Assessment Endpoint	Benchmark Effects Level	Benchmark Value	Benchmark Source
Mercury (methyl)	Fish-eating mammals feeding from lake	NOAEL–mink	0.0247 (mg/kg BW/day)	Sample et al. 1996 from Verschuuren et al. 1976
		LOAEL–mink	0.123 (mg/kg BW/day)	
Mercury (methyl)	Lake benthic sediment community	Threshold level	0.2 (mg/kg dry sediment)	MacDonald et al. 2000
		Probable-effect level	1 (mg/kg dry sediment)	
Mercury (methyl)	Surface soil – birds and mammals that consume soil invertebrates; soil plant and invertebrate communities	Threshold–montane shrew	0.0068 (mg/kg dry soil)	U.S. EPA 2015, Region 4
		Threshold–American robin	0.0011 (mg/kg dry soil)	
		Threshold–plant community	0.3 (mg/kg dry soil)	U.S. EPA Region 6 cites Efroymson et al. 1997a
		Threshold–invert. community	0.1 (mg/kg dry soil)	U.S. EPA 2015, Region 4
Mercury (methyl)	Water-column community	Threshold level (chronic)	0.0028 (µg/L)	U.S. EPA 2015, Region 4, cites Suter and Tsao 1996
		Frank-effect level (acute)	0.099 (µg/L)	
Benzo[a]-pyrene	Fish-eating mammals feeding from lake	NOAEL–mink	0.417 (mg/kg BW/day)	Sample et al. 1996, from Mackenzie and Angevine 1981
		LOAEL–mink	4.17 (mg/kg BW/day)	
Benzo[a]-pyrene	Lake benthic sediment community	No-effect level	0.032 (mg/kg dry sediment)	CCME 2012
		Threshold level	0.15 (mg/kg dry sediment)	U.S. EPA 1996b, 2006
		Probable-effect level	1.45 (mg/kg dry sediment)	
Benzo[a]-pyrene	Surface soil – mammals that consume soil invertebrates	Threshold–masked shrew	1.52 (mg/kg dry soil)	U.S. EPA 2003a, Region 5
Benzo[a]-pyrene	Water-column community	Threshold level (chronic)	0.014 (µg/L)	U.S. EPA 2003a, Region 5, from Suter and Tsao 1996
		Frank-effect level (acute)	0.24 (µg/L)	Suter and Tsao 1996
Lead	Ambient Air	NAAQS Secondary Standard	0.15 (µg/m^3)	U.S. EPA 2016a

Acronyms/abbreviations: BW = avian or mammalian body weight; invert. = invertebrates; CCME = Canadian Council of Ministers of the Environment; GLWQI = Great Lakes Water Quality Initiative; NAAQS = National Ambient Air Quality Standards; LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect-level; OW = EPA's Office of Water; TCDD = 2,3,7,8-tetrachlorodibenzo-p-dioxin.

* Average of 8 threshold-effect levels: U.S. EPA (1996b) 0.18 mg/kg dry sediment; MacDonald et al. (2000) 0.18 mg/kg; Florida Department of Environmental Protection (FDEP, MacDonald 1994) 0.13 mg/kg; U.S. EPA (1996a) 0.15 mg/kg; U.S. EPA (2015) 0.13 mg/kg; U.S. EPA (2006) 0.18 mg/kg; U.S. EPA (2003a) 0.174 mg/kg); and Region 6 (TNRCC 2001) 0.174 mg/kg.

** Average of 4 probable-effect levels: U.S. EPA (1996b) 1.06 mg/kg; MacDonald et al. (2000) 1.06 mg/kg; FDEP (MacDonald 1994) 0.70 mg/kg; and CCME (2001) 0.486 mg/kg.

3.2.2 Hydrogen Fluoride

HF is one of the most phytotoxic air pollutants. It is 10 to 1000 times more toxic to plants than ozone, and many species of plants are more sensitive to the chronic effects of HF than are humans (APIS 2010). Reports from decades ago document commercially significant injuries to plants near facilities that emitted fluoride. The damages included "commercially significant" reductions in crops of citrus fruits (Wander and McBride 1956); grapes (Brewer et al. 1957; Wann 1953); Italian prunes (Miller et al. 1948; Wann 1953); peaches (Daines et al. 1952); ponderosa pine (Adams et al. 1956); apricots (Wann 1946; De Ong 1946); and many varieties of

gladioli (Johnson et al. 1950; Miller et al. 1953) (examples cited by Hill and Pack 1983). In an area around one industrial emitter of HF, before installation of control equipment, a high proportion of the ponderosa pine trees surrounding the facility had died (Adams et al. 1956). Incidents like this in the United States, however, have declined; no publications describing similar events in the past few decades were identified in our literature search.

Atmospheric fluoride ion accumulates in the leaves of plants, entering through stomata on the underside of leaves. Atmospheric fluoride deposition to soils also can occur, but most soil fluoride changes to insoluble forms that are not readily bioavailable to plants. Several researchers have concluded that the limited amounts of fluoride that reach soils from contaminated atmospheres do not affect plant uptake overall (MacIntire et al. 1949; Hansen et al. 1958). Researchers also have demonstrated that leaves can absorb the fluoride from soluble fluoride particles (such as calcium fluoride, which yields a fluoride ion), particularly when the leaves are moist with dew. Nonetheless, fluoride as gaseous HF is the most bioavailable and causes much greater injuries to plants (Hill and Pack 1983).

Gas-phase HF is particularly hazardous to plants because of its tendency to accumulate over time in foliar tissue. Plants can accumulate HF to concentrations 1,000,000 times higher than ambient atmospheric concentrations. Thus, unlike many pollutants, HF is expected to cause injury to plants primarily from exposures over weeks to months, and the longer the exposure, the more severe the effects (Hill 1969).

Susceptibility to HF varies widely among plant species and varieties. Species known to be sensitive to HF exposure include gladioli, apricots, prunes, sorghum, corn, grapes, and conifers (Hill and Pack 1983). Species that are relatively insensitive to HF exposure include cotton, celery, alfalfa, and tomatoes (Hill and Pack 1983). Relatively low air concentrations can damage sensitive species, while less sensitive species can exhibit little to no damage at somewhat higher concentrations (TCEQ 2009; CEPA/FPAC WGAQOG 1996; Hill 1969). Several monocotyledons rank among the most sensitive taxa, including the genera *Gladiolus*, *Allium*, *Crocus*, *Tulipa*, *Lilium*, and *Polygonatum* (APIS 2010, citing Weinstein et al. 1998).

Attachment A, Section A.2.3 contains the following background sections.

- Section A.2.3.1: Methods for Establishing HF Benchmarks – presents three bases that can be used to establish HF regulatory standards.
- Section A.2.3.2: HF Regulatory Levels – summarizes atmospheric (air concentration) criteria and regulatory levels that states and other countries have established for HF for the protection of vegetation and other endpoints.
- Section A.2.3.3: Studies Showing the Effects of HF Exposure on Plants – discusses the bulk of readily available data relating HF exposures to plant responses based on atmospheric concentrations. Those data are presented to assist EPA risk managers in interpreting the results of screens of HF emissions. Comparisons of the criteria for protecting productivity of agricultural plants and livestock from fluorosis to those available for protecting human health indicate that air concentration benchmarks for HF developed for plants are lower than those developed to protect livestock and human health.

Two HF benchmarks are used for the environmental risk screen. The value of 0.5 μg HF/m^3 is based on the Washington State criterion for gaseous HF. The value of 0.4 μg HF/m^3, which is 20 percent lower, is based on the Environment Canada criterion. Both criteria were developed for 90-day averaging periods during the growing season.

For HF, we model annual estimates of facility emissions in HEM/AERMOD to obtain average annual HF air concentrations. When screening for chronic HF risks to plants in the environmental risk screen, we compare the average *annual* HF air concentrations from the HEM/AERMOD runs to the 90-day criteria. If exposures are not the same during the growing season and the nongrowing season, the use of annual average exposures could underestimate or overestimate risks. An additional uncertainty in evaluating chronic HF risks to plants is the wide variation in plant sensitivity to airborne HF and the relatively few nonagricultural plants that have been tested (Attachment A, Section A.2.3.2).

Empirical models that relate exposure concentration, exposure duration, and plant response for different plant groups are not simple mathematical relationships (e.g., see McCune et al. (1991) equations to predict severity *and* incidence of foliar injury from HF exposure concentration *and*

duration). In other words, although plant foliage accumulates fluoride from HF in air over time, effects on plants are not proportional to air concentration only, nor are they proportional to the simple product of average exposure concentration and duration (e.g., a time-weighted average exposure concentration). This lack of proportionality could be due to factors such as more frequent periods of rain wash-off that can leach fluoride from leaves over longer exposure periods and slower fluoride absorption rates as fluoride concentrations in plant leaves increase.

Short-term exposure data and criteria were not used to assess risk to plant communities from HF for several reasons. Characterizing possible adverse effects on the assessment endpoints of plant productivity and community structure (e.g., as habitat for wildlife, agricultural productivity) over the long term from data on species-specific effects on plants from short-term exposures (or short-term exposure criteria) would require many assumptions and include major uncertainties. Data are lacking to link effects like "foliar markings" and mild leaf necrosis to plant reproduction and productivity over the long term. Also lacking are data on the recovery of plants after short-term exposures and the frequency of high short-term exposures that could be tolerated if time needed for recovery is adequate. In addition, some long-term effects (e.g., annual seed production) that might result from short-term exposures would occur only if a short-term peak in HF concentration occurred during the few days of a sensitive life-stage of the plant (e.g., flowering).

4 Exposure Assessment

This section presents the models and methods used to estimate HAP exposures in the environment. We describe how to use the effect levels to calculate emission "screening thresholds" and how these thresholds are compared to facility emissions to screen for adverse environmental effects.

The first step in the ecological exposure assessment is to determine whether any facilities in the source category of interest emit any of the eight environmental HAPs (see Figure 2-1 and Figure 2-2 in Section 2.3). This step is performed by querying the emissions data for the source category in question. Typically, emissions data are obtained from the National Emissions Inventory, section 114 surveys of the industry, or from facility stack emissions tests. Emissions data for facilities identified in this step are used to perform the environmental risk screen, as described in this section. The approach for the overall environmental risk screen uses separate methods to

assess ecological exposures to PB-HAPs, lead, and acid gases. Section 4.1 details the exposure assessment methods for PB-HAPs. Section 4.2 details the exposure assessment methods for lead and the acid gases.

4.1 ENVIRONMENTAL RISK SCREEN FOR PB-HAPS

Figure 2-1 in Section 2.3 provides an overview of the approach for the environmental risk screen for PB-HAPs. This approach includes three tiers of assessment designed for implementation with a minimum of required site-specific or other assessment-specific inputs. The Tier 1, Tier 2, and Tier 3 approaches are discussed in further detail in Sections 4.1.1, 4.1.2, and 4.1.3. See Section 5 for further discussion of outputs from an environmental risk screen.

Possible exposure pathways from facility air emissions to biological receptors of concern were identified from HAP-specific chemical properties, the conceptual model of multimedia fate and transport, and the GEAEs in Table 2-2. The wildlife populations most highly exposed to PB-HAPs would be those that consume aquatic or terrestrial biota that have bioaccumulated the chemical along food chains. Thus, we assumed that some local populations of birds or mammals could be exposed to PB-HAPs that have bioaccumulated in food chains to relatively high concentrations in fish and in terrestrial prey. Additionally, persistent HAPs could accumulate over time in surface soils and reach concentrations toxic to terrestrial plants and to invertebrate communities in soils (e.g., earthworms).

The biotic compartments in the lake(s) for which TRIM.FaTE simulates whole-organism contaminant concentrations in Tiers 1, 2, and 3 are described below.

1. Phytoplankton, suspended algae in the water column, is modeled as a “phase” of the water column.
2. Zooplankton are modeled as a compartment in the water column that is in chemical equilibrium with the phases in the water column, including aqueous and algal phases.
3. Macrophytes in a lake can accumulate and “sequester” some chemicals and are modeled as a separate compartment in the water column.

4. Benthic invertebrates such as mollusks, crustacea, and aquatic insect nymphs that consume periphyton and detritus are modeled as a compartment in chemical equilibrium with bottom sediments.

5. Benthivorous fish are bottom-feeding fish (e.g., young catfish) that consume primarily benthic invertebrates.

6. Bottom-feeding carnivores (e.g., adult catfish) consume both benthic invertebrates and young benthivorous fish.

7. Water-column planktivores, such as young-of-the-year for many species and other small fish (e.g., shiners, minnows), consume primarily planktonic organisms.

8. Water-column omnivores are larger fish that consume invertebrates and smaller fish from both the benthic and pelagic environments (e.g., "panfish" like bluegill, yellow perch, and young age classes of the game species).

9. Water-column piscivores are larger game-fish species that primarily consume smaller fish in pelagic or benthic environments (e.g., walleye, largemouth bass).

The same aquatic food webs developed in TRIM.FaTE for the human health screen for fish ingestion are used to estimate doses to fish-eating wildlife species chosen as assessment populations for the environmental risk screen. The parameterization of those compartments is described in Appendix 6 to the Risk Report.

For wildlife exposed to PB-HAPs via consumption of aquatic life, we assume that the assessment populations obtain 100 percent of their diet from the appropriate biotic compartments corresponding to the different types of aquatic prey they consume. Parameterization of the wildlife diets and other relevant exposure factors (e.g., body weight) is described in Attachment A, Section A.6.

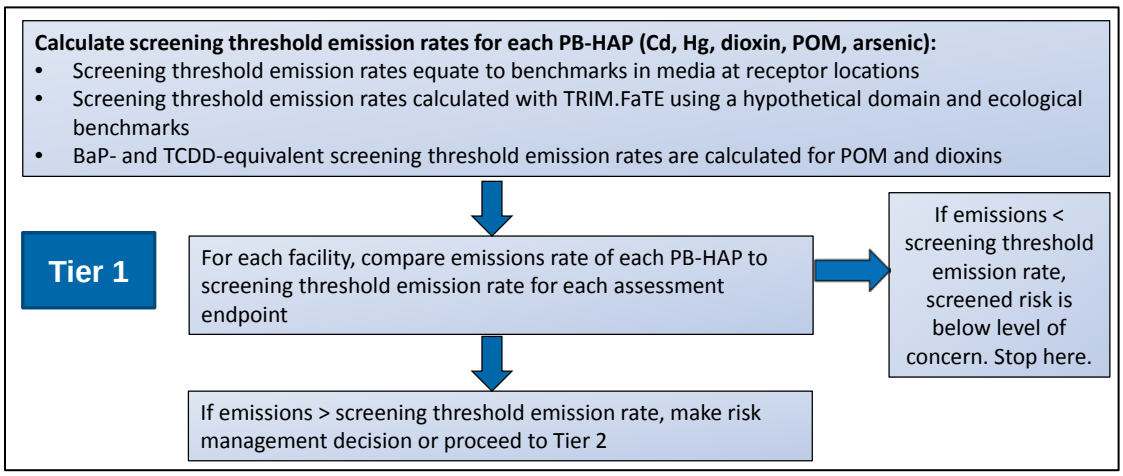
We also assumed that ground-feeding birds and mammals that consume primarily soil invertebrates (e.g., earthworms, grubs) could be exposed to PB-HAPs that have bioaccumulated in the invertebrates from ingestion of or contact with soils. We assumed that the assessment populations obtained 100 percent of their diet from the assessment area (radius of 10 km). We did not assess risks to higher-level carnivores (e.g., wolves, eagles) because their feeding ranges generally are large and difficult to link to specific facilities.

For benthic and water-column aquatic communities, we estimate exposure to PB-HAPs using the TRIM.FaTE-model-estimated concentrations in sediments and the water column, respectively, for the lake(s) situated in Tiers 1, 2, and 3.

4.1.1 Tier 1 Exposure Assessment

Figure 4-1 summarizes the Tier 1 screening approach for PB-HAPs. The Tier 1 assessments for all source categories use ecological screening threshold emission rates for each GEAE and PB-HAP. The screening threshold emission rates (in tons per year) yield concentrations in environmental media at receptor locations in the hypothetical TRIM.FaTE environmental setting that equal the ecological benchmarks. The ratio of a facility's PB-HAP emissions to the corresponding screening threshold emission rate is called the "screening value" (SV). When rounded to one significant figure, SVs greater than 1 indicate that adverse ecological effects within 10 km of the facility cannot be ruled out, and further assessment (e.g., Tier 2, see Section 4.1.2) might be needed.

Figure 4-1. Approach for Tier 1 Environmental Risk Screen for PB-HAPs



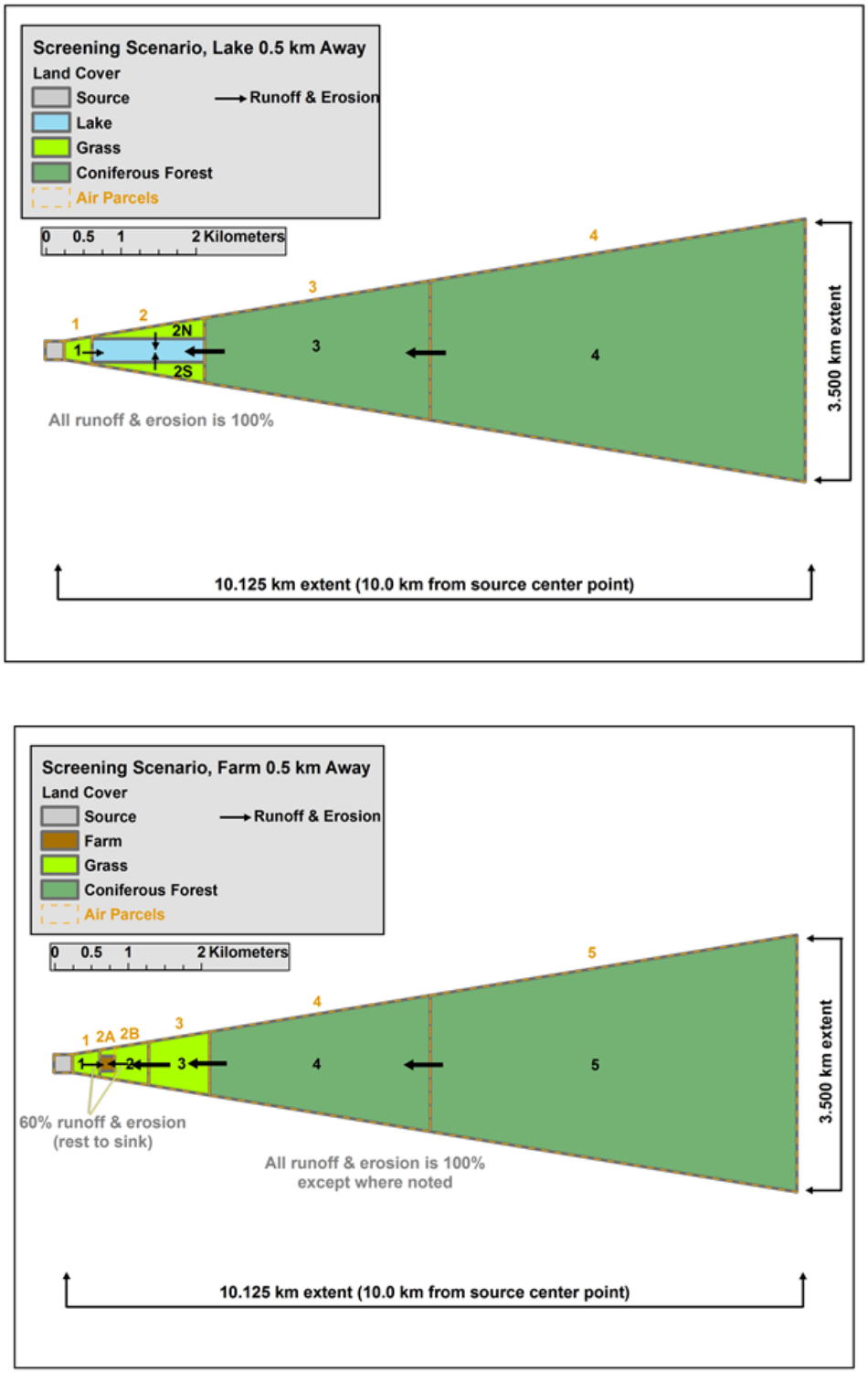
The hypothetical environmental settings are the same as used in the human health risk screen. The lake-centric setting (top panel of Figure 4-2) is used to assess fish and other biota in surface water and sediment. The nonfarm (i.e., grass and forest) parcels in the farm-centric setting (bottom panel of Figure 4-2) are used for the environmental risk screen related to soil.[9] Both

[9]The farm itself is not used in the environmental risk screen.

spatial layouts include an emission source on the west side and several modeling compartments extending to 10 km east of the source. The compartments are shown with arbitrary names (e.g., 1, 2, 3) and are modeled with the indicated land-cover properties and runoff patterns. The assessment of aquatic-related endpoints uses modeled concentrations for water, sediment, fish tissue, and benthic invertebrates at a lake close to the facility (see top panel of Figure 4-2). The assessment of soil-related endpoints uses the modeled surface soil concentrations at five distances from the facility, up to 7.5 km (see bottom panel of Figure 4-2), not including the farming parcel.

The Tier 1 environmental modeling scenario was parameterized to include hypothetical environmental conditions that would provide conservatively high PB-HAP concentration estimates. For example, in the Tier 1 scenario, emissions blow from the facility into the narrow wedge depicted for both settings in Figure 4-2 for 3 days per week, or 43 percent of the time—an unusually consistent long-term wind pattern but not unrealistic (e.g., similar to wind direction patterns in Yakima, Washington). Model settings maximize runoff from terrestrial parcels into the hypothetical lake (for aquatic-related assessment), which in turn maximizes the chemical concentrations in the water, sediments, and fish. The lake situated near the facility also would receive relatively high levels of direct air-to-surface wet and dry deposition. Further details of the Tier 1 TRIM.FaTE environmental modeling scenario, including a description of the aquatic food web, are available in Appendix 6 to the Risk Report. EPA's Science Advisory Board reviewed the approach to parameterizing the hypothetical environmental setting, and other aspects of the TRIM-based modeling used to develop screening threshold emission rates, in 2009/2010.

Figure 4-2. TRIM.FaTE Lake-centric (Top) and Farm-centric (Bottom) Surface Layouts for the Tier 1 Screen



Note: For the environmental risk screen, the lake-centric layout is used for fish, surface water, and sediment endpoints, while the grass and forest parcels of the farm-centric layout are used for soil endpoints.

To calculate the environmental screening threshold emission rates, we ran TRIM.FaTE with a standardized emission rate of 1 g/day for each PB-HAP and saved the resulting PB-HAP concentrations in media at receptor locations throughout the hypothetical environment. We then calculated the environmental screening threshold emission rates by multiplying the 1 g/day emission rate by the ratio of ecological benchmark concentrations to modeled media concentrations. This approach is possible because, for any single period and location (all things being held constant), changes in TRIM.FaTE-predicted PB-HAP concentrations are linear with changes in emission rate. Attachment A provides the final Tier 1 environmental screening threshold emission rates.

Two of the six PB-HAPs for which environmental screening threshold emission rates have been developed (POM and dioxins) are chemical groups comprising numerous individual compounds. For example, for POM, emissions reported include various chemicals, such as benz[a]anthracene, 2-methylnaphthalene, and chrysene, and a few nonspecific entries, such as "PAH, total." As explained below, the results for individual compounds in the POM and dioxin groups are summed, using a TEF approach (see Appendix 6 of the Risk Report for additional information) and an exposure equivalency factor (EEF) approach (described below), to provide one POM result in BaP-equivalents and one dioxin result in 2,3,7,8-TCDD-equivalents.

For POM and dioxins, ecological exposure equivalency factors (EcoEEFs) are calculated for surface water, soil, and sediment by dividing the media concentrations predicted by TRIM.FaTE for each chemical by the predicted concentration of the reference (index) chemical for each group. For example, the EcoEEF for chrysene in soil is calculated as the TRIM.FaTE-estimated concentration of chrysene in soil divided by the estimated concentration of BaP in soil at the same location.

Application of EcoEEFs for POMs and dioxins for piscivorous wildlife differs from the approach described above for surface water, soil, and sediment because TRIM.FaTE does not model PB-HAP exposure doses for the representative animal fish-eating wildlife (i.e., mink, American merganser). The exposure doses for each individual chemical (arsenic, cadmium, mercury, each congener of the POM and dioxin groups) are calculated outside of TRIM.FaTE using the TRIM.FaTE-estimated concentrations in fish and using fish ingestion rates and body weights

specific to the mink and merganser. Each chemical's EcoEEF then is calculated as the ratio of its exposure dose to the exposure dose of the index chemical. The wildlife exposure doses vary across chemicals because the relative concentrations of individual chemicals in each food type consumed (e.g., different fish compartments) vary across chemicals relative to the index chemical due to the variation in chemical-specific assimilation efficiencies, among other factors, for a given fish compartment. The wildlife-specific characteristics influencing the types and quantity of aquatic biota consumed are described in Attachment A, Section A.6, including the data used to assess ingestion of chemicals from each dietary component for mink and common mergansers.

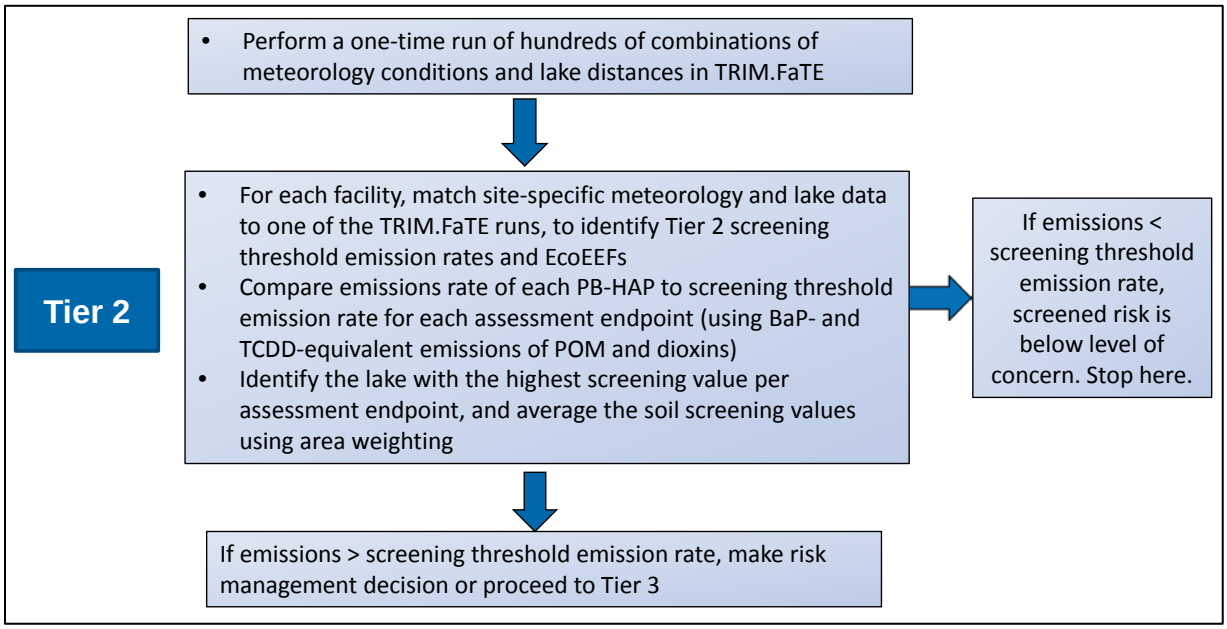
For wildlife-consuming aquatic biota, no adjustments were needed for variation in chemical assimilation efficiency among POM and dioxin/furan congeners, respectively. All toxicity data used to estimate TRVs for POM and dioxin/furan congeners for birds and mammals were based on "administered" doses (the amount of chemical ingested with food, not the amount absorbed into the blood stream). Thus, no adjustments for absorption are needed; differences in absorption among congeners are reflected in the TRVs. That is in contrast to the aquatic food chain modeling, for which congener-specific absorption, metabolic degradation, and elimination rates were estimated for fish and invertebrates and incorporated into the TRIM.FaTE compartment models to estimate bioaccumulation through the aquatic food chains more accurately when calculating EEFs.

The Tier 1 SV for a chemical's emissions from a facility is calculated as Emissions × ecological toxic equivalency factor (EcoTEF) × EcoEEF ÷ Screening Threshold Emission Rate. For each assessment endpoint and benchmark, the SVs are summed for all POM congeners at a facility (into a total BaP-equivalent SV), and the SVs are summed for all dioxin congeners at a facility (into a total 2,3,7,8-TCDD-equivalent SV).

4.1.2 Tier 2 Environmental Risk Screen

After reviewing the results of the Tier 1 environmental risk screen, EPA might choose to evaluate sources with HAP emissions above the Tier 1 screening threshold emission rates (with SVs of 2 or more when rounded to one significant figure). The Tier 2 environmental screening approach, summarized in Figure 4-3, consists of the following steps.

Figure 4-3. Approach for Tier 2 Environmental Risk Screen for PB-HAPs



First, TRIM.FaTE is used to estimate environmental concentrations associated with an emission rate of 1-g/day for 64 combinations of meteorological conditions (see Section 3 of Appendix 6 of the Risk Report for more information). We assess five different distances of the lake from the facility (see Section 3 in Appendix 6 of the Risk Report for a discussion on modeling domain sizes, including modeled lake location values). For the soil endpoints, we use the Tier 1 farm-centric layout (locations of soil endpoints are unchanged from Tier 1). All other attributes of the TRIM.FaTE runs for the Tier 2 environmental risk screen are identical to those of Tier 1. The Tier 2 TRIM.FaTE runs are performed once, for use in both the human health and ecological risk screening.

Second, for aquatic-related endpoints, each lake near the facility that meets inclusion criteria is identified by its location relative to the facility and by its surface area (see Section 3 of Appendix 6 of the Risk Report for more information). Section 3 of Appendix 6 of the Risk Report also describes the lake database used to identify appropriate lakes. Several lake-selection criteria used in the human health assessment (not swampy or covered in algae, not closed to public access) are not used as criteria for the environmental assessments. Facility-specific meteorology and lake location data are used to identify which combination of meteorological conditions and lake distance is most similar to that of the facility and each individual lake.

Third, for soil endpoints, facility-specific meteorological data are used to identify which combination of meteorological conditions is most similar to that of the facility, and the corresponding chemical-specific environmental screening threshold emission rates and EcoEEFs are identified for each of the five soil locations.

The second-pass Tier 2 SV is based on additional adjustments for how frequently the wind blows toward the lake or soil locations of interest (compared with Tier 1) and for the relationship between site-specific air mixing height.

The third-pass Tier 2 screen accounts for multifacility chemical loading to lakes (e.g., two facilities from the same source category located within 100 km of each other, each contributes chemical mass to the same lake). For each ecological assessment endpoint and benchmark effects level, the SVs are summed for all POM congeners (into a total BaP-equivalent SV) and the SVs are summed for all dioxin congeners (into a total 2,3,7,8-TCDD-equivalent SV).

For each facility, for each assessment endpoint, benchmark, and PB-HAP (with POM and dioxins summed to BaP- and 2,3,7,8-TCDD equivalents, respectively), we identify the lake with the largest Tier 2 SV—the final Tier 2 SV for that facility, endpoint, benchmark, and PB-HAP.

