

HUMAN HEALTH RISK ASSESSMENT
In Support of a Proposed Air Use Permit
For a New Circulating Fluidized Bed Boiler
at
Holland Board of Public Works
James DeYoung Generating Plant
Holland, Michigan

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EXECUTIVE SUMMARY

The Holland Board of Public Works (HBPW) is proposing to construct and install a new circulating fluidized bed (CFB) boiler (Boiler Unit 10) at the James DeYoung Generation Station located in Holland, Michigan. Boiler Unit 10 will be replacing existing Boiler Unit 3 at the facility. The Michigan Department of Environmental Quality (MDEQ) Air Quality Division (AQD) has requested that a human health risk assessment (HHRA) be conducted as part of the permitting process for the new boiler. The original HBPW HHRA focused on lead and mercury emissions and compared potential human health impacts associated with combined operation of Boiler Units 4, 5, and 10 (i.e., future configuration) against combined operation of Boiler Units 3, 4, and 5 (i.e., current configuration). In contrast, the current revision of the HHRA focuses only on post-modification emissions from Boiler Units 4, 5 and 10.

At the request of the AQD, a subset of USEPA default receptor scenarios were evaluated in the HHRA for both direct and indirect exposures to lead and mercury. The default receptor scenarios included:

- Resident Child;
- Recreational Fisher; and
- Recreational Fisher Child.

Consistent with current USEPA guidance, all three receptors were assumed to live at the same residential location, identified through evaluation of air modeling outputs, consideration of existing zoning and examination of digitized aerial photographs. Potential exposure to emitted lead and mercury through inhalation, incidental ingestion of surface soil and ingestion of homegrown plants/vegetables was evaluated for all three default receptor scenarios at the selected residential location. In addition, the Recreational Fisher and Recreational Fisher Child were evaluated for exposure to lead and mercury through the ingestion of fish caught in Lake Macatawa.

The HHRA results indicate that post-modification exposure to mercury emissions from Boiler Units 4, 5 and 10 should not pose a threat to individuals residing within the study area. Potential impacts from the various mercury species were quantified through generation of a hazard index (HI); direct and indirect exposure levels were compared against appropriate toxicity criteria and the resulting ratio values were summed across pathways and chemicals for each receptor group.

The highest combined HI was associated with the Recreational Fisher (0.02) followed by the Recreational Fisher Child (0.01) and Resident Child (0.0006). This pattern is not surprising given the consumption of fish

by the two Fisher groups. Again, the combined HI estimates for all three receptor groups indicated that the incremental mercury impacts should not present a human health concern. Typically, a combined HI ≤ 1 indicates an exposure level that can be tolerated by all individuals, including sensitive subpopulations, throughout a lifetime without any adverse effects. Although the USEPA recommends an alternate more conservative target level (i.e., combined HI ≤ 0.25), the combined HI was well below that target level for all three receptor scenarios.

Although the current revision of the HHRA evaluates anticipated combined emissions from Boiler Units 4, 5 and 10 it is important that these impacts be put in perspective. Combined mercury emissions from Boiler Units 3, 4 and 5 (the current facility configuration) were also evaluated (data not shown) and the highest combined HI values were again associated with the Recreational Fisher (0.02) and the Recreational Fisher Child (0.01). Although the replacement of Boiler Unit 3 with Boiler Unit 10 in the future configuration results in a modest increase in the HI from combined emissions for these receptor groups (i.e., less than 20 percent), the potential human health impacts are still anticipated to be well-below any level of regulatory concern.

The increases in media lead levels resulting from the planned replacement of Boiler Unit 3 with Boiler Unit 10 were evaluated using USEPA's IEUBK model, which integrates multiple exposure pathways and predicts blood lead levels in children. As there was uncertainty associated with the potential contribution of lead-based paint to dust levels in area homes, two different residential scenarios were evaluated.

In the first, the assumption was made that no lead-based paint was present in area homes; all lead in household dust was assumed to result from the tracking of soil into the homes and the deposition of airborne lead. The IEUBK-modeled geometric mean blood lead level under that background scenario was 1.54 $\mu\text{g}/\text{dL}$. Under the second scenario, the assumption was made that lead-based paint was present in area homes, with the paint was in good condition. The modeled geometric mean blood lead level under the second background scenario was 2.67 $\mu\text{g}/\text{dL}$. When the impact of combined lead emissions from Boiler Units 4, 5 and 10 was evaluated using the IEUBK model, the resulting geometric mean blood lead concentration under the first scenario (i.e., 1.57 $\mu\text{g}/\text{dL}$) represented an increase of only 2.0 percent; under the second scenario, the modeled geometric mean blood lead concentration (i.e., 2.70 $\mu\text{g}/\text{dL}$) represented an increase of only 1.0 percent. Under both scenarios, the incremental blood lead levels resulting from boiler emissions were well below CDC's level of concern.

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Given the level of conservatism inherent in USEPA's guidance, the results of the revised HBPW HHRA indicate that the impact of lead and mercury emissions resulting from the planned modification of the HBPW James DeYoung Generating Plant should not present a human health threat to individuals living in the surrounding area.

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Appendix A IEUBK Output Files

LIST OF ACRONYMS

ADD	Average daily dose
AERMOD	AMS/EPA Regulatory Model Improvement Committee (AERMIC) Model
AQD	Air Quality Division
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BW	Body weight
C _a	Concentration in air
CAA	Clean Air Act
CDC	Centers for Disease Control
CFB	Circulating fluidized bed
COPC	Compound of potential concern
DEM	Digital elevation model
DW	Dry weight of soil or plant/animal tissue
FW	Fresh weight (or whole/wet weight) of plant or animal tissue
HBPW	Holland Board of Public Works
HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment
HI	Hazard index
HQ	Hazard quotient
IEUBK	Integrated Exposure Uptake Biokinetic (Model)
IRIS	Integrated Risk Information System
LOAEL	Lowest observed adverse effect level
MAERS	Michigan Air Emissions Reporting System
MDL	Method detection limit
MDEQ	Michigan Department of Environmental Quality
MW	Megwatt
NAAQS	National Ambient Air Quality Standards
NAD	North American datum
NOAEL	No observed adverse effect level
NWS	National Weather Service
PSD	Prevention of significant deterioration

RfC	Reference air concentration
RfD	Reference dose
RME	Reasonable maximum exposure
TDF	Tire-derived fuel
USEPA	U.S. Environmental Protection Agency
USLE	Universal soil loss equation
UTM	Universal transverse mercator

1.0 INTRODUCTION

The Holland Board of Public Works (HBPW) is proposing to construct and install a new circulating fluidized bed (CFB) boiler at the James DeYoung Generation Station located in Holland, Michigan. As part of the overall project, HBPW will be removing existing Boiler Unit 3 at the facility. Boiler Unit 3 is a pulverized coal boiler with a rated generating capacity of approximately 11.5 Megawatts (MW). The new unit (Boiler Unit 10) will have a maximum heat input of 865 MMBtu/hr and will be rated at approximately 78-MW (gross) electrical output.

Due to increased energy demand predicted in the coming decades, the City of Holland has determined that additional generating capacity will be required in order to meet the needs of existing and future residents. Further, given the market conditions and pressure in natural gas prices, HBPW is forced to consider other fossil and renewable fuels. Consequently, the new Boiler Unit 10 will be capable of firing coal, virgin wood waste, tire-derived fuel (TDF), and sewage sludge. However, less than 10% of the total heat input to the CFB will be the result of fuels other than coal.

The Michigan Department of Environmental Quality (MDEQ) Air Quality Division (AQD) has requested that a human health risk assessment (HHRA) be conducted as part of the permitting process for the new boiler. The original HBPW HHRA (HBPW, 2006) focused on lead and mercury emissions and compared potential human health impacts associated with combined operation of Boiler Units 3, 4, and 5 (i.e., existing configuration) against combined operation of Boiler Units 4, 5, and 10 (i.e., future configuration). The current version of the HHRA focuses again on lead and mercury but addresses potential human health impacts associated with combined operation of Boiler Units 4, 5 and 10. The HHRA is based on current federal risk assessment guidance titled Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities released by the Office of Solid Waste (OSW) in final form in September 2005 (USEPA, 2005).

The purpose of the revised HBPW HHRA is to present, in a detailed fashion, the methods, assumptions, and some of the variable values that have been used to estimate potential health impacts on human receptors resulting from reconfiguration of the HBPW boilers. The HHRA consists of the following components:

- Facility description;
- Emissions characterization;
- Air modeling;
- Exposure assessment;
- Toxicity assessment;

- Risk characterization;
- Uncertainty Analysis; and
- Summary and Conclusions.

Potential risks have been estimated for several exposure scenarios and several identified sensitive populations. It must be emphasized that preparation of a HHRA according to current USEPA guidance provides a conservative evaluation of the potential human health risks associated with reconfiguration of the HBPW boilers. Through the incorporation of a series of reasonable maximum exposure (RME) default parameters, the HHRA is designed not to underestimate potential risks.

2.0 SITE DESCRIPTION

This section provides general information about both the HBPW James DeYoung Generating Station and the area surrounding the facility. Its purpose is several-fold, including to provide the reader with some characteristics of the combustion unit under evaluation, to provide some understanding of the surrounding land use, and to clarify the process used to identify potential receptors which have been evaluated in the HBPW HHRA.