For each facility, endpoint, benchmark, and PB-HAP (with POM and dioxins summed to BaP- and 2,3,7,8-TCDD equivalents, respectively), we average the Tier 2 SVs across all 40 soil locations (8 directional octants × 5 soil distances). Each estimate is area weighted (points distant from the source represent larger soil areas than nearer points in the radial domain) to obtain an area-weighted average soil SV.

If Tier 2 SVs are less than or equal to 1, after rounding to one significant figure, the facility screens out (the emissions are below environmental screening threshold emission rates), and it is typically not evaluated further. If Tier 2 SVs after rounding to one significant figure are greater than 1, the facility might be evaluated further with additional site-specific data and modeling refinements as described for Tier 3.

4.1.3 Tier 3 Exposure Assessment

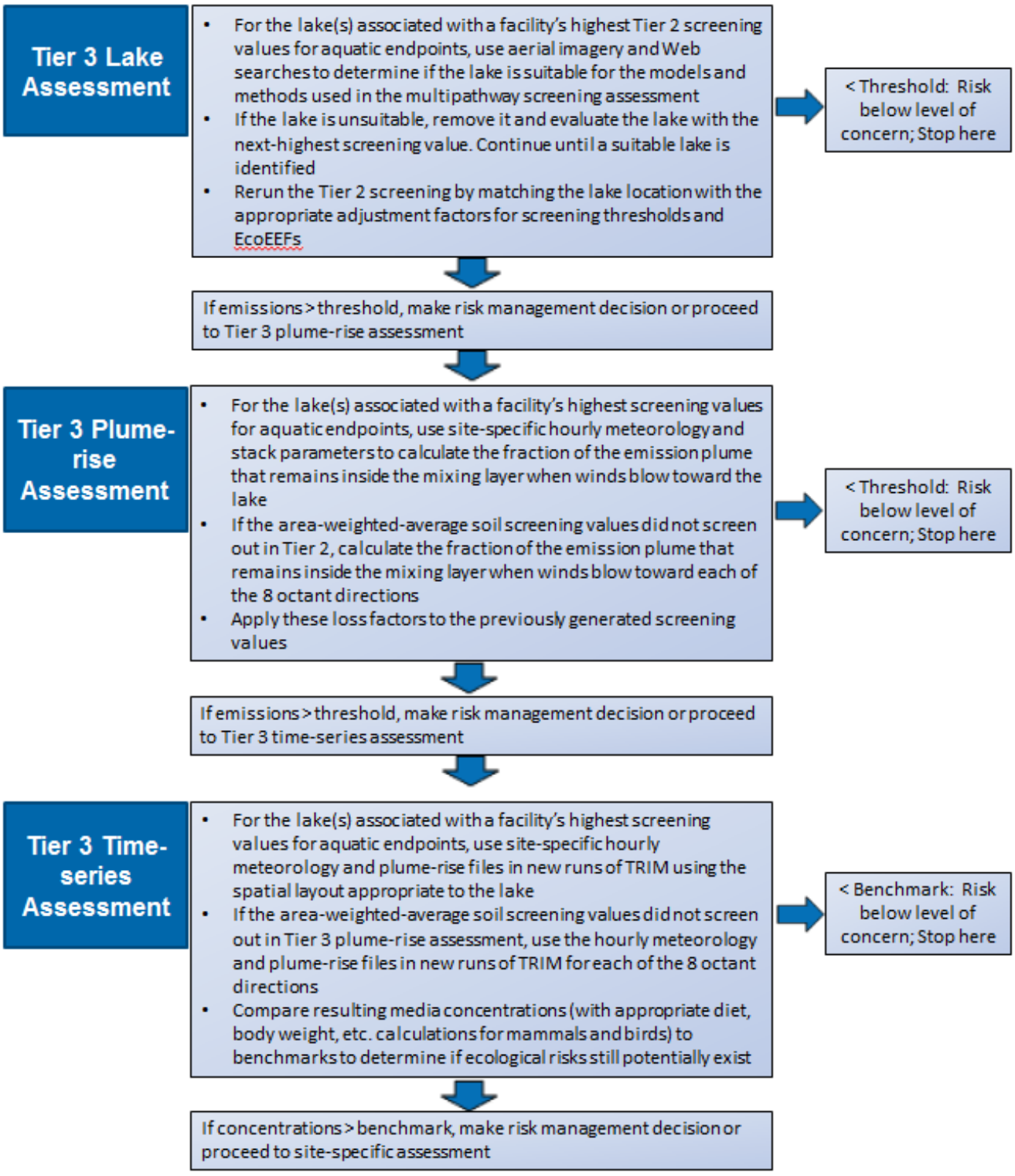
A Tier 3 screen can be conducted on facilities that do not screen out in Tier 2. The Tier 3 screening approach consists of three individual assessments (shown in Figure 4-4 and described

in more detail in Section 4 of Appendix 6 of the Risk Report) that further refine the screening scenario (beyond Tier 2) based on additional site-specific data and evaluations. The refinements are conducted in a step-wise fashion, and all three might not always be needed (e.g., a facility might screen out after the first refinement in Tier 3).

In the first step of the Tier 3 assessment (the lake assessment), we investigate further the lakes assessed in Tier 2 (the lake at each facility associated with the largest aquatic-related SVs per PB-HAP). If we modify, add, or remove any lakes from the assessment, we also modify the lake database and rerun the Tier 2 assessment (e.g., identify a new, more appropriate lake for assessment). If SVs still exceed 1, in the second step of the Tier 3 assessment (i.e., the plume-rise assessment), we estimate how often the chemical plume rises above the mixing layer and, therefore, disperses out of the modeling domain (no ground-level exposures). Finally, if SVs still exceed 1, in the third step of the Tier 3 assessment (the time-series-meteorology assessment), we conduct new runs of TRIM.FaTE and the Multimedia Ingestion Risk Calculator with time-series data for meteorology and plume rise. This last set of SVs typically is smaller than those produced by the Tier 3 plume-rise assessment.

Information about the number and proportion of facilities in a source category exceeding the environmental screening threshold emission rates (SVs >1), proportion and absolute area over which soil-based screening threshold emission rates are exceeded, and magnitude of those SVs help EPA decide whether adverse ecological effects are potentially widespread and significant. If a facility exceeds Tier 3 screening threshold emission rates, it could be further evaluated to consider the degree to which the emission rates are exceeded, which endpoints and effect levels are exceeded, the geographic setting (e.g., proximity to protected areas and resources), and the total area exceeding the screening threshold emission rates. If, after additional refinement, the facility still exceeds the screening threshold emission rates, a site-specific assessment could be conducted. The site-specific assessment uses model parameter values and scenario designs intended to better represent the modeled facility—aspects such as local terrain (influencing runoff and erosion patterns), watersheds, actual lake boundaries and water retention rates, soil types, and land cover. Site-specific environmental assessments are not presented in this report.

Figure 4-4. Approach for Tier 3 Environmental Risk Screen for PB-HAPs



4.2 ENVIRONMENTAL RISK SCREEN FOR LEAD AND ACID GASES

4.2.1 Lead

The level of the primary and secondary NAAQS for lead, 0.15 µg/m^3, is intended to protect humans from both excess inhalation and ingestion exposures and, secondarily, to protect the environment from adverse effects (U.S. EPA 2016a).[10] Therefore, RTR multipathway assessments evaluate modeled air concentrations of lead compounds against the NAAQS level directly, without additional fate, transport, and exposure modeling. We compare the AERMOD-modeled air concentrations of lead for each individual emission point for each facility in the source category to the 0.15-µg/m^3 level of the secondary NAAQS for lead. The environmental risk screen for lead consists of this single tier. We consider air concentrations below the level of the secondary lead NAAQS unlikely to cause adverse environmental effects.

4.2.2 Acid Gases

We needed a separate approach for exposure modeling for acid gases because TRIM.FaTE does not explicitly model gas-phase dispersion in ambient air around a source and the estimated ground-level ambient concentrations are uncertain, particularly with respect to relatively fine spatial resolution. Based on the nature of the GEAE selected for acid gases and the mode of exposure for these chemicals (direct contact of plant foliage with acid gases present in ambient air), EPA used AERMOD (an air dispersion model), which is the same model used in the human inhalation risk assessment. The typical defaults for AERMOD are to model 13 concentric rings at various distances from the facility with 16 concentration data points equally spaced across each ring for 208 modeled air concentrations.

Relative to the PB-HAPs exposure estimates, the acid gas exposure estimates are less health protective and more facility specific, primarily due to the characteristics of the acid gas analysis:

- Only one environmental medium assessed (air only in contrast to air, soil, and water)
- Direct contact of the chemical in air with plant foliage, which eliminates the need for multimedia modeling of chemical transfers

[10] The secondary lead NAAQS (U.S. EPA 2016a) is a reasonable measure of determining whether an adverse environmental effect is present because it was established considering "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

- Refined air modeling approach, using hourly meteorology data and multiple emission sources.

The environmental risk screen for acid gases includes a single tier. Screening compares modeled ambient air concentrations of each acid gas, HF and HCl, to the air concentration benchmarks for terrestrial plants. For HF, we assume that all HF emitted by facilities would remain in the atmosphere in vapor phase; none would be adsorbed to particles that also might be emitted by the facility. That assumption could substantially overestimate the HF concentrations to which terrestrial plant foliage might be exposed.

Because modeled air concentrations are compared directly to the acid-gas ecological benchmarks expressed as air concentrations, emission-based screening thresholds are not calculated for acid gases as they are in the environmental risk screen for PB-HAPs.

For HF, the exposure durations for the available benchmarks (Section 3.2.2) do not correspond precisely to the exposure averaging times of the HEM/AERMOD results. The benchmarks for HF are equivalent to the 90-day Washington State criterion (0.5 µg HF/m^3) and the 90-day Canadian Ambient Air Quality Objective for the growing season (0.4 µg HF/m^3). Although some risk assessors would consider those two values to be essentially equivalent, and might propose using the more health-protective (lower) value, others might consider the 20-percent difference between the two values an important distinction and propose using a value applied within the United States. We therefore have retained both benchmarks for now. The exposure averaging time output from HEM/AERMOD for chronic scenarios is an annual average. Given that 90 days (the approximate growing season when foliage is present and exposed to air) is the longest duration for which HF criteria are available for jurisdictions within North America, the 90-day criteria are considered the best available benchmarks for direct comparison to annual average concentrations from HEM/AERMOD.

For HCl, our calculations to estimate a chronic benchmark for terrestrial plants expressed as air concentrations are the same as described in Appendix K of the 2009 SAB report (U.S. EPA 2009). Specifically, as summarized on page 3-23 of that report:

> *"We extrapolated the LOEL and LOAEL exposures to 1-hour equivalent concentrations of 0.5 and 1 mg/m^3, respectively using the common application of Haber's law, as*

> *modified by Ten Berge et al. [1986]. Lacking long-term study data, we applied an additional uncertainty factor of 10 to extrapolate the lower of the two acute thresholds (0.5 mg/m^3) from a 1-hour to a 1-year exposure threshold of 0.05 mg/m^3."*

Therefore, in our environmental risk screen, we compare the annual average HEM/AERMOD concentrations to the HCl benchmark of 0.05 mg/m^3 (50 µg/m^3).

5 Environmental Risk Characterization/Screening Results

In this section, we discuss the outputs and analyses generated as part of the environmental risk screen.

5.1 ENVIRONMENTAL RISK SCREEN METRICS FOR PB-HAPS

5.1.1 Tier 1

The modeling domain for Tier 1 consists of a health-protective set of conditions (see Section 4.1.1). The modeled area for Tier 1 does not fully extend around the facility but, rather, is a single, downwind wedge. The wedge includes point locations (centroids for modeled surface soil compartments) for estimating chemical concentrations in untilled surface soils at five locations (at 312 m, 850 m, 1500 m, 3500 m, and 7500 m from the facility; measured from the facility center point to the center point of the parcel). The wedge contains one freshwater lake or pond at approximately 500 m from the facility (with one compartment each for surface water, sediment, benthic invertebrates, and five categories of fish). Therefore, for water, sediment, and fish tissues, the Tier 1 environmental risk screen for a PB-HAP is based on the TRIM.FaTE-modeled chemical concentration in the lake water-column compartment, in the lake sediment compartment, and in each of the six aquatic animal compartments in the one lake, respectively. For surface soils, the Tier 1 environmental risk screen is based on the location with the highest soil concentration. Use of the highest soil concentration for Tier 1 is consistent with Tier 1 being a health-protective scenario.

The Tier 1 environmental risk screen for a PB-HAP is performed with a computational tool that automates steps from assembling emissions data to presenting results in preformatted spreadsheet tables. The tool calculates the Tier 1 SV, which is the emissions of the PB-HAP from a facility (adjusted to the BaP and 2,3,7,8-TCDD index chemicals for POM and dioxins, respectively) divided by the environmental screening threshold emission rate for that PB-HAP.

An SV less than or equal to 1 (after rounding to 1 significant figure) indicates that the facility screened out; an SV greater than 1 indicates the potential for adverse environmental effects cannot be ruled out. Outputs provided by this tool include the Tier 1 SVs, the number of facilities that did not screen out in the Tier 1 screen, and the highest Tier 1 SV. The SVs also can be presented for each facility, PB-HAP, assessment endpoint, and benchmark effects level and can be summarized across all facilities. See Table 5-1 for a summary of PB-HAP environmental risk screen metrics.

Facilities not passing the Tier 1 screen for any PB-HAP, assessment endpoint, or benchmark effects level are evaluated in Tier 2. Facilities that screened out of the Tier 1 screen are not evaluated further for potential environmental effects.

5.1.2 Tiers 2 and 3

For Tier 2, TRIM.FaTE was run once with hundreds of combinations of meteorological conditions (from 823 meteorological stations) and lake locations [five distances in eight octants (wedges) that together fully surround the source]. For each combination, environmental screening threshold emission rates are calculated for each PB-HAP and assessment endpoint. For a Tier 2 assessment for a given source category, each facility not ruled out by Tier 1 can be evaluated. First, a computational tool identifies which combination of meteorological conditions and lake location best matches the facility. The SVs for the facility equal the ratio of the facility's emissions to the environmental screening threshold emission rate for that combination from the Tier 2 TRIM.FaTE runs. Tier 2 soil calculations use the same five facility-to-soil distances as in Tier 1, but in all eight directional octants.

As in Tier 1, the Tier 2 environmental risk screen for PB-HAPs uses a computational tool that automates the steps described above. The Tier 2 environmental SVs are tabulated by facility, PB-HAP group, and assessment endpoint. For aquatic assessment endpoints, the final Tier 2 SVs are for the lake with the highest chemical concentrations (a protective setting). For soil-based assessment endpoints, the final Tier 2 SV is the average of the area-weighted SVs across all 40 surface soil compartments (5 distances in each of 8 octants). Facility-level results include the percentage of the total modeled soil area not passing the screen for each facility and each PB-

HAP. The tool also identifies lake names, sizes (acres), and locations. Table 5-1 summarizes the PB-HAP environmental risk screen metrics.

Table 5-1. Summary of PB-HAP Environmental Risk Screen Metrics

Tier	Modeling Domain	Source Category Results
Tier 1	Soils and Lake	• Tier 1 emission screening value (SV) for each facility for each combination of PB-HAP, assessment endpoint, and benchmark effects level. [For soils, the SV is based on the highest concentration from among the five soil locations.] • Number of facilities that do not screen out (for each combination of PB-HAP, assessment endpoint, and benchmark effects level; associated with SVs of 2 or more). • Highest Tier 1 screening ratio for the category (for each combination of PB-HAP, assessment endpoint, and benchmark effects level).
Tier 2	Soils	• Tier 2 SVs for each facility for each combination of PB-HAP, assessment endpoint, and benchmark effects level. [Overall SV is based on the area-weighted average for all 40 calculated soil concentrations within a 7.5-km radius.] • Number of facilities that do not screen out (for each combination of PB-HAP, assessment endpoint, and benchmark effects level; associated with SVs of 2 or more). • Highest Tier 2 SV for the category (for each combination of PB-HAP, assessment endpoint, and benchmark effects level). • Percentage of the total soil area with an SV of 2 or more for each facility (if at all).
	Lakes	• Tier 2 SVs for each facility for each combination of PB-HAP, assessment endpoint, and benchmark effects. [SV is based on the highest lake concentrations, after accounting for possible multifacility chemical loading.] • Number of facilities that do not screen out (for each combination of PB-HAP, assessment endpoint, and benchmark effects level; associated with SVs of 2 or more). • Highest Tier 2 SV for the category (for each combination of PB-HAP, assessment endpoint, and benchmark effects level). • For each modeled lake: lake name, lake surface area (acres), facility-to-lake distance, and latitude/longitude of the lake.
Tier 3	Same as Tier 2.	

Facilities that screen out of the Tier 2 screen for all assessment endpoints are not evaluated further. Facilities that do not screen out might be evaluated further with additional site-specific data and modeling refinements as described for Tier 3 (see Section 4.1.3).

The Tier 3 screening approach consists of three individual assessments (shown in Figure 4-4 and described in more detail in Section 4 of Appendix 6 of the Risk Report) that further refine the screening scenario (beyond Tier 2) based on additional site-specific data and evaluations. The refinements are conducted in a step-wise fashion, and all three might not always be needed (e.g.,

a facility might screen out after the first refinement in Tier 3). The three tier 3 assessments include the lake assessment, plume-rise assessment, and time-series meteorological assessment. The environmental risk screen metrics for Tier 3 are the same as for Tier 2.

As with the multipathway human health risk assessment, a site-specific assessment could be conducted if the Tier 3 screening results indicate a potential for adverse environmental effects. The site-specific assessment uses model parameter values and scenario designs intended to better represent the modeled facility—aspects such as local terrain (influencing runoff and erosion patterns), watersheds, actual lake boundaries and water retention rates, soil types, and land cover. This report does not present site-specific assessments.

5.2 ENVIRONMENTAL RISK SCREEN METRICS FOR ACID GASES

The HEM/AERMOD domain extends 50 km from the center of the facility. The HEM/AERMOD approach includes 13 concentric rings at various distances (out to 50 km) from the facility with 16 locations, each separated by 22.5 degrees on each ring. Therefore, the HEM/AERMOD model generates 208 point estimates of acid gas concentration.

Although an SV could be calculated for all 208 point estimates of air concentration, an SV for a single data point would have little meaning in the context of assessing "significant and widespread" effects over "broad areas" as specified in the CAA definition of "adverse environmental effects." For example, the area of a parcel close to the facility is only a few acres in size. Therefore, in the context of the statutory definition of adverse environmental effects, we use the metrics shown in Table 5-2 to identify effects that are significant and widespread (covering broad areas).

For acid gases, we report the following:

- If individual locations with an SV of 2 or more are present around a facility, we indicate the percentage of the modeling area that had an SV of 2 or more.
- If all locations (i.e., 208 modeled locations) for which HEM/AERMOD estimated acid gas concentrations had SVs less than 2, we indicate that all estimated concentrations around the facility are below the ecological benchmarks for acid gases in air.

Table 5-2. Summary of Acid Gas Environmental Risk Screen Metrics

	Metric	Description
Facility	Modeled area exceeding the ecological benchmarks, in acres and km^2	• All 208 modeled acid gas concentrations in air are compared with the ecological benchmarks (concentration/benchmark = screening value). Those SVs of 2 or more do not screen out. • The total modeled area with an SV of 2 or more.
	Percentage of the modeled area exceeding the ecological benchmarks	• The total modeled area with an SV of 2 or more divided by the total area of the 50-km (radius) modeling domain.
	Area-weighted average SV	• The area-weighted average concentration of all 208 modeled data points divided by the ecological benchmark.
Source Category	Number of facilities with exceedances	• The number of facilities in the category that did not screen out according to area-weighted averaging.

5.3 ENVIRONMENTAL RISK SCREEN METRICS FOR LEAD

For lead compounds, we currently have no ability to calculate concentrations in multiple environmental media using the TRIM.FaTE model. Therefore, to evaluate the potential for adverse environmental effects from lead compounds, we compare the HEM/AERMOD air concentrations of lead around each facility in the source category to the 0.15-µg/m^3 level of the secondary NAAQS for lead (U.S. EPA 2016a). The environmental risk screen for lead consists of one tier. We consider values below the level of the secondary lead NAAQS unlikely to cause adverse environmental effects.

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Attachment A. Environmental Effects Assessment

CONTENTS

TABLES

ACRONYMS

AE	assimilation efficiency
ALC	aquatic life criteria
ARCS	Assessment and Remediation of Contaminated Sediments
As	arsenic
BaF	benzo[a]fluoranthene
BAF	bioaccumulation factor
BaP	benzo[a]pyrene
BeP	benzo[e]pyrene
BCF	bioconcentration factor
BbF	benzo[b]fluoranthene
BjF	benzo[j]fluoranthene
BMD	benchmark dose
BSAF	biota-sediment accumulation factor
BTAG	Biological Technical Assistance Group
bw	body weight
CAS	Chemical Abstracts Service
CCME	Canadian Council of Ministers of the Environment
Cd	cadmium
DaP	dibenzo[a,i]pyrene
DMA	dimethylarsenic acid
DOE	Department of Energy
dw	dry weight
ECxx	effective concentration (xx-percent response)
Eco-TEFs	ecological toxicity equivalency factors
EPA	U.S. Environmental Protection Agency
EqP	equilibrium partitioning
ESL	ecological screening level
ESTER	environmental screening threshold emission rate
F	fluorine
FIR	food ingestion rate
FMR	free-living metabolic rate
GE	gross energy
GEAE	generic ecological assessment endpoint
GLNPO	Great Lakes National Program Office
GLWQI	Great Lakes Water Quality Initiative
GMAT	geometric mean
GMATC	geometric mean maximum acceptable toxic concentration
HAP	hazardous air pollutant
HCl	hydrogen chloride
HF	hydrogen fluoride
Hg	mercury
Hg++	divalent mercury
HMW	high-molecular-weight
ISQG	interim sediment quality guideline
Koc	organic carbon partitioning factor
Kow	octanol-water partitioning coefficient
LANL	Los Alamos National Laboratory
LC50	lethal concentration for 50 percent of animals tested
LEL	lowest-effect level
LOAEL	lowest-observed-adverse-effect level
LOEC	lowest-observed-effect concentration
LOEL	lowest-observed-effect level
MACT	maximum achievable control technology
MATC	maximum allowable toxicant concentration
MATL	maximum allowable toxicant level
ME	metabolizable energy
MeHg	methyl mercury
MOA	mode of action
MMA	monomethylarsonic acid
NAWQC	National Ambient Water Quality Criteria
NEC	no-effect concentration
NEL	no-effect level
NOAEL	no-observed-adverse-effect level
NOEC	no-observed-effect concentration
NOEL	no-observed-effect level
OEHHA	California Office of Environment and Health Hazard Assessment
OME	Ontario Ministry for the Environment

ORNL	Oak Ridge National Laboratory
OSWER	Office of Solid Waste and Emergency Response
OW	Office of Water
PAH	polycyclic aromatic hydrocarbon
PB-HAP	persistent bioaccumulative HAP
PCDD	polychlorinated dibenzo-p-dioxin
PCDF	polychlorinated dibenzofurans
PEL	probable-effect level
PHE	phenanthrene
PMC	photomodification
POM	polycyclic organic matter
PSC	photosensitization
PYR	pyrene
QSAR	quantitative structure-activity relationship
RAIS	Risk Assessment Information System
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RTR	Risk Technology and Review
SAV	secondary acute value
SCV	secondary chronic value
SESL	soil ecological screening level
SQB	sediment quality benchmark
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCEQ	Texas Commission on Environmental Quality
TEC	threshold-effects concentration
TEF	toxicity equivalency factor
TEL	threshold-effect level
TL	trophic level
TMA	trimethylarsenic
TOC	total organic carbon
TPY	tons per year
TRIM.FaTE	Total Risk Integrated Methodology, Environmental Fate, Transport, and Ecological Exposure
TRV	toxicity reference value
UF	uncertainty factor
WEFH	Wildlife Exposure Factors Handbook
WHO	World Health Organization
WQB	water quality benchmark
WQG	water quality guideline
ww	wet weight
YOY	young of the year

A.1 Introduction

Pursuant to the Clean Air Act, the U.S. Environmental Protection Agency (EPA) developed both human health and environmental risk screens under its Risk Technology and Review (RTR) program. The program assesses 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 attachment provides materials supporting EPA's approach to the effects assessment, as described in Section 3 of the main report.

EPA developed the environmental risk screen to examine the potential for adverse environmental effects as required under Section 112(f)(2)(A) of the Clean Air Act. Section 112(a)(7) of the Act defines "adverse environmental effect" as "any significant and widespread adverse effect, which may reasonably be anticipated, to wildlife, aquatic life, or other natural resources, including adverse impacts on populations of endangered or threatened species or significant degradation of environmental quality over broad areas."

The environmental risk screen includes eight HAPs, which we refer to as "environmental HAPs": six persistent bioaccumulative HAPs (PB-HAPs) and two acid gases. The six PB-HAPs are arsenic; cadmium; mercury (both inorganic mercury and methyl mercury); dioxins/furans (referred to herein as dioxins); polycyclic organic matter (POM); and lead. The two acid gases are hydrogen chloride (HCl) and hydrogen fluoride (HF). The remainder of this attachment is organized in eight sections.

Section A.2. We first provide supplemental information for the derivation of ecological benchmarks for surface waters, sediment, surface soils, and air. Benchmarks are expressed as the concentrations of individual chemicals in the environmental media listed above. The benchmarks are compared with exposure estimates to screen for risks to generic ecological assessment endpoints (GEAEs).

Section A.3. For POM and dioxins, we discuss derivation of toxicity equivalency factors (TEFs) for each group relative to their index chemicals, benzo[a]pyrene (BaP) and 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), respectively, for surface waters, sediment, and surface soils.

Section A.4. We describe the derivation of toxicity reference values (TRVs) for two wildlife species—mink and common (American) merganser—intended to represent fish-eating mammals and fish-eating birds, respectively. In contrast to ecological benchmarks, which are expressed as concentrations of chemicals in environmental media, TRVs are expressed as ingested doses in milligrams chemical ingested per kilogram wildlife body weight per day. TRVs are calculated for mink and American merganser based on key toxicity studies in the literature.

Section A.5. We discuss derivation of ecological toxicity equivalency factors (Eco-TEFs) for POM and dioxins relative to their index chemicals, BaP and TCDD, respectively, for TRVs for birds and mammals.

Section A.6. Data on dietary habits and values for exposures factors (e.g., ingestion rates, body weight) are provided for mink and American merganser. Those data are used to estimate exposure doses for wildlife from estimates of chemical concentrations in smaller and larger fish made with the Total Risk Integrated Methodology, Environmental Fate, Transport, and Ecological Exposure module (TRIM.FaTE).

Section A.7. Empirical data by which a bioaccumulation factor (BAF) was derived for arsenic in the water column and in benthic sediments are presented.

Section A.8. Screening emission rate thresholds, expressed as tons of chemical per year (TPY) released by a facility, are presented for each chemical, assessment endpoint, and environmental medium evaluated in the environmental risk screen.

Section A.9. This attachment concludes with a list of the references cited.

A.2 Ecological Benchmarks

Benchmark concentrations are derived for several GEAEs (U.S. EPA 2003a, 2016a) that are relevant to the different environmental media. GEAEs can be defined for individual organisms, specified populations of species, biological communities or assemblages, and ecosystems. Effects at the population or community level usually are inferred from scientific measurement of adverse effects at the individual or population level, respectively. Table 2-2 in the main report presents a list of GEAEs used in the RTR screen. We assess both populations (e.g., mink,

merganser) and communities (e.g., sediment benthic invertebrates, soil communities, water column communities) for the RTR assessment.

In this section, we provide supplemental information for the ecological benchmarks described in Section 3 of the main report. Section A.2.1 describes differences between "population-level" and "community-level" benchmarks in more detail than in the main report. Section A.2.2 provides supplemental information supporting the derivation of ecological benchmarks for PB-HAPs. Section A.2.3 provides background information and data from original studies used to derive the air concentration benchmarks for plants exposed to HF in air. Derivation of air concentration benchmarks for plants exposed to HCl was presented in materials prepared for the previous 2009 EPA Science Advisory Board review of the RTR assessment risk screens (U.S. EPA 2009a) and is not repeated here.

A.2.1 Population-level and Community-level Benchmarks

For readers familiar with EPA human health risk assessment, for which EPA identifies benchmarks and TRVs intended to protect individual humans from adverse health effects (e.g., noncancer effects) or to ensure risks (e.g., of cancer) are no higher than 1-in-ten thousand to 1-in-one million, the basis of ecological benchmarks and TRVs can be confusing. Federal risk assessments for endangered or threatened species might be conducted with individual-level TRVs, as is done for humans.

For nonthreatened wildlife, risks of losing local populations of economically important, "ecological indicator" species or most "exposed species" often are assessed (Section A.2.1.1). For other biota, such as invertebrates in aquatic sediments or in soils, community assemblages generally are assessed for their ability to provide habitat or other ecosystems services (Section A.2.1.2). Three of EPA's twelve GEAEs (USEPA 2003a) were not used because established benchmarks are not available (Section A.2.1.3).

Similar to the situation for human health risk assessment, we prefer to use previously established and peer-reviewed ecological benchmarks and TRVs (Section A.2.1.4). We also considered three effect levels that could assist EPA decision-makers in interpreting the results of RTR environmental risk screens (Section A.2.1.5).

A.2.1.1 Population-level Benchmarks

In general, population-level effects are inferred from available single-species toxicity tests for the assessment species (or the most closely related species as data allow). The results of single-species chronic toxicity tests with animals usually have been reported as NOELs (no-observed-effect levels) and LOELs (lowest-observed-effect levels) for a specified effect. The NOEL and LOEL (NOEC and LOEC where the C stands for "concentration" instead of level) are identified by hypothesis testing. The LOEL is the lowest exposure level at which the test-group response differs from the response of the control group with a probability, *p* (usually <0.05), that the difference is due to chance alone. The NOEL is the highest exposure level at which the test group response does not statistically differ from that of the control group.

For nonhuman biota, "health" usually is assessed at the population level (Biddinger et al. 2008). Therefore, generally only effects that readily can be linked to negative population-level consequences (or higher level impacts such as on communities or ecosystems) have been considered to represent lowest-observed-*adverse*-effect levels (LOAELs) in ecological risk assessments. Four effect categories for individual-level effects are considered closely linked with population-level effects: survival, reproduction, development, and growth (Rodier and Zeeman 1994; U.S. EPA 1998). When using both the statistical and biological definitions of "significant" effects, distinguishing biological significance (e.g., average weight loss of the test group of 10 percent is considered biologically significant) from statistical significance (i.e., less than a 5-percent chance that the difference from the control or reference area is due to chance alone) is important.

For a given species, if different sensitivities are associated with different lifestages, results from tests of the most sensitive lifestage are used to represent the species in chronic exposure scenarios. If some effects occur at lower concentrations than others (e.g., impaired reproductive success compared with growth), the most sensitive effect is used. If multiple studies on the same species' most sensitive lifestage report the same most sensitive effect, the geometric mean of the no-observed-adverse-effect level (NOAEL) values and the geometric mean of the LOAEL values across tests can be used to represent the NOAEL and LOAEL, respectively, for the species and endpoint. Otherwise, well-tested species could be over-represented in criteria or benchmark development (Stephan et al. 1985; U.S. EPA 1999).

Because of costs, fewer exposure levels typically are used in chronic toxicity tests than are used in acute toxicity tests. That has resulted in many reports of tests in which the LOAEL is the lowest exposure level tested or in which the NOAEL is the highest concentration tested (i.e., "unbounded" LOAEL and NOAEL values, respectively). The numeric values for unbounded LOAELs and NOAELs generally have the "<" and ">" signs, respectively, included. Tests in which both a NOAEL and a LOAEL are identified provide "bounded" values amenable to evaluating toxicity to the species used in that test.

A recent trend with the advent of the benchmark dose (BMD) approach is to evaluate the response at all chronic exposure concentrations. The BMD approach now is preferred to establish points of departure for toxicity when deriving reference values protective of human health, provided that available data are adequate to use the approach (U.S. EPA 2012a). Similarly, for ecotoxicity testing, particularly as reported in peer-reviewed journals, the trend is to report several points along the exposure-response curve for sublethal effects of chronic exposures, for example an EC_{05} or EC_{10}, an EC_{20}, EC_{25}, or EC_{30}, as well as an EC_{50}. An EC_{xx} is the "effective concentration" at which a specified effect is observed in xx percent of the test animals.

When EC values are available or can be calculated, and when the lower percent-effect concentrations have not been extrapolated "too far" below the range of observed responses, risk assessors consider an EC_{05} or EC_{10} to be roughly equivalent to historical NOECs or NOAECs in aquatic animal toxicity testing (SETAC 1994, p. 6; Sijm et al. 2002, p. 234). The effect level considered equivalent to LOECs or LOAECs is greater than an EC_{10}, with some risk assessors citing an EC_{20} (Anderson and Norberg-King 1991; Sijm et al. 2002, p. 235) and others indicating that LOAECs can be equivalent to EC_{25} or higher EC values, depending on many factors (e.g., number of animals per exposure group, number of exposure groups, spacing of exposure concentrations or doses) (Suter et al. 2000, 2003). The advantages of using all exposure-response data to fit exposure-response models to estimate low-effect levels instead of using NOAELs and LOAELs determined by hypothesis testing have been discussed in several texts and EPA guidance documents (e.g., Efroymson et al. 1997a,b; Suter 1993; U.S. EPA 1998, 2005a).

Assuming the availability of a robust toxicity test for a species of similar or greater sensitivity than the assessment species, usually a NOAEL (or EC_{05}–EC_{15}) and a LOAEL (or EC_{15}–EC_{25}) can be defined. For environmental screens, some EPA program offices prefer to use a NOAEL-

based benchmark (e.g., Superfund). Other offices have preferred using a GMAT—the geometric mean of the NOAEL and LOAEL, often referred to as a maximum allowable toxicant level (MATL) or concentration (MATC). The MATC is roughly equivalent to a "threshold for effects." The LOAEC often is associated with an effect level (e.g., 20–25 percent) that might not be sustainable for a local population, depending on species, its life history, sample sizes in the toxicity experiment, and other factors (Suter et al. 2000, 2003). Generally, however, the NOAEL and LOAEL are within one order of magnitude of each other in chronic experiments; hence, the utility of calculating the geometric mean between them is limited.

A.2.1.2 Community-level Benchmarks

Usually, ecological communities are valued by humans for the services they provide to humans, to wildlife, to valued species, to landscapes, or to functioning of ecosystems in general (Daily 1997; NRC 2004). For example, soil invertebrate communities are needed to recycle nutrients and to aerate soils. Measureable attributes of a soil invertebrate community that might influence its provision of those services include the presence and abundance of one (or more) key organism(s) (e.g., earthworms) or a diversity of organisms. Benthic (sediment-dwelling) invertebrates in lakes and rivers are important for recycling detritus and in providing food for fish communities.

Protection of ecosystem services provided by ecological communities usually requires an adequate number, abundance, and diversity of different species present to perform key ecological functions despite natural variation in local conditions (e.g., weather). For example, soil invertebrate communities generally require earthworms for soil aeration and conditioning to support plant life adequately; however, a diversity of other soil invertebrates assist. Benthic communities often require invertebrates that graze on algae or detritus to support higher tropic levels. To support fisheries, surface waters require a diversity of potential prey species, including smaller fish (e.g., minnows), young-of-year fish, and invertebrates (e.g., aquatic insect larvae such as midge and mayfly larvae).

For most ecological communities to provide an appropriate structure (e.g., tree canopy with understory) and to serve various functions (e.g., as bird habitat, flood protection), not all species in the community are required. In most ecosystems, several species perform similar or overlapping functions, and loss of one does not necessarily mean loss of the ecological service it

provides (this is particularly true of benthic invertebrates and plant communities). Some keystone species, however, are critical to community structure and function. Loss of those (e.g., sea otters consuming sea urchins in kelp beds, blue mussels occupying space in the intertidal zone, wolves feeding on other mammals on the prairies) can profoundly change the presence and abundance of other major species and thus profoundly change the structure of the ecosystem.

For sediments, exposure-effect data for some chemicals directly relate measures of benthic community structure (e.g., related to species diversity and abundance) to the concentration of specific chemicals. For water-column and soil-based communities, on the other hand, exposure-response functions generally are not available for community structure or function. Thus, EPA has used the premise that community structure (and therefore function) is unlikely to be affected if fewer than 5 percent of species (Office of Water [OW], U.S. EPA 1998; Stephan et al. 1985) or 10 percent of species (Solomon and Takacs 2002; Efroymson et al. 1997a,b) in the community might be locally extirpated. The rationale for allowing 5 or 10 percent of species to be affected, and potentially to disappear from a local community, is the concept of ecosystem resiliency, that is, the functional redundancy of groups of species (Solomon and Takacs 2002; van Straalen and van Leeuwen 2002).

Functional redundancy in most ecosystems has evolved owing to natural fluctuations in environmental conditions and has been demonstrated in several experimental multispecies tests (Solomon and Takacs 2002). In general, such experiments suggest that the 5-percent species-protection level does protect ecosystem structure and function against significant changes (Posthuma et al. 2002). Identifying upper percentile species “protection” benchmarks, however, requires testing of many phylogenetically distinct species; therefore, derivation of community-level benchmarks often is precluded for chemicals for which few species have been tested.

A.2.1.3 Assessment Endpoints Not Used in RTR Environmental Screen

Nine GEAEs (U.S. EPA 2003a) used in the RTR environmental screen are listed in Table 2-2 of the main report. We evaluated, but did not use, the remaining three EPA GEAEs for the environmental risk screen (Table A-1):

- Animals exposed to airborne HAPs by inhalation,
- Microbial community in soils, and
- Amphibians and reptiles in their respective habitats.

Table A-1. Generic Ecological Assessment Endpoints Not Used in the Nationwide RTR Environmental Risk Screen

Exposure Media	No.	Assessment Endpoint	Entities	Relevant Attributes	Benchmark
Air	10	Maintain local populations of wildlife and aboveground invertebrates exposed to airborne HAPs via inhalation	Birds, mammals, bees, butterflies, etc.	Individual survival, growth and development; area contaminated	No avian or invertebrate data available
Other	11	Maintain microbial function in soils (e.g., nitrogen fixation, decomposition of detritus to nutrients)	Assemblages of bacteria, fungi	Species diversity; decomposition rate for leaf litter; "soil" oxygen consumption rates; area contaminated	No consensus benchmarks available
	12	Maintain local populations of amphibians and reptiles (aquatic-stage amphibia should be covered by ambient water criteria)	Frogs, salamanders, toads, turtles, lizards	Individual survival, growth and development; area contaminated	No consensus benchmarks available; cold blooded, food ingestion rates substantially lower than for birds and mammals

A.2.1.4 Preferred Sources of Benchmarks

We prefer to use established and peer-reviewed ecological benchmarks when available. Benchmarks for sediments, surface waters, and soils initially were identified using the Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS) (http://rais.ornl.gov/). The ORNL RAIS database is maintained by the Department of Energy (DOE) for use in its risk assessments at hazardous waste sites. It includes virtually all TRVs and benchmarks developed to date that might be used by federal agencies in the United States and several other countries to assess risks to human health and the environment (ecological receptors). RAIS therefore provides "one-stop shopping" to identify the availability of and values for ecotoxicity benchmarks for chemicals of concern to U.S. regulatory communities.

All screening-level benchmarks available from Suter and Tsao (1996), which was a key source of benchmarks for the Coke Oven MACT Residual Risk Assessment (U.S. EPA 2003b), are included in RAIS, as are the other sources of benchmarks used in that assessment (e.g., U.S. EPA National Ambient Water Quality Criteria [NAWQA], EPA Region 4 values, National Oceanic and Atmospheric Administration benchmarks, Florida Department of Environmental Protection benchmarks). Once we identified ecological benchmarks in RAIS, we obtained the original sources to confirm values. Our most recent query of RAIS was in August 2016, to check for updates and possibly new benchmarks; we found both.

Finally, we established a hierarchy of preferred benchmark sources to enable selection of benchmarks for each environmental HAP for each ecological assessment endpoint. In general, we used EPA sources at a programmatic level (e.g., OW, Superfund Program), if available. If not, we used EPA benchmarks used in regional programs (e.g., region-specific Superfund). If benchmarks were not available at a programmatic or regional level, we used benchmarks developed by other federal agencies (e.g., DOE), state agencies, or Canada.

A.2.1.5 Effect Levels

In our review of existing benchmarks derived by EPA program offices, EPA regions, other agencies, and states, we found that for some environmental media, notably sediments, benchmarks had been established for two or three different effect levels, not just a "threshold for effects." Several physical attributes of sediments can modify the response of biota living in them. These include pH, sediment particle size, interstitial pore size, organic carbon content, acid volatile sulfide, content, sediment depth, and characteristics of benthic organisms (e.g., sizes, method of feeding, depth of burial, mobility). Therefore, over the past several decades, sediment benchmarks often have been defined at three different levels of effect: no-effect level (NEL: low probability of changes in the structure or function of the benthic community); threshold-effect level (TEL: concentrations above threshold might cause adverse effects in structure and function of benthic community); and probable-effect level (PEL: high probability of frank changes in community structure, function, and provision of ecosystem services).

We therefore decided to look for benchmarks that might represent all three effect levels (i.e., NEL, TEL, and PEL) for each exposure medium/GEAE/chemical combination. Only TELs were available for most benchmarks; we included NEL and PEL values, if available, to provide more information to EPA decision-makers who need to consider whether adverse ecological effects are significant and widespread.

A.2.2 Ecological Benchmarks for Persistent and Bioaccumulative Hazardous Air Pollutants (PB-HAPs)

Ecological benchmarks for PB-HAPs are needed for three environmental media: the water column in lakes (Section A.2.2.1), the sediment bed in lakes (Section A.2.2.2), and surface soils in terrestrial environments (Section A.2.2.3).

A.2.2.1 Water-Column Benchmarks

For organisms that live primarily in the water-column of aquatic ecosystems, EPA's NAWQC-ALC (aquatic life criteria) are used as available (Stephan 1985, 2002; U.S. EPA 2002, 2016b). According to Suter and Tsao (1996), the *acute* NAWQC-ALC are considered "upper" screening levels in EPA's Superfund program—which we interpret to mean *probable effect levels* if associated with continuous long-term (chronic) exposures. The *chronic* NAWQC-ALC are considered "lower" screening-level benchmarks in EPA's Superfund program (Suter and Tsao 1996). Given the methods by which both acute and chronic NAWQC-ALC are derived, we interpret the chronic NAWQC-ALC to represent a threshold for adverse effects in aquatic communities (water-column compartment) rather than an NEL.

For chemicals for which available data do not cover the taxonomic groups required to establish NAWQC, EPA's OW established a Tier II approach (not to be confused with the RTR ecological or human health Tier 2 assessment) allowing derivation of a secondary acute value (SAV) and a secondary chronic value (SCV) based on toxicity data for fewer taxonomic groups than the eight specified for NAWQC. The Tier II approach was developed for the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA 1993a). Depending on the number of taxa for which acute toxicity data are available, a sliding scale of uncertainty factors (UFs) is applied to the lowest acute and chronic toxicity values to estimate the Tier II SAVs and SCVs. EPA's Superfund program adopted the Tier II SAV methodology from the GLWQI, but on occasion varies its approach to calculating SCVs from SAVs when chronic aquatic toxicity data are limited.

For chemicals for which NAWQC-ALC and Tier II secondary values were not available, we turned to benchmarks developed by EPA Regions 3, 4, 5, or 6.

We describe the sources of the TELs and PELs (acute and chronic criteria) for the PB-HAPs below. For arsenic, we present our review of available data in detail to document our approach. For cadmium, mercury (divalent and methyl), POM, and dioxins, we simply present the benchmarks selected based on the preferred hierarchy of sources.

Arsenic (As) Surface Water Column Screening Benchmarks

EPA derived NAWQC-ALC for arsenic (III). No data are available to determine whether the effects of arsenic (III) and (IV) are additive (U.S. EPA 1995a). Therefore, the values are applied

to total dissolved inorganic arsenic. The multiple freshwater benchmarks identified in DOE ORNL RAIS are listed in Table A-2.

Table A-2. Ecological Freshwater Benchmarks for Dissolved Inorganic Arsenic (µg/L)

Name of Benchmark	Arsenic (III)	Arsenic, Inorganic
Canadian WQG Surface Water Screening Benchmark	NA	5
U.S. EPA Region 4 Acute Surface Water Screening Benchmark	360	360
U.S. EPA Region 4 Chronic Surface Water Screening Benchmark	190	190
U.S. EPA NAWQC Acute Criterion	NA	340
U.S. EPA NAWQC Chronic Criterion	NA	150
U.S. EPA OSWER (Superfund) Water Quality Screening Level	NA	190
U.S. EPA Region 5 ESL Surface Water Screening Benchmark	NA	148
U.S. EPA Region 6 FW Surface Water Screening Benchmark	NA	190

Abbreviations and Acronyms: ESL = ecological screening level; FW = freshwater; NAWQC = National Ambient Water Quality Criteria (U.S. EPA, for the protection of aquatic life); OSWER = Office of Solid Waste and Emergency Response (Superfund, U.S. EPA); NA = not available; µg/L = micrograms per liter; WQG = water quality guideline

Source: Department of Energy (DOE) Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (RAIS) Ecological Benchmark Tool. Listed in order of RAIS output. Marine values excluded.

The acute and chronic NAWQC for freshwater aquatic life, 340 and 150 µg/L, respectively, are applicable nationwide. Therefore, they were selected as the PEL and TEL freshwater benchmarks for arsenic (listed in Table 5-1 of the main report).

Most benchmarks identified by RAIS are similar for acute and chronic exposures; an exception is the Canadian water quality guideline (WQG) of 5 µg/L. It was derived from the 50-µg/L arsenic concentration that reduced growth in one algal species by 50 percent (Vocke et al. 1980). That value was multiplied by a safety factor of 0.1 to calculate the Canadian WQG (Canadian Council of Ministers of the Environment [CCME] 1991). In surface waters, many different algal species can provide the same ecological services. Thus, in the field, the loss of a single algal species does not necessarily alter the ecological structure or function of the aquatic community. We therefore considered the Canadian WQG to be too conservative for the RTR assessment.

Cadmium (Cd) Surface Water Column Screening Benchmarks

Cadmium is one chemical for which we found a 2016 revision to the NAWQC in our review of benchmarks in RAIS: chronic criterion (TEL) of 0.72 µg/L and acute criterion (PEL) of 1.8 µg/L dissolved Cd assuming water hardness of 100 mg/L as $CaCO_3$ (in Table 3-1 of the main report;

U.S. EPA 2016c). EPA's NAWQC for the protection of aquatic life for cadmium depend on water hardness (U.S. EPA 2001a).

Divalent Mercury (Hg^{++}) Surface Water Column Screening Benchmarks

For inorganic, divalent mercury (e.g., dissolved mercuric chloride), EPA's NAWQC are 0.77 µg/L for the chronic criterion and 1.4 µg/L for the acute criterion (U.S. EPA 2016b) (listed in Table 3-1 of the main report). The 1995 criteria (U.S. EPA 1995b) were updated by multiplying the criteria by 0.85 to account for the fraction dissolved in water, as per guidance (U.S. EPA 1993b) that was not widely available in 1995.

Methyl Mercury (MeHg) Surface Water Column Screening Benchmarks

Facilities in RTR source categories emit inorganic mercury, which deposits to surface waters and soils, and from soils, runoff and erosion transport it to the lake, where it enters sediments. Although the divalent mercury is methylated primarily in sediments, some net methylation also occurs in surface soils. TRIM.FaTE estimates bioaccumulation of MeHg through the aquatic food chain, predicting concentrations in the various biotic compartments, particularly fish.

EPA's OW decided to publish its NAWQC criteria for MeHg as concentrations in fish rather than as concentrations in water, because measured BAFs for MeHg in surface waters vary substantially across lakes. Thus, we could have compared TRIM.FaTE-estimated concentrations of MeHg in fish with the NAWQC MeHg concentrations in fish. Instead, we chose to identify MeHg concentrations in the water column to serve as benchmarks for the aquatic community.

EPA Region 4 cites Suter and Tsao (1996) as its source for a Tier II SCV (chronic, TEL) of 0.0028 µg/L and Tier II SAV (acute or PEL) of 0.099 µg/L (U.S. EPA 2015) (listed in Table 5-1 of the main report). Suter and Tsao (1996) followed the EPA GLWQI guidance for deriving Tier II SCV and SAV values (U.S. EPA 1995b).

POM—Benzo[a]pyrene (BaP) Surface Water Column Screening Benchmarks

Data available for BaP are insufficient for deriving an EPA NAWQC. BaP is highly lipophilic; thus, toxicity testing for aquatic organisms is difficult because toxicity might not be reached at the limit of solubility. Suter and Tsao (1996) calculated a Tier II SCV and SAV using EPA GLWQI (1993a) guidance, and other groups have adopted their values. The SCV (chronic TEL) of 0.014 µg/L has been adopted by EPA Region 5 (U.S. EPA 2003c) and the State of Texas

(TNRCC 2001), and Region 6 recommends its use to its risk assessors (ORNL RAIS).[11] The SAV (acute, PEL) of 0.24 µg/L, calculated by Suter and Tsao (1996) has not been adopted by the EPA regions, but is included in the RTR ecological benchmarks rather than having no PEL freshwater benchmark.

Dioxins—2,3,7,8-TCDD Surface Water Column Screening Benchmarks

Dioxins also are lipophilic and difficult to test for aquatic toxicity; thus, no NAWQC are available for TCDD. Nonetheless, EPA Region 4 developed chronic and acute freshwater screening values for TCDD of 1E-05 µg/L and 0.1 µg/L, respectively (U.S. EPA 2001b) (in Table 3-1 of the main report).

A.2.2.2 Sediment Benchmarks

This section describes the selection of sediment benchmarks for arsenic, cadmium, divalent mercury, methyl mercury, BaP for POM, and 2,3,7,8-TCDD for dioxins. We demonstrate our approach using arsenic, and provide briefer accounts for the remaining five PB-HAPs.

Arsenic (As) Sediment Screening Benchmarks

Many groups and investigators have developed chronic sediment quality criteria for arsenic, including those for freshwater sediments listed in Table A-3. Further, many different acronyms and terms are used to describe the same concepts within sediment benchmark terminology. For example, some sediment criteria experts consider a TEL or threshold-effects concentration (TEC) to be a level below which adverse effects are unlikely to occur (MacDonald et al. 2000), while others define a lowest-effect level (LEL) or a minimal effect threshold as the 15th percentile of species-specific threshold concentrations across diverse taxa (Jones et al. 1997). Few studies have examined the success/failure rate of sediment benchmarks to predict sediment toxicity accurately in the field. The Canadian Council of Ministers of the Environment (CCME 1999a,b) reported that the incidence of effects in sediment samples below the Canadian *interim* sediment quality guideline (ISQG) concentration for arsenic (i.e., 5.9 mg/kg dry sediment) is only 3 percent, which is close to a no-effect incidence rate (CCME 1999a,b).

[11] EPA recently merged Regional Screening Levels for Chemical Contaminants at Superfund Sites for Regions 3, 6, and 9 at a single website (https://www.epa.gov/risk/regional-screening-levels-rsls).

Table A-3. Sediment Screening Benchmarks Identified in ORNL RAIS Database

Sediment Screening Benchmark	mg/kg dw	Rationale for Not Using*
U.S. EPA ARCS highest NEC (similar to Washington State MAEL)	92.9	biological meaning of *highest* NEC for sediment communities is unclear
U.S. EPA ARCS PEC	33	*selected for use for RTR as probable effect level
U.S. EPA ARCS TEC	9.79	lower "threshold" available
Canadian ISQG	5.9	Canadian
Canadian PEL	17	lowest PEL
Consensus PEC (MacDonald et al. 2000)	33	*selected for use for RTR as probable effect level
Consensus TEC (MacDonald et al. 2000)	9.79	lower "threshold" available
Florida Department of Environmental Protection PEL	41.6	Florida conditions unusual
Florida Department of Environmental Protection TEL	7.24	Florida conditions unusual
Ontario Low (Persaud et al. 1993)	6	Canadian
Ontario Severe (Persaud et al. 1993)	33	*selected for use for RTR as probable effect level
U.S. EPA OSWER (Superfund) ERL	8.2	*selected for use for RTR as threshold for effect
U.S. EPA Region 4 TEL	7.24	could not verify online
U.S. EPA Region 5 RCRA ESL	9.79	lower "threshold" available
U.S. EPA Region 6 freshwater	5.9	could not verify online
Washington State freshwater MAEL	93	higher than PELs & PECs
Washington State freshwater NEL	57	higher than other threshold levels
U.S. EPA Region 3 BTAG, freshwater	9.8	lower "threshold" available

Acronyms: ARCS = Assessment and Remediation of Contaminated Sediments (Program); BTAG = Biological Technical Assistance Group (Superfund); EPA = Environmental Protection Agency; ERL = effects range – low; ESL = ecological screening level; ISQG = interim sediment quality guideline; MAEL = Sediment Impact Zone Maximum Level; NEC = no-effects concentration; NEL = no-effect level; ORNL = Oak Ridge National Laboratory; PEC = probable effects concentration; PEL = probable effect level; RCRA = Resource Conservation and Recovery Act; RAIS = risk assessment information system (Department of Energy); TEC = threshold effects concentration
Abbreviations: mg/kg dw = milligrams arsenic per kilogram dry weight sediment
* Value selected for use in RTR screens; see text.

For purposes of RTR assessments, we selected a threshold-effects benchmark of 8.2 mg[As]/kg dry weight sediment from EPA's Superfund program, because it is an EPA benchmark (preferred over DOE ORNL and state and Canadian benchmarks), and we could verify its derivation (U.S. EPA 1996a). Not all benchmarks included in RAIS can be verified using original sources, because several sources do not explain derivation of the benchmarks.

Values in Table A-3 associated with benchmark names suggesting that adverse effects are "probable," likely to be "frequent," or likely to be "severe" range from 33 to 93 mg[As]/kg[dry

weight (dw) sediment]. With three different groups identifying 33 mg/kg dw sediment as a probable or severe effects level [i.e., U.S. EPA Assessment and Remediation of Contaminated Sediments (ARCS program); MacDonald et al. 2000; Ontario (Persaud et al. 1993)], we recommend 33 mg[As]/kg dw sediment to represent the probable-effect benchmark.

Cadmium (Cd) Sediment Screening Benchmarks

Although we would prefer to have NEL, TEL, and PEL benchmarks from the same source for sediments; that was not possible for cadmium. EPA has recommended only a TEL (U.S. EPA 1996a, OSWER – Superfund Program) of 1.2 mg[Cd]/kg dw sediment. The CCME (1999b) had recommended an ISQG of 0.6 mg[Cd]/kg dw sediment, but more recently defined an even lower effect level, called the rare-effect level (EC & MDQuébec 2007) of 0.33 mg[Cd]/kg dw sediment. The CCME (1999b) PEL is 3.5 mg[Cd]/kg dw sediment.

Divalent Mercury (Hg^{++}) Sediment Screening Benchmarks

For Hg^{++}, we found no benchmarks representing an NEL but many benchmarks that could be interpreted as TELs and PELs. Given the similarity of the benchmarks, we could not clearly recommend one over another and decided, in this case, to average the values across sources to develop a TEL and a PEL for sediments.

For a TEL, we calculated the arithmetic mean of eight available benchmarks for inorganic (or total) mercury. That approach gives equal weight to the eight sediment benchmarks:

- U.S. EPA (1996b) – Great Lakes National Program Office (GLNPO) Assessment and Remediation of Contaminated Sediments (ARCS) program – 0.18 mg/kg[dry weight sediment] (mg/kg dw);
- MacDonald et al. (2000) – Consensus Threshold Effects Concentration – 0.18 mg/kg dw;
- Florida Department of Environmental Protection (MacDonald 1994) – sediment screening benchmark – 0.13 mg/kg dw;
- U.S. EPA (1996a) OSWER – Ecotox Threshold sediment screening level – 0.15 mg/kg dw;
- U.S. EPA (2015) Region 4 – sediment screening benchmark – 0.13 mg/kg dw;
- U.S. EPA (2006a) Region 3 Biological Technical Assistance Group (BTAG) – sediment screening benchmark – 0.18 mg/kg dw;
- U.S. EPA (2003c) Region 5 – Resource Conservation and Recovery Act (RCRA) – sediment screening benchmark – 0.174 mg/kg dw; and
- U.S. EPA Region 6 (TNRCC 2001) – sediment screening benchmark – 0.174 mg/kg dw.

The benchmarks listed above range from 0.13 mg/kg dw sediment to 0.18 mg/kg dw, with arithmetic mean 0.16 mg/kg dw sediment (in Table 3-1 of the main report).

For a PEL, we averaged the four values available for freshwater sediment probable effect levels:

- U.S. EPA (1996b) – GLNPO ARCS probable effects concentration – 1.06 mg/kg dw;
- MacDonald et al. (2000) – Consensus probable effects concentration – 1.06 mg/kg dw;
- Florida Department of Environmental Protection (MacDonald 1994) – PEL – 0.70 mg/kg dw; and
- CCME (2001) – PEL – 0.486 mg/kg dw sediment.

The benchmarks listed above range from 0.486 mg[Hg]/kg dry sediments to 1.06 mg[Hg]/kg dw, with arithmetic mean 0.84 mg [Hg]/kg dry sediments (in Table 3-1 of the main report).

Methyl Mercury (MeHg) Sediment Screening Benchmarks

We identified no benchmarks for MeHg in sediments. MacDonald et al. (2000) estimated a consensus TEC of 0.2 mg[total Hg]/kg dry sediments and a PEC of 1 mg[total Hg]/kg dry sediments (rounded to one significant digit). MeHg generally is 4 percent (range 1 to 11 percent) of total Hg in sediments (Krabbenhoft et al. 1999). Thus, we could have set benchmarks at 0.005 and 0.04 mg[MeHg]/kg dry sediments if we had confidence in the proportion of MeHg in sediments. TRIM.FaTE, however, estimates mercury transformations between Hg^{++} and MeHg for the environmental input parameters (e.g., pH, chloride ions, fraction organic carbon) and empirical values for equilibrium partitioning between aqueous phase and particulate phase chemical. Thus, over-riding those calculations based on the data reported by Krabbenhoft et al. (1999) would not have been reasonable. We therefore kept the TEC and PEC values estimated by MacDonald et al. (2000). Because the TEC and PEC values for Hg^{++} (see previous paragraph) are lower than for MeHg, and because most Hg in sediments is likely to be inorganic, the sediment benchmarks for Hg^{++} are the limiting benchmarks. Effectively, we have no benchmarks for MeHg in sediments.

POM—Benzo[a]pyrene [BaP] Sediment Screening Benchmarks

Several freshwater sediment benchmarks are available for BaP for the NEL, TEL, and PEL. For the NEL, we used the value of 0.032 mg[BaP]/kg dry sediments, which is recommended by CCME (1999b) and Region 6 (TNRCC 2001). Three sources recommend a TEL of 0.15 mg[BaP]/kg dry sediments: GLNPO ARCS (U.S. EPA 1996b); Region 3 BTAG (U.S. EPA

2006); and MacDonald et al. (2000). The same three sources recommend a PEL of 1.5 mg[BaP]/kg dry sediments (in Table 3-1 of the main report).

Dioxins—2,3,7,8-TCDD Sediment Screening Benchmarks

Dioxins are difficult to test for aquatic toxicity, because they basically do not partition to the water column or to sediment pore water. In addition, they are toxic at very low concentrations that are difficult to measure. We did identify TELs for 2,3,7,8-TCDD in sediments of 8.5E-07 mg/kg dry sediment (U.S. EPA 2006, Region 3), 2.5E-06 mg/kg dw (U.S. EPA 2001b, Region 4), and 1.2E-07 mg/kg dw (U.S. EPA 2003c, Region 5). The arithmetic mean of those three benchmarks rounded to two significant digits is 1.2E-06 mg/kg dw (in Table 3-1 of the main report). A geometric mean would be more conservative; however, the Los Alamos National Laboratory (LANL) recently has made its database of benchmarks available via the internet, recommending a screening LOAEL value of 8.5E-06 mg/kg dw (LANL 2015). We attempted to verify the derivation of that value; however, the references are to previous LANL versions of the database (e.g., LANL 2012 and earlier), rather than to original toxicity studies. Thus, we retain the arithmetic mean of three EPA TCDD benchmarks for sediments.

Initially, we found no benchmarks for an NEL or a PEL for TCDD. In 2016, we found a NOAEL of 8.5E-07 mg/kg dw in the LANL (2015) database and a PEL of 0.022 (rounded to two significant digits) mg/kg dw for Canadian sediments (CCME 2001; previously overlooked). We have not verified the derivation of the NEL or PEL; therefore, they each represent a single point-estimate of a sediment benchmark, in contrast to the TEL, which represents three separate point-estimates of a sediment benchmark.

A.2.2.3 Soil Benchmarks

For soils, EPA's national Superfund Program (formerly called the Office of Solid Waste and Emergency Response or OSWER) Eco-Soil Screening Levels (Eco-SSLs, U.S. EPA 2005c) were selected, if available, as the soil ecological benchmarks for the ecological risk environmental screens for the RTR assessment. The OSWER Eco-SSLs are the only EPA-vetted ecological toxicity screening benchmarks for soils established for use by the Agency nationwide. For chemicals for which no Eco-SSLs were available, EPA regional sources of soil ecotoxicity benchmarks were sought (e.g., Regions 4, 5, and 6). The general methods for deriving those

benchmarks differ from the methods EPA used to derive Eco-SSLs, and some are not available via the internet.

For some chemicals, EPA regions use soil ecological benchmarks developed by other agencies such as DOE or one of the states in the region. If not specified in published information, we assumed that whichever group of organisms was most sensitive to the chemical in soil (e.g., earthworms, insect larvae, plant roots, and in some cases herbivorous animals consuming plants grown in the contaminated soil) was likely to have been the basis for a soil screening criterion. If an EPA region and another non-EPA agency were identified as using the same numeric benchmark value, the sources that designated that value are acknowledged. Finally, if the only source providing a screening-level benchmark for soils was not an EPA office or region (e.g., DOE, ORNL, Environment Canada, a state), the value was used as last priority.