2.1 Location and Topography

The HBPW facility is located in the southwest part of Ottawa County, Michigan. The site appears on the Holland-West, MI Quadrangle (o42086g2), United States Geological Survey (USGS) 7.5-minute topographic map.

Current HHRA guidance developed by USEPA (2005) recommends that the study area used to evaluate potential risks/hazards should extend 10-kilometers (km) in all directions from the combustion unit(s). In fact, experience indicates that the maximum impacts from combustor units tend to occur within 3-km of the emission source. Figure 2-1 shows a digitized topographic map of the area surrounding HBPW facility out to a distance of approximately 3-km. The figure represents a mosaic of several digitized topographic maps. Several features of importance to the HHRA are highlighted in Figure 2-1, including schools, surface water bodies and areas of significant population density. Also shown in Figure 2-1 is the property boundary for the HBPW facility.

Figure 2-2 provides the same coverage as Figure 2-1; however, the background represents a mosaic created from several digital orthophoto quarter-quadrangles (DOQQs), representing conditions in 1998. This figure provides additional features on land use and population density within 3-km of the facility not available from digital topographic maps. Examination of Figure 2-2 shows that land use to the north and west of the facility, comprising Holland Township, is primarily residential. The City of Holland extends from the southwest to the southeast of the facility and is also primarily residential in composition.

2.2 Demographics and Land Use

Ottawa County encompasses an area of approximately 4,227 square kilometers of which approximately 65-percent is surface water. Based on the 2000 census, the population of the county was 238,314. Ottawa County has a median household income, in 1999 dollars, of \$52,347 and a median family income of \$59,896. The per capita income was \$21,676 with 3.1 percent of families below the poverty level. The demographic

profile of Ottawa County residents, compiled during the 2000 census, is as follows:

- Caucasian (91.5 percent);
- African American (1.0 percent);
- Asian (2.1 percent);
- American Indian (0.4 percent);
- Other (3.5 percent); and
- Reporting more than one race (1.5 percent); and
- Hispanic/Latino of any race (7.0 percent).

Based on the 2000 census, the population of the City of Holland was 35,048. However, the southern portion of Holland is located in Allegan County which had a population of 105,665 in 2000. Holland had a median household income, in 1999 dollars, of \$42,291 and a median family income of \$50,316. The per capita income was \$18,823 with 6.7 percent of families below the poverty level. The demographic profile of Holland residents, compiled during the 2000 census, is as follows:

- Caucasian (78.2 percent);
- African American (2.5 percent);
- Asian (3.6 percent);
- American Indian (0.6 percent);
- Other (12.4 percent); and
- Reporting more than one race (2.7 percent); and
- Hispanic/Latino of any race (22.2 percent).

Figure 2-3 presents a zoning map for the City of Holland.

2.3 Facility and Combustion Unit Description

A full description of the HBPW James DeYoung Facility and the proposed upgrade to the facility are provided in Sections 1 and 2 of this Permit to Install Application. The information will not be repeated within the HHRA, however, if interested, the reader is referred to those sections of the application.

3.0 EMISSIONS CHARACTERIZATION

Based on discussions with the MDEQ AQD, lead and mercury are the chemicals of potential concern (COPCs) for the revised HBPW HHRA. More precisely, the goal of the revised HHRA is to evaluate the potential human health impacts associated with stack emissions generated during normal operation of Boiler Units 4, 5 and 10 following its replacement of existing Boiler Unit 3. Although the selection of COPCs for the HHRA was straightforward, the development of representative emission rates for those COPCs was somewhat more complicated. A description of the approach used is provided in the following sections.

3.1 Selection of Lead Emission Rates

In order to determine the modeled lead emission rates from each boiler, past actual data from the Michigan Air Emissions Reporting System (MAERS) reports were examined. For the calculation of potential emissions, similar emission factors were utilized for all existing boilers (Boiler Units 3, 4 and 5); it was determined that the highest emission factor (on a lb/MMBtu basis) was 1.76E-6 lb/MMBtu. The 2-year average heat input was also determined by examining the past five years of actual data for each boiler's coal consumption, and the hourly heat input represents an annual average hourly heat input (annual heat input/8,760 hours).

Lead emission estimates for new Boiler Unit 10 were based upon proximate coal analysis data for the grade of coal to be burned in the CFB and the mine from where the coal will be obtained. A control factor (i.e., 99 percent) was then applied to calculate the expected emission rate based upon the combustion design features of the CFB (i.e., limestone injection and add-on control technology including fabric filter, SNCR, and activated carbon injection). Since the permit will limit the emissions of lead on a maximum potential basis, the emission estimates used in the HHRA are conservative (i.e., actual stack emissions of lead should be lower than those evaluated in the HHRA). A summary of the lead emission estimates evaluated in the HHRA is presented in Table 3-1.

3.2 Selection of Mercury Emission Rates

Unlike most other COPCs, mercury emitted from combustor units can exist in several different chemical forms. As will be discussed in later sections of the HHRA, these different mercury species have different toxic characteristics. They also have different physicochemical characteristics which can influence their air dispersion characteristics and their susceptibility to wet and dry deposition. This requires that, where possible, the emissions of mercury be partitioned into the three forms of mercury that are known to encompass the total mercury emissions. These three forms are: vapor phase elemental mercury (Hg⁰), vapor phase divalent

mercury (Hg₂), and particle bound mercury (HgP). USEPA documentation indicates that the mercury partitioning for coal-fired utility boilers can be approximated as indicated in Table 3-2.

As requested by the MDEQ AQD, the air dispersion and deposition modeling performed for mercury used a slightly different methodology to estimate stack emission rates than that used for the estimation of lead emission rates. Instead of using past actual emission rates of mercury, the AQD requested the use of past potential emission rates determined by taking the past actual emission factor for each boiler and the multiplying it by the respective potential heat input for that boiler. Past actual data from MAERS reports were examined to determine a past actual emission factor for total mercury from each of the boilers. The emission factors (on a lb/MMBtu basis) are listed in Table 3-3 for each existing boiler. The potential hourly heat input presented for each boiler represents the hourly heat input based on each boiler's capacity.

Mercury emission estimates for new Boiler Unit 10 were determined from a rigorous case-by-case Maximum Achievable Control Technology (MACT) determination. The MACT limit for mercury was based upon a review of available test data from similar sources and an estimate of the maximum control of mercury that could be obtained by the unit's air quality control system (AQCS). See the July, 2008 Mercury MACT determination for further detail on the methodology for determining the mercury emission rate. Since the permit will limit the emissions of mercury on a maximum potential basis, the emission estimates used in the HHRA are conservative (i.e., actual stack emissions of mercury should be lower than those evaluated in the HHRA). Once the total mercury emission rate was determined for each of the boilers, these total rates were divided according to the partitioning provided in Table 3-2 to establish the emission rates of each form of mercury shown in Table 3-3.

4.0 AIR MODELING

A detailed description of the air modeling conducted in support of the HHRA has been provided in Sections 6 (i.e., Ambient Air Analysis) and 7 (Deposition Modeling Input Parameters) of the Permit to Install Application. As the HHRA is being submitted as an appendix to that application, the decision was made not to repeat that information; instead, the current section only provides information which supplements Sections 6 and 7. It must be noted again that Appendix C of the application contains detailed modeling background information and electronic files generated during the air modeling activity.

4.1 Air Modeling Output

COPC-specific AERMOD output files were generated for each of the three modeling years (i.e., 2003 through 2005). In addition, a plot (i.e., *.plt) file was generated for each run; these files contain the output data in a format which permits post-processing on a grid node-specific basis. As can be seen in Table 4-1, each line of the plot files contains output data for a discrete modeling node; the output data include the predicted air concentration, dry deposition flux, wet deposition flux and total deposition flux.

As described previously, the AERMOD runs for lead and mercury were based on actual/estimated stack emission rates (see Tables 3-1 and 3-3) rather than the default 1 g/s emission rate recommended in the HHRA guidance (USEPA, 2005). This approach was found to yield very low air concentration and deposition flux values when expressed in the default units of $\mu\text{g}/\text{m}^3$ and $\text{g}/\text{m}^2\text{-yr}$, respectively. To compensate for this problem, the AERMOD Control (CO) file was adjusted to generate air concentration and deposition flux values in units of ng/m^3 and $\mu\text{g}/\text{m}^2\text{-yr}$, respectively. Although the raw output data in the plot files are expressed in these units, they were converted to the default units for use in the HHRA.

4.1.1. Post-Processing of Output Data

The COPC-specific air modeling output plot files were averaged over the three modeling years to generate an average annual value for each output parameter at each of the 9,087 grid nodes. As each grid node is georeferenced (i.e., each has an easting and northing UTM coordinate), GIS techniques could be used to evaluate the output data. Such an approach is necessary as the grid node pattern developed for the air modeling is not uniform (see Figure 4-1) with a higher density of nodes (i.e., 25-m spacing) close to the facility and a lower density (i.e., 300-m spacing) beyond 2-km from the facility boundaries. The GIS software used in the HHRA was ArcGIS™ with its extension ArcGIS SpatialAnalyst™, developed by ESRI, Redlands, California.