Arsenic (As) Soil Screening Benchmarks

Arsenic has not been demonstrated to bioaccumulate significantly in soil invertebrates. Data compiled to develop and validate bioaccumulation models for earthworms indicate that arsenic concentrations in earthworms tend to be approximately one order of magnitude lower than the concentration in soils on a mg/kg dry weight basis (i.e., both soils and earthworm arsenic concentrations measured per unit dry weight; Sample et al. 1998). Thus, for arsenic, the Eco-SSL for plants is lower than the Eco-SSLs for ground-feeding birds and mammals that ingest soil invertebrates. In contrast, the most appropriate Eco-SSLs for bioaccumulative substances (e.g., mercury, cadmium) are for birds or mammals consuming soil invertebrates. The lowest arsenic Eco-SSL value for plants, 18 mg[As]/kg[dry weight soil] (Table A-4), is the geometric mean of the maximum allowable toxicant concentration (MATC) for three plant studies (with ryegrass, cotton, and rice) that EPA judged to have appropriate arsenic bioavailability.

The three studies included both a low pH (5.6) and organic matter content (0.7%) and a higher pH (7.9) and organic matter content (1.1%) (Table 3.1 in U.S. EPA 2005b). For each of the three plant species, the MATC represents the geometric mean of the experimentally determined LOAEL and the NOAEL for plant growth.

Table A-4. Ecological Soil Benchmarks for Inorganic Arsenic, CAS No. 7440-38-2

Name of Benchmark	mg/kg dw soil
U.S. EPA OSWER Eco-SSL Plants	18
U.S. EPA OSWER Eco-SSL Avian	43
U.S. EPA OSWER Eco-SSL Invertebrate	NA
U.S. EPA OSWER Eco-SSL Mammalian	46
U.S. EPA Region 6 Earthworms Surface Soil Screening Benchmark	60
U.S. EPA Region 6 Plants Surface Soil Screening Benchmark	37
U.S. DOE ORNL Invertebrates Soil Screening Benchmark	60
U.S. DOE ORNL Microbes Soil Screening Benchmark	100
U.S. DOE ORNL Plants Screening Benchmark	10

Abbreviations and Acronyms: CAS = Chemical Abstracts Service; dw = dry weight; Eco-SSL = U.S. EPA Ecological Soil Screening Level (Superfund); ORNL = Oak Ridge National Laboratory; DOE =Department of Energy; mg/kg dw soil = milligrams arsenic per kilogram dry weight soil; NA = not available

The avian Eco-SSL (woodcock) is based on one of four toxicity experiments that both met EPA's criteria for study acceptability and examined growth and reproduction in birds. Of those, only one experiment identified NOAELs for both growth and reproduction at 2.24 mg[As]/kg [body weight]-day (arsenate oxide) in domestic chickens (Holcman and Stibilj 1997, as cited in U.S. EPA 2005b). Camardese et al. (1990) identified a lower LOAEL of 1.49 mg/kg-day (arsenate) for growth for mallard duck; however, because that study did not identify a NOAEL, EPA used 2.24 mg/kg-day as a TRV for birds (U.S. EPA 2005b). Using that TRV and back-calculating a soil concentration based on woodcock consumption of arsenic with a diet of earthworms yields an Eco-SSL for ground-feeding birds of 43 mg/kg dw soil (U.S. EPA 2005b).

More toxicity studies of acceptable quality were available for mammals than for birds. From 55 mammalian studies, over 100 toxicity values were identified. EPA calculated the geometric mean of 27 bounded[12] NOAELs for reproduction and growth to be 2.47 mg[As]/kg-day. One study using beagle dogs (initially 7–8 months old) identified a bounded LOAEL of 1.66 mg/kg-day (Neiger and Osweiler 1989, as cited in U.S. EPA 2005b), which is lower than 2.47 mg/kg-day. EPA therefore used the NOAEL associated with the dog study, 1.04 mg/kg-day, to calculate a

[12]A bounded NOAEL is one from a study in which a LOAEL was identified. A bounded LOAEL is one from a study in which a NOAEL was identified.

TRV for mammals. Back-calculation of a soil concentration for a shrew that consumes invertebrates in soils yielded an Eco-SSL for ground-feeding mammals of 46 mg[As]/kg dw soil.

Five other LOAELs are from studies [two in mice measuring growth and reproduction (total four LOAELs), and one in Guinea pigs measuring growth] that did not identify a NOAEL and for which the LOAELs for reproduction, growth, or survival were lower than 2.47 mg[As]/kg-day (see Figure 6.1 in USEPA 2005b). Those were not considered in deriving the Eco-SSL for mammals because they were not bounded by a NOAEL identified in the same experiment. Thus, the Eco-SSL for soils for shrews might be based on a NOAEL that is not necessarily protective of some sensitive species or sensitive effect endpoints.

Cadmium (Cd) Soil Screening Benchmarks

EPA has derived four Eco-SSLs for cadmium (Table A-5). As is often the case for Eco-SSLs for bioaccumulative substances, the benchmarks protective of birds and mammals that feed on soil invertebrates are lower (more restrictive) than those for plants and invertebrates. That is because chemicals bioaccumulate from soils to the soil invertebrates that then are consumed by the wildlife. Although nominally based on NOAELs for adverse effects on reproduction and growth, the Eco-SSLs for insectivorous wildlife are based on the geometric mean of NOAELs across both types of effect and across all species for which data are available within each group, birds or mammals, respectively.

For the cadmium Eco-SSL for birds, most (15/20) NOAELs used to derive the geometric mean NOAEL came from toxicity tests using chickens and quail (Order Galliformes) with a minority (4/20) of toxicity values from mallard duck and one value from wood duck (Order Anseriformes includes ducks, mergansers, and other waterfowl). The avian geometric mean NOAEL calculated for the Eco-SSL is 1.47 mg[Cd]/kg bw-day. Back-calculating a soil concentration that corresponds to the avian TRV for woodcock consuming 100% earthworms yields an Eco-SSL of 0.77 mg[Cd]/kg dw soil (U.S. EPA 2005d) (Table A-5). We calculated a NOAEL and LOAEL for piscivorous birds (in Section A.4 below) as 1.0 and 0.7 mg[Cd]/kg bw-day, respectively. We conclude that the avian Eco-SSL, based on the geometric mean of NOAELs across species and endpoints, is similar to a LOAEL for ducks and mergansers as discussed in Section A.4.

Table A-5. Screening Soil Benchmarks for Cadmium, Thresholds for Effect

Benchmark Type	Value	Units	Benchmark	Reference
Mammals (shrew)	0.36	mg[total Cd]/kg dry weight soil	Eco-SSL for four soil communities specified under Benchmark Type	U.S. EPA 2005d, OSWER
Birds (American woodcock)	0.77			
Plants	32			
Invertebrates	140			

Acronym: Eco-SSL = U.S. EPA Ecological Soil Screening Level (Superfund)

For the cadmium Eco-SSL for mammals, the geometric mean of 23 NOAELs for reproduction (21 from rats and 2 from mice) and 59 NOAELs for growth (most from rats, but a few from mice, cattle, sheep, pigs, dogs, and voles) of 1.86 mg[Cd]/kg bw-day turned out to be higher than the highest bounded NOAEL (0.77 mg cadmium/kg bw-day) below the lowest bounded LOAEL. EPA therefore set the TRV used to calculate the Eco-SSL for mammals to 0.77 mg cadmium/kg bw-day. Back-calculating the corresponding soil concentrations for shrews that consume 100% earthworms resulted in an Eco-SSL of 0.36 mg[Cd]/kg dry soil (U.S. EPA 2005d). The values we identified as the LOAEL and NOAEL for mammals for a sensitive species and endpoint (in Section A.4) are 7.42 and 0.742 mg[Cd]/kg bw-day, respectively. Thus, in this case, the mammalian Eco-SSL is based on a TRV that is similar to a NOAEL for a sensitive mammalian species and endpoint.

Divalent Mercury (Hg^{++}) Soil Screening Benchmarks

EPA has not estimated Eco-SSLs for divalent mercury in soils. Inorganic mercury is not expected to bioaccumulate. Thus, the only soil screening levels that we identified were the EPA Region 6 recommendation of 0.3 mg[Hg]/kg dry soil for plants (Efroymson et al. 1997a) and the EPA Regions 4 and 6 recommendation of 0.1 mg[Hg]/kg dry soil for earthworms in soil (U.S. EPA 2015 and Efroymson et al. 1997b, respectively). See Table 3-1 of the main report.

Methyl Mercury (MeHg) Soil Screening Benchmarks

Methyl mercury is expected to bioaccumulate; however, its concentrations in soils that receive air deposition of divalent mercury are expected to be low. Nonetheless, some methylation of mercury can occur in soils, so in 2016, we sought benchmarks for MeHg in soils (Table A-6).

Table A-6. Soil Screeing Benchmarks for Methyl Mercury

Benchmark Type	Units	Value	Source: Benchmark Name [Comment]
Mammals (shrew)	mg/kg dry soil	0.0068	GMATC values calculated from U.S. EPA (2015) Region 4 SESLs for mammals and birds [LANL (2012) ECORISK Database Version 3.2]
Birds (robin)		0.0011	
Plants		0.3	U.S. EPA (2015) Region 4 cites Efroymson et al. (1997a)
Invertebrates		0.1	U.S. EPA (2015) Region 4

Acronyms: GMATC = geometric mean maximum allowable toxicant concentration = geometric mean of LOAEL and NOAEL, SESL = soil ecological screening level

In a recent update of its ecological screening benchmarks, Region 4 cited the September 2012 release of the LANL ECORISK (Version 3.2) database as its source of estimated soil-screening levels for MeHg protective of ground-feeding birds and mammals (U.S. EPA 2015). As of August 20, 2016, a more recent version of the ECORISK database (Version 3.3) was available (LANL 2015), which we checked for MeHg soil ecological screening levels (SESLs). We provide a summary of the derivation of the LANL ECORISK SESLs below. Unlike the EPA Eco-SSLs, which use a geometric mean of all NOAELs from all studies and all avian species of acceptable quality for growth and reproduction for which both a NOAEL and LOAEL were identified, the LANL ECORISK SESLs are based on a single critical study, a sensitive species, and sensitive endpoints (i.e., according to U.S. EPA 1995b GLWQI Guidelines). After LANL has selected TRVs for sensitive endpoints and species from the available data, it uses the TRVs to back-calculate SESLs, as does EPA when deriving Eco-SSLs.

For birds, LANL uses American robin (wide habitat and geographic range) instead of woodcock as the ground-feeding bird for which to back-calculate a soil concentration. As shown in Table A-7, the lowest SESLs for American robin are associated with a diet consisting entirely (100%) of soil invertebrates. That is the same diet assumed for woodcock for U.S. EPA (2007) Eco-SSLs. Both LANL and EPA assume that the soil invertebrates are earthworms, which bioaccumulate MeHg from the soils.

LANL (2015) cited the Heinz et al. (1979) study of mallard duck exposed to MeHg in the diet for three generations. A significant decrease in egg and duckling production was observed at that 0.5 ppm in the diet. Sample et al. (1996) used the food consumption rate from Heinz et al. (1979) and typical body weights for growing mallards from another data source to convert the 0.5-ppm MeHg concentration in food to a TRV dose of 0.064 mg/kg-day. Using a LOAEL-to-NOAEL UF of 10, Sample et al. (1996) estimated a NOAEL of 0.0064 mg/kg-day. Back-calculating the

corresponding soil concentration for a robin consuming 100 percent earthworms that had bioaccumulated MeHg from the soil, LANL (2015) estimated a NOAEL and LOAEL of 0.00035 and 0.0035 mg/kg dry soil, respectively (Table A-7).

Table A-7. Soil Ecological Screening Levels for Methyl Mercury from Los Alamos National Laboratory

Species	Diet	Soil Ecological Screening Level (mg/kg dry soil)		
		SESL NOAEL	SESL LOAEL	GMATC
American robin (avian ground-feeding bird)	100% plants (berries)	0.075	0.75	0.2372
	100% soil invertebrates	0.00035	0.0035	**0.0011**
	50:50 plants/soil invertebrates	0.00071	0.0071	0.0022
American kestrel (avian top carnivore)	100% small mammal flesh	0.0078	0.078	0.0247
	50:50 small mammals and soil invertebrates	0.0017	0.017	0.0054
Deer mouse	50:50 soil invertebrates and seeds	0.0063	0.031	0.0140
Montane shrew	100% soil invertebrates	0.0031	0.015	**0.0068**

Acronyms: GMATC = geometric mean maximum acceptable toxic concentration; calculated in this table as the geometric mean of the SESL NOAEL and LOAEL. SESL = soil ecological screening level

Because the EPA Superfund Eco-SSLs provide a single SSL for each assessment endpoint, and because we are using each Eco-SSL as a TEL, having two different LANL SESLs (i.e., a NOAEL and a LOAEL) would be inconsistent. We therefore calculated the geometric mean of the NOAEL and LOAEL SESLs (i.e., the GMATC) to represent a TEL for the robin (0.0011 mg/kg dw soil, value in bold in Table A-7).

For mammals, LANL used a montane shrew to represent ground-feeding small mammals. LANL cited the Verschuuren et al. (1976) toxicity study of rat exposed to MeHg in the diet for three generations at three dietary concentrations—0.1-, 0.5-, and 2.5-ppm MeHgCl, where Hg makes up 79.9% of the compound. Reduced pup viability was observed in the 2.5-ppm MeHgCl, and no adverse effects were observed in the other two groups. LANL (2015) cited Sample et al. (1996) for the conversion of dietary concentrations to ingested doses based on rat food ingestion rates (FIRs) and body weights: the chronic TRV NOAEL is 0.032 mg[Hg]/kg bw-day and the chronic TRV LOAEL is 0.16 mg[Hg]/kg bw-day. Back-calculating the corresponding soil concentrations for montane shrew consuming 100-percent earthworms that had bioaccumulated MeHg from the soil, LANL (2015) estimated a NOAEL of 0.0031 mg[Hg]/kg dry soil and a LOAEL of 0.015 mg[Hg]/kg dry soil (listed in the last row of Table A-6). Again, we calculated the geometric

mean of the NOAEL and LOAEL (i.e., the GMATC) to represent a TEL for the shrew, 0.0068 mg[Hg]/kg dry soil (in bold in Table A-7).

POM—Benzo[a]pyrene (BaP) Soil Screening Benchmark

EPA has developed no Eco-SSLs for BaP, although it has estimated an Eco-SSL for mammals and an Eco-SSL for invertebrates for HMW polycyclic aromatic hydrocarbons (PAHs) (i.e., 4 or more fused benzene rings) of 1.1 mg/kg dry soil and 18 mg/kg dry soil, respectively (U.S. EPA 2007). EPA Region 5 has developed a soil screening value for BaP for masked shrew of 1.52 mg/kg dry soil. Because we are using the toxicity equivalency approach to evaluate the joint toxicity of POM based on their BaP-toxic equivalents, we use the EPA Region 5 value for BaP.

Dioxins—2,3,7,8-TCDD Soil Screening Benchmark

EPA Region 5 estimated an ESL for soils of 2.0E-07 mg/kg dry soil to protect masked shrews that consume earthworms contaminated with TCDD from soils (U.S. EPA 2003c). LANL (2015) lists its soil screening levels for montane shrew as a NOAEL of 2.9E-07 mg/kg dry soil and LOAEL of 1.9E-06 mg/kg dry soil. Those values bracket the Region 5 ESL; therefore, we use the Region 5 value to represent a TEL for the shrew.

No screening benchmarks were identified for birds or plants exposed to TCDD in soils. For invertebrates, LANL (2015) calculated a NOAEL of 5 mg/kg dry soil and a LOAEL of 10 mg/kg dry soil for SELS for TCDD. The geometric mean of 5 and 10 equals 7.1 mg/kg dry soil, which we use for the soil invertebrate community TEL benchmark.

A.2.3 Hydrogen Fluoride (HF) Air Benchmarks for Terrestrial Plants

Gaseous fluorides, such as HF, are phytotoxic (i.e., toxic to plants). Gaseous HF enters leaves of plants through the stomata, which generally are open during daylight hours and closed at night. Gaseous HF is much more rapidly absorbed than fluoride associated with particulates, which do not diffuse through the stomata. Fluoride absorption is fairly uniform over the entire leaf under-surface. It readily dissolves and is then transported in ionic form through the apoplastic aqueous spaces of the mesophyll cell walls driven by transpiration. Thus, fluoride moves via translocation to the leaf tip and edges where cell necrosis occurs first (Hill and Pack 1983). Leaf tips can contain up to 100 times more fluoride than the leaf basal section after long-term exposure (Hill 1969; Hill and Pack 1983).

The most common initial symptoms of fluoride injury are necrotic lesions at leaf tips and edges, extending toward the leaf base as exposure continues (Hill and Pack 1983). In a few species, including corn and citrus, chlorosis (i.e., loss of chlorophyll and green color) is evident before necrosis appears. Although loss of functional leaf area can reduce growth and yield in many species of plants, a few species show little effect on yield depending on the part of the plant harvested and the stages at which exposures occurred (e.g., some species are most sensitive during rapid growth of seedlings or during flowering) (Hill and Pack 1983).

Susceptibility to HF also varies with lifestage of the plant and abiotic factors. For broadleaf plants, several studies indicate that damage from HF exposure is more pronounced when plant tissues are expanding or elongating (WHO 2002; Hill 1969). Some pine species are included among species of concern due to their sensitivity to HF during needle growth (Adams et al. 1956; APIS 2010). Abiotic factors, such as humidity, air temperature, wind (speed and direction), and soil water content, can influence exposure by modifying the rate of HF absorption by plants. For example, dry conditions reduce HF absorption due to reduced transpiration and stomatal conductance (APIS 2010). Excessive rain also can reduce exposure due to "washing," while light rain can effectively increase the amount of fluoride deposited on the leaves (Hill 1969). Abiotic factors also can affect inherent plant sensitivity to HF exposures. In the field, some plants stressed by unfavorable conditions of low fertility and limited water are more sensitive to HF exposure than the same species grown under more favorable conditions (Hill and Pack 1983).

The remainder of this section provides background information for the derivation of HF air concentration benchmarks for terrestrial plant communities (Section 3.2.2 of the main report). Section A.2.3.1 discusses three distinct approaches to setting limits for plant exposures to HF. Section A.2.3.2 lists existing regulatory benchmarks for HF in the United States and other countries. Section A.2.3.3 summarizes exposure-response data for effects of air HF on plants, both for short-term exposures (e.g., 1-day maximum concentration) and over the longer term (e.g., average 4-month concentration).

A.2.3.1 Methods of Establishing HF Benchmarks

In theory, environmental standards for HF effects on vegetation could be defined in at least three ways (Hill 1969): atmospheric fluoride concentrations, vegetation fluoride concentrations, or the

presence of leaf necrosis or chlorosis. Table A-8 presents the pros and cons of each method outlined by Hill (1969).

Table A-8. Overview of Three Approaches to Hydrogen Fluoride (HF) Environmental Standards (Hill 1969)

Approach	Traditional Use/Benefit	Complicating Factors with Hydrogen Fluoride
Atmospheric concentration	Used frequently in air quality standards Simple Ease of use for control programs	Inter- and intraspecies variation in effects (lack of data for levels that are protective of large majority of species for site-specific assessments) Need to understand contribution of exposure duration Variation in responses associated with abiotic factors (e.g., rainfall, humidity, temperature) Atmospheric fluoride includes total soluble inorganic fluorides (speciation data and effects data for various species lacking) and might include fluoride adsorbed to particles in the air
Vegetation concentration	Useful for protecting wildlife (or livestock) via plant consumption Leaves accumulate most HF (compared with other plant parts) Leaf sampling relatively simple and cost effective	Need for standardization in: Leaf age (at time of exposure) Lifestage (at time of exposure, e.g., fast growth, flower set) Time of sampling Species/varieties sampled Random selection of leaves Method of analysis Need to remove F from plant surfaces without leaching F from leaf interior Fluoride content concentrated along leaf margins and tips
Leaf appearance (necrosis or chlorosis)	Time effective Summary outcome (no detailed analysis of complex variables)	Need qualified/trained personnel Leaf appearance can be influenced by other (non-HF-related) factors Need fluoride analysis to confirm

Most existing HF standards are based on plant concentration data collected for what have been identified thus far as particularly sensitive species and for livestock forage. Hill (1969) noted that adequate data generally are not available to develop site-specific HF air benchmarks for the protection of plants. To estimate fluoride concentrations in plants, however, TRIM.FaTE would need to be parameterized for plant uptake of fluoride from the air and possibly from uptake through the roots. That level of effort is beyond a Tier 1 or 2 screen for ecological risks.

For RTR ecological risk screens of acid gases, which are conducted using modeled estimates of ambient air concentrations based on emissions from the regulated source, the most expedient expression of an air benchmark for HF for plants is as an air concentration. The remaining sections of this document, therefore, focus on the relationship between HF air concentrations and

adverse effects in plants. In addition, for purposes of the RTR ecological risk screen, chronic benchmarks are relevant to the chronic exposure scenarios evaluated.

A.2.3.2 HF Regulatory Levels

Although EPA has not established environmental criteria for HF, at least 13 other countries have established national environmental criteria or standards (Newman 1984). In the United States, at least 12 states have established criteria or standards, most based on protecting forage grasses from accumulating fluoride to concentrations exceeding 35–40 mg[F]/kg dry weight plant. Some data suggest higher concentrations in forage result in development of fluorosis in cattle/calves (Newman 1984).

Most of the available criteria or standards are expressed as concentrations in plants, not as atmospheric concentrations, particularly if the intent is to protect livestock from fluorosis from fluoride in their forage. Use of plant-based HF concentrations would require a plant-fluoride uptake model. At this time, TRIM.FaTE is not parameterized for HF uptake in plant compartments. The remaining discussion focuses on criteria and standards expressed as concentrations of gas-phase HF in air, not total fluoride in plants. The criteria or standards that were readily available from Canada and several U.S. states are summarized in Table A-9.

Guidelines to protect vegetation from exposures to HF expressed as air concentrations were first developed in Canada under the Canadian Environmental Protection Act by Bourgeau and colleagues in 1996 (EC 1996). To protect vegetation from adverse effects resulting from HF exposure, CCME (1999c) recommends HF concentrations not exceed 0.4 µg/m^3 air over 30 to 90 days (Alberta Environment 2006; HF concentrations can be higher for shorter exposures).

Environment Canada (EC 1996; CCME 1999c) defined the criteria as:

> "The level above which there are demonstrated effects on human health and/or the environment. It is scientifically based and defines the boundary between the LOAEL and the NOAEL. It is considered to be the level of exposure just below that most likely to result in a defined and identifiable but minimal effect. The reference levels have no safety factors applied to them, as they are related directly to the LOAEL, and are the most conservative estimates of the effect level." (emphasis added; CCME 1999c)

Table A-9. Governmental Air Criteria for Hydrogen Fluoride (HF) to Protect Plants

Reference	Specific Information[a]	Air Criteria for Hydrogen Fluoride (µg HF/m³) for Specified Duration (Averaging Period)						
		30 min	12 h	24 h	7 d	30 d	70 d	90 d
Canada (EC 1996; CCME 1999c)	Gaseous, growing season	–	–	1.1	0.5	0.4	–	0.4
Alberta and Manitoba (Alberta Environment 2006)	Gaseous	–	–	0.85	0.55	0.35	0.2	0.2
Ontario (OME 2004)	Gaseous, growing season	4.3	–	0.86	–	0.34	–	–
Ontario (OME 2004)	Total, growing season	8.6	–	1.72	–	0.69	–	–
Ontario (OME 2004)	Total, nongrowing season	17.2	–	3.44	–	1.38	–	–
Texas Commission on Environmental Quality (TCEQ 2009)[b]	Gaseous	–	–	3.0	–	–	–	0.6
Kentucky, Jefferson County[c]	Gaseous	–	3.68	2.86	0.80	0.50	–	–
New York State[d]	Gaseous	–	3.7	2.85	1.65	0.80	–	–
Washington State[e]	Gaseous	–		2.9	1.7	0.84	0.5	0.5
Tennessee[f]	Not specified	–	3.7	2.9	1.6	1.2	–	–

Abbreviations: min = minutes; h = hours; d = days; "–" means no criterion for that exposure duration
[a]"Total" atmospheric HF includes both gaseous and particulate-bound HF.
[b]Air quality standards for the State of Texas were removed in 2000.
[c]See http://www.epa.gov/region4/air/sips/ky/lou/3.04.pdf.
[d]See http://www.dec.ny.gov/regs/4146.html.
[e]See https://fortress.wa.gov/ecy/publications/publications/wac173481.pdf; the bold highlighted values are HF benchmarks for RTR environmental risk screening (see text).
[f]See http://www.state.tn.us/sos/rules/1200/1200-03/1200-03-03.pdf.

The Environment Canada criteria were based on regression analysis of exposure-concentration vs. exposure-duration data from the studies shown in Section A.2.3.3 and from additional unpublished studies.[13] The linear regression model used log(exposure concentration × duration), specified as "dose," as the dependent variable. Log(exposure duration) was the independent variable. Environment Canada pointed out, however, the selection of data to include in the regression was based on expert judgment, and the data set used did not meet some assumptions associated with estimating confidence intervals for the regression equation. Also, the value for

[13]References cited by Environment Canada (1996) from conference proceedings abstracts or other nonpeer-reviewed/nonpublished sources are not included in this report.

"dose" is not independent of the duration value, violating a key assumption for simple regression analyses.

Most investigators plot a specified effect level (e.g., initial evidence of leaf necrosis) for each study using log(exposure concentration) for the y-axis and log(exposure duration) for the x-axis. If Haber's rule applies, a straight line with a slope of 1.0 would result across all exposure durations. Haber's rule states that response is directly proportional to the exposure duration multiplied by the exposure concentration. Over the short term (i.e., a few days), the accumulation of HF in plants generally follows Haber's rule (data presented in McCune 1969a). The slope of the relationship decreases (becomes more horizontal; more dependent on concentration and less dependent on exposure duration) as exposure duration increases beyond 1 or 2 days (McCune 1969a). Thus, for chronic exposures, only exposure concentration need be specified.

Provincial guidelines for Alberta include a 30-day average limit of 0.35 µg HF/m^3 and 70- and 90-day average limits of 0.20 µg HF/m^3. Although Alberta Environment did not specify the level of effect associated with 0.2 µg HF/m^3 (see Table A-11), given the available data, only grapevines might be expected to show some evidence of injury at that concentration, and the significance of that injury to grape productivity is unknown. Thus, we conclude that the provincial guidelines for Alberta are similar to an NEL for plant communities and populations, including the most HF-sensitive commercial crops.

The Ontario Ministry for the Environment (OME 2004) has established provincial guidelines for Ontario that distinguish between the growing season and the nongrowing season and between total HF in air (including particulates) and gaseous HF only. The 30-day criterion for gas-phase HF during the growing season is 0.34 µg HF/m^3; longer-duration criteria were not established. This criterion and other air concentration criteria for HF established in Canada are listed in Table A-9. The criteria are based on studies of agricultural crops, horticultural plants, and coniferous trees, as described in Section A.2.3.3.

In the United States, for the states having ambient air quality standards or criteria for gaseous HF, the values are generally less than 1.0 µg/m^3 as a 30-day limit. Examples for several states are included in Table A-9. The Texas Commission on Environmental Quality (TCEQ) established effect screening levels for the protection of vegetation, cattle, and human health (TCEQ 2009, Table A-9). The TCEQ chronic (90-day) criterion was based on a LOAEL for

soybean productivity; nonagricultural plants were not evaluated. The other state and county standards or criteria included in Table A-9 are similar in magnitude to the TCEQ values for 90-day durations.

For purposes of the RTR environmental risk screen, the two benchmarks for HF were evaluated as representing an LEL: the 90-day criterion from Washington State of 0.5 µg HF/m^3 and the Environment Canada 90-day criterion of 0.4 µg HF/m^3. Both criteria are presented in bold and highlighted in Table A-9. Section A.2.3.3 below includes summaries of original data on HF toxicity to plants.

For comparison with long-term human health criteria, the California Office of Environment and Health Hazard Assessment (OEHHA) has recommended a chronic inhalation reference exposure limit for humans of 14 µg/m^3 based on the occurrence of skeletal fluorosis.[14] Thus, the 90-day criteria for plants are lower than the reference exposure limit to protect human health from inhalation toxicity.

A.2.3.3 Hydrogen Fluoride (HF) Exposure-Response for Plants

Critical concentrations cited in criteria documents often are based on the prevention of visible injury to plants by HF rather than on measured reductions in plant productivity as measured by vegetative growth and seed yield, for two reasons. First, data on effects of HF on plant growth and productivity are limited. Second, concentrations inducing visible injury are lower than those affecting growth and are therefore protective of both endpoints (APIS 2010).

Short-term Exposures

Short-term exposure to HF typically results in leaf lesions and necrosis along the tips and margins of leaves where fluoride has accumulated. Table A-10 summarizes information on the phytotoxic effects of short-term exposure to HF available from the literature. Consequently, a longer averaging time (e.g., 24 hours) is more relevant than a shorter averaging time (e.g., 30 minutes, 1 hour).

[14] See http://oehha.ca.gov/air/chronic_rels/HyFluoCREL.html.