One GIS approach for processing the AERMOD output data involved raster analysis. In the raster analysis conducted in support of the HBPW HHRA, a uniform raster grid (25-m by 25-m) was created covering the entire study area; each 25-m cell in the grid has known geographic (i.e., x-y) coordinates and can be assigned a z-value. For each AERMOD output parameter (e.g., air concentration of lead), spline interpolation methods were used to assign parameter values to each grid cell, resulting in a cell with x-y-z values (i.e., utm-x, utm-y and air concentration of lead (z)). Conceptually, spline interpolation is like bending a sheet of rubber to pass through all the 'z' data points while minimizing the curvature of the surface. It fits a mathematical function to a specified number of nearest input points (in this case 12 points), while passing through the sample points.

For each output parameter (e.g., air concentration of lead), the air modeling activity generated a value for each discrete grid node. Spline interpolation was then used to generate a georeferenced surface for each output parameter. To illustrate, surfaces describing the modeled air concentration of divalent mercury vapor (Hg₂) and the total deposition flux of lead are provided in Figures 4-2 and 4-3, respectively. As these surfaces are georeferenced, they can be linked to aerial photos or topographic maps to identify the locations of greatest impact (i.e., residential locations). Once these locations are identified, location-specific air modeling output parameters can be identified from the identified grid nodes or directly from the interpolated surface.

4.1.2. Evaluation of Surface Water Impacts Using Raster Analysis

Evaluation of surface water impacts using the HHRA guidance (USEPA, 2005) requires the separation of air modeling impacts on the surface water body from impacts on the watershed. The HBPW HHRA has focused on Lake Macatawa and the corresponding watershed which encompasses most of the remainder of the study area; Figure 4-4 shows the boundaries of both Lake Macatawa and its watershed. Raster analysis was used to provide the average air parameter impacts on the water body and the watershed.

The approach is relatively simple. First, two separate raster grids were created, one for Lake Macatawa (1-m by 1-m cells) and one for the watershed (25-m by 25-m cells). Each grid cell was assigned a z-value of 1 and the raster calculator in ArcGIS SpatialAnalyst™ was used to isolate that portion of each air modeling output surface which overlaps the raster grid. Figure 4-5 shows the isolated surface for the total incremental deposition flux of divalent mercury vapor (Hg₂) associated with Lake Macatawa. Statistical analysis of the isolated surface grids was used to generate the average z-value across the grid.

5.0 EXPOSURE ASSESSMENT

5.1 Introduction

The purpose of the exposure assessment is to quantify human exposure to the targeted COPCs. The routes, duration, frequency, and magnitude of potential exposures are estimated in the exposure assessment which typically comprises the following steps:

- Identification of potentially exposed populations;
- Identification of potential exposure pathways;
- Quantification of media concentrations; and
- Quantification of exposure intakes.

The available guidance specifies particular exposure scenarios that should be evaluated and provides default values for most input parameters. The guidance does allow the flexibility to use available site-specific information to refine risk estimates to better represent plausible receptors and exposure scenarios. If the final estimated risk from the HHRA is below regulatory levels of concern, additional analysis of the risks from expected stack emissions is usually considered to be unnecessary.

The evaluation endpoints selected for use in the HHRA are estimates of individual risk for several exposure scenarios and the selected exposure scenarios are considered by MDEQ AQD to be of greatest significance for emissions from the HBPW boilers. The following subsections present the exposure assessment according to the steps outlined above.

5.2 Definition of the Study Area

For the purposes of the HHRA, the study area is defined as a square area extending from Lake Michigan on the west (approximately 7.7 km from the HBPW facility center) approximately 16.3 km to the east of the facility, and approximately 8.5 km to the north and 10.4 km to the south (See Figure 5-1). This area, encompassing 453.6 km², approximates the functional boundaries of the Lake Macatawa watershed. Although potentially-sensitive human populations may reside beyond the study area, COPC air concentrations and particle/vapor deposition rates beyond that distance would typically be orders-of-magnitude lower. Consequently, the risk assessment methodology, to be used in the HHRA, should also be protective of individuals located outside of the study area.

5.3 Identification of Potentially Exposed Populations

As stack emissions disperse downwind of the stack(s), individuals may be exposed directly to COPCs via

inhalation. COPCs also may be deposited on soil, surface water, and vegetation. Consequently, individuals may be exposed indirectly to COPCs by ingesting affected soils, surface water (if used as a source of potable water), vegetation, livestock, poultry products, or fish.

5.4 Identification of Potential Exposure Pathways

An exposure pathway describes the course a COPC will take from the facility stack(s) to a potentially exposed individual. At the request of MDEQ AQD, the revised HBPW HHRA has evaluated chronic exposure to facility emissions in the following population subgroups:

- Resident child;
- Recreational fisher; and
- Recreational fisher child.

Site-specific land use information and the results of the air modeling activity have been used to identify the locations where maximum off-site incremental impacts would be expected to occur. Residential locations were selected based on existing residences, as well as on an evaluation of reasonable potential future land use. It must be noted that the only difference between the Resident Child and the Recreational Fisher Child is the consumption of fish; all other exposure pathways and intakes are identical. The Recreational Fisher and Recreational Fisher Child are assumed to live at the maximally impacted residential location and consume fish caught from the maximally impacted surface water body. As discussed previously, an evaluation of the area surrounding the facility and discussions with the AQD indicate that Lake Macatawa represents the nearest surface water body capable of supporting a recreational fishery.

Examination of the results of the air modeling (see Figures 5-2 through 5-9) indicated that the areas of highest incremental impact from both lead and mercury (all forms) occurred within a relatively short distance (i.e., within 850-m) from the facility. Based on those results and the current land use, the area selected as the residential location for the HHRA is located to the northeast of the James DeYoung Plant. It is bounded on the south by W 1st Street and is zoned C-1 (neighborhood commercial). Even though this zoning permits residential usage (Holland, 2006), there are currently very few residents living within the selected area. Table 5-1 summarizes the air modeling results for lead and mercury within the selected residential area. To be conservative, the highest modeled air parameter output values within the C-1 zone were selected even if the selected values were not co-located (USEPA, 2005). The maximum lead and mercury impact locations were approximately 128-m apart.

The receptors described above could potentially be exposed to COPCs via both direct and indirect pathways. A discussion of these pathways is presented in the following sections.

5.4.1. Direct Exposures

Individuals may be exposed directly to emitted COPCs by inhaling vapors and particulates released to the air. The direct exposure pathway will be evaluated for all targeted receptors.

5.4.2. Indirect Exposures

The potentially exposed population subgroups requested by the AQD may be exposed indirectly to COPCs by ingesting media affected by stack emissions. The following indirect exposure pathways are currently recommended in USEPA HHRA guidance for quantitative evaluation in the HHRA (USEPA, 2005):

- Incidental ingestion of surface soil [all receptors];
- Consumption of drinking water [all receptors, where applicable];
- Consumption of above-ground produce [all receptors];
- Consumption of below-ground (root) produce [all receptors]; and
- Consumption of locally-caught fish [Fisher receptors only].

COPCs could potentially be deposited on area soils via wet and dry particle deposition, wet and dry deposition of vapors, and diffusion of vapor. Individuals may be exposed indirectly to COPCs through incidental ingestion of affected surface soil. Such exposures are most significant for younger children, who may come in contact with the soil when playing outdoors. Individuals may also be exposed to COPCs in soil while handling outdoor pets, gardening, or engaging in other outdoor activities. All receptors are assumed to be exposed to COPCs through this exposure pathway.

Consumption of affected food is an additional indirect exposure pathway to COPCs. COPCs could be deposited on homegrown produce within the study area and/or COPCs may be taken up from the soil directly into plants. The Recreational Fisher and Recreational Fisher Child may also be exposed to COPCs indirectly by consuming fish that bioaccumulate COPCs which deposit on watershed soils and migrate to sediments and surface waters.

Receptors may also be exposed to COPCs in surface water, if the impacted surface water is used as a drinking water source. The City of Holland obtains its municipal water supply from Lake Michigan. The Holland Water Filtration Plant, a 38.5 million-gallon per day facility, is located seven miles northwest of the

City of Holland with its water intake located 4,700 feet from shore. Exposure of area residents to emitted COPCs via consumption of drinking water is considered to be insignificant. As a consequence, this pathway has not been included in the revised HBPW HHRA.

According to USEPA guidance, the potential transport of COPCs from combustion facilities into groundwater is considered to be insignificant compared to the other exposure pathways (USEPA, 2005). Dermal contact with surface water and soil was also not considered in the HHRA, as current USEPA guidance indicates that dermal contact is likely to be much less significant than ingestion pathways (USEPA, 2005). The derivation of expected COPC concentrations in area soils, produce, surface water and fish is presented in Section 5.5.

5.5 Quantification of Media Concentrations

This section describes the approaches to be used in the HHRA to estimate media COPC concentrations; included are the modeling procedures used to estimate COPC concentrations in air, soil, homegrown produce, surface water, and fish. Exposure estimates have been based primarily on USEPA HHRA guidance (USEPA, 2005). It should be noted that, under this guidance, different algorithms are recommended for the estimation of soil concentrations of carcinogenic and non-carcinogenic COPCs. As mercury and lead are both considered by USEPA to be non-carcinogenic, none of the algorithms relevant to carcinogenic COPCs are presented in the following sections. Table 5-2 summarizes the fate and transport parameters used in the following section to estimate media COPC concentrations.

5.5.1. Air Concentration Modeling

Air concentrations were derived from both the average annual vapor-phase and particulate-phase concentrations in air (see Section 4). Inhalation exposures are assumed to occur only for the operational life of the boilers (estimated to be 30 years). When the air modeling is based on a unit emission rate (i.e., 1 g/s), air concentrations are calculated using the following equation [See Table B-5-1 from USEPA, 2005]:

$$C_a = Q \cdot [F_v \cdot C_{yv} + (1.0 - F_v) \cdot C_{yp}]$$

[Equation 5-1]

where:

- | | | |
|----------|---|---|
| C_a | = | COPC air concentration ($\mu\text{g}/\text{m}^3$); |
| Q | = | COPC stack emission rate (g/s); |
| F_v | = | COPC fraction in vapor phase (unitless); |
| C_{yv} | = | Normalized air concentration-vapor phase COPC ($\mu\text{g}\cdot\text{s}/\text{g}\cdot\text{m}^3$); and |
| C_{yp} | = | Normalized air concentration-particle phase COPC ($\mu\text{g}\cdot\text{s}/\text{g}\cdot\text{m}^3$). |

In the HBPW HHRA actual/estimated COPC emission rates have been modeled which means that the above equation needed to be modified as follows:

$$C_a = F_v \cdot C_{yv} + (1.0 - F_v) \cdot C_{yp}$$

[Equation 5-2]

where:

- C_a = COPC air concentration ($\mu\text{g}/\text{m}^3$);
- F_v = COPC fraction in vapor phase (unitless);
- C_{yv} = Air concentration-vapor phase COPC ($\mu\text{g}/\text{m}^3$); and
- C_{yp} = Air concentration-particle phase COPC ($\mu\text{g}/\text{m}^3$).

Note that the units for C_{yv} and C_{yp} are changed in Equation 5-2. In the revised HBPW HHRA, lead is assumed to exist completely in the particle phase (i.e., $F_v = 0$), further simplifying Equation 5-2. Vapor phase mercury (Hg_2 and Hg_0) and particle(-bound) phase mercury (HgP) were each modeled separately which also simplifies the equation. It must be remembered from Section 4 that the modeling of Hg_2 represents divalent mercury (Hg^{+2}) in the vapor phase, Hg_0 represents elemental mercury (Hg^0) in the vapor phase and HgP represents divalent mercury (Hg^{+2}) in the particle-bound phase. The resulting air concentrations for mercury and lead at the selected residential location are summarized in Table 5-3.

5.5.2. Soil Concentration Modeling

Emissions from the boilers can be deposited onto the soil surface by dry and wet deposition of particulates and vapors. Concentrations of COPCs in surface soils have been calculated to permit estimation of COPC intake from incidental soil ingestion. Soil concentrations in targeted area watersheds have also been calculated to permit estimation of water body and fish tissue COPC concentrations.

AERMOD was used to estimate air concentrations and deposition flux rates for each COPC, as previously described in Section 4. Soil concentrations were then developed at selected receptor locations. Soil concentrations are a function of the COPC-specific deposition term, which includes COPC-specific parameters and modeled stack emission and dispersion/deposition rates. COPC concentrations in surface soil were calculated based on a mixing depth of 2-cm and continuous operation of the boiler(s) for 30 years; COPC concentrations in tilled soil were based on a mixing depth of 20-cm (i.e., 7-inches) (USEPA, 2005). Tilled soil concentrations are used to estimate the uptake of COPCs into both root vegetables and above-ground produce.

Soil concentrations for non-carcinogenic COPCs are based on the deposition term (Ds) which is calculated using the following equation [i.e., See Table B-1-1 from USEPA, 2005]:

$$D_s = \frac{UCF \cdot Q}{z \cdot BD} \cdot [F_v (Dy_{dv} + Dy_{wv}) + (Dy_{dp} + Dy_{wp}) \cdot (1 - F_v)]$$

[Equation 5-3]

where:

Ds	=	Deposition term (mg/kg-yr);
Q	=	COPC stack emission rate (g/s);
Fv	=	COPC fraction in vapor phase (unitless);
Dy _{dv}	=	Normalized annual dry deposition flux-vapor phase COPCs (s/m ² -yr);
Dy _{wv}	=	Normalized annual wet deposition flux-vapor phase COPCs (s/m ² -yr);
Dy _{dp}	=	Normalized annual dry deposition flux-particle phase COPCs (s/m ² -yr);
Dy _{wp}	=	Normalized annual wet deposition flux-particle phase COPCs (s/m ² -yr);
z	=	Soil mixing depth (cm);
BD	=	Soil bulk density (g/cm ³); and
UCF	=	Units conversion factor (100 mg-m ² /kg-cm ²).

Again, the nature of the air modeling conducted for the revised HBPW HHRA requires that Equation 5-3 be modified to account for actual/estimated COPC emission rates being modeled rather than the default unit (i.e., 1 g/s) emission rate. This modification results in the following equation:

$$D_s = \frac{UCF}{z \cdot BD} \cdot [F_v (Dy_{dv} + Dy_{wv}) + (Dy_{dp} + Dy_{wp}) \cdot (1 - F_v)]$$

[Equation 5-4]

where:

Ds	=	Deposition term (mg/kg-yr);
Fv	=	COPC fraction in vapor phase (unitless);
Dy _{dv}	=	Annual dry deposition flux-vapor phase COPCs (g/m ² -yr);
Dy _{wv}	=	Annual wet deposition flux-vapor phase COPCs (g/m ² -yr);
Dy _{dp}	=	Annual dry deposition flux-particle phase COPCs (g/m ² -yr);
Dy _{wp}	=	Annual wet deposition flux-particle phase COPCs (g/m ² -yr);
z	=	Soil mixing depth (cm);
BD	=	Soil bulk density (g/cm ³); and
UCF	=	Units conversion factor (100 mg-m ² /kg-cm ²).

Note that the units for Dy_{dv}, Dy_{wv}, Dy_{dp} and Dy_{wp} are changed in Equation 5-4. In the revised HBPW HHRA, lead is assumed to exist completely in the particle phase (i.e., F_v = 0), further simplifying Equation 5-4. Vapor phase mercury (Hg₂ and Hg₀) and particle(-bound) phase mercury (HgP) were each modeled

separately which also simplifies the equation. The values calculated for Ds in tilled and untilled soil are summarized in Table 5-4. It should be noted that, under existing HHRA guidance (USEPA, 2005), the assumption is made that 2-percent of the divalent mercury deposition (Ds) in residential soils exists as methylmercury (MeHg).

For the estimation of soil concentrations of non-carcinogenic COPCs, the following equation has been used [i.e., See Table B-1-1 from USEPA, 2005]:

$$C_{S_{tD}} = \frac{D_s \cdot (1 - \exp(-k_s \cdot tD))}{k_s}$$

[Equation 5-5]

where:

- $C_{S_{tD}}$ = Soil COPC concentration at time tD (mg/kg);
- k_s = Soil loss constant (yr^{-1}); and
- tD = Time period over which deposition occurs (yr).

Estimated COPC concentrations in tilled and untilled residential soils are summarized in Table 5-5. In Equation 5-5, the soil loss constant term, k_s , reflects the loss of COPCs from soil due to leaching, degradation, erosion, volatilization, and surface runoff and is calculated using the following equation [i.e., See table B-1-2 from USEPA, 2005]:

$$k_s = k_{sl} + k_{sr} + k_{sg} + k_{sv} + k_{se}$$

[Equation 5-6]

where:

- k_s = Soil loss constant due to all processes (yr^{-1});
- k_{sl} = Soil loss constant due to leaching (yr^{-1});
- k_{sr} = Soil loss constant due to surface runoff (yr^{-1});
- k_{sg} = Soil loss constant due to degradation (yr^{-1});
- k_{sv} = Soil loss constant due to volatilization (yr^{-1}); and
- k_{se} = Soil loss constant due to soil erosion (yr^{-1}).

Estimated values for the soil loss constant (k_s) are summarized in Table 5-6 and the calculations for the individual soil loss constants are described in the following sections.

Soil loss due to leaching (Table 5-7) was estimated using the following equation [i.e., See Table B-1-5 from USEPA, 2005]:

$$ksl = \frac{P + I - RO - E_v}{z \cdot (\theta_{sw} + Kd_s \cdot BD)}$$

[Equation 5-7]

where:

ksl	=	Soil loss coefficient due to leaching (yr ⁻¹);
P	=	Annual average precipitation (cm/yr);
I	=	Annual average irrigation (cm/yr);
E _v	=	Annual average evapotranspiration (cm/yr);
RO	=	Annual average runoff (cm/yr);
θ _{sw}	=	Soil volumetric water content (mL/cm ³);
z	=	Soil mixing depth (cm);
BD	=	Bulk soil density (g/cm ³); and
Kd _s	=	Soil-to-water partition coefficient (mL/g).