Table A-10. Adverse Effects in Terrestrial Plants Following Short-term Exposures to HF

Species Tested	Study Protocol[a]	Results	LOEL ($\mu g/m^3$)	C × D ($\mu g/m^3$-d)[b]	Reference
Ponderosa pine (*Pinus ponderosa*)	1.46 µg F/m^3 for 24 h	Leaf injury index = 0.5, that is 50% of the length of needles injured	1.46	1.46	Adams et al. (1956)
Jerusalem cherry (*Solannum pseudo-capsicum*)	0.9 or 4.0 µg F/m^3 for 4 d in dark	Mild leaf necrosis in "sensitive" clone during exposure in dark, which became "severe" (40–60%), leaf necrosis after plant was exposed to light	0.9	0.9	MacLean et al. (1982)
Gladiolus sp.	0.17 µg F/m^3 for 9 d	Necrotic leaf tips (% not specified)	0.17	1.53	Hitchcock et al. (1962), as cited in WHO (2002)
Wheat (*Triticum aestivum*)	0.9 µg or 2.9 µg F/m^3 for 4 d	Reduced mean yield by 25% dry weight in grain spikes when exposure occurs during anthesis (i.e., flowering)	0.9	3.6	MacLean and Schneider (1981)
Sorghum sp. Northrup King 22A hybrid	"0"[c],1.6, 2.2, 2.8, or 3.3 µg/m^3 (mean concentration over 9 d); experiment varied the order in which different exposure concentrations (1.5, 1.8, 3.2, or 3.6 µg F/m^3) were applied over three successive 3-day periods	Reduced total dry weight biomass at harvest by 20% after 72-d exposure and reduced grain dry weight yield by 9% with exposures at 1.5, 3.2, then 1.8 µg/m^3 for three successive 3-d periods	2.2	20	MacLean et al. (1984)
Black spruce (*Picea mariana*); 2 years old	0.3, 2.3, 4.2, or 8.1 µg F/m^3 for 78 h, observed 20 d after exposure ceased	At 2.3 µg/m^3, 23% of trees exhibited slight (12%), moderate (10%), or severe (1%) injury to needles. At 4.2 µg/m^3, 61% of trees exhibited needle injury. At 8.1 µg/m^3, 96% of trees exhibited needle injury, and 72% of injury was moderate to severe.	2.3	7.5	McCune et al. (1991)
White spruce (*Picea glauca*); 3 years old	0.3, 2.6, 5.2, or 11.1 µg F/m^3 for 50 h, observed 20 d after exposure ceased	At 5.2 µg/m^3, 9% of trees categorized with needle injury. At 11 µg/m^3, 40% of trees with needle injury: 32% categorized with moderate to severe needle necrosis; remaining 8% with slight needle necrosis	5.2	11	McCune et al. (1991)
Tobacco (*Nicotiana tabacum* L.)	0.5 or 45 µg HF/m^3 for 1 d	Growth (plant height) reduced by 50% at 45 µg/m^3 compared with controls, accompanied by 63% reduction in chlorophyll content	45	45	Döğeroğlu et al. (2003)
Tobacco (*Nicotiana tabacum*)	0.5 or 45 µg HF/m^3 for 3 d	Growth (plant height) reduced by 70% at 45 µg/m^3 compared with controls, accompanied by 85% reduction in chlorophyll	45	135	Döğeroğlu et al. (2003)

Species Tested	Study Protocol[a]	Results	LOEL (µg/m^3)	C × D (µg/m^3-d)[b]	Reference
"Conifers"	Summary of dose-response relationships from the available literature based on 24-h average HF concentrations	Increased foliar markings	3.0[d]	3.0	McCune (1969b)
"Fruit Trees"		Increased foliar markings	4.5[d]	4.5	
Gladiolus		Reduced growth or yield	6.0[d]	6.0	
Corn		Reduced growth or yield	10.5[d]	10.5	
Tomato		Increased foliar markings	12[d]	12	

[a]Concentrations can be reported for hydrogen fluoride (HF) or the fluoride ion (F) only. Atomic weight of H = 1 g/mole, and F = 19 g/mole. Thus, the difference in an air concentration expressed as µg HF/m^3 and an air concentration expressed as µg F/m^3 is only 5%. For comparison with other measurements of HF concentrations in air, note that 1 µg/m^3 of fluoride (F) is equal to 0.874 ppb (parts per billion) fluoride by weight or 1.33 ppb by volume of any gas containing 1 fluorine atom per molecule. These conversions hold true at an atmospheric pressure of 29.9 inches of Hg and 60 °F (Hill and Pack 1983).
[b]C × D = exposure concentration multiplied by exposure duration, assuming Haber's rule applies over short-term exposures.
[c]The authors stated that "no HF" exposure occurred for this group, but a background concentration around 0.01–0.03 µg/m^3 likely was used for this group.
[d]Values reported by McCune (1969) are 24-hour mean threshold concentrations based on an evaluation of the available literature (exposure concentration, duration, and plant-response data plotted with curves).

Concentrations listed in the LOEL column of Table A-10 represent the lowest concentration at which statistically significant effects on growth, yield, or leaf necrosis were evident when the test group exposed at the LOEL was compared with the control group of plants. We use LOEL instead of LOAEL terminology because the significance of low levels of leaf necrosis and several other types of effects on plant productivity has not been quantified. The study protocol column includes a list of the exposure concentrations tested. In some cases, the lowest concentration listed is the "background" concentration the control plants experience. The highest concentration listed in the study-protocol column that is lower than the concentration listed in the LOEL column represents a NOEL. Effects, if present, at a NOEL were not statistically different from effects shown in the control plants (or the NOEL represents the control plants). Table A-10 indicates that effects evident after short-term exposures include foliar chlorosis and necrosis and, in some tests, reduced plant growth rates.

Longer-term Exposures

Longer-term (i.e., greater than 30 days) exposures of plants to HF usually result in leaf chlorosis and necrosis and can result in reduced growth and productivity even when leaf damage is not apparent. More data are available for longer-term exposures of plants to HF (Table A-11) than for short-term exposures.

Table A-11. Adverse Effects in Terrestrial Plants Following Longer-term Exposure to HF

Species Tested	Study Protocol	Results	LOEL (µg/m^3)	Reference
Tendergreen bean	0.6 µg F/m^3 for 43 d	Reduced number and mass of marketable pods by 20% and 25%, respectively; no influence on growth or foliar appearance	0.6	MacLean et al. (1977)
Tomato (Fireball 861 VR)	0.6 µg F/m^3 for 93 d	No effect on growth or fruiting	–	MacLean et al. (1977)
Soybean	0.64, 2.1, or 5.0 µg F/m^3, 10–16 h/d for 98 d	Reduced number of fruit per pot by more than 90%	<0.64	Pack and Sulzbach (1976)
Bell pepper	0.01, 0.63, 2.2, 4.5, or 10 µg F/m^3, 10–16 h/d for 112 d	Reduced number of peppers by more than 65%	2.2	Pack and Sulzbach (1976)
Sorghum	0.01, 0.53, 2.2, 4.7, or 10.6 µg F/m^3, 10–16 h/d for 114 d	Slightly reduced weight per seed; at 4.7 µg F/m^3, number of seeds reduced by 85%	2.2	Pack and Sulzbach (1976)
Sweet corn	0.01, 0.54, 2.0, 2.3, or 8.7 µg F/m^3, 10–16 h/d for 97 d	Seed production totally (100%) inhibited (after anthers released, ears and seeds did not develop)	2.0	Pack and Sulzbach (1976)
Cucumber	0.01, 0.61, 2.3, 4.4, 4.6, 5.5, 7.8, or 8.9 µg F/m^3, 10–16 h/d for 104 d	Reduced number of fruit by 24%	4.6	Pack and Sulzback (1976)
Pea	0.01, 2.1, 4.4, 5.3, or 9.0 µg F/m^3, 10–16 h/d for 56 d	Reduced number of seeds per fruit by approximately 5%	4.4	Pack and Sulzback (1976)
Wheat	0.01, 5.0, or 8.2 µg F/m^3, 10–16 h/d for 130 d	Reduced number of seeds by 50%; reduced weight per seed by 18%	8.2	Pack and Sulzback (1976)
Oat	0.01, 2.2, 4.3, or 9.1 µg F/m^3, 10–16 h/d for 147 d	Reduced seed production (proportion not specified)	9.1	Pack and Sulzbach (1976)
Cotton	0.01, 3.1, 5.0, or 8.0 µg F/m^3, 10–16 h/d for 164 d	No significant differences for all measured parameters	>8	Pack and Sulzbach (1976)
Snow princess gladiolus (*Gladiolus grandiflorus*)	0.03, 0.35, 0.36, 0.41, 0.44, 0.50 and higher up to 1.85 µg F/m^3 for up to 117 d	Leaf necrosis (65% of leaves); 117 d	0.36	Hill and Pack (1983)
Freesia sp. (commercial flower)	Continuous fumigation at 0.5 µg HF/m^3 for 5 mo OR intermittent fumigation with 0.3 µg HF/m^3 (6 h/d, 3 or 4 times/wk) for 18 wk	Leaf necrosis over 30% of exposed leaf surface area compared with 5% in control plants	0.3	Wolting (1975)
Gladiolus sp. (commercial flower)	0.35 or 0.76 µg F/m^3 for 40 d	Increased necrosis by 46% and increased respiration by 39%	0.76	Hill et al. (1959)
Apple (*Malis domestica* Borkh)	0.03, 0.44, 0.82 µg HF/m^3 for 164 d	Slightly reduced growth and necrosis (see text)	0.44	Hill and Pack (1983)
Pole bean (*Phaseolus vulgaris*)	0.03, 0.54, 0.79 µg HF/m^3 for 83 d	Fruit set reduced by 80%	0.54	Hill and Pack (1983)

Species Tested	Study Protocol	Results	LOEL (µg/m³)	Reference
Grapevine (*Vitis vinifera*)	0.07 (control), 0.17, or 0.27 µg/m³ for 189 d	Foliar necrosis after 99 and 83 d at 0.17 and 0.27 µg/m³, respectively; reduced chlorophyll a and total chlorophyll noted	0.17	Murray (1984)
Grapevine (3 varieties)	0.37 µg F/m³ to 6.0 µg F/m³ for four growing seasons (season duration varied from 54–159 d) for 12 different exposure concentration/duration combinations	No substantial effects up to 1.5 µg F/m³ for 54 d; exposure at 2.2 µg F/m³ for 60 d reduced leaf area by up to 45%	2.2	Doley (1986)
Wheat (*Triticum aestivum*)	0.03 or 0.38 µg HF/m³ for 90 d	No effects on yield	–	Murray and Wilson (1988a)
Barley (*Hordeum vulgare*)	0.03 or 0.38 µg HF/m³ for 90 d	Increase in grain protein concentration; not necessarily an adverse effect	0.38	Murray and Wilson (1988a)
Tendergreen bean plant	0.58, 2.1, 9.1, or 10.5 µg F/m³ seedling to maturity to next generation	At 2.1 µg F/m³, lower starch content of seeds (15–21%) compared with controls (35% starch) resulting in reduced F_1 generation plant height (−17%) and leaf surface area (−23%) and increased (+137%) proportion abnormal trifoliate leaves	2.1[a]	Pack (1971)
Eucalyptus (*Eucalyptus tereticornis*)	0.03 or 0.38 µg F/m³ for 90 d in open-top chambers	Reduced leaf surface area and weight in mature and immature leaves	0.38	Murray and Wilson (1988b)
Marri (*E. calophylla*)	0.03 or 0.39 µg F/m³ for 120 d	Reduced leaf surface area and weight in immature leaves, reduced surface area in mature leaves	0.39	Murray and Wilson (1988c)
Tuart (*E. gomphocephala*)	0.03 or 0.39 µg F/m³ for 120 d	Reduced leaf surface area and weight in mature and immature leaves	0.39	Murray and Wilson (1988c)
Jarrah (*E. marginata*)	0.03 or 0.39 µg F/m³ for 120 d	Reduced leaf surface area and weight in immature leaves only	0.39	Murray and Wilson (1988c)

[a]Primary leaves of some F1 progeny noted as being severely stunted and distorted at 2.1 µg/m³ (dosing protocol unclear).

Although many plant species do not exhibit adverse effects from short-term exposures at ambient air concentrations less than 1 µg F/m^3, several do show effects after longer-term exposures at

concentrations of 0.5 µg F/m^3 or less (Table A-11).[15] Several studies of plants of agricultural importance are described in more detail below.

Pack and Sulzbach (1976) fumigated nine species of agricultural crops with HF gas from seed through flowering to the time of harvest. Table A-11 lists the exposure concentrations and the exposure durations associated with the LOEL concentration for each crop. The crop that was most sensitive to HF was soybean, with a 90-percent reduction in the number of bean pods at the lowest exposure concentration tested (0.64 µg F/m^3). The next most sensitive crop appears to be sweet corn. Although no effects other than brown streaks through the plant leaves were observed at 0.54 µg F/m^3, at the next higher exposure concentration (2.0 µg F/m^3), ears and seeds failed to develop in all corn plants. Cotton was the most resistant to fumigation with HF of the plants tested, with no effects observed at a concentration of 8.0 µg F/m^3 for 164 days.

Hill and Pack (1983) grew apples (1-year-old whips of the delicious variety) in three greenhouses, starting HF exposures 5 weeks after planting and continuing for 164 days.

Air was filtered in two greenhouses to remove gaseous (and particulate) fluoride. One of those greenhouses served as a "clean air" control (0.03 µg HF/m^3), while HF was added to another greenhouse to achieve an air concentration of 0.44 µg HF/m^3. The third greenhouse received ambient air with an average concentration of 0.83 µg HF/m^3. The group exposed at 0.44 µg HF/m^3 exhibited an 11-percent reduction in leaf length and a 6-percent reduction in leaf width ($p < 0.01$) compared with the control. In addition, leaves exposed during their expansion sporadically exhibited leaf tip necrosis and chlorosis, with leaf growth ceasing once necrosis was visible. Leaf injury often was apparent soon after 24-h air sample readings of up to 0.99 µg HF/m^3.

Hill and Pack (1983) also examined the response of Chinese apricot trees fumigated with HF during three growing seasons (Experiments A, B, and C). Experiments A and B used higher exposure concentrations over shorter durations than did experiment C. In trials B and C, both ambient air and test air HF concentrations were 0.35 µg HF/m^3, and the "clean" air greenhouse (at 0.03 µg HF/m^3) served as the control. Trees were exposed as soon as they began to develop

[15]Air concentrations are variously reported as µg HF/m^3 or µg F/m^3. We report the original units without adjusting one to the other. The atomic weight of F is approximately 95% of the molecular weight of HF.

leaves. Necrosis of leaf tips and edges, necrotic spots on leaves, leaf curling, and increased leaf drop were observed. In Experiment C, after 117 days of exposure at 0.35 µg HF/m^3, leaf drop averaged 18 percent, average tree trunk diameters were 53 percent that of controls, and average shoot length was 54 percent that of controls.

Peach trees exposed to gaseous HF under conditions similar to those described above appeared to be even more sensitive to HF. Specifically, leaves of HF-exposed peach trees tended to be smaller than those of controls and also tended to drop prematurely (Hill and Pack 1983). In one part of the study, leaves on trees exposed at 0.41 µg HF/m^3 for 73 days were 24-percent smaller than leaves on control trees. In another part of the study, 1,768 leaves dropped from trees exposed at 0.34 µg HF/m^3 for 110 days, while only 102 leaves dropped from the control trees.

Pack (1971) evaluated effects on tendergreen bean plants grown from seeding to maturity under continuous exposure to HF gas at 0.58, 2.1, 9.1, or 10.5 µg F/m^3. No significant growth or yield effects were observed at any test concentration, with the exception of a 15- to 21-percent reduction in bean starch content at the three highest concentrations tested. Beans from the exposed parental generation (F0) then were planted and grown in "clean" air to produce the F1 generation. For the plants exposed at 2.1 µg F/m^3, the F1 generation plants exhibited a 17-percent reduction in plant height and a 23-percent reduction in leaf surface area. Subsequent plantings of F2 and F3 generations (grown in clean air) indicated that the traits exhibited in the F1 generation were not heritable.

Murray and Wilson (1988c) evaluated adverse effects from 120 days of HF exposure for three eucalyptus species by conducting an analysis of variance for the exposed (0.39 µg HF/m^3) versus control plants (background concentration of 0.03 µg HF/m^3) for several parameters. For immature leaves, reduced leaf area and reduced leaf weight were significant at $p = 0.001$ for *Eucalyptus calophylla*. For *E. marginata*, reduced immature leaf area was significant at $p = 0.01$, and reduced immature leaf weight was significant at $p = 0.05$. For *E. gomphocephala*, reduced immature leaf area was significant at $p = 0.05$, and reduced immature leaf weight was significant at $p = 0.01$. In contrast, for mature leaves, only *E. gomphocephala* showed both significantly reduced leave area ($p = 0.01$) and weight ($p = 0.001$).

Murray and Wilson (1988c) also estimated visible foliar injury for three eucalyptus species using two factors: "*A*" (the proportion of necrotic leaf area on damaged leaves) and "*L*" (the proportion of all damaged leaves). The injury index (*I*) formula then was calculated using Equation A-1:

$$I = (A \times L)^{0.5} \quad \text{Eq. A-1}$$

Analysis of variance for the exposed plants compared with control plants indicated that *E. calophylla* was significantly affected at 0.39 µg/m^3 (p = 0.001). Murray and Wilson (1988c) did not report actual measurements for leaf area, weight, or necrotic leaves.

Considering the data as a whole, a benchmark of 0.4 or 0.5 µg HF/m^3 air would appear protective of most plant species included in the table, but not some species of commercial flowers or ornamental plants (see gladiolus Table A-10) and freesia, grapevine, and eucalyptus (Table A-11). Streaking of leaves is an adverse effect for plants bred for their appearance. Thus, air HF concentration benchmark of 0.4 or 0.5 µg HF/m^3 air appears consistent with a TEL for assessing plant communities for wildlife food and habitat and for agricultural crops. Some species of HF-sensitive ornamental plants would not be protected at that level.

A.3 Wildlife Toxicity Reference Values

To assess risks to piscivorous wildlife, a TRV for wildlife, expressed as an oral dose, is needed for comparison with estimated dietary exposures via the chemical in prey (i.e., in fish and invertebrates consumed). The estimated total chemical intake via all types of prey in the diet, expressed as mg[chemical]/kg[wildlife body weight]/day (mg/kg-day), can be compared with the TRV (expressed in the same units) to estimate a hazard quotient. An emission rate that corresponds to a hazard quotient of 1.0 (i.e., the emissions screening threshold rate) then is used to screen facilities in Tiers 1 through 3 of the RTR ecological risk environmental screens.

Avian and mammalian TRVs are included in the RTR ecological assessment in two contexts. The first is in OSWER's derivation of Eco-SSLs, expressed as chemical concentrations in soil, to protect wildlife that feed on soil invertebrates (Section A.2.2.3 and Section A.3.2). The second is use of TRVs, expressed as chemical doses to avian and mammalian wildlife (mg/kg-day), to compare with their estimated ingestion of chemicals in fish from the onsite lake. These TRVs are calculated in this section using an approach similar to that used for the EPA GLWQI (U.S. EPA

1995b) (Section A.2.2.1). One exception is allometric scaling of dose from a test animal to dose for the wildlife species based on relative body weights instead of using an interspecies UF of 10.

An interspecies UF generally has two components: a toxicokinetic component and a toxicodynamic component (U.S. EPA 2005a, 2011a). The toxicokinetic component generally can be represented by scaling the toxicity value for the test species to the assessment species on the basis of relative body weights to the ¾ power. That scaling is based on the allometric relationship of metabolic rate to body weight for mammals in general (U.S. EPA 1993c) and assumes that much of the toxicokinetic difference among species scales to metabolic rate. Toxicodynamic differences are associated with taxonomic differences in physiology between the test and assessment species that might affect sensitivity to a toxicant. Such differences generally increase in magnitude with increasing taxonomic distance (Brown et al. 2000); for example, rodents might be more sensitive to some plant toxins than ungulates such as cows or goats or other herbivores that have evolved metabolic pathways to detoxify those compounds.

Given the maximum value for the interspecies UF is 10, a common recent EPA practice has been to assign each component, toxicokinetic and toxicodynamic, a UF of 3 (U.S. EPA 2011). Thus, if toxicokinetic differences are accounted for by scaling to relative body weight, the maximum value of the remaining UF would equal 3 (i.e., $3 \times 3 = 9$; close to 10). The approach is consistent with that used most recently by EPA to estimate reference doses (RfDs) for humans (U.S. EPA 2011) and that EPA has used for some time in estimating cancer potency factors for humans from animal data (U.S. EPA 2005a). For purposes of clarity and simplicity, however, we did not apply a UF of 3 if the test species taxon differs from the assessment species taxon at the level of order (e.g., test species is a rodent [rat] and assessment species is a carnivore [mink]; both are mammals).

A.3.1 Derivation of TRVs for Piscivorous Wildlife in RTR Assessment

As described in Section 3.1.1 of the main report, we selected mink (*Mustela vison*, recently renamed *Neovison vison* based on cytogenetic and biochemical data that distinguish it from other members of the genus *Mustela*; Wozencraft 2005) to represent fish-eating mammals and common (American) merganser (*Mergus merganser americana*) to represent fish-eating birds. These two species are of moderate size (moderate metabolic rate and FIR per kg body weight), but can catch and consume larger fish than other moderate-sized mammals or birds, respectively.

The TRVs used to assess risk to piscivorous wildlife for Tiers 1 through 3 of the RTR ecological risk screen were calculated for the RTR assessment using the methods developed for the GLWQI (U.S. EPA 1995b). In the GLWQI approach, the most sensitive type of effect of the most sensitive of the species tested is used to identify a LOAEL and NOAEL, which then can be used to calculate TRVs. For most chemicals, only a few (e.g., 2–7) species of birds (e.g., quail, mallard, chicken, pheasant) and a few species of mammals (e.g., mice, rats, hamster, mink) have been tested sufficiently to provide both a LOAEL and a NOAEL for effects resulting from chronic exposures. Thus, using toxicity data from the most sensitive of the few species tested is not necessarily an overly protective approach.

For wildlife, chronic TRVs were derived after reviewing the following sources of toxicity study summaries:

- chronic (or reproductive) toxicity studies of mammals and birds as compiled by EPA for the GLWQI (U.S. EPA 1995b),
- studies compiled by Sample et al. (1996),
- studies reported in Eco-SSL documents for individual chemicals (i.e., cadmium, U.S. EPA 2005d), or
- studies identified by a literature search for TRVs or toxicity benchmarks for the six PB-HAPs for birds and mammals (e.g., CA DTSC HERD 2009).

For each source listed above, the author(s) had evaluated the individual toxicity study reports for scientific adequacy. We used the study for the most sensitive species showing an adverse effect on survival, growth and development, or reproduction to identify the lowest LOAEL and lowest NOAEL for use as wildlife TRVs. When not available, a NOAEL was set equal to the LOAEL divided by a UF of 10 (U.S. EPA 1995b). For TRVs obtained from the GLWQI documentation, we used the LOAELs and NOAELs from the key study without application of any UFs, which is consistent with Sample et al. (1996), maximizes clarity, and minimizes the number of assumptions used in developing the TRVs.

To estimate TRVs for the RTR piscivorous wildlife risk screen, we used the LOAELs and NOAELs from a single key study (most sensitive effect and species). Doses were scaled between a test species and the assessment species on the basis of relative body weight to the ¾ power (U.S. EPA 2011), as described below if the difference in body weight was more than 20 percent.

For mammals, for which the test species, usually rats (350 g) or mice (30 g), is of smaller body size and higher metabolic rate than mink (1,000 g), dose conversions from the test animal to mink were based on allometric scaling of metabolic rate between mammalian species (U.S. EPA 1993c,1995b; Equation A-2 below):

$$Dose_{wildlife} = Dose_{test\text{-}species} \times (BW_{test\text{-}species}/BW_{wildlife})^{1/4} \quad \text{Eq. A-2}$$

where

Dose = chemical ingestion (mg[chemical]/kg[wildlife BW]-day)

BW = body weight

For birds, given the similarity of the body weight of test species (e.g., chicken, pheasant, mallard duck about 1 kg) to American merganser (1.27 kg), no dose conversions were performed.

A.3.2 Chemical-specific Wildlife TRVs for PB-HAPs

In the main report, Table 3-1 lists the TRVs, both the NOAEL and the LOAEL, used for fish-eating birds and mammals for each PB-HAP. Further details are provided below. The discussion for arsenic demonstrates our approach. The remaining derivations are described more briefly.

A.3.2.1 Arsenic (As) Wildlife TRVs

Data were available to calculate a TRV for both (1) mink (*Mustela vison, or Neovison vison*) and (2) American merganser (*Mergus merganser americana*).

Mink Arsenic (As) TRV

We based our wildlife TRV for arsenic toxicity to mink on a three-generation study of mice. Schroeder and Mitchener (1971) administered a soluble arsenite (AsO_3^{-3}) salt in drinking water of mice at 3 ppm (or 5 mg[As]/L). They found a statistically significantly reduced litter size (25 percent, 8 percent, and 23 percent for generations 1, 2, and 3, respectively) for female mice ingesting the arsenite in drinking water. Because arsenic is naturally occurring, feed for both control and experimental mice contained 0.06 ppm arsenic. Sample et al. (1996) calculated the dose at the LOAEL to be 1.26 mg[As]/kg[mouse body weight]-d. To estimate a NOAEL, the LOAEL is divided by a UF of 10 (GLWQI, U.S. EPA 1995b).

LOAEL for mouse = 1.26 mg[As]/kg-day

NOAEL for mouse = LOAEL/10

= 0.126 mg[As]/kg-day

LOAEL for mink = daily dose to mouse × (mouse body weight/mink body weight)$^{1/4}$

= 1.26 mg/kg mouse/day × (0.03 kg[mouse]/1 kg[mink])$^{1/4}$

= 0.52 mg[As]/kg-day

NOAEL for mink = 0.052 mg[As]/kg-day

American Merganser Arsenic (As) TRV

As described above for the Eco-SSL for birds, EPA identified an arsenic TRV for birds based on one of four toxicity studies of acceptable quality that examined growth and reproduction (U.S. EPA 2005b). Of those four studies, one reported NOAELs for both reproduction and growth at 2.24 mg/kg[body weight]-day in domestic chickens (Holcman and Stibilj 1997, cited by U.S. EPA 2005b). Although a study of Camardese et al. (1990) identified a lower LOAEL of 1.49 mg/kg-day for growth for mallard duck, EPA did not use it to estimate a TRV because a NOAEL was not determined in that study (U.S. EPA 2005b).

We are concerned that mallards might be more sensitive to arsenic than domestic chickens. Camardese et al. (1990) exposed mallard ducklings to arsenic in food from days 1 through 14 after hatching. Although four doses were administered, effects on growth were seen at the lowest dose tested (1.49 mg/kg-day). For purposes of RTR screening, we use the mallard duck LOAEL. The NOAEL is estimated as the LOAEL divided by a UF of 10 (and rounded to 2 significant digits).

LOAEL for mallard duck = 1.5 mg[As]/kg-day

NOAEL for mallard duck = 0.15 mg[As]/kg-day

Given the similarity in size between mallard (1 kg) and American merganser (1.27 kg), no dose conversions were estimated:

LOAEL for merganser = 1.5 mg[As]/kg-day

NOAEL for merganser = 0.15 mg[As]/kg-day

A.3.2.2 Cadmium (Cd) Wildlife TRVs

Data were available to calculate a TRV for both mink and American merganser.

Mink Cadmium (Cd) TRV

Sample et al (1996) identified the study of Sutou et al. (1980), which reported a NOAEL and a LOAEL for reproduction in rats. Sutou et al. (1980) exposed female rats (mean body weight 0.30 kg) to cadmium for 6 weeks (from mating through gestation) by oral gavage adjusted to body weight to attain three doses: 0.1, 1.0, and 10.0 mg[Cd]/kg[body weight]-day. At the LOAEL of 10 mg/kg-day, fetal implantations were reduced 28 percent, fetal survivorship was reduced by 50 percent, and fetal resorptions increased by 400 percent; the NOAEL in the experiment was 0.1 mg/kg-day.

NOAEL for mink = daily dose to rat × (rat body weight / mink body weight)$^{1/4}$

= 1 mg/kg[rat]-day × (0.30 kg[rat] /1 kg[mink])$^{1/4}$

= 0.74 mg/kg-day

LOAEL for mink = 10 × NOAEL

= 7.4 mg/kg-day

Common Merganser Cadmium (Cd) TRV

For the Eco-SSLs to protect ground-feeding birds, EPA calculated the geometric mean of all bounded NOAELs for reproduction and growth across several species of birds to estimate a TRV of 1.47 mg/kg-day (U.S. EPA 2005d). In 2009, the EPA Region 9 BTAG reevaluated the Eco-SSL TRV for cadmium considering data published after 2004 and using revised allometric equations (Nagy 2001) to estimate FIRs rather than the earlier equations (Nagy 1987) used for the Eco-SSL TRVs.

Based on kidney toxicity in mallards (Cain et al. 1983), EPA Region 9 and the California Department of Toxic Substances Control, Human and Ecological Risk Division recommended an avian LOAEL of 1.0 mg/kg-day (U.S. EPA 2009b; CA DTSC HERD 2009). Cain et al. (1983) reported mild-to-severe kidney degeneration in four growing mallard ducklings fed 14.6 ppm cadmium in their diet for 12 weeks, which they calculated to equal an ingested dose of 1.0 mg/kg-day. Other studies also identified potential reproductive effects near that dose (White et al. 1978; Leach et al. 1979). EPA Region 9 and CA DTSC HERD identified a NOAEL of

0.7 mg/kg-day from a study by Mayack et al. (1981) that identified kidney damage in wood ducks after 3 months of exposure to 7 mg/kg-day, but not in wood ducks exposed at 0.68 mg/kg-day (which we round to 0.7 mg/kg-day).

We follow EPA Region 9 and use the lowest LOAEL of 1 mg/kg-day from Cain et al. (1993) and the highest NOAEL of 0.7 mg/kg-day from Mayack et al. (1981) for merganser TRVs for cadmium (Table 5-1 in the main report). Given the similarity in size between mallard (1 kg) and American merganser (1.27 kg), no dose conversions were estimated.

A.3.2.3 Divalent Mercury (Hg^{++}) Wildlife TRVs

We did not calculate TRVs for mink and American merganser for divalent mercury because it is not bioaccumulative. Instead, we focused on methyl mercury for fish-eating wildlife (Section A.3.2.4).

A.3.2.4 Methyl Mercury (MeHg) Wildlife TRVs

Data were available to calculate a TRV for both (1) mink and (2) American merganser.

Mink Methyl Mercury (MeHg) TRV

Verschuuren et al. (1976) exposed rats to methyl mercury chloride (which is 79.89% Hg by weight) at doses of 0.1, 0.5, and 2.5 ppm in the diet for three generations. Reduced pup survival was observed at 2.5 ppm MeHgCl, but not at the lower dietary concentrations. The exposure level of 0.5 ppm MeHgCl, or 0.4 mg[Hg]/kg[diet], is considered the NOAEL. Sample et al. (1996) calculated the doses for the rat assuming a rat body weight of 0.35 kg and FIR of 28 g/day (U.S. EPA 1988a). The calculations below are based on doses expressed in mg Hg, not MeHg or MeHgCl, per kg body weight per day.

NOAEL for rat = (concentration in food × FIR/day) / body weight

= (0.4 mg[Hg]/kg[food] × 28 g[food]/day) / 0.35 kg[rat body weight]

= 0.032 mg[Hg]/kg-day

LOAEL for rat = (2.0 mg[Hg]/kg[food] × 28 g[food]/day) / 0.35 kg[rat body weight]

= 0.16 mg[Hg]/kg-day

NOAEL for mink = daily dose to rat × (rat body weight / mink body weight)$^{1/4}$

= 0.032 mg[Hg]/kg[rat]-day × (0.35 kg[rat] / 1 kg[mink])$^{1/4}$

= 0.0246 mg[Hg]/kg-day

LOAEL for mink = 0.16 mg[Hg]/kg[rat]-day × (0.35 kg[rat] / 1 kg[mink])$^{1/4}$

= 0.123 mg[Hg]/kg-day

American Merganser Methyl Mercury (MeHg) TRV

Heinz (1974, 1975, 1976a,b, and 1979) identified a LOAEL for reduced production of eggs and ducklings for mallards exposed for up to three generations to MeHg added to the diet as methyl mercury dicyandiamide at 0.5 ppm Hg. EPA estimated the average daily dose to the mallards at that dietary concentration to be 0.078 mg[Hg]/kg bw-day (U.S. EPA 1995b). Sample et al. (1996) also calculated a dose to mallards from 0.5 ppm Hg in the diet to be 0.064 mg[Hg]/kg bw-day based on slightly different assumptions about body weight and FIR than used by EPA. To estimate a NOAEL, EPA used a compound UF of 6: a UF of 2 for the LOAEL-to-NOAEL extrapolation, because the effect level at the LOAEL was slight, and a UF of 3 for interspecies extrapolation (U.S. EPA 1995b).

LOAEL for mallard = 0.078 mg[Hg]/kg-day

NOAEL for mallard = 0.078 mg[Hg]/kg-day / 6 (UF)

= 0.013 mg[Hg]/kg-day

LOAEL for merganser = 0.078 mg[Hg]/kg-day

NOAEL for merganser = 0.013 mg[Hg]/kg-day

A.3.2.5 POM Index Chemical—Benzo[a]pyrene (BaP) Wildlife TRV

Data were available to calculate a TRV only for mink; insufficient data were identified to estimate a TRV for birds.

Mink Benzo[a]pyrene (BaP) TRV

Mackenzie and Angevine (1981) exposed female mice to BaP during days 7 to 16 of gestation via oral intubation. Exposure doses were 10, 40, and 160 mg/kg-day. Total sterility occurred in 97 percent of offspring in the 40- and 160-mg/kg-day groups; fertility was impaired in offspring at the lowest exposure dose tested of 10 mg/kg-day (Sample et al. 1996). To estimate a NOAEL for the mouse from the unbounded LOAEL, the LOAEL is divided by a UF of 10 (U.S. EPA 1995b).

LOAEL for mouse	=	10 mg/kg-day
NOAEL for mouse	=	1 mg/kg-day
LOAEL for mink	=	daily dose to mouse × (mouse body weight/mink body weight)$^{1/4}$
	=	10 mg/kg[mouse]/day × (0.03 kg[mouse] / 1 kg[mink])$^{1/4}$
	=	4.17 mg/kg-day
NOAEL for mink	=	0.417 mg/kg-day

Common Merganser Benzo[a]pyrene (BaP) TRV

In the absence of data for BaP toxicity to birds, we did not estimate TRVs for birds for BaP.

A.3.2.6 Dioxins Index Chemical—2,3,7,8-TCDD Wildlife TRV

Data were available to calculate a TRV for both (1) mink and (2) American merganser.

Mink 2,3,7,8-TCDD TRV

Using a three-generation study design, Murray et al. (1979) identified a NOAEL and LOAEL for reproductive effects of 2,3,5,8-TCDD in rats of 0.001 and 0.01 µg/kg-day (U.S. EPA 1995b, Sample et al. 1996):

NOAEL for rat	=	0.001 µg/kg-day
LOAEL for rat	=	0.01 µg/kg-day
NOAEL for mink	=	daily dose to rat × (rat body weight / mink body weight)$^{1/4}$
	=	0.000001 mg/kg[rat]/day × (0.35 kg[rat] / 1 kg[mink])$^{1/4}$
	=	7.71E-07 mg/kg-day
LOAEL for mink	=	7.71E-06 mg/kg-day

American Merganser 2,3,7,8-TCDD TRV

No avian toxicity studies are available for TCDD administered orally. We did identify an intraperitoneal (i.p.) injection study. Nosek et al. (1992, 1993) dosed female ring-necked pheasants (*Phasianus colchicus*) one time per week for 10 weeks by i.p. injection. The equivalent average daily doses were 0.14, 0.014, and 0.0014 µg/kg-day. This route of administration ensures "uptake" of the complete dose and avoids the "first pass through the liver." We investigated, however, the possibility that oral administration can result in lower uptake.

Available data indicate no differences in gastrointestinal tract absorption of dioxins across taxonomic groups of mammals and some birds (van den Berg et al. 1984). Moreover, uptake of 2,3,7,8-TCDD by mammals following oral administration appears high, ranging from 75 percent (hamster) to >86 percent (humans), with absorption depending on the oil content of the vehicle (van den Berg et al. 1984). In mammals, the tissue distribution of administered 2,3,7,8-substituted polychlorinated dibenzo-p-dioxins (PCDDs) and 2,3,7,8-substituted polychlorinated dibenzofurans (PCDFs) following i.p. and subcutaneous administration is similar to that following oral administration, with the highest proportion of the dose retained in the liver and in adipose tissues (van den Berg et al. 1984). Based on that information, we conclude that i.p. administration can represent ingestion toxicity.

The NOAEL and LOAEL values for egg production by pheasants administered 2,3,7,8-TCDD were 0.014 and 0.14 µg/kg-day, respectively (Nosek et al. 1992, 1993, U.S. EPA 1995b). Given the similarity in size between female ring-necked pheasant (0.9 to 1.1 kg) and American merganser (1.3 kg), no dose conversions were estimated:

NOAEL for merganser = 1.4E-05 mg/kg-day

LOAEL for merganser = 1.40E-04 mg/kg-day

A.4 Derivation of Ecological TEFs for POM and Dioxin Benchmarks

Section A.4.1 covers the derivation of TEFs for POM relative to BaP for the benchmarks for surface waters, sediments, and soils. If the POM is more toxic than BaP, the POM's benchmark would be lower than the benchmark for BaP, and the TEF would be greater than 1.0. If the POM is less toxic than BaP, the POM's benchmark would be higher than the benchmark for BaP, and the TEF would be less than 1.0

Section A.4.2 covers the derivation of TEFs for dioxins relative to 2,3,7,8-TCDD. If the congener is less toxic than TCDD, the TEF would be less than 1. All TEFs for dioxins are less than or equal to 1.

A.4.1 TEFs for POM for Surface Water, Sediments, and Soils

Table A-12 lists the TEFs for POM compounds relative to BaP. Physical and chemical properties of the unsubstituted PAHs, and their toxic mode of action (MOA), tend to be similar, with values for some parameters, including toxic potency, changing predictably with the number of aromatic

rings and the configuration of those rings (e.g., compact, elongated). With any substitutions (e.g., alkyl groups, alcohol groups, chlorine or bromine atoms) or with noncarbon atoms (e.g., nitrogen) included in five-carbon non-aromatic rings, the MOA can change for some groups of organisms (e.g., crustaceans, insects, algae, terrestrial plants) in ways that would not be predicted on the basis of other groups (e.g., aquatic or terrestrial vertebrates).

Table A-12. Toxicity Equivalency Factors (TEFs) for Surface Waters, Soils, Sediments, and Mammalian Wildlife—POM Compounds Relative to BaP

Polyaromatic Organic Matter	CAS RN	Surface Water TEF	Soil TEF	Sediment TEF	Mammalian TEF
1-Methylnaphthalene	90-12-0	0.000042	0.47	7.4	0.014
2-Acetylaminofluorene	53-96-3	0.000026	2.55	9.79	1
2-Chloronaphthalene [beta]	91-58-7	0.0354	125	0.36	1
2-Methylnaphthalene	91-57-6	0.000042	0.470	7.4	0.014
3-Methylcholanthrene	56-49-5	0.16	19.5	0.000018	1
7,12-Dimethylbenz[a]anthracene	57-97-6	0.026	0.093	0.002	1
Acenaphthene	83-32-9	0.00037	0.002	22.4	0.0057
Acenaphthylene	208-96-8	0.000003	0.002	25.6	0.056
Anthracene	120-12-7	0.40	0.001	2.62	0.001
Benz[a]anthracene	56-55-3	0.56	0.292	1.39	1
Benz[a]anthracene/Chrysene	NA	0.1	0.1	0.1	0.1
Benzo[a]fluoranthene	203-33-8	0.0015	0.025	0.014	7.5
Benzo[c]phenanthrene	195-19-7	0.42	0.292	1.4	1
Benzo[g,h,i]fluoranthene	203-12-3	0.71	0.292	1.39	1
Benzo(g,h,i)perylene	191-24-2	0.0018	0.013	0.882	1
Benzo[a]pyrene	50-32-8	1	1	1	1
Benzo[b]fluoranthene	205-99-2	0.0015	0.025	0.014	4.4
Benzo[b+k]fluoranthene	NA	0.0015	0.010	0.625	7.5
Benzo[e]Pyrene	192-97-2	3	1	1	1
Benzo[j]fluoranthene	205-82-3	0.0015	0.01	0.625	7.5

Polyaromatic Organic Matter	CAS RN	Surface Water TEF	Soil TEF	Sediment TEF	Mammalian TEF
Benzo[k]fluoranthene	207-08-9	0.0015	0.010	0.625	7.5
Carbazole	86-74-8	0.0054	0.2	0.36	0.008
Chrysene	218-01-9	0.0020	0.321	0.904	6
Dibenzo[a,h]anthracene	53-70-3	0.0028	0.083	4.54	2
Dibenzo[a,i]pyrene	189-55-9	0.003	0.14	0.8	1
Dibenzo[a,j]acridine	224-42-0	0.43	0.29	1.4	0.1
Fluoranthene	206-44-0	0.0074	0.012	0.355	0.0067
Fluorene	86-73-7	0.00074	0.012	1.94	0.008
Indeno[1,2,3-c,d]pyrene	193-39-5	0.0032	0.014	0.75	1
PAH, Total	NA	0.1	0.1	0.1	0.1
Perylene	198-55-0	2	1	1	1
Phenanthrene	85-01-8	0.0039	0.033	0.735	0.001
Polycyclic organic matter	NA	0.1	0.1	0.1	0.1
Pyrene	129-00-0	0.047	0.019	0.77	0.013
Retene	483-65-8	0.015	0.093	0.002	1

Note: If the TEF is less than 1, the chemical is not as toxic to organisms in that medium as is BaP (in bold). If the TEF is equal to or greater than 1, the chemical is as toxic or more toxic to organisms in that medium as BaP.

Most research on toxic effects of PAHs and similar POM in the United States has focused on their mutagenic and carcinogenic potential in mammals, with several being known human carcinogens. As stated in the introduction, cancer is not an endpoint pursued for wildlife and nonvertebrate animal risk assessment (CCME 2010); thus, TEFs based on carcinogenic potency of POM relative to BaP are not applicable to ecological risk assessments.

General considerations for deriving TEFs for POM for surface water, soil, and sediment in Table A-12 are described in Sections A.4.1.1 through A.4.1.5. Chemical-specific derivations are described in Section A.4.1.6.

A.4.1.1 Data Retrieval and Comparison to Estimate TEFs for POM

To develop TEFs for POM relative to BaP, we first consulted ORNL RAIS to identify any benchmarks available for POM compounds. We used the same hierarchy of preferred data

sources as described in Section A.2.1.4. When available, if the source was the same source that we used for the BaP benchmark for the particular environmental medium (e.g., surface water, sediment, soil), we could compare the POM benchmark to the BaP benchmark to calculate a TEF.

For some POM chemicals, EPA OW or an EPA region had calculated sediment quality criteria using the using the equilibrium partitioning (EqP) approach. That approach includes several assumptions about environmental characteristics, as explained below.

The EqP approach estimates pore-water concentrations of a chemical assuming an equilibrium between the chemical adsorbed to organic carbon in the sediments and the chemical freely dissolved in the pore water. The model uses a chemical-specific surface water quality benchmark (WQB), such as an NAWQC-ALC, and an organic carbon partitioning factor (K_{oc}), which is based on experimentally measured value(s) or can be estimated using Equation A-3 from an experimentally measured octanol-water partitioning coefficient(s) (K_{ow}) for the specified chemical (provided suitable empirical data are available):

$$SQB = f_{oc} \times K_{oc} \times WQB \qquad \text{Eq. A-3}$$

where

SQB	=	chemical-specific sediment quality benchmark
f_{oc}	=	fraction total organic carbon (TOC) in sediments
K_{oc}	=	chemical-specific organic carbon/water partition coefficient
WQB	=	chemical-specific water-quality benchmark for the protection of water-column biota

The EqP model requires the risk assessor to assign a total organic carbon (TOC) concentration in sediments using site-specific measurements or to use values typical of certain types of water bodies [e.g., data presented in U.S. EPA (2003d) are from sediments with 0.201 to 15.2 percent organic carbon]. For a regional or nationwide environmental screen, however, a common approach is to assume a relatively low TOC value to maximize the chemical's bioavailability. Several EPA regions and Environment Canada have adopted the 1-percent TOC value used by Jones et al. (1997) for DOE. Using that assumption, one can calculate a chemical-specific SQB

as the total concentration of the chemical in sediment (on a dry-weight basis) that would produce a sediment pore-water concentration equal to the WQB.

TRIM.FaTE assumes a TOC for sediments of 2 percent. Had a TOC of 2 percent been used instead of 1 percent with the EqP model to estimate SQBs for the non-ionic organic chemicals, the EPA-calculated SQB values would have been higher (i.e., less conservative) by a factor of 2. In that case, the ratio of TRIM.FaTE-predicted sediment concentrations to the sediment benchmarks would have been lower, meaning that more facilities might have passed the tiered screening (i.e., be removed from further consideration).

For many POM chemicals, however, no benchmarks are included in RAIS. We next consulted the EPA NAWQC, the Eco-SSLs, and the EPA regional benchmark compilations to identify benchmarks for POM that might not have been included in ORNL RAIS. When those efforts failed, we finally sought individual toxicity study entries in EPA's ECOTOX database. Data presentation in ECOTOX is difficult to interpret because the results from one experiment are presented as separate records depending on the endpoint (EC_{10}, EC_{50}, NOEC, LOEC, LC_{50}) and sometimes experimental conditions that are not coded into ECOTOX (e.g., presence or absence of UV radiation). We therefore used ECOTOX primarily to identify original publications with titles indicating a focus on endpoints and chemicals of interest. Finally, for chemicals not included in ECOTOX, we conducted web searches by chemical name or CAS Registry Number for ecotoxicity tests, revealing additional original study reports for several POM.

A.4.1.2 General Characteristics of RTR POM

Most POM included for RTR multipathway assessment are PAHs. Excluding naphthalene, PAHs have relatively high melting and boiling points and low water solubility. Their water solubility increases with decreasing molecular weight. Most PAHs are highly lipophilic, with lipophilicity (i.e., K_{ow}) increasing with increasing molecular weight. Overall, aquatic invertebrates (e.g., annelids, insect larvae, daphnids) are more sensitive than fish, and benthic fish are among the least sensitive species to PAHs (Wang et al. 2013, 2014, as cited by Wu et al. 2016). Four characteristics of POM challenge attempts to develop new TEFs as discussed in the paragraphs that follow:

- Aquatic toxicity testing is complicated by low solubility of high-K_{ow} chemicals.
- Quantitative structure-activity relationships (QSARs) are not available for PAH modes of action.
- Sunlight can modify the toxicity of PAHs to plants and invertebrates.
- Bioaccumulation depends on taxonomy.

A.4.1.3 Aquatic Toxicity Testing Limited by Low Solubility of High-K_{ow} Chemicals

Aquatic toxicity testing for PAHs, including BaP, and other POM has been limited by the low solubility of high-K_{ow} chemicals. Typical endpoints often are not reached at the limit of solubility for the high-molecular-weight (HMW) polycyclics (e.g., four or more aromatic rings, 225 grams per mole or higher). In an early-lifestage study of BaP toxicity to rainbow trout (*Oncorhynchus mykiss*), a NOEC of 1.5 µg/L and an EC_{10} of 2.9 µg/L were identified for developmental abnormalities (Hannah et al. 1982, ECHA 2016). *Danio rerio* (zebra danio) exposed for 28 days, on the other hand, showed no abnormalities at 4 µg/L (Hooftman and Evers-de Ruiter 1992, as cited by ECHA 2016), which is at or above the water solubility of BaP (approximately 3.8 µg/L). As a consequence, many of the high K_{ow} POM have not been tested for aquatic toxicity. Fish in bodily contact with sediments (e.g., salmon eggs, other fish eggs and fry, flatfish) can be exposed both dermally and via desorption from sediment particles; thus embryo toxicity tests with spiked sediments are available for some HMW POM.

A.4.1.4 QSAR Applicability is Limited for High K_{ow} Chemicals

QSAR models that predict the aquatic toxicity of HMW non-ionic organic chemicals (e.g., ECOSAR in EPA EPI-Suite, U.S. EPA 2012b) are generally not valid for high-K_{ow} chemicals because HMW chemicals with logK_{ow} values over 6 are too large to readily penetrate membranes despite their lipophilicity. For example, the maximum logK_{ow} for which ECOSAR estimates of a fish 96-hour LC_{50}, a daphnid 48-hour LC_{50}, or a mysid 96-hour LC_{50} are valid is 5.0, and the maximum for an ECOSAR prediction of an earthworm LC_{50} is 6.0.

The maximum logK_{ow} for which chronic values for fish and invertebrates might be valid is 8.0. Droge et al. (2006) demonstrated, however, that PAHs can induce mortality via narcosis (corresponding to K_{ow} at concentrations for which the PAH is soluble), whereas reproductive effects did not follow K_{ow}. We do not recommend a QSAR based on narcosis as a valid predictor of POM-induced endocrine disruption or developmental abnormalities. Sverdrup et al. (2001) demonstrated that some PAHs are more or less toxic than predicted on the basis of neutral

organic QSAR models. For example, carbazole and acridine are more toxic to springtail reproduction than predicted on the basis of K_{ow} for nonpolar organics, while fluoranthene is less toxic than predicted on the basis of K_{ow} values and estimated pore-water EC_{10} values (Sverdrup et al. 2001, 2002a).

We conclude that the QSAR models available for aquatic or earthworm toxicity, such as those included in EPA's ECOSAR model, are unlikely to provide reasonable predictions of POM toxicity to aquatic organisms, acute or chronic. Instead, for POM chemicals without toxicity data, we used chemical structure (e.g., elongated versus compact, locations of substitutions) in addition to K_{ow} and number of benzene rings to identify which parameterized POM appeared most similar, as described in Section A.4.1.6.

A.4.1.5 Photomodification of PAH Toxicity

Another attribute of PAHs that complicates interpretation of aquatic and surface soil toxicity testing is that sunlight can increase the toxicity of many congeners. For PAHs in surface waters and surface soils, two or more conjugated benzene rings facilitate absorption of UV-A and UV-B, and, in some instances, visible light (i.e., wavelengths of 400–700 nm) (Lampi et al. 2006). PAHs strongly absorb photons in the UV-B (290–320 nm) and UV-A (320–400 nm) wavelength regions (both regions are in sunlight). The toxicity of PAHs can be enhanced in the presence of UV radiation; however, lighting in laboratory settings usually is in the visible range only. Photosensitization (PSC) reactions result from generation of singlet-state oxygen (Krylov et al. 1997). Photomodification (PMC) results from photooxidation or photolysis (Huang et al. 1997).

Krylov et al. (1997) examined the phytotoxicity of 16 PAHs to *Lemna gibba* (duckweed). All 16 PAHs exhibited half-lives in simulated sunlight including UV-A and UV-B of 100 hours or less. Anthracene was by far the most toxic of the PAHs examined. Intact anthracene is not a strong photosensitizer; perhaps its degradation products cause its toxicity. K_{ow} values do not predict photoinduced toxicity for PAHs. Krylov et al. (1997) provided a QSAR model based on the 16 PAHs that includes both PSC and PMC. The predictive model indicates that PSC and PMC contribute additively to toxicity. We consider attempts to use this model beyond the scope of identifying TEFs for aquatic plants for PAHs. Moreover, because plants generally are less

sensitive to PAHs than are invertebrates and fish, we did not use aquatic plant toxicity tests to estimate TEFs for surface water.

PSC and PMC reactions can affect PAH toxicity to aquatic invertebrates, such as *Daphnia magna.* Lampi et al. (2006) found that toxicity increased (EC_{50} decreased) approximately threefold in simulated sunlight compared with visible-plus-UVA (no UV-B). Again, K_{ow} does not predict PSC or PMC reactions. Lampi et al. (2006) demonstrated that some PAHs absorb UV-A poorly (e.g., chrysene, fluorene), while decreases in EC_{50} values were substantial for PAHs that strongly absorb in the UV-B region (benzo[e]pyrene, benzo[g]pyrene, dibenzo[a,i]pyrene). Accounting for PSC and PMC reactions and toxicity to invertebrates is beyond the scope of this work. To estimate TEFs by matching individual toxicity tests of a congener with BaP, however, we did attempt to match the lighting conditions (e.g., simulated sunlight or visible light only).

A.4.1.6 TEFs for POM for Surface Waters, Soils, and Sediments

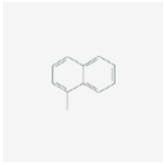
For POM chemicals for which we identified appropriate benchmarks to compare with the BaP benchmarks for surface water, sediment, or soil, we used the ratio of the benchmarks to calculate a TEF appropriate for the ecological assessment endpoint and environmental medium. Benchmarks were not available, however, for many individual POM chemicals. We therefore needed to use original toxicity tests to estimate TEFs.

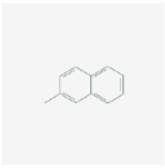
To calculate TEFs from individual toxicity tests requires a different approach than estimating TEFs from community benchmarks already calculated on the basis of many different species' tests and possibly some "uncertainty" factors based on available data. We compared individual ecotoxicity tests for POM *only to the same type of study* for BaP. We therefore also used ECOTOX and web searches to compile individual toxicity test data for BaP to enable those comparisons. Study types and endpoints include 96-hour algal EC_{50} values, 48-hour daphnid LC_{50} values, 96-hour fish LC_{50} values, 2- to 4-week early-lifestage studies with fish (considered chronic), and 4-week earthworm or springtail survival and reproduction tests (soil toxicity tests), although only one or two study types/endpoints were available for most of the POM not included in RAIS. A compilation of those data is available on request. We document below the comparisons on which we based individual POM TEFs, presented in Table A-12, where

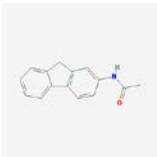
benchmarks were not already established. For each POM, we include its CAS Registry Number, its logK_{ow}, and a schematic of its chemical structure to help the reader follow our rationale.

Benzo[a]pyrene (BaP; CAS # 50-32-8): LogK_{ow} = 5.97. Index chemical for POM TEFs. The average of six 4-day and one 2-day daphnid LC_{50} values is 4.0 µg/L (range 1.0–6.1 µg/L) (Lampi et al. 2006; Wu et al. 2016; Trucco et al. 1983; Ikenaka et al. 2013). With sunlight (which includes UV-A and UV-B), BaP is more toxic to daphnids than under visible light plus UV-A, which is more toxic than under laboratory lighting with no UV-A or UV-B. When fed to *Chlorella* sp., BaP is less toxic than it is to daphnids not fed during the exposure period (Ikenaka et al. 2013). Nonetheless, the range of LC_{50} values across those conditions is limited (i.e., 1.3–6.1 µg/L). For bluegill fish (*Lepomis macrochirus*), the 4-day LC_{50} is 5 µg/L (Wu et al. 2016). For rainbow trout (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*), a 36-day EC_{10} for abnormalities in development of early lifestages is 2.9 µg/L (NOEC is 1.5 µg/L) (ECHA 2016 calculated from exposure-response data reported by Hannah et al. 1982). Algae are not as sensitive as daphnids or fish by two or more orders of magnitude (Warshawsky et al. 1995). The aquatic toxicity benchmarks border on the limit of solubility of 0.0063 µmol/L (Pearlman et al. 1984) or about 1.6 µg/L (BaP molecular weight = 252.3 g/mole). These toxicity data are compared to available toxicity test data for other POM chemicals below.

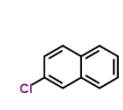
1-Methylnaphthalene (CAS # 90-12-0): LogK_{ow} = 3.87. In freshwater, the 4-day LC_{50} for fathead minnow (static test) is 9,000 µg/L (Mattson et al. 1976), compared with the BaP-exposed bluegill (*Lepomis macrochirus*) 4-day LC_{50} of 5 µg/L (Wu et al. 2016). The ratio of those values yields an acute TEF of 0.00056 µg/L. Those studies, however, do not predict chronic toxicity of 1-methylnaphthalene to aquatic organisms or to soil communities and birds and mammals. Therefore, we assigned the same TEFs as for 2-methylnaphthalene (CAS # 91-57-6) (figure above right) to 1-methylnaphthalene.







2-Acetylaminofluorene (CAS # 53-96-3): An aromatic amine with LogK_{ow} = 3.28. TEFs for surface water, soil, and sediment are from Region 5 ESL benchmarks relative to Region 5 ESLs for BaP for each medium, respectively (U.S. EPA 2003c).

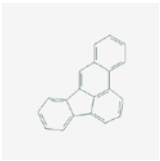


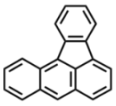
2-Chloronaphthalene (CAS # 91-48-7): $LogK_{ow}$ = 4.14. TEFs for surface water, soil, and sediment are from Region 5 ESLs relative to Region 5 ESLs for BaP for each medium, respectively (U.S. EPA 2003c).

3-Methylcholanthrene (CAS # 56-49-5): $LogK_{ow}$ = 6.42. TEFs for surface water, soil, and sediment are from Region 5 ESLs relative to Region 5 ESLs for BaP for each medium, respectively (U.S. EPA 2003c).

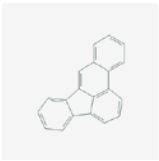
Benzo[e]pyrene (BeP, CAS # 192-97-2): More compact and with a higher $logK_{ow}$ (6.44) than BaP. Under visible light plus UV-A, the 48-hour daphnid immobility EC_{50} (= LC_{50}) = 1.43 µg/L, whereas under simulated sunlight spectrum, the EC_{50} = 0.325 µg/L (Lampi et al. 2006). For BaP, under visible light plus UV-A, the 48-hour daphnid immobility EC_{50} = 1.62 µg/L, whereas under simulated sunlight spectrum, the EC_{50} = 0.98 µg/L (Lampi et al. 2006). No other data on freshwater organisms was identified. Freshwater TEF for BeP = under simulated sunlight = 0.98/0.325 = 3.0. No ecotoxicity data were identified for sediments or soils; therefore, we set the remaining TEFs to 1.0 assuming similarity to BaP.

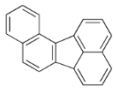
Benzo[a]fluoranthene (BaF, CAS # 203-33-8): $LogK_{ow}$ = 6.11, which is higher than the $logK_{ow}$ for benzo[b]fluoranthene (BbF, CAS # 205-99-2, $logK_{ow}$ = 5.78, figure to the right). BaF also has a higher $logK_{ow}$ than benzo[k]fluoranthene (BkF, $logK_{ow}$ 5.94) and a lower $logK_{ow}$ than benzo[j]fluoranthene (BjF, $logK_{ow}$ 6.4). No ecotoxicity data were identified for BaF for water, sediment, or soils. TEFs were set equal to those for BbF (figure right).



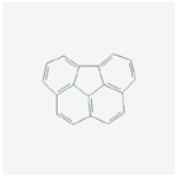


Benzo[j]fluoranthene (BjF, CAS # 205-82-3): $LogK_{ow}$ = 6.4, which is higher than for the other benzofluorenes. All benzo[x]fluorenes have the same molecular weight (252.3 g/mole). No toxicity data were identified for BjF for water, sediment, or soils. TEFs were set equal to those for BbF (figure right).

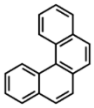




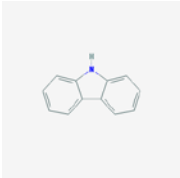
Benzo[g,h,i]fluoranthene (CAS # 203-12-3): $LogK_{ow}$ = 5.52 (molecular weight 226.3 g/mole). With $logK_{ow}$ close to 5.5, we used EPA EPI-Suite ECOSAR Version 4.11 (U.S. EPA 2012b) to estimate four freshwater TEFs: 48-hour LC_{50} for daphnids, 96-hour LC_{50} value for fish, chronic value for daphnids, and chronic value for fish. Toxicity to algae is not evaluated because algae are generally less sensitive than invertebrates to PAHs and because less sensitive species can replace more sensitive species in the water column community. The four toxicity values were compared with the same values from EPI-Suite ECOSAR for BaP to calculate the four corresponding TEFs. The highest of the four corresponding TEFs (chronic fish TEF of 0.71) represents the surface water TEF (range of four TEFs from 0.60 to 0.71). For the remaining TEFs for sediment, soil, birds, and mammals, for which no toxicity data were identified, we set TEFs equal to those for benz[a]anthracene which has a $logK_{ow}$ of 5.79, a similar molecular weight (226.3 g/mole), and a similar TEF (0.56) for surface waters.

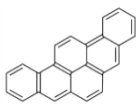


Benzo[c]phenanthrene (CAS # 195-19-7): $LogK_{ow}$ = 5.52. With $logK_{ow}$ close to 5.5, we used EPA's EPI-Suite ECOSAR Version 4.11 to estimate four freshwater TEFs as explained for benzo[g,h,i]fluoranthene above. The highest of the four corresponding TEFs, chronic fish TEF of 0.42, represents the surface water TEF (range of four TEFs from 0.32 to 0.42). For the remaining TEFs for sediment and soil, for which no toxicity data were identified, we set TEFs equal to those for benz[a]anthracene, which has a $logK_{ow}$ of 5.79, the same molecular weight (228.29 g/mole), and a similar TEF (0.56) for surface waters.

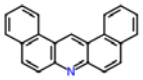


Carbazole (CAS # 86-74-8): $LogK_{ow}$ = 3.72. In freshwater, fathead minnow 4-day LC_{50} (flow-through design) = 930 µg/L (Brooke 1991) compared with BaP exposed bluegill (*Lepomis macrochirus*) 4-day LC_{50} of 5 µg/L (Wu et al. 2016) for a TEF of 0.0054. For soils, earthworm 28-day LC_{50} = 106/2 (division by 2 because endpoint is 50 percent lethality) = 53 mg/kg dry soil and EC_{50} for growth = 54 mg/kg dry soil (Sverdrup et al. 2002b) compared with a BaP 28-day LOEC for earthworm survival of 10 mg/kg dry soil (Achazi et al. 1995 as cited by Sverdrup et al. 2007) for TEF of 0.20. For sediments, no data were found; therefore, we assign a sediment TEF of 7.5, which is similar to the other PAHs with $logK_{ow}$ values between 3.28 and 3.87. Carbazole is structurally similar to fluorene, except the nitrogen atom is at the apex of a five-member nonaromatic ring in center.



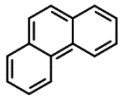


Dibenzo[a,i]pyrene (DaP, CAS #189-55-9): $LogK_{ow}$ = 7.28. Extremely low solubility. We assigned the same TEFs as indeno[1,2,3-c,d]pyrene, which has a K_{ow} value of 6.72. Aquatic toxicity benchmarks are higher than the limit of solubility.

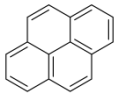


Dibenzo[a,j]acridine (CAS # 224-42-0): $LogK_{ow}$ = 5.63. With $logK_{ow}$ under 6.0, we used EPA EPI-Suite ECOSAR Version 4.11 to estimate four freshwater TEFs as explained for benzo[c]phenanthrene (above). The highest of the four corresponding TEFs (chronic fish TEF of 0.43) represents the surface water TEF (range of four TEFs from 0.35 to 0.43). That aquatic toxicity benchmarks are not reached at the limit of solubility is possible.

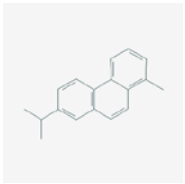
Perylene (CAS # 198-55-0): $LogK_{ow}$ = 5.82 (although the MSDS, http://datasheets.scbt.com/sc-206007.pdf, states 6.25 for $logK_{ow}$). Fish 4-day LC_{50} values range from 1.1 to 5.0 (MSDS). In a daphnid acute test, 0.6 µg/L kills 50% of individuals in 0.764 days (LT_{50} in renewal system). Thus, perylene appears to be more toxic in the water column to both fish and daphnids than is BaP. Based on those data, we set the TEF for freshwater to 2.0 compared with BaP. We set the remaining TEFs for perylene for soil and sediments to 1.0 compared with BaP.