Soil loss from surface runoff (Table 5-8) was estimated using the following equation [i.e., See Table B-1-4 from USEPA, 2005]:

$$ksr = \frac{RO}{z \cdot (\theta_{sw} + Kd_s \cdot BD)}$$

[Equation 5-8]

where:

ksr	=	Soil loss coefficient due to surface runoff (yr ⁻¹);
RO	=	Annual average runoff (cm/yr);
θ _{sw}	=	Soil volumetric water content (mL/cm ³);
z	=	Soil mixing depth (cm);
BD	=	Bulk soil density (g/cm ³); and
Kd _s	=	Soil-to-water partition coefficient (mL/g).

Default values for the soil loss constant due to degradation are provided in the current guidance (USEPA, 2005).

There is considerable controversy concerning whether or not the soil loss constant due to erosion (kse) should be included in the estimation of ks. Current HHRA guidance indicates that kse should be set equal to zero (USEPA, 2005), based on the argument that impacted soils erode both onto and away from any targeted area with no net impact. This might not always be the case, particularly at sites with elevated terrain. In the HBPW HHRA, the decision was made to set kse equal to zero, a conservative approach.

The soil loss constant due to volatilization (Table 5-9) was estimated using the following equation [i.e., See Table B-1-6 from USEPA, 2005]:

$$k_{sv} = \left[\frac{UCF \cdot H}{z \cdot Kd_s \cdot R \cdot T_a \cdot BD} \right] \cdot \left[\frac{D_a}{z} \cdot \left(1 - \left(\frac{BD}{\rho_s} \right) - \theta_{sw} \right) \right]$$

[Equation 5-9]

where:

k_{sv}	=	Soil loss constant due to volatilization (yr^{-1});
UCF	=	Units conversion factor (3.1536×10^7 s/yr);
H	=	Henry's law constant ($atm \cdot m^3/mol$);
Kd_s	=	Soil-water partitioning coefficient (cm^3/g);
R	=	Universal gas constant ($atm \cdot m^3/mol \cdot ^\circ K$);
T_a	=	Ambient air temperature ($^\circ K$);
BD	=	Soil bulk density (g/cm^3);
D_a	=	Diffusivity of contaminant in air (cm^2/s);
z	=	Soil mixing depth (cm);
ρ_s	=	Solids particle density (g/cm^3); and
θ_{sw}	=	Volumetric soil water content (mL/cm^3).

Although this same series of equations was used for tilled soil, it should be noted that the value for soil mixing depth (z) is different; a soil mixing depth of 20-cm is used for tilled soil. The equations used to calculate the soil loss constants k_{sl} and k_{sr} take the soil mixing depth into account resulting in different k_s values.

5.5.3. Above-Ground Plant Concentration Modeling

Above-ground plants are defined as those plants whose edible portion is above the ground surface (USEPA, 2005). COPCs may be transported to above-ground plants through direct deposition of particulates onto exposed plant surfaces, by transfer of vapor directly into the plant tissue (i.e., air-to-leaf transfer), and through the uptake of COPCs in soil through the roots.

The concentration of COPCs in above-ground plants due to direct deposition is estimated using the following equation [i.e., See Table B-2-7 from USEPA, 2005]:

$$Pd = \frac{UCF \cdot Q \cdot (1 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

[Equation 5-10]

where:

Pd	=	COPC concentration in plant due to direct deposition (mg/kg DW);
Q	=	COPC stack emission rate (g/s);
Dydp	=	Normalized annual dry deposition flux-particle phase COPCs ($s/m^2 \cdot yr$);
Dywp	=	Normalized annual wet deposition flux-particle phase COPCs ($s/m^2 \cdot yr$);
Fw	=	Fraction of wet deposition that adheres to plant surfaces (unitless);

- Fv = COPC fraction in vapor phase (unitless);
- Rp = Interception fraction of the edible portion of plant tissue (unitless);
- kp = Plant surface loss coefficient (yr⁻¹);
- Tp = Length of plant's exposure to deposition per harvest (yr);
- Yp = Yield of edible portion of the plant (kg DW/m²); and
- UCF = Units conversion factor (10³ mg/g).

Again, the nature of the air modeling conducted for the revised HBPW HHRA requires that Equation 5-10 be modified to account for actual/estimated COPC emission rates being modeled rather than the default unit (i.e., 1 g/s) emission rate. This modification results in the following equation:

$$Pd = \frac{UCF \cdot (1 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

[Equation 5-11]

where:

- Pd = COPC concentration in plant due to direct deposition (mg/kg DW);
- Dydp = Annual dry deposition flux-particle phase COPCs (g/m²-yr);
- Dywp = Annual wet deposition flux-particle phase COPCs (g/m²-yr);
- Fw = Fraction of wet deposition that adheres to plant surfaces (unitless);
- Fv = COPC fraction in vapor phase (unitless);
- Rp = Interception fraction of the edible portion of plant tissue (unitless);
- kp = Plant surface loss coefficient (yr⁻¹);
- Tp = Length of plant's exposure to deposition per harvest (yr);
- Yp = Yield of edible portion of the plant (kg DW/m²); and
- UCF = Units conversion factor (10³ mg/g).

For the modeling of mercury, Equation 5-11 was also used to calculate Pd, however, consistent with current USEPA guidance, the resulting Pd value was then apportioned into divalent mercury (78-percent) and methyl mercury (22-percent). Table 5-10 summarizes the modeled COPC concentrations in plants resulting from direct deposition.

The concentration of COPCs in above-ground plants due to direct uptake of vapor phase chemical (Pv) is estimated using the following equation [i.e., See Table B-2-8 from USEPA, 2005]:

$$Pv = Q \cdot F_v \cdot \frac{C_{yv} \cdot Bv \cdot VG_{ag}}{\rho_a}$$

[Equation 5-12]

where:

- Pv = COPC concentration in plant due to air-to-plant transfer (mg/kg DW);
- Q = COPC stack emission rate (g/s);
- Fv = COPC fraction in vapor phase (unitless);

- Cyv = Normalized air concentration-vapor phase COPC ($\mu\text{g}\cdot\text{s}/\text{g}\cdot\text{m}^3$);
- VG_{ag} = Empirical correction factor for above-ground plants (unitless);
- Bv = Air-plant biotransfer factor ($[\text{mg COPC}/\text{kg plant DW}]/[\mu\text{g COPC}/\text{g air}]$); and
- ρ_a = Density of air (g/m^3).

Again, the nature of the air modeling conducted for the revised HBPW HHRA requires that Equation 5-12 be modified to account for actual/estimated COPC emission rates being modeled rather than the default unit (i.e., 1 g/s) emission rate. This modification results in the following equation:

$$P_v = \frac{F_v \cdot C_{yv} \cdot B_v \cdot V_{G_{ag}}}{\rho_a}$$

[Equation 5-13]

where:

- Pv = Concentration of COPC in plant due to air-to-plant transfer (mg/kg DW);
- Fv = COPC fraction in vapor phase (unitless);
- Cyv = Air concentration-vapor phase COPC ($\mu\text{g}/\text{m}^3$);
- VG_{ag} = Empirical correction factor for above-ground plants (unitless);
- Bv = Air-plant biotransfer factor ($[\text{mg COPC}/\text{kg plant DW}]/[\mu\text{g COPC}/\text{g air}]$); and
- ρ_a = Density of air (g/m^3).

For the modeling of mercury, Equation 5-13 was also used to calculate Pv. However, consistent with current USEPA guidance, the resulting Pv value was then apportioned into divalent mercury (78-percent) and methyl mercury (22-percent). Table 5-11 summarizes the modeled COPC concentrations in plants resulting from air-to-plant transfer.

The concentration of COPCs in above-ground plants due to direct uptake from soil (Pr) was estimated using the following equation [i.e., See Table B-2-9 from USEPA, 2005]:

$$Pr_{ag} = Cs \cdot Br_{ag}$$

[Equation 5-14]

where:

- Pr_{ag} = COPC concentration in above-ground plant due to direct uptake from soil (mg/kg DW);
- Cs = Soil COPC concentration (mg/kg); and
- Br_{ag} = Plant-soil bioconcentration factor for above-ground produce ($[\text{mg COPC}/\text{kg plant DW}]/[\text{mg COPC}/\text{kg soil}]$).

Equation 5-14 was also used to model mercury concentrations in above-ground plants resulting from root uptake; it is calculated using the C_s and Br_{ag} values for divalent mercury (Hg^{+2}) and methylmercury (MeHg), respectively. COPC-specific Pr values are summarized in Table 5-12.

5.5.4. Below-Ground Plant Concentration Modeling

Below-ground plants are defined as those plants, such as carrots and potatoes, whose edible portion is below the ground surface, (USEPA, 2005). Contamination of below-ground plants via direct deposition of particles and vapor transfer is not considered, because the root (or tuber) is protected from direct contact with airborne COPCs. Below-ground plant COPC concentrations depend on the tilled soil concentrations at the locations of interest and are estimated using the following equation [i.e., See Table B-2-10 from USEPA, 2005]:

$$Pr_{bg} = Cs \cdot Br_{rveg} \cdot VG_{rveg} \quad \text{[Equation 5-15]}$$

where:

Pr_{bg}	=	COPC concentration in below-ground plant due to direct uptake from soil (mg/kg DW);
C_s	=	Soil COPC concentration (mg/kg);
Br_{rveg}	=	Plant-soil bioconcentration factor = RCF/Kd_s produce ([mg COPC/kg plant DW]/[mg COPC/kg soil]);
RCF	=	Root concentration factor (unitless);
VG_{rveg}	=	Empirical correction factor for below-ground plants (unitless); and
Kd_s	=	Soil-water partition coefficient (cm^3/g).

Under current HHRA guidance (USEPA, 2005), a below-ground vegetable correction factor (VG_{rveg}) of 0.01 is used in the calculation of Pr_{bg} for all organic COPCs with $\log K_{OW}$ values equal to or greater than 4. A correction value of 1.0 is used for organic COPCs with $\log K_{OW}$ less than 4 and for metals. COPC-specific Pr_{bg} values are summarized in Table 5-13.

5.5.5. Surface Water and Edible Fish Tissue Concentration Modeling

As the calculation of surface water concentrations is a precursor to the calculation of fish tissue concentrations, these processes are described together. First, the average concentration of COPCs throughout the selected watershed was calculated; COPC loading to the water body was calculated next. Pathways contributing to water body load include:

- Direct deposition;
- Runoff from impervious watershed surfaces;
- Runoff from pervious watershed surfaces;

- Vapor phase diffusion of COPCs; and
- Soil erosion from the watershed.

Table 5-14 summarizes the air modeling results for lead and mercury associated with Lake Macatawa and its watershed. The values represent impacts associated with emissions from Boiler Units 4, 5 and 10 following replacement of Boiler Unit 3 with Boiler Unit 10. Consistent with the HHRA guidance (USEPA, 2005), those impacts represent average parameter values determined for the selected water body and watershed areas. Table 5-15 summarizes the fate and transport parameters used in the modeling of COPC movement in Lake Macatawa and its watershed as described in the following sections.

The equation used to calculate watershed soil concentrations for non-carcinogenic COPCs uses the deposition term (Ds) calculated using the following equation adapted from Equation 5-4:

$$D_s = \frac{UCF}{z \cdot BD} \cdot [F_v (D_{ytwv}) + (D_{ytwp}) \cdot (1 - F_v)]$$

[Equation 5–16]

where:

- | | | |
|-------|---|--|
| Ds | = | Watershed deposition term (mg/kg-yr); |
| Fv | = | COPC fraction in vapor phase (unitless); |
| Dytwv | = | Annual average total deposition flux onto watershed-vapor phase COPCs (g/m ² -yr); |
| Dytwp | = | Annual average total deposition flux onto watershed-particle phase COPCs (g/m ² -yr); |
| z | = | Soil mixing depth (cm); |
| BD | = | Soil bulk density (g/cm ³); and |
| UCF | = | Units conversion factor (100 mg-m ² /kg-cm ²). |

The values calculated for Ds in watershed soil are summarized in Table 5-16. It should be noted that, under the existing HHRA guidance (USEPA, 2005), the assumption is made that 2-percent of the divalent mercury deposition (Ds) onto watershed soils exists as methylmercury (MeHg).

For the estimation of watershed soil concentrations of non-carcinogenic COPCs, the following equation has been used:

$$C_{s,tD} = \frac{D_s \cdot (1 - \exp (-ks \cdot tD))}{ks}$$

[Equation 5-17]

where:

- CS_{tD} = Watershed soil COPC concentration at time tD (mg/kg);
- ks = Soil loss constant (yr⁻¹); and
- tD = Time period over which deposition occurs (yr).

Estimated COPC concentrations in watershed soils are summarized in Table 5-17. As before, the soil loss constant term (ks), described by Equation 5-6, reflects the loss of COPCs from soil due to leaching, degradation, erosion, volatilization, and surface runoff. The watershed soil loss values for leaching (ksl), degradation (ksg), volatilization (ksv) and surface runoff (ksr) are identical to those calculated for untilled residential soils (see Tables 5-18 through 5-20). In contrast to the situation with residential soils, where the soil loss constant due to erosion (kse) was set equal to zero, in watershed soils kse was calculated using the following equation [i.e., See Table B-1-3 from USEPA, 2005]:

$$kse = \frac{0.1 \cdot X_e \cdot SD \cdot ER}{BD \cdot z} \cdot \left(\frac{Kd_s \cdot BD}{\theta_{sw} + (Kd_s \cdot BD)} \right)$$

[Equation 5-18]

where:

- kse = Soil loss coefficient due to erosion (yr⁻¹);
- X_e = Unit soil loss (kg/m²-yr);
- SD = Sediment delivery ratio (unitless);
- ER = Soil enrichment ratio (unitless);
- θ_{sw} = Soil volumetric water content (mL/cm³);
- z = Soil mixing depth (cm);
- BD = Bulk soil density (g/cm³); and
- Kd_s = Soil-to-water partition coefficient (mL/g).

Table 5-21 summarizes the values calculated for kse in watershed soils; the composite values for ks are summarized in Table 5-22.

The total COPC load (L_T) to Lake Macatawa was calculated using the following equation [i.e., See Table B-4-7 from USEPA, 2005]:

$$L_T = L_{Dep} + L_{Dif} + L_{RI} + L_R + L_E + L_I$$

[Equation 5-19]

where:

- L_T = Total COPC load to the surface water body (g/yr);
- L_{dep} = Total particle phase and wet vapor phase deposition to water body (g/yr);
- L_{dif} = Vapor phase diffusion load to water body (g/yr);
- L_{RI} = Runoff load to water body from impervious surfaces (g/yr);
- L_R = Runoff load to water body from pervious surfaces (g/yr);

L_E = Soil erosion load to water body (g/yr); and
 L_I = Internal transfer (g/yr).

Current HHRA guidance (USEPA, 2005) recommends using a default value of zero for L_I unless site-specific conditions indicate a need to consider internal transfer. As described previously, the air modeling conducted for the revised HBPW HHRA has been based on actual/estimated COPC emission rates rather than the default unit (i.e., 1 g/s) emission rate. As a consequence, the following equations describing the estimation of L_{dep} , L_{dif} and L_{RI} were modified from the equations found in the HHRA guidance (USEPA, 2005).

Table 5-23 describes the wet and dry deposition of particle-phase and vapor-phase COPCs (L_{Dep}) directly onto the surface of Lake Macatawa. It was estimated using the following equation [i.e., modified Table B-4-8 from USEPA, 2005]:

$$L_{Dep} = [F_v \cdot Dytwv + (1 - F_v) \cdot Dytwp] \cdot A_w \quad \text{[Equation 5-20]}$$

where:

L_{dep} = Total particle phase and wet vapor phase deposition to water body (g/yr);
 F_v = COPC fraction in vapor phase (unitless);
 $Dytwv$ = Annual average total (wet and dry) deposition flux onto surface water body-vapor phase COPCs (g/m^2 -yr);
 $Dytwp$ = Annual average total (wet and dry) deposition flux onto surface water body-particle phase COPCs (g/m^2 -yr); and
 A_w = Total water body surface area (m^2).

Table 5-24 describes COPC vapor-phase diffusion loading (L_{Dif}) directly onto the surface of Lake Macatawa. It was estimated using the following equation [i.e., modified Table B-4-12 from USEPA, 2005]:

$$L_{Dif} = \frac{K_v \cdot F_v \cdot C_{yww} \cdot A_w \cdot UCF}{\frac{H}{R \cdot T_{wk}}} \quad \text{[Equation 5-21]}$$

where:

L_{dif} = Vapor phase diffusion load of COPCs to water body (g/yr);
 K_v = Diffusion mass transfer coefficient (m/yr);
 F_v = COPC fraction in vapor phase (unitless);
 C_{yww} = Annual average air concentration over water body-vapor phase COPCs ($\mu g/m^3$);
 A_w = Water body surface area (m^2);
 H = Henry's law constant ($atm \cdot m^3/mol$);
 R = Universal gas law constant ($atm \cdot m^3/mol \cdot ^\circ K$);

T_{wk} = Water body temperature (°K); and
UCF = Units conversion factor (10^{-6} g/μg).

Table 5-25 describes COPC runoff loading to Lake Macatawa from impervious watershed surfaces (L_{RI}). It was estimated using the following equation [i.e., See Table B-4-9 from USEPA, 2005]:

$$L_{RI} = [F_v \cdot Dytwv + (1 - F_v) \cdot Dytwp] \cdot A_i \quad \text{[Equation 5-22]}$$

where:

L_{RI} = Runoff load to water body from impervious surfaces (g/yr);
 F_v = COPC fraction in vapor phase (unitless);
 $Dytwv$ = Annual average total (wet and dry) deposition onto watershed-vapor phase COPCs (g/m^2 -yr);
 $Dytwp$ = Annual average total (wet and dry) deposition onto watershed-particle phase COPCs (g/m^2 -yr); and
 A_i = Impervious watershed area (m^2).