Phenanthrene (PHE, CAS # 85-01-8): $LogK_{ow}$ = 4.46. TEFs for surface water, soil, and sediment are from Region 5 ESLs relative to Region 5 ESLs for BaP for each medium, respectively (U.S. EPA 2003c).



Pyrene (PYR, CAS # 129-00-0): $LogK_{ow}$ = 4.88. TEFs for surface water, soil, and sediment are from Region 5 ESLs relative to Region 5 ESLs for BaP for each medium, respectively (U.S. EPA 2003c).



Retene (CAS # 483-65-8): $LogK_{ow}$ = 6.35. In freshwater, the 14-day LC_{50} (flow-through design) for zebra Danio fish = 353 µg/L (Billiard et al. 1999) compared with bluegill 4-day LC_{50} of 5 µg/L for BaP (Wu et al. 2016). Comparing those two studies as "acute" values, the TEF equals 0.014. A zebra Danio early lifestage 42-day LOEC (flow-through) = 180 µg/L (NOEC = 100 µg/L; Billiard et al. 1999). Compared with the LOEC of 2.9 µg/L for developmental abnormalities in a 36-day BaP exposure of early lifestage *Oncorhynchus mykiss* (rainbow trout, ECHA 2016, exposure-response calculation from

data in Hannah et al. 1982), the chronic TEF equals 0.016. Surface water TEFs based on both acute and chronic exposures of fish equal 0.015. No relevant data were found for sediments or soils; therefore, those TEFs for retene were assigned based on 7,12-dimethylbenz[a]anthracene, which has a similar freshwater TEF of 0.026 µg/L, a similar $\log K_{ow}$ of 5.8, and two alkyl groups attached to its rings (figure above right).

A.4.2 TEFs for Dioxins for Surface Water, Sediments, and Soils

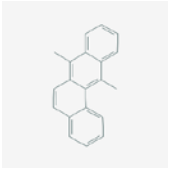


Table A-13 presents the TEFs for dioxins for surface water, soils, and sediments. Surface water TEFs are based on 1998 World Health Organization (WHO) TEFs for fish (from Van den Berg et al. (1998) as presented in Table 4 of *Framework for Application of the Toxicity Equivalence Methodology for Polychlorinated Dioxins, Furans, and Biphenyls in Ecological Risk Assessment* (U.S. EPA (2008). For sediments, we set the TEF for each congener to the TEF for surface water based on the concept of equilibrium partitioning as per the Canadian ISQG for the protection of aquatic life (CCME 2001).

For soils, we adopted a different approach. Plants and most invertebrate groups are not adversely affected by dioxins, because they lack the aryl hydrocarbon (Ah) receptor that mediates the adverse effects in vertebrates, including birds and mammals (UKDTER 1999).We concluded that the soil TEFs should be based on relative toxicity to birds or to mammals to reflect possible toxicity to ground-feeding birds and mammals. We therefore set the soil TEFs for dioxins to the TEF for mammalian or avian wildlife, whichever of the two was higher.

A.5 TEFs for Wildlife TRVs

This section describes the derivation of TEFs for the wildlife TRVs for POM and for dioxins.

A.5.1 TEFs for Wildlife for POM

Most POM in the RTR multipathway list have been screened in vitro (cell cultures) for carcinogenic potential; however, cancer is not an endpoint evaluated for wildlife risk assessments (CCME 2010). Most animals die from starvation, disease, extreme weather, or predation before tumors can develop. Disruption of vertebrate endocrine systems, immune effects, and fetal abnormalities are endpoints of concern for wildlife (CCME 2010).

Table A-13. Toxicity Equivalency Factors (TEFs) for Surface Waters, Soils, Sediments, and Mammalian and Avian Wildlife—Dioxins Relative to 2,3,7,8-TCDD

Congener	CAS RN	Surface Water TEF	Soil TEF	Sediment TEF	Mammalian TEF[a]	Avian TEF
1,2,3,4,6,7,8,9-OCDD	3268-87-9	0.0001	0.0003	0.0001	0.0003	0.0001
1,2,3,4,6,7,8,9-OCDF	39001-02-0	0.0001	0.0003	0.0001	0.0003	0.0001
1,2,3,4,6,7,8-HpCDD	35822-46-9	0.001	0.01	0.001	0.01	0.0005
1,2,3,4,6,7,8-HpCDF	67562-39-4	0.01	0.01	0.01	0.01	0.01
1,2,3,4,7,8,9-HpCDF	55673-89-7	0.01	0.01	0.01	0.01	0.01
1,2,3,4,7,8-HxCDD	39227-28-6	0.5	0.1	0.5	0.1	0.05
1,2,3,4,7,8-HxCDF	70648-26-9	0.1	0.1	0.1	0.1	0.1
1,2,3,6,7,8-HxCDD	57653-85-7	0.01	0.1	0.01	0.1	0.01
1,2,3,6,7,8-HxCDF	57117-44-9	0.1	0.1	0.1	0.1	0.1
1,2,3,7,8,9-HxCDD	19408-74-3	0.01	0.1	0.01	0.1	0.1
1,2,3,7,8,9-HxCDF	72918-21-9	0.1	0.1	0.1	0.1	0.1
2,3,4,6,7,8-HxCDF	60851-34-5	0.1	0.1	0.1	0.1	0.1
1,2,3,7,8-PeCDD	40321-76-4	1	1	1	1	1
1,2,3,7,8-PeCDF	57117-41-6	0.05	0.1	0.05	0.03	0.1
2,3,4,7,8-PeCDF	57117-31-4	0.5	1	0.5	0.3	1
2,3,7,8-TCDD	**1746-01-6**	**1**	**1**	**1**	**1**	**1**
2,3,7,8-TCDF	51207-31-9	0.05	1	0.05	0.1	1

Abbreviations: CDD = chlorinated dibenzo-p-dioxins; CDF = chlorinated dibenzo-p-furans. Hp = hepta (seven); Hx = hexa (six); O = octa (eight), Pe = penta (five); T = tetra (four)
Note: If the TEF is less than 1, the chemical is not as toxic to organisms as is 2,3,7,8-TCDD (in bold). If the TEF is equal to or greater than 1, the chemical is as toxic or more toxic to organisms as 2,3,7,8-TCDD.
[a] Source: Van den Berg et al. (2006).

As was the case for the benchmarks for surface water, soils, and sediments, we found no additional avian or mammalian toxicity data for many of the recently added POM. Although EPA's ECOTOX database does include avian and toxicity data in addition to aquatic toxicity information, we found that few of the new POM are included in ECOTOX.

We found avian embryo toxicity data for several POM chemicals based on egg injection studies. Brunstrom et al. (1990) reported the proportion of eider duck embryos that died or were malformed after a single injected dose (2 mg/kg egg) for several POM (BaP, 30% mortality; BkF, 100%; fluoranthene, 20%; benzo[g,h,i]perylene, 15%; and indeno[1,2,3-c,d]pyrene, 85% mortality). Many of the POM chemicals were not toxic to eggs at 2 mg/kg egg (i.e., anthracene,

fluorene, pyrene, BeP, perylene, benzo[g,h,i]perylene). These data are insufficient to estimate avian toxicity TEFs for most RTR POM; we therefore did not estimate avian TEFs.

For mammals, we checked the Canadian TRV data for wildlife in CCME (2010) for unsubstituted PAHs to identify original toxicity study data that focused on endpoints other than carcinogenicity and mutagenicity. For other POM, we checked EPA's Integrated Risk Information System. We considered subchronic or chronic oral administration studies for which the concentration of chemical in the diet had been converted to a dose in mg/kg body weight per day. In addition, for several POM, we compared the immunocompetence of mice following a single intraperitoneal dose of the POM with the immunocompetence of mice following a single dose of BaP (Silkworth et al. 1995). We did not consider LD_{50} data for mammals to be appropriate for estimating chronic TEFs because the MOA of acute lethality and chronic effects on immunity, reproduction, or development likely differs. The variety of chemical compounds included in the 2016 list of POM also suggests that several different MOAs might be relevant.

Table A-14 presents the data used to estimate TEFs for the RTR POM for mammalian wildlife. Insufficient data were available to calculate TEFs for POM for birds. The mammalian TEFs also are included in Table A-12 for comparison with other benchmark TEFs.

Table A-14. TEFs for Oral Exposures of Mammalian Wildlife—POM Congeners Relative to BaP

Compound (surrogate PAH)	CAS RN	NOAEL/LOAEL[a] (mg/kg-d)	Species/Effect (exposure regimen) [notes]	NOAEL-based TEF	Reference
1-Methylnaphthalene (Naphthalene surrogate)	90-12-0 (91-20-3)	71/143	Rats/decreased body wt (5 d/wk for 13 wk) [dose is time adjusted]	0.014	BCL (1980) in CCME (2010)
2-Acetylaminofluorene	53-96-3	ND	Set = BaP reproduction	1	none identified
2-Chloronaphthalene	91-58-7	ND	Set = BaP reproduction	1	none identified
2-Methylnaphthalene (Naphthalene surrogate)	91-57-6 (91-20-3)	71/143	Rats/decreased body wt (5 d/wk for 13 wk) [dose is time adjusted]	0.014	BCL (1980) in CCME (2010)
3-Methylcholanthrene	56-49-5	ND	Set = BaP reproduction	1	none identified
7,12-Dimethylbenz[a] anthracene	57-97-6	ND	Set = BaP reproduction	1	none identified

Compound (surrogate PAH)	CAS RN	NOAEL/LOAEL[a] (mg/kg-d)	Species/Effect (exposure regimen) [notes]	NOAEL-based TEF	Reference
Acenaphthene	83-32-9	175/350	Mouse/liver wt (13 wk)	0.0057	U.S. EPA (1989a) in CCME (2010) and ATSDR (1995)
Acenaphthylene	208-96-8	18/180	Mouse/immunocompetence (12 d) TDLo (NEL = LEL/10)	0.056	RTECS (1999 Toxicologist 48:13, in CCME 2010)
Anthracene	120-12-7	1000/ >1000	Mouse/multiple systems examined (13 wk)	0.001	U.S. EPA (1989b) in CCME (2010) and ATSDR (1995)
Benz[a]anthracene[a]	56-55-3	−8% at 1	Mouse/immunocompetence (1 dose)	1	Silkworth et al. (1995)
Benzo[a]fluoranthene	203-33-8	ND	Set = BkF immune	7.5	none identified
Benzo[c]phenanthrene	195-19-7	ND	Set = BaP reproduction	1	none identified
Benzo[g,h,i] fluoranthene	203-12-3	ND	Set = BaP reproduction	1	none identified
Benzo[g,h,i]perylene	191-24-2	ND	Set = BaP reproduction	1	none identified
Benzo[a]pyrene[a]	50-32-8	−8% at 1	By definition of index chemical	1	Silkworth et al. (1995)
Benzo[a]pyrene	50-32-8	1/10	Mouse/reduced fertility of progeny of exposed animals (gd 7–16)	1	Mackenzie & Angevine (1981)
Benzo[b]fluoranthene[a]	205-99-2	−35% at 1	Mouse/immuno-competence (1 dose)	4.4	Silkworth et al. (1995)
Benzo[e]pyrene	192-97-2	ND	Set = BaP reproduction	1	none identified
Benzo[j]fluoranthene	205-82-3	ND	Set = BkF immune	7.5	none identified
Benzo[k]fluoranthene[a]	207-08-9	−60% at 1	Mouse/immunocompetence (1 dose)	7.5	Silkworth et al. (1995)
Carbazole	86-74-8	ND	Set = fluorene	0.008	none identified
Chrysene[a]	218-01-9	−48% at 1	Mouse/immunocompetence (1 dose)	6	Silkworth et al. (1995)
Dibenzo[a,h] anthracene[a]	53-70-3	−15% at 1	Mouse/immunocompetence (1 dose)	2	Silkworth et al. (1995)
Dibenzo[a,i]pyrene	189-55-9	ND	Set = BaP reproduction	1	none identified
Dibenzo[a,j]acridine	224-42-0	ND	Less toxic than BaP	0.1	none identified

Compound (surrogate PAH)	CAS RN	NOAEL/LOAEL[a] (mg/kg-d)	Species/Effect (exposure regimen) [notes]	NOAEL-based TEF	Reference
Fluoranthene	206-44-0	150/250	Rat/increased liver wt (13 wk)	0.0067	U.S. EPA (1988b); Knuckles et al. (2004)
Fluorene	86-73-7	125/250	Mouse/liver wt hemato-logical effects (13 wk)	0.008	U.S. EPA (1989c) in CCME (2010)
Indeno[1,2,3-c,d] pyrene	193-39-5	ND	Set = BaP reproduction	1	none identified
Perylene	198-55-0	ND	Set = BaP reproduction	1	none identified
Phenanthrene	85-01-8	1000/ >1000	Set = anthracene	0.001	none identified
Pyrene	129-00-0	75/125	Mouse/nephrotoxicity (90 d, gavage)	0.013	U.S. EPA (1989d) in CCME (2010)
Retene	483-65-8	ND	Set = BaP reproduction	1	none identified

Abbreviations: Ah = aromatic hydrocarbon; d = day; gd = gestation day; LEL = lowest-effect level; NEL = no effect level; ND = no data found; TDLo = threshold dose–lowest observed effect level; wk = week

[a]For Silkworth et al. (1995), data in NOAEL/LOAEL column are the percent decrease in ability to suppress the antibody response in $Ah^{+/+}$ mice immunized 12 hours after administration of one dose of chemical at 1 mg/kg bw.

A.5.2 TEFs for Wildlife for Dioxins

To estimate TEFs for dioxins mammals and birds (listed in Table A-13 along with TEFs for soils, sediments, and surface waters), we used the 1998 and 2005 WHO TEFs for dioxins and furans as presented in EPA's *Framework for Application of Toxicity Equivalency Methodology* (U.S. EPA 2008; Van den Berg et al. 1998; Van den Berg et al. 2006). The dioxin TEFs apply to both cancer and noncancer (e.g., reproductive) endpoints, and therefore we did not need to look for noncancer toxicity tests for individual dioxin congeners.

A.6 Piscivorous Wildlife Exposure Factors

To calculate wildlife exposures via fish ingestion, a series of exposure factor values and an assumed diet are required for the representative species: mink and American merganser. Those values are then used with the TRIM.FaTE estimates of chemical concentrations in fish in the most contaminated lake to estimate mink and merganser chemical intake, in mg/kg-day, via fish ingestion.

Although conceptually considered part of the "exposure assessment" described in the main report, the values selected to parameterize the wildlife exposures via consumption of aquatic

prey are used to backcalculate facility emission screening threshold rates that correspond to the TRVs. Therefore, the input data used for the piscivorous wildlife exposure assessments, calculated outside of TRIM.FaTE, are described in this section.

For the RTR environmental screen, the wildlife are assumed to consume their entire diet from the lake located near the emissions source in the screening scenarios. To calculate the wildlife exposure for each TRIM.FaTE screening scenario, the TRIM.FaTE estimates of chemical concentrations in various compartments of the aquatic biota were calculated first. Then, wildlife exposure based on those data and values for the wildlife exposure factors were calculated. The wildlife exposure factors include an estimated FIR, the caloric energy of the food ingested, the ability of the wildlife species to assimilate calories from the food, and the proportion of the animal's diet consisting of each food type. Food ingestion rates were either obtained from measured values in the open literature or calculated from estimates of free-living metabolic rate (FMR) using allometric equations developed by Nagy (1987). Measured data were selected from the information presented in EPA's (1993c,d) *Wildlife Exposure Factors Handbook* (WEFH) to be "representative" of the data available for the species across its range.

Estimates of FMRs across animals of varying body size within numerous taxa have become available with modern techniques using labeled oxygen measurements. Nagy and his colleagues used the empirical data to develop allometric equations relating FMR to body weight for numerous taxonomic groups (Nagy 1987; Nagy 2001). Estimates of FMR with body weight within a taxon allows estimates of the required daily caloric intake from food. As described in EPA's WEFH (U.S. EPA 1993c,d), with additional information on the caloric content of different types of food and the food habits of a wildlife species, one can estimate the total weight of different foods (e.g., different trophic levels of prey) ingested.

Information on the diets of wildlife species are obtained from field studies in which animals are captured and their gut contents removed or from studies of animals found dead in the field. In general, even the most specialized of feeders must adjust its food sources based on circumstance. For piscivorous wildlife, consumption of fish and invertebrate species varies with availability according to location and season. Nonetheless, comparisons of studies of the same species across years and locations have revealed some consistent patterns that can be used as default assumptions in an ecological risk screening scenario.

The next two subsections describe the exposure parameter values and assumed diets used to estimate consumption of fish for both mink (Section A.6.1) and American merganser (Section A.6.2).

A.6.1 Mink Exposure Factor Values and Assumed Diet

For mink (*Mustela vison or Neovison vison*), none of the measured FIRs available for captive animals were considered representative of free-living animals. Caged animals might not be as active as free-ranging animals that must catch their prey in cold waters and escape predators. We therefore used Nagy's (1987) allometric model for nonherbivorous mammals to estimate an FMR first, which was converted to units of kcal/day as recommended by EPA (U.S. EPA 1993c). The FMR then was normalized to body weight (Table A-15). The estimate of a FMR of 245 kcal/kg bw/day in Table A-12 is similar to the estimated metabolic rate of 258 kcal/kg bw/day for farm-raised (ranch cage) female mink as estimated by Farrell and Wood (1968).

Table A-15. Mink Exposure Factor Values

Parameter	Value	Comments/References
Body weight (kg)	0.8	Average of male and female body weights in summer in Montana (Mitchell 1961)
Free-living metabolic rate (FMR):		Estimated for 1.0-kg mink using Nagy's (1987) allometric equation for nonherbivorous mammals
FMR (kJoules/day)	821	FMR (kJoules/day) = 2.582 × BW (g)$^{0.862}$ (Nagy 1987)
FMR (kcal/day)	196	FRM (kcal/day = 0.6167 × BW (g)$^{0.862}$ (U.S. EPA 1993c)
FMR normalized to BW (kcal/kg-day)	245	FMR normalized to body weight (kcal/kg-day) = FMR (kcal/day) / BW (kg)
Gross energy (GE) of fish (kcal/g ww)	1.20	Table 4-1 of U.S. EPA (1993c)
Food assimilation efficiency (AE) for mammal consuming fish	0.91	U.S. EPA (1993c), Table 3-1
Metabolizable energy (ME) in fish (kcal/g ww)	1.09	ME (kcal/g ww) = GE (kcal/g wet weight) × AE
Normalized food ingestion rate (FIR) (g/g-day)	0.225	FIR (g/g-day) = FMR (kcal/kg-day) × 0.001 kg/gram / ME (kcal/g wet weight)
FIR (percent total body weight)	22.5%	(see previous cell)
FIR per animal (g/d)	180	assuming an 800-g mink

Acronyms: BW = body weight

The gross energy (GE) content for fish and a caloric assimilation efficiency (AE) for a mammal consuming fish were obtained from the WEFH to estimate the metabolizable energy (ME) for the diet on a wet-weight basis (Table A-15). Based on the energy requirements (FMR) of mink and

the ME per unit wet-weight prey, an FIR then could be calculated as the FMR/ME (with units corrected), which in this case equals 22.5 percent of the adult mink's body weight daily. For an individual mink weighing 800 grams, that would be 180 grams of fish, wet weight, ingested per day. To determine chemical ingestion rates, the proportion of the diet obtained by mink from each aquatic biotic compartment in TRIM.FaTE must be specified. All data summarized in EPA's 1993 WEFH, Volume 2, Appendices (U.S. EPA 1993d) were consulted to generalize the dietary assumptions for the RTR environmental screen and to maximize the higher trophic level components of the diet. Those assumptions are listed in Table A-16 (Diet Composition column). The total daily FIR of 180 grams of fish could then be divided among the TRIM.FaTE aquatic biota compartments. Table A-16 shows the resulting FIR in three different units.

Table A-16. Mink Diet Assumptions[a]

Food Type	Percent Diet Composition	Food Ingestion Rate (g/day)	Food Ingestion Rate (kg/day)	Food Ingestion Rate (kg/kg bw-day)
Benthic invertebrates[b]	25	44.9	0.0449	0.0561
Benthivorous fish (consuming benthic invertebrates only)	25	44.9	0.0449	0.0561
Bottom-feeding carnivores)	0	0.0	0.0000	0.0000
Water-column herbivore (planktivore)	25	44.9	0.0449	0.0561
Water-column omnivore	25	44.9	0.0449	0.0561
Water-column carnivore	0	0.0	0.0000	0.0000
TOTAL	100	179.6	0.1796	0.2245

[a]Dietary studies provided in U.S. EPA (1993d) were reviewed to develop assumptions in this table.
[b]The gross energy (GE) and assimilation efficiency (AE) for invertebrates are not identical to the GE and AE for fish; however, assuming that they are the same should have negligible effects on the overall results of the screen.

To evaluate the spatial extent of chemical contamination above a level that would be toxic to mink consuming fish from a water body, the home range of a mink or a mink family is important. Home range size depends on the location, type of habitat, season, and type of water body. In the prairie potholes region of the United States, mink home ranges of 259–380 hectares have been reported (U.S. EPA 1993d). In the pothole region of Manitoba, Canada, Arnold and Fritzell (1987) reported breeding home ranges of 770 hectares per mink or mink family. Along rivers and very large lakes, home ranges generally are expressed as length of river or shoreline. In Sweden, Gerell (1970) reported home ranges between 1.0 and 5.0 km in length depending on age and sex.

A.6.2 Merganser Exposure Factor Values and Assumed Diet

For American merganser (*Mergus merganser americanus*), a few measured FIRs were available from the literature (Salyer and Lagler 1940; Gooders and Boyer 1986; Alexander 1977) that suggested FIR values between 33 and 50 percent of the bird's body weight daily. Using Nagy's (1987) allometric equation for nonpasserine birds,[16] we estimated a FIR of 20 percent daily for a 1.27-kg American merganser. Based on that broad range of possible values, we selected 33 percent as the normalized FIR to use in the RTR screening scenarios. Assuming the body weight of mergansers in Michigan, the FIR equals 419 grams of fish, wet weight, per day per merganser (Table A-17).

Table A-17. Common Merganser Exposure Factor Values

Parameter	Value	References, Comments
Body weight (kg)	1.27	Salyer and Lagler (1940), Michigan
Normalized food ingestion rate (FIR) (g/g-day)	0.33	Salyer and Lagler (1940), Alexander (1977), Gooders and Boyer (1986), and estimated from Nagy (1987)
FIR (percent total body weight)	33%	(see previous cell)
FIR per animal (g/d)	419	Assuming a 1.27-kg American merganser

Estimates of the diet of American merganser, shown in Table A-18, are based on the reported lengths of fish caught in Michigan (Alexander 1977), with some consideration of studies from other locations (e.g., White 1936, 1937; Huntington and Roberts 1959) and experimental choice studies (Latta and Sharkey 1966).

Table A-18. Common Merganser Diet Assumptions[a]

Food Type	Diet Composition (%)	Food Ingestion Rate (g/day)	Food Ingestion Rate (kg/day)	Food Ingestion Rate (kg/kg bw-day)
Benthic invertebrates	0	0.0	0.000	0.00
Benthivorous fish (consuming benthic invertebrates only)	35	146.7	0.147	0.1155
Bottom-feeding carnivores (e.g., eel)	0	0.0	0.000	0.00
Water-column planktivore (YOY fish, shiners, 1–5 inches)	35	146.7	0.147	0.1155
Water-column omnivore (perch, young trout; 6–10 inches)	25	104.8	0.105	0.0825

[16]Groups of birds that generally are larger with slower metabolic rates per unit body weight than are birds in the Order Passeriformes, which includes the song birds such as warblers, robins, thrushes.

Food Type	Diet Composition (%)	Food Ingestion Rate (g/day)	Food Ingestion Rate (kg/day)	Food Ingestion Rate (kg/kg bw-day)
Water-column piscivore (e.g., largemouth bass >12 inches)	5	21.0	0.021	0.0165
TOTAL	100	419.1	0.419	0.33

Acronyms: YOY = young of the year
[a]Diet consumption compartmentalized into TRIM.FaTE biotic compartments is based on the lengths of fish reported caught in Michigan by Alexander (1977), with some consideration of studies from other locations (e.g., White 1936,1937; Huntington and Roberts 1959) and experimental choice studies (Latta and Sharkey 1966)

Most fish consumed are 10–30 cm long, although American merganser will choose larger fish in higher proportion than their availability relative to smaller fish (Mallory and Metz 1999). Fish up to 36 cm long are commonly consumed; mergansers have been reported to eat eels up to 55 cm long. The size of fish consumed apparently is determined by fish girth not length.

American merganser is not territorial. Groups of several females might nest together near productive water bodies during the breeding season, while in winter, large flocks often travel together from one body of water to another. In the Canadian Clay Belt Region (north of the Great Lakes), breeding densities of 7.2 pairs/100 km^2 (7.2 pairs /10,000 hectares) have been reported. Overall breeding densities in Atlantic Canada range from 0 to 81 pairs/10,000 hectares, with densities of 9–10 pairs/10,000 hectares typical of Newfoundland and Nova Scotia (Mallory and Mertz 1999). Along California rivers, 0.5–4.7 birds per linear km have been reported throughout the year (Mallory and Mertz 1999).

A.7 Derivation of Bioaccumulation Factors for Arsenic

Use of BAFs or biota-sediment accumulation factors (BSAFs) "*depends on the assumption that the concentration of chemicals in organisms is a linear no threshold function of the concentration in sediment. This will not be the case if uptake or depuration of the chemical in question is well-regulated by the organism, either because it is an essential nutrient or because it is a toxicant for which the organism has inducible mechanisms for metabolism or excretion*" (BJC 1998). Thus, for several metals, aqueous concentrations are not good predictors of concentrations in fish (BJC 1998; Chen and Folt 2000; Williams et al. 2006).

In addition, bioaccumulation of ionic inorganic chemicals that dissolve in water is different in marine vs. freshwater ecosystems. Because cations and anions are abundant in marine waters, they compete with chemical contaminant ions for transport through gills, although the overall

concentration of "salts" in fish blood and tissues is similar to that in ocean water. In freshwaters, aquatic organisms must osmoregulate, retaining cations and anions at higher concentrations in blood and tissues than in the surrounding water. Physiological mechanisms, therefore, differ between saltwater and freshwater fish and among species that can tolerate excess salinity or that live in estuarine environments.

We therefore conducted a literature search for studies of arsenic bioaccumulation in freshwater fish only, looking for field-measured BAFs for both pelagic and benthic feeding fish (many freshwater species feed in both habitats). Of particular concern was the possibility that bottom-feeding carnivorous fish might accumulate more arsenic than pelagic carnivorous fish. The bottom-feeding fish could ingest arsenic from both their prey and from sediment particles. We first present BAFs that relate dissolved arsenic concentrations in the water column to arsenic concentrations in top trophic-level fish. We then present data for BSAFs for bottom-dwelling freshwater fish.

The next three subsections discuss differences between freshwater and marine fish-tissue arsenic concentrations (Section A.7.1), BAFs (Section A.7.2), and biota-sediment accumulation factors (Section A.7.3).

A.7.1 Differences between Freshwater and Marine Fish

Differences between marine and freshwater organisms are evident from the concentrations of inorganic arsenic in water that produce acute lethality. For As(III) in saltwater, acute toxicity ranges from 250 µg/L for invertebrates (crabs and copepods) to more than 1,500 µg/L for filter-feeding mollusks and for fish (U.S. EPA 1985, 2003e). For As(III) in freshwaters, however, acute toxicity values range from 1,000 to 3,000 µg/L for invertebrates (amphipods and cladocerans) to more than 10,000 µg/L for most freshwater fish.

Marine fish usually contain more arsenic (0.19–65 mg[As]/kg[fish dry weight]) than freshwater fish (0.007–1.46 mg[As]/kg[fish dw]) (Donohue and Abernathy 1999). Table A-19 summarizes arsenic concentration data for marine and freshwater fish. As reported by ATSDR (2007), Hellou et al. (1996) measured 8–37 mg[As]/kg[fish fillet dw] in yellowtail flounder from the Northwest Atlantic in 1993. Assuming fish to be 75-percent water, the tissue concentration on a wet-weight (ww) basis would be approximately 2–9.3 mg/kg ww. Buchet and Lison (1998) measured total

arsenic concentrations in several fish species in Belgian markets; they found total arsenic at concentrations from 2.4 to 19.8 mg[total As]/kg[fish dw], which would equal approximately 0.6–5.0 mg/kg ww. They also found that inorganic arsenic contributed only a small fraction (0.003–0.2 mg[As]/kg[fish dw]) to the total arsenic.

Table A-19. Marine and Freshwater Fish Tissue Concentrations

Habitat	mg[As]/kg[fish dry weight]	mg[As]/kg[fish wet weight]	Species/location	Reference
Marine	0.190–65[a]	0.048–16	fish, marine	Donohue and Abernathy (1999)
Marine	8–37[a]	2–9.3	yellowtail flounder, Northwest Atlantic Ocean	Hellou et al. (1996)
Marine	2.4–19.8 (inorganic: 0.003–0.2)[a]	0.6–5	several species in Belgian fish market	Buchet and Lison (1998)
Freshwater	0.007–1.46[a]	0.028–5.8	fish, freshwater	Donohue and Abernathy (1999)
Freshwater	6.4	0.16 ± 0.23[a]	bottom feeding	Kidwell et al. (1995)
Freshwater	6.4	0.16 ± 0.14[a]	predatory fish	Kidwell et al. (1995)
Freshwater	<0.4	<0.1[a]	several, Savanna River	Burger et al. (2002)
Freshwater	1.3	0.32 ± 0.040[a]	bowfin, Savanna River	Burger et al. (2002)
Freshwater	NC	0.01–0.03	bluegill, yellow perch, largemouth bass	Chen and Folt (2000)
Freshwater	NC	0.017 (0.012.5–0.028)	6 fish species, California	CA OEHHA (2012)
Freshwater	<0.005–0.2[a]	<0.001–0.05	mixed, Candamo River, Peru	Gutleb et al. (2002)

Acronyms: NC = not calculated

[a]Fish tissue concentrations reported as wet weight were converted to dry weight (and the reverse) assuming 75% moisture content in fresh fish.

Arsenic concentrations in freshwater fish are much lower. As reported in ATSDR (2007), Kidwell et al. (1995) analyzed data from the National Contaminant Biomonitoring Program (1984–1985, 112 stations) and found similar concentrations in bottom-feeding fish (0.16 ± 0.23 mg[As]/kg[fish ww]; n = 2,020) and in "predatory" fish (0.16 ± 0.14 mg[As]/kg[fish ww]; n = 12). In fish from the Savannah River below DOE's Savanna River Site, Burger et al. (2002) found concentrations less than 0.1 mg[As]/kg[fish fillet ww] for bass, channel catfish, pickerel, yellow perch, black crappie, American eel, bluegill, and other fish, with only the bowfin showing higher concentrations—0.32 ± 0.04 mg[As]/kg[fish fillet ww]. Similarly, Gutleb

et al. (2002) found concentrations in freshwater fish from the unpolluted Candamo River in Peru from <0.005 to 0.2 mg[As]/kg[fish fillet dw], which would approximate <0.001–0.05 mg/kg ww.