Table 5-26 describes COPC runoff loading to Lake Macatawa from pervious watershed soil surfaces (L_R). It was estimated using the following equation [i.e., See Table B-4-9 from USEPA, 2005]:

$$L_R = RO \cdot (A_L - A_i) \cdot \frac{Cs \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot UCF \quad \text{[Equation 5-23]}$$

where:

L_R = Runoff load to water body from pervious surfaces (g/yr);
RO = Average annual runoff from pervious areas (cm/yr);
 A_L = Total watershed area receiving COPC deposition (m^2);
 A_i = Impervious watershed area receiving chemical deposition (m^2);
Cs = Average COPC concentration in watershed soils (mg/kg);
BD = Soil bulk density (g/cm^3);
 θ_{sw} = Volumetric soil water content (cm^3/cm^3);
 Kd_s = Soil-water partition coefficient (L/kg); and
UCF = Unit conversion factor (10^{-2} kg-cm²/mg-m²).

Table 5-27 describes COPC loading to Lake Macatawa resulting from watershed soil erosion (L_E). It was calculated using the following equation [i.e., See Table B-4-11 from USEPA, 2005]:

$$L_E = X_e \cdot (A_L - A_i) \cdot SD \cdot ER \cdot \frac{Cs \cdot Kd_s \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot UCF \quad \text{[Equation 5-24]}$$

where:

L_E	=	Soil erosion load of COPCs to water body (g/yr);
X_e	=	Unit soil loss (kg/m ² -yr);
A_L	=	Total watershed area receiving COPC deposition (m ²);
A_I	=	Impervious watershed area receiving COPC deposition (m ²);
SD	=	Watershed sediment delivery ratio (unitless);
ER	=	Soil enrichment ratio (unitless);
Cs	=	Average COPC concentration in watershed soils (mg/kg);
BD	=	Soil bulk density (g/cm ³);
θ_{SW}	=	Volumetric soil water content (cm ³ /cm ³);
K_d_s	=	Soil-water partition coefficient (L/kg); and
UCF	=	Unit conversion factor (10 ⁻³ [g/kg]/[mg/kg]).

Table 5-28 shows the values estimated for the unit soil loss (X_e) term and watershed sediment delivery ratio (SD) as used in the above equation. They were calculated using the following equations [i.e., See Tables B-4-13 and B-4-14 from USEPA, 2005]:

$$X_e = RF \cdot K \cdot LS \cdot C \cdot PF \cdot \frac{UCF_1}{UCF_2}$$

[Equation 5-25]

where:

X_e	=	Unit soil loss (kg/m ² -yr);
RF	=	USLE rainfall factor (yr ⁻¹);
K	=	USLE erodibility factor (ton/acre);
LS	=	USLE length-slope factor (unitless);
C	=	USLE cover management factor (unitless);
PF	=	USLE supporting practice factor (unitless);
UCF_1	=	Unit conversion factor (907.18 kg/ton); and
UCF_2	=	Unit conversion factor (4047 m ² /acre).

and

$$SD = a \cdot (A_L)^b$$

[Equation 5-26]

where:

SD	=	Watershed sediment delivery ratio (unitless);
a	=	Empirical intercept coefficient (unitless);
A_L	=	Total watershed area receiving COPC deposition (m ²); and
b	=	Empirical slope coefficient (unitless).

The total COPC loading to Lake Macatawa (L_T) based on Equation 5-19 is summarized in Table 5-29. It should be noted that the loading of methylmercury is limited to erosion (L_E) and runoff from pervious surfaces (L_R). Both are based on watershed soil methylmercury concentrations and, under current HHRA guidance

(USEPA, 2005), it is assumed that 2-percent of the divalent mercury deposited onto the watershed soils is converted to methylmercury.

The total water body COPC concentration (C_{wtot}), including the water column and sediments, is calculated from the total water body load. C_{wtot} can then be partitioned into a dissolved water concentration, a total water column concentration, and a bed sediment concentration. The total water body concentration for each COPC is presented in Table 5-30. It was calculated using the following equation [i.e., See Table B-4-15 from USEPA, 2005]:

$$C_{wtot} = \frac{L_T}{Vf_x \cdot f_{wc} + k_{wt} \cdot A_W \cdot (d_{wc} + d_{bs})} \quad \text{[Equation 5-27]}$$

where:

- C_{wtot} = Total water body COPC concentration, including water column and bed sediment (mg/L);
- L_T = Total COPC load into water body, including deposition, diffusion, runoff, and erosion (g/yr);
- Vf_x = Average volumetric flow rate through water body (m^3/yr);
- f_{wc} = Fraction of total water body chemical concentration that occurs in the water column (unitless);
- A_W = Total water body surface area (m^2);
- d_{wc} = Depth of the water column (m);
- d_{bs} = Depth of the upper benthic layer (m); and
- k_{wt} = Total water body dissipation rate constant (yr^{-1}).

In the above equation, values for f_{wc} and k_{wt} were calculated using the following equations [i.e., See Tables B-4-16 and B-4-17 from USEPA, 2005] and the estimated values are presented in Tables 5-31 and 5-32:

$$f_{wc} = \frac{(1 + Kd_{sw} \cdot TSS \cdot UCF) d_{wc} / d_z}{d_{wc} / d_z (1 + Kd_{sw} \cdot TSS \cdot UCF) + d_{bs} / d_z (\theta_{bs} + Kd_{bs} \cdot C_{BS})} \quad \text{[Equation 5-28]}$$

where:

- f_{wc} = Fraction of total water body COPC concentration that occurs in water column (unitless);
- Kd_{sw} = Suspended sediment/surface water partition coefficient (L/kg);
- Kd_{bs} = Bed sediment/sediment pore water partition coefficient (cm^3/g);
- TSS = Total suspended solids (mg/L);
- UCF = Unit conversion factor (10^{-6} kg/mg);
- θ_{bs} = Bed sediment porosity (unitless);
- d_{wc} = Depth of water column (m);
- d_{bs} = Depth of the upper benthic layer (m);

d_z = Total water body depth (m); and
 C_{BS} = Bed sediment concentration (g/cm^3).

and

$$k_{wt} = f_{wc} \cdot k_v + f_{bs} \cdot k_b$$

[Equation 5-29]

where:

k_{wt} = Overall total water body dissipation rate (yr^{-1});
 f_{wc} = Fraction of total COPC concentration in water column (unitless);
 k_v = Water column volatilization rate (yr^{-1});
 f_{bs} = Fraction of total COPC concentration in benthic sediment (unitless);
and
 k_b = Benthic burial rate (yr^{-1}).

Several factors are required in order to solve Equation 5-29. The benthic burial rate (k_b), shown in Table 5-33 was estimated using the following equation [i.e., See Table B-4-22 from USEPA, 2005]:

$$k_b = \left(\frac{X_e \cdot A_L \cdot SD \cdot UCF_1 - V_{f_x} \cdot TSS}{A_w \cdot TSS} \right) \cdot \left(\frac{TSS \cdot UCF_2}{C_{BS} \cdot d_{bs}} \right)$$

[Equation 5-30]

where:

k_b = Benthic burial rate constant (yr^{-1});
 X_e = Unit soil loss ($kg/m^2/yr$);
 A_L = Total watershed area receiving fallout (m^2);
 SD = Watershed sediment delivery ratio (unitless);
 UCF_1 = Units conversion factor ($10^3 g/kg$);
 V_{f_x} = Average volumetric flow rate through water body (m^3/yr);
 TSS = Total suspended solids (mg/L or g/m^3);
 A_w = Water body surface area (m^2);
 C_{BS} = Benthic solids concentration (kg/L);
 d_{bs} = Depth of upper benthic layer (m); and
 UCF_2 = Units conversion factor ($10^{-6} kg/mg$).

For a flowing water body like Lake Macatawa, the water column volatilization rate (k_v) is calculated from the following linked equations [i.e., See Tables B-4-18, B-4-19 and B-4-20, respectively, from USEPA, 2005]:

$$k_v = \frac{K_v}{d_z \cdot (1 + Kd_{sw} \cdot TSS \cdot UCF)}$$

[Equation 5-31]

where:

k_v = Water column volatilization rate constant (yr^{-1});
 K_v = Overall transfer rate (m/yr);

- d_z = Total water body depth (m);
- $K_{d_{sw}}$ = Suspended sediment/surface water partition coefficient (L/kg);
- TSS = Total suspended solids (mg/L); and
- UCF = Units conversion factor (10^{-6} kg/mg).

$$K_v = \left[K_L^{-1} + \left(K_G \cdot \frac{H}{R \cdot T_{wk}} \right)^{-1} \right]^{-1} \cdot \theta^{(T_{wk} - 293)}$$

[Equation 5-32]

where:

- K_v = Overall transfer rate (m/yr);
- K_L = Liquid phase transfer coefficient (m/yr);
- K_G = Gas phase transfer coefficient (m/yr);
- H = Henry's law constant (atm-m³/mol);
- R = Universal gas constant (atm-m³/mol-°K);
- T_{wk} = Water body temperature (°K); and
- θ = Temperature correction factor (unitless).

$$K_L = \sqrt{\frac{10^{-4} \cdot D_w \cdot u}{d_z}} \cdot UCF$$

[Equation 5-33]

where:

- K_L = Liquid phase transfer coefficient (m/yr);
- D_w = Diffusivity of COPC in water (cm²/s);
- u = Current velocity (m/s);
- d_z = Total water body depth (m); and
- UCF = Units conversion factor (3.1536×10^7 s/yr).