In marine, estuarine, and freshwater bodies, inorganic arsenic (As), predominates (U.S. EPA 2003e). In fish, however, organoarsenical compounds predominate, with arsenobetaine, arsenocholine, monomethylarsonic acid (MMA), dimethylarsenic acid (DMA), and trimethylarsenic (TMA) identified in various species (U.S. EPA 2003e). In marine fish and shellfish, only 10–15 percent of arsenic is inorganic (U.S. EPA 2003e). In freshwater fish, limited field data suggest that organoarsenical compounds might predominate, but laboratory data indicate a wide range of organic-to-total arsenic ratios (U.S. EPA 2003e). Kaise et al. (1997) reported 88–99 percent organic arsenic in six freshwater fish species caught in a river, with more than half as TMA and most of the remainder as DMA. On the other hand, in laboratory studies in which fish were exposed to As(III) or As(V) in water, the fraction of total arsenic comprising organic arsenic compounds varied substantially from 0 to 94 percent (U.S. EPA 2003e).

Laboratory data on measured bioconcentration factor (BCF) values in saltwater and freshwater fish species are too sparse to allow comparison. For selecting BAFs and BSAFs, preference is given to field studies that are adequately conducted, with concentrations measured in water, sediments, and fish that are sampled at the same locations on the same dates. Those data for freshwater fish are described in the next section.

A.7.2 BAFs for Arsenic in Freshwater Fish

For the RTR Tiers 1 and 2 environmental screens for arsenic, the screening scenario assumes that people catch and consume fish from an onsite pond and that they eat 50-percent trophic level 4 (TL4) fish from the water column and 50-percent trophic level 3 (TL3) fish from the benthic environment. For arsenic modeling, EPA chose not to use the biokinetic model of aquatic food chain bioaccumulation (or trophic transfers) included in TRIM.FaTE. Instead, EPA uses arsenic-specific BAFs and BSAFs applied to TRIM.FaTE-estimated water and sediment concentrations, respectively. The BAF/BSAF approach should require fewer empirical data to estimate values for fewer model parameters than the biokinetic approach, which requires values for parameters

related to uptake and elimination via gills and ingestion with food for six components of an aquatic food web.

As of February 2016, EPA has not published BAFs for arsenic in fish that could be used to estimate bioaccumulation and risk at a national level. The current EPA NAWQC for arsenic are based on a BAF of 44, with the value for fish 1.0 and the value for oysters 350 (U.S. EPA 1985; Williams et al. 2006). Recently, EPA published BAF values and other data related to arsenic in organisms in marine and freshwaters (U.S. EPA 2003e). For BAFs, EPA separated data by habitat (marine, freshwater) and by trophic level (i.e., TLs 2, 3, and 4). The water-column fish consumed by people in the screening scenario for RTR assessments is assumed TL4. We therefore recommended using the highest BAF reported, 46.1 L/kg, for a freshwater carnivorous fish, largemouth bass, in the compilation for freshwater lentic ecosystems (see Table 3-4 in U.S. EPA 2003e). That value rounds to 46 L/kg for the arsenic BAF for the water-column carnivore for use in RTR environmental screens.

More recently, the State of California Office of Environmental Health Hazard Assessment (CA OEHHA 2012) derived a freshwater fish BAF of 17 L/kg[fish ww], calculated as the arithmetic mean arsenic BAF from six species of freshwater fish (based on Baker and King 1994, Huang et al. 2003, Lin et al. 2001, Liao et al. 2003, and Skinner 1985) (range of field-measured BAFs in natural lakes 12.5–28). California OEHHA concluded that a BAF of 44 is too high for its freshwater fish risk assessments and now uses the calculated value of 17 L/kg[fish ww] instead.

Given the variation in arsenic BAFs (and BSAFs) in the data presented by EPA (2003e), we decided to investigate arsenic bioaccumulation in more detail to provide additional information for consideration by EPA's Office of Air Quality Planning and Standards. In its 2003 technical review, EPA concluded that arsenic BAF values were too variable to allow the Agency to recommend a single BAF that would apply nationwide (U.S. EPA 2003e). Arsenic concentrations tend to be higher in estuarine and marine fish than in freshwater fish (Table A-19) and higher in filter-feeding invertebrates, including oysters and mussels, than in fish. Arsenic does not bioaccumulate in food chains (U.S. EPA 2003e, Section 1.2). In its grouping of BAF data in 2003, EPA calculated BAFs for animals in trophic level 2 (TL2), TL3, and TL4 for lakes, rivers, and estuaries separately. Thus, BAFs can potentially differ for TL2 lakes, TL2 rivers, and TL2 estuaries; TL3 lakes, TL3 rivers, and TL3 estuaries; and TL4 lakes, TL4 rivers, and TL4

estuaries (U.S. EPA 2003e). The Agency grouped organisms from different phyla (e.g., fish, insect larvae, mussels) if their food habits indicated the same or similar trophic level in the same habitat (e.g., TL3 lakes). We believe that including BAFs for species from different phyla for a specified habitat and trophic level contributed to the variation among BAFs within each habitat/trophic level group.

We found one study that appears to have identified a parameter that explains much of the variation in the freshwater BAF data reviewed by EPA (U.S. EPA 2003e). Williams et al. (2006) focused on field and lab studies of arsenic bioaccumulation and bioconcentration in freshwater *fish* only. They found an inverse relationship between field BAFs and arsenic concentrations in water, a trend observed for other metals (McGeer et al. 2003). Overall, measured concentrations of arsenic in the fillet or in the whole body of fish collected in the field were relatively constant (i.e., 51–370 µg[As]/kg[fish ww]),[17] although most freshwater fish contained less than 200 µg[As]/kg[fish ww] across fish species, trophic levels, and sizes (Table A-19).

In contrast, measured arsenic concentrations in the water ranged over roughly 3.5 orders of magnitude (0.02–56 µg[As]/L[freshwater]) (Williams et al. 2006). The measured BAFs ranged from 0.5 to 1,600 L/kg. Measured BAFs in waters with the highest concentrations (56 µg[As]/L) were 6.1 L/kg ww or less (one exception), while waters with the lowest arsenic concentration (0.085 µg[As]/L) yielded the highest BAF (1,600 L/kg, bluegill) as shown in Table A-20. The inverse correlation between the magnitude of field-measured BAFs and arsenic concentrations in water suggests some degree of internal regulation of arsenic by the fish at typical environmental concentrations (Williams et al. 2006).

BCFs measured in the laboratory, with higher arsenic concentrations in water than in the field studies, ranged from 0.1 to 15 L/kg at water concentrations ranging from 10 to 18,100 µg/L; whole-fish concentrations ranged from 100 to 11,700 µg[As]/kg[fish ww]. The laboratory BCF values are presented after the BAF values in Table A-20.

[17] From over 50 separate fish species/sizes sampled over 6 field studies, Table 1, in Williams et al. (2006). Four unidentified composite samples and one measurement from creek chub of 2,360 µg[As]/kg[fish ww] excluded.

Table A-20. BAF/BCF Values for Freshwater Fish Exposed to Different Water Concentrations of Arsenic

Fish species, condition	Study Type	µg[As]/ L[water]	BAF or BCF (L/kg)	Location	Reference
Bluegill	Field BAF	0.085	1600	20 lakes in northeastern United States for U.S. EPA EMAP	Chen et al. (2000)
Mixed salmonids		0.022	3091		
Smallmouth bass		0.107	542		
Smallmouth bass		0.107	533		
White perch		0.367	322		
Pumpkinseed		0.113	265		
Largemouth bass		0.409	46		
Mottled sculpin	Field BAF	0.37	811	Blacklick Run, MD	Mason et al. (2000), as cited in Williams et al. (2006) [incorrectly cited as 2002 in Table 1]
Blacknose dace			541		
Brook trout, small			541		
Brook trout, large			270		
White sucker	Field BAF	0.67	448	Harrington Creek, MD	Mason et al. (2000), as cited in Williams et al. (2006) [incorrectly cited as 2002 in Table 1]
Brook trout, large			299		
Brook trout, small			299		
Creek chub			299		
Alewife	Field BAF	0.78	46	Upper Mystic Lake, MA	Chen and Folt (2000)
Killifish			41		
Yellow perch			28		
Largemouth bass			23		
Bluegill			22		
Black crappie			19		
Miscellaneous “omnivores”	Field BAF	5.1	5.1	Moon Lake, MS	Cooper and Gillespie (2001)
Carp (n = 5)	Field BAF	12	12	Upper Gila River, AZ	Baker and King (1994)
Channel catfish (n = 4)		20	9.7		
Flathead catfish		20	6.3		
Amphidormous goby	Field BAF	30	12	Haya-kawa River, Japan	Kaise et al. (1997)
Goby			11		
Fatminnow			8.9		
Japanese dace			3.3		
Sweet fish			1.7		
Creek chub	Field BAF	56	42*	Moira Lake, Ontario Canada	Azcue and Dixon (1994) *considered an outlier
Pumpkinseed			6.1		
Golden shiner			3.0		
White sucker			2.4		
Rock bass			2.3		
Banded killifish			1.8		
Largemouth bass			1.5		
Yellow perch			1.4		
Walleye			1.4		
Bluntnose minnow			0.9		
Longnose gar			0.9		
Emerald shiner			0.6		
Spottail shiner			0.5		
Northern pike			0.4		

Fish species, condition	Study Type	µg[As]/ L[water]	BAF or BCF (L/kg)	Location	Reference
Bluegill juvenile	Lab BCF	10	12	Laboratory mesocosm, 16 weeks	Gilderhus (1966)
Bluegill adult		10	14		
juvenile		50	10		
adult		50	7.8		
juvenile		260	2.5		
adult		260	2.0		
juvenile		610	2.5		
adult		610	1.9		
Rainbow trout 5 °C	Lab BCF	10	15	Lab, 11-week exposure, Ontario groundwater, at 5 and 15 °C	McGeachy and Dixon (1990)
Rainbow trout 15 °C		10	15		
5 °C		1,400	0.2		
15 °C		1,400	0.2		
15 °C		8,400	0.2		
5 °C		16,300	0.1		
15 °C		18,100	0.2		
Rainbow trout	Lab BCF	<20	15	Lab, 181-day exposure	Rankin and Dixon (1994)
		760	0.3		
		2,480	0.2		

Acronyms and abbreviations: BAF = bioaccumulation factor (i.e., arsenic accumulation from both water and food); BCF = bioconcentration factor (i.e., arsenic accumulation from water via the gills); EMAP = U.S. EPA Environmental Monitoring and Assessment Program; Lab = laboratory
Source: Williams et al. (2006).

Williams et al. (2006) demonstrated an inverse relationship between arsenic concentrations in water and in fish for low, environmentally common arsenic concentrations in surface waters (i.e., 0.02–56 µg/L). The relationship (Equation A-4) is close, with an r^2 of 0.82.

$$\textit{Field\_BAF}\ (\text{L/kg}) = 87.4 * \textit{Water\_Concentration}\ (\mu\text{g/L})^{-0.925} \qquad \text{Eq. A-4}$$

At higher arsenic concentrations in water (e.g., 10–12,000 µg/L), the laboratory BCFs were still inversely related to water concentration; however, the exponent was smaller (Equation A-5; Williams et al. 2006). The relationship is close ($r^2 = 0.79$).

$$\textit{Lab\_BCF}\ (\text{L/kg}) = 78.7 * \textit{Water\_Concentration}\ (\mu\text{g/L})^{-0.669} \qquad \text{Eq. A-5}$$

The smaller exponent suggests that internal arsenic regulation might be impaired at higher water concentrations.

The trends shown in Table A-20 are apparent despite grouping fish that feed at different trophic levels. In fact, some evidence indicates that arsenic concentrations in fish decrease slightly with increasing trophic level. For example, Chen and Folt (2000) measured arsenic and lead concentrations in Upper Mystic Lake, Massachusetts, in small and large zooplankton and in six

species of fish in three different seasons. The lake, designated as a Superfund site, had been contaminated by past leather and chemical manufacturing upstream. Arsenic was elevated in the zooplankton relative to zooplankton in uncontaminated lakes. Arsenic decreased, however, with increasing trophic level. Fish from Mystic Lake contained the same arsenic concentrations as fish from uncontaminated lakes in the northeastern United States. The highest arsenic concentrations were in planktivorous fish that consumed zooplankton that were high in arsenic. Subsequent consumers in the food chain had lower tissue concentrations of arsenic, leading to the idea that arsenic "biodiminishes" with increasing trophic level in fish. Chen and Folt (2000) found that arsenic concentrations in fish were 10–20 times lower than in the zooplankton, and concentrations in larger plankton (>202 µm) were less than in smaller plankton (45–202 µm). Arsenic concentrations in all fish sampled (planktivores—alewife and killifish; omnivores—black crappie, bluegill sunfish, and yellow perch; and piscivores—largemouth bass) were between 0.01 and 0.03 µg/g wet weight.

Based on the analysis of Williams et al. (2006), for refined site-specific RTR assessments, we recommend using the two equations above (Equation A-4 and Equation A-5) to estimate bioaccumulation of arsenic in water-column fish (water-column carnivore). Application of the equations would be conditional on the TRIM.FaTE-estimated arsenic concentration in the water column being less than or more than 10 µg/L. A warning flag should alert the user if the estimated arsenic concentrations in water are less than 0.01 µg/L or more than 20,000 µg/L, which are concentrations beyond the observed data upon which the empirical models are based.

For simplicity, however, we applied a BAF for the water-column carnivore of 46 L[water]/kg[fish wet weight] (USEPA 2003e, Tables 3.4 and 3.9, highest value for TL4 fish, largemouth bass). That BAF is below 1,000 L/kg, which is a typical criterion for a chemical to be considered bioaccumulative. The BAF values for TL3 fish (alewife) and TL2 fish (carp) were 95 L/kg and 71 L/kg, respectively (USEPA 2003e).

A.7.3 BSAFs for Arsenic in Freshwater Benthic Invertebrates and Fish

As discussed in detail in Appendix 6 of the Risk Report,[18] for the RTR Tiers 1, 2, and 3 human health screens for arsenic, EPA relies on the BSAF/BAF approach rather than biokinetic modeling of aquatic food chain bioaccumulation (or trophic transfers). Predicting bioaccumulation of metals and transition elements requires chemical-specific empirical data; no chemical property, such as K_{ow}, predicts bioaccumulation of these elements across organisms in aquatic food chains.

Bechtel Jacobs Company (BJC 1998) assembled data to estimate freshwater BSAFs for benthic invertebrates (predominantly the aquatic larval stage of several groups of insects) for use in risk assessments on DOE properties. As for most estimates of BSAFs for metals published in the literature, BJC (1998) reported BSAFs as the ratio of dry-weight biota concentration to dry-weight sediment concentration (i.e., kg[dry weight sediments]/kg[dry weight biota]. For a dataset of 55 sediment-invertebrate BSAFs, BJC (1998) found a mean value of 0.329 kg[dw]/kg[dw]. For 49 of those studies for which the organisms had not been depurated (i.e., moved to clean sediments and allowed to eliminate the chemical), the mean BSAF was 0.240 kg[dw]/kg[dw]. TRIM.FaTE calculates both invertebrate and fish concentrations on a wet-weight basis. For the benthic invertebrates reviewed by BJC, typically 70-percent water, the fresh-weight BSAF would be lower. The BSAF multiplied by 0.30 (fraction dry weight) yields BSAFs of 0.1 and 0.07 kg[dry sediment]/kg[wet weight invertebrates] for the set of 55 and set of 49 studies, respectively.

The data described above could be used to parameterize the beginning of the benthic food chain in TRIM.FaTE for arsenic. For the RTR human health and environmental screens, however, we are not employing the TRIM.FaTE biokinetic food-web model to estimate bioaccumulation. Thus, we needed to find a BSAF value for freshwater fish that consume benthic invertebrates and small bottom fish to calculate their tissue concentrations relative to sediment concentrations.

We found a single study that measured a BSAF for freshwater fish in the field. Davis et al. (1996) measured arsenic concentrations in fish and sediments in a holding pond at the

[18] Appendix 6 to the Risk Report is the *Technical Support Document for the TRIM-Based Multipathway Tiered Screening Methodology for RTR*.

Industriplex Superfund Site north of Boston, Massachusetts, that had been contaminated with arsenic in the 1970s. At a depth of 45 cm in the sediments, they measured approximately 500 µg[As]/L[pore water] and 1,000 mg[As]/kg[dry weight sediment]. They found increasing arsenic concentrations with decreasing depth in the sediment column: 1,700 µg[As]/L[pore water] and 1,200 mg[As]/kg[sediment dw] at a depth of 30 cm; and 5,500 µg[As]/L[pore water] and 3,000 mg[As]/kg[sediment dw] at the surface (the top few cm). They calculated a sediment-water Kd for arsenic of 560 L/kg. Arsenic near the surficial sediments was 1,700 µg[total As]/L, with <1.0 µg[As]/L MMA, <1.9 µg[As]/L DMA, 1,100 µg/L as As(III), and 610 µg/L as As(V).

Davis et al. (1996) measured arsenic in the fillet portion of bottom-feeding fish (brown bullhead and white sucker) and in nearby surficial sediments. Although they did not describe their methods for estimating arsenic concentrations in the fish or in bulk sediments in detail, their goal was to report a BSAF that could predict wet-weight fish concentrations of arsenic. They reported 1.19 mg[As]/kg[ww fish fillet] and a surficial sediment concentration of 1,830 mg[As]/kg[sediment]. Those data indicate a BSAF of 6.5×10^{-4} kg[bulk sediment]/kg[ww fish fillet], which we have adopted for RTR analyses.

We have only a single estimate of a BSAF for freshwater fish. This BSAF might be lower than is typical in most surface water bodies for two reasons. First, the exposure concentration is relatively high. Based on the findings of Williams et al. (2006), high exposure concentrations would likely result in low bioaccumulation for arsenic. Second, Davis et al. (1996) measured a relatively high sediment-water Kd for arsenic of 560 L/kg, which is higher than the median value of 316 L/kg (logKd of 2.5 L/kg, range of logKd 1.6–4.3 L/kg) reported by EPA for a sediment-water Kd (U.S. EPA 2005b). Thus, the bioavailability of arsenic in sediments at the Superfund site investigated by Davis et al. (1996) might have been lower than at most locations.

A.8 Environmental Screening Threshold Emission Rates

As described in the main report, the Tier 1 environmental screening thresholds are expressed as chemical- and assessment-endpoint-specific emission rates (in tons per year). They are backcalculated from media-specific benchmarks or TRVs for fish-eating birds and mammals using TRIM.FaTE. Those screening emission thresholds are listed in Table A-21. The methods of changing thresholds for Tiers 2 and 3 also are described in the main report.

Table A-21. Tier 1 Environmental Screening Threshold Emission Rates (ESTER) for each PB-HAP and each Benchmark Assessed in the Environmental Risk Screen

PB-HAP	Assessment Endpoint	Benchmark and Effect Level[a]	Tier 1 ESTER (TPY)
Arsenic	Fish-consuming birds	NOAEL (American merganser)	6.20E+00
		LOAEL (American merganser)	6.20E+01
	Fish-consuming mammals	NOAEL (mink)	6.57E-01
		LOAEL (mink)	6.57E+00
	Sediment Community	Threshold Level	5.97E-01
		Probable-effect Level	2.40E+00
	Surface Soil – Dist. 1 – 312 m	Threshold – Mammalian Insectivores (shrew)	1.92E+00
		Threshold – Avian Insectivores (woodcock)	1.80E+00
		Threshold Level – Plant Community	7.53E-01
	Surface Soil – Dist. 2 – 850 m	Threshold – Mammalian Insectivores (shrew)	3.63E-01
		Threshold – Avian Insectivores (woodcock)	3.39E-01
		Threshold Level – Plant Community	1.42E-01
	Surface Soil – Dist. 3 – 1,500 m	Threshold – Mammalian Insectivores (shrew)	7.25E-01
		Threshold – Avian Insectivores (woodcock)	6.77E-01
		Threshold Level – Plant Community	2.84E-01
	Surface Soil – Dist. 4 – 3,500 m	Threshold – Mammalian Insectivores (shrew)	3.35E+00
		Threshold – Avian Insectivores (woodcock)	3.13E+00
		Threshold Level – Plant Community	1.31E+00
	Surface Soil – Dist. 5 – 7,500 m	Threshold – Mammalian Insectivores (shrew)	1.55E+01
		Threshold – Avian Insectivores (woodcock)	1.45E+01
		Threshold Level – Plant Community	6.06E+00
	Water-column Community	Threshold Level (chronic)	7.24E+01
		Frank-effect Level (acute)	1.64E+02
Cadmium	Fish-consuming birds	NOAEL (American merganser)	2.22E-02
		LOAEL (American merganser)	3.17E-02
	Fish-consuming mammals	NOAEL (mink)	4.43E-02
		LOAEL (mink)	4.44E-01
	Sediment Community	No-effect Level	1.04E-01
		Threshold Level	3.77E-01
		Probable-effect Level	1.10E+00
	Surface Soil – Dist. 1 – 312 m	Threshold – Mammalian Insectivores (shrew)	3.28E-02
		Threshold – Avian Insectivores (woodcock)	7.01E-02
		Threshold Level – Plant Community	2.91E+00
		Threshold Level – Invertebrate Community	1.27E+01

PB-HAP	Assessment Endpoint	Benchmark and Effect Level[a]	Tier 1 ESTER (TPY)
	Surface Soil – Dist. 2 – 850 m	Threshold – Mammalian Insectivores (shrew)	7.46E-03
		Threshold – Avian Insectivores (woodcock)	1.60E-02
		Threshold Level – Plant Community	6.64E-01
		Threshold Level – Invertebrate Community	2.90E+00
	Surface Soil – Dist. 3 – 1,500 m	Threshold – Mammalian Insectivores (shrew)	1.51E-02
		Threshold – Avian Insectivores (woodcock)	3.23E-02
		Threshold Level – Plant Community	1.34E+00
		Threshold Level – Invertebrate Community	5.88E+00
	Surface Soil – Dist. 4 – 3,500 m	Threshold – Mammalian Insectivores (shrew)	8.52E-02
		Threshold – Avian Insectivores (woodcock)	1.82E-01
		Threshold Level – Plant Community	7.58E+00
		Threshold Level – Invertebrate Community	3.31E+01
	Surface Soil – Dist. 5 – 7,500 m	Threshold – Mammalian Insectivores (shrew)	3.99E-01
		Threshold – Avian Insectivores (woodcock)	8.53E-01
		Threshold Level – Plant Community	3.54E+01
		Threshold Level – Invertebrate Community	1.55E+02
	Water-column Community	Threshold Level (chronic)	2.41E-01
		Frank-effect Level (acute)	6.02E-01
Mercury – divalent mercury (Hg++) emissions and exposures	Sediment Community	Threshold Level	3.64E-03
		Probable-effect Level	1.91E-02
	Surface Soil – Dist. 1 – 312 m	Threshold Level – Plant Community	1.96E-03
		Threshold Level – Invertebrate Community	6.54E-04
	Surface Soil – Dist. 2 – 850 m	Threshold Level – Plant Community	9.15E-04
		Threshold Level – Invertebrate Community	3.05E-04
	Surface Soil – Dist. 3 – 1,500 m	Threshold Level – Plant Community	2.20E-03
		Threshold Level – Invertebrate Community	7.35E-04
	Surface Soil – Dist. 4 – 3,500 m	Threshold Level – Plant Community	1.15E-02
		Threshold Level – Invertebrate Community	3.83E-03
	Surface Soil – Dist. 5 – 7,500 m	Threshold Level – Plant Community	7.23E-02
		Threshold Level – Invertebrate Community	2.41E-02
	Water-column Community	Threshold Level (chronic)	2.91E-01
		Frank-effect Level (acute)	5.30E-01
Mercury – Hg++ emissions, but exposure to MeHg	Fish-consuming birds	NOAEL (American merganser)	3.37E-03
		LOAEL (American merganser)	2.02E-02
	Fish-consuming mammals	NOAEL (mink)	1.79E-02
		LOAEL (mink)	8.89E-02

PB-HAP	Assessment Endpoint	Benchmark and Effect Level[a]	Tier 1 ESTER (TPY)
	Sediment Community	Threshold Level	2.08E+00
		Probable-effect Level	1.04E+01
	Surface Soil – Dist. 1 – 312 m	Threshold Level – Invertebrate Community	3.94E-02
	Surface Soil – Dist. 2 – 850 m	Threshold Level – Invertebrate Community	1.84E-02
	Surface Soil – Dist. 3 – 1,500 m	Threshold Level – Invertebrate Community	4.42E-02
	Surface Soil – Dist. 4 – 3,500 m	Threshold Level – Invertebrate Community	2.32E-01
	Surface Soil – Dist. 5 – 7,500 m	Threshold Level – Invertebrate Community	1.45E+00
	Water-column Community	Threshold Level (chronic)	1.48E-01
		Frank-effect Level (acute)	5.23E+00
BaP-equivalents	Fish-consuming mammals	NOAEL (mink)	1.33E+02
		LOAEL (mink)	1.33E+03
	Sediment Community	No-effect Level	1.32E+00
		Threshold Level	6.20E+00
		Probable-effect Level	5.99E+01
	Surface Soil – Dist. 1 – 312 m	Threshold – Mammalian Insectivores (shrew)	6.56E-01
	Surface Soil – Dist. 2 – 850 m	Threshold – Mammalian Insectivores (shrew)	8.17E-01
	Surface Soil – Dist. 3 – 1,500 m	Threshold – Mammalian Insectivores (shrew)	1.43E+00
	Surface Soil – Dist. 4 – 3,500 m	Threshold – Mammalian Insectivores (shrew)	5.06E+00
	Surface Soil – Dist. 5 – 7,500 m	Threshold – Mammalian Insectivores (shrew)	1.83E+01
	Water-column Community	Threshold Level (chronic)	5.16E+00
		Frank-effect Level (acute)	8.84E+01
2,3,7,8-TCDD equivalents	Fish-consuming birds	NOAEL (American merganser)	6.61E-06
		LOAEL (American merganser)	6.61E-05
	Fish-consuming mammals	NOAEL (mink)	8.58E-06
		LOAEL (mink)	8.58E-05
	Sediment Community	Threshold Level	6.68E-06
	Surface Soil – Dist. 1 – 312 m	Threshold – Mammalian Insectivores (shrew)	1.17E-07
	Surface Soil – Dist. 2 – 850 m	Threshold – Mammalian Insectivores (shrew)	5.04E-08
	Surface Soil – Dist. 3 – 1,500 m	Threshold – Mammalian Insectivores (shrew)	8.33E-08
	Surface Soil – Dist. 4 – 3,500 m	Threshold – Mammalian Insectivores (shrew)	2.80E-07
	Surface Soil – Dist. 5 – 7,500 m	Threshold – Mammalian Insectivores (shrew)	8.78E-07
	Water-column Community	Threshold Level	6.67E-04
		Frank-effect Level	6.67E+00
Lead	Ambient Air	NAAQS Secondary Standard	NA

Acronyms and abbreviations: BaP = benzo[a]pyrene; Dist. = distance; TCDD = tetrachlorodibenzo-p-dioxin; Hg = mercury; Hg++ = divalent mercury; MeHg = methyl mercury; NA = not applicable; NAAQS = National Ambient Air

Quality Standards; NOAEL = no-observed-adverse-effect level; LOAEL = lowest-observed-adverse-effect level; TPY = tons per year

[a]Insectivore means diet of insects; however, here insectivore means specifically feeding on both insects (larvae and adults) and other invertebrates (e.g., earthworms) that dwell in surface soil, as the named species (shrew and woodcock) suggest.

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Appendix 10

Detailed Risk Modeling Results

Table 1. Facility Identification Information

EIS ID[1]	Facility Name	Address	City	State
17640111	DENKA PERFORMANCE ELASTOMER LLC	586 HWY 44	LAPLACE	LA

[1]Emissions Inventory System (EIS) facility ID

Inhalation Risk Modeling Results

Chronic Inhalation Risks

Table 2. Maximum Predicted HEM-4 Chronic Inhalation Risk – Actual and Allowable Emissions

Facility EIS ID	Source Categories Chronic Risk[1]			Whole Facility Chronic Risk[1]			% Source Contribution (Cancer MIR)
	Cancer MIR	Non-cancer Max HI	Target Organ	Cancer MIR	Non-cancer Max HI	Target Organ	
17640111	**500**	0.05	respiratory	**600**	0.3	respiratory	83%

[1]**BOLD** indicates a cancer Maximum Individual Risk (MIR) value greater than 100-in-1 million or chronic non-cancer maximum Hazardous Index (HI) value greater than 1

Table 3. Maximum Predicted HEM-4 Cancer Inhalation Risk – Neoprene Production Source Category Baseline & Post Control

Facility EIS ID	Baseline Cancer Risks[1]		Post Control Cancer Risks[1]	
	MIR	Incidence	MIR	Incidence
17640111	**500**	0.05	100	0.01

[1]**BOLD** indicates a cancer Maximum Individual Risk (MIR) value greater than 100-in-1 million

Table 4. Maximum Predicted HEM-4 Cancer Inhalation Risk – Whole Facility Baseline & Post Control

Facility EIS ID	Baseline Cancer Risks[1]		Post Control Cancer Risks[1]	
	MIR	Incidence	MIR	Incidence
17640111	**600**	0.06	**200**	0.02

[1]**BOLD** indicates a cancer Maximum Individual Risk (MIR) value greater than 100-in-1 million

Acute Inhalation Risks

Table 5. Maximum Predicted HEM-4 Acute Inhalation Risks (Neoprene Production Source Category)

Facility EIS ID	Pollutant	Maximum Hazard Quotient (HQ)[1,2]				
		REL	AEGL1	AEGL2	ERPG1	ERPG2
17640111	carbon disulfide	0.0003	4E-05	3E-06	0.0005	3E-06
17640111	chloroform	0.3	---	0.0002	---	0.0002
17640111	chloroprene	---	---	---	---	---
17640111	formaldehyde	0.0005	2E-05	2E-06	2E-05	2E-06
17640111	glycol ethers	0.007	---	---	---	---
17640111	hydrochloric acid	0.001	0.0008	7E-05	0.0005	7E-05
17640111	methyl chloride	---	---	4E-06	21E-05	4E-06
17640111	methylene chloride	0.003	7E-05	2E-05	5E-05	2E-05
17640111	n-hexane	---	---	6E-08	---	6E-08
17640111	tetrachloroethene	0.0001	9E-06	1E-06	3E-06	1E-06
17640111	toluene	---	0.0009	0.0001	0.001	0.0001
17640111	xylenes (mixed)	9E-05	4E-06	5E-07	---	5E-07

[1]Note that there were no HQs greater than 1, so further refinement (off-site) was not required.
[2] "---" indicates a benchmark was not available

Appendix 11

Site-Specific Human Health Multipathway Residual Risk Assessment Report

A Site-Specific Multipathway Assessment was not warranted for this source category and therefore this Appendix was intentionally left blank.