Total suspended solids (TSS) is a parameter in several of the previous equations. Although the HHRA guidance (USEPA, 2005) provides a range of default TSS values, the availability of sampling data collected by the MDEQ provided the opportunity to use site-specific TSS values. The values calculated for k_v , K_v and K_L in Lake Macatawa are summarized in Tables 5-34, 5-35 and 5-36.

The total water column COPC concentration (C_{wctot}), summarized in Table 5-37, includes both the dissolved chemical and chemical sorbed to suspended solids. It was calculated using the following equation [i.e., See Table B-4-23 from USEPA, 2005]:

$$C_{wctot} = f_{wc} \cdot C_{wtot} \cdot \frac{d_{wc} + d_{bs}}{d_{wc}}$$

[Equation 5-34]

where:

- C_{wctot} = Total COPC concentration in water column (mg/L);
- f_{wc} = Fraction of total water body COPC concentration that occurs in water column (unitless);
- C_{wtot} = Total COPC concentration in surface water system, including water column and bed sediment (mg/L);
- d_{wc} = Total depth of water column (m); and
- d_{bs} = Depth of the upper benthic layer (m).

Table 5-38 shows the concentration of COPCs dissolved in the water column (C_{dw}). It was calculated using the following equation [i.e., See Table B-4-24 from USEPA, 2005]:

$$C_{dw} = \frac{C_{wctot}}{1 + Kd_{sw} \cdot TSS \cdot UCF}$$

[Equation 5-35]

where:

- C_{dw} = COPC water concentration in the dissolved phase (mg/L);
- C_{wctot} = Total water column COPC concentration (mg/L);
- Kd_{sw} = Suspended sediment/surface water partition coefficient (L/kg);
- TSS = Total suspended solids (mg/L); and
- UCF = Units conversion factor (10^{-6} kg/mg).

Two different C_{dw} values are shown in Table 5-38 for the modeling of mercury. As discussed earlier, the approach followed in the revised HBPW HHRA assumes that a small amount of methylmercury is formed from divalent mercury in watershed soils. When that methylmercury is carried through the fate and transport process used to predict surface water concentrations, a C_{dw} of $5.3E-10$ mg/L results. However, the current HHRA guidance also assumes that the modeled C_{dw} value for divalent mercury (Hg^{+2}) should itself be apportioned into divalent mercury (85-percent) and methylmercury (15-percent) (USEPA, 2005). In Table 5-38, this results in a C_{dw} for divalent mercury of $6.3E-9$ mg/L (i.e., 85-percent of the C_{dw} for Hg^{+2}) and a C_{dw} for methylmercury of $1.7E-9$ mg/L (i.e., the modeled C_{dw} for methylmercury plus 15-percent of the C_{dw} for Hg^{+2}).

A primary concern of the revised HBPW HHRA is the partitioning of COPCs from the waters of Lake Macatawa into fish, which could then be consumed by local recreational fishermen and their families. A bioaccumulation factor (BAF) is normally used to calculate the COPC concentration in fish based on the concentration of COPC in the water. The general relationship is described by the following equation:

$$C_{fish} = C_{water} \cdot BAF_{fish}$$

[Equation 5-36]

where:

C_{fish} = COPC concentration in fish (mg/kg FW);
 C_{water} = COPC concentration in water (mg/L); and
 BAF_{fish} = Bioaccumulation factor for COPC in fish (L/kg FW).

Two variations of Equation 5-36 have been considered in the revised HBPW HHRA for the modeling of methylmercury concentrations in fish tissue (Table 5-39). The first approach, described in Table B-4-27 of the HHRA guidance (USEPA, 2005) recommends that the dissolved phase water concentration of methylmercury should be multiplied by the BAF for methylmercury as shown in the following equation:

$$C_{fish} = C_{dw(MeHg)} \cdot BAF_{MeHg} \quad \text{[Equation 5-37]}$$

In the second approach, recommended by the MDEQ AQD, fish methylmercury concentrations are estimated using the following relationship derived from the Great Lakes Water Quality Initiative (GLWQI):

$$C_{fish} = C_{wctot(Hg)} \cdot BAF_{MeHg} \quad \text{[Equation 5-38]}$$

The BAFs used to generate the results in Table 5-39 are composite values reflecting a diet consisting of 76-percent trophic level 4 (TL4) fish and 24-percent trophic level 3 (TL3) fish, as recommended by the MDEQ AQD (see Table 5-40). It is important to note that the MDEQ approach, described by Equation 5-38, correlates fish tissue methylmercury concentrations with the total concentration of mercury in the water column (i.e., C_{wctot}). This requires the use of a different set of BAF values (see Table 5-39), although the TL4:TL3 ratio remains the same as in the first approach.

5.6 Quantification of Exposure Intakes by Pathway

Estimates of COPC intake or dose are based on the modeled COPC concentrations in media, as described in Section 5.5, and the estimated magnitude of exposure. Daily COPC intakes, expressed in units of milligrams of COPC per day (mg/d), have been calculated for each COPC and for each pathway. Note that these intakes were described in terms of mg/kg-d in the previously submitted protocol. Conversion to these units is not ignored in the HBPW HHRA, however, it does occur in a later step in the process. Table 5-41 lists the exposure parameters used in the quantification of exposure intakes for the revised HBPW HHRA.

5.6.1 Daily Intake of COPCs Via Incidental Soil Ingestion

Individuals can be exposed to emitted COPCs by inadvertent hand-to-mouth transfer of surface soil. Daily

intake of chemical resulting from the ingestion of soil will be estimated using the following equation [See Table C-1-1 from USEPA, 2005]:

$$I_{soil} = Cs_{tD} \cdot CR_{soil} \cdot F_{soil} \quad \text{[Equation 5-39]}$$

where:

- I_{soil} = Daily intake of COPCs from soil ingestion (mg/d);
- Cs_{tD} = Soil COPC concentration (untilled) (mg/kg);
- CR_{soil} = Daily consumption rate of soil (kg/d); and
- F_{soil} = Fraction of consumed soil contaminated (unitless).

The daily intake of COPCs in the Resident Child, Recreational Fisher and Recreational Fisher Child resulting from the incidental ingestion of surface soils (I_{soil}) is summarized in Tables 5-42, 5-43 and 5-44, respectively.

5.6.2. Daily Intake of COPCs Via Ingestion of Homegrown Plants

The daily intake of COPCs via ingestion of homegrown plants has been calculated using the following equation [See Table C-1-2 from USEPA, 2005]:

$$I_{plants} = [(Pd + Pv + Pr_{ag}) \cdot CR_{ag}] + (Pr_{ag} \cdot CR_{pp}) + (Pr_{bg} \cdot CR_{bg}) \cdot F_{ag} \quad \text{[Equation 5-40]}$$

where:

- I_{plant} = Daily COPC intake from produce ingestion (mg/d);
- Pd = COPC concentration in above-ground produce due to direct deposition (mg/kg DW);
- Pv = COPC concentration in above-ground produce due to air-plant transfer (mg/kg DW);
- Pr_{ag} = COPC concentration in above-ground produce due to root uptake (mg/kg DW);
- Pr_{bg} = COPC concentration in below-ground produce due to root uptake (mg/kg DW);
- CR_{ag} = Daily consumption rate of above-ground produce (kg DW/d);
- CR_{bg} = Daily consumption rate of below-ground produce (kg DW/d);
- CR_{pp} = Daily consumption rate of protected above-ground produce (kg DW/d); and
- F_{ag} = Fraction of produce contaminated (unitless).

The daily intake of COPCs in the Resident Child, Recreational Fisher and Recreational Fisher Child resulting from the incidental ingestion of homegrown plants (I_{plants}) is summarized in Tables 5-45, 5-46 and 5-47, respectively.

5.6.3. Daily Intake of COPCs Via Fish Ingestion

The daily intake of COPCs resulting from the ingestion of fish taken from Lake Macatawa has been estimated using the following equation [See Table C-1-4 from USEPA, 2005]:

$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish} \quad \text{[Equation 5-41]}$$

where:

I_{fish}	=	Daily intake of COPC from fish ingestion (mg/d);
C_{fish}	=	COPC concentration in fish (mg/kg FW);
CR_{fish}	=	Daily consumption rate of fish (kg FW/d); and
F_{fish}	=	Fraction of fish contaminated (unitless).

The daily intake of COPCs in the Recreational Fisher and Recreational Fisher Child resulting from the ingestion of fish from Lake Macatawa (I_{fish}) is summarized in Tables 5-48 and 5-49, respectively. Note that two different I_{fish} values are presented in each of those tables, reflecting the two different approaches considered in the revised HBPW HHRA.

5.7 Quantification of Exposure Intakes by Receptor Group

The combined daily intake of COPCs resulting from indirect exposure pathways is obtained by summing the appropriate contributions from the ingestion of soil, homegrown garden produce and fish. The total intake for each receptor is described in the following sections. The total estimated daily intake of COPCs is then used in the determination of indirect risk to exposed receptors.

All receptors are also exposed to airborne COPCs through the direct (inhalation) exposure pathway. Consistent with the HHRA guidance (USEPA 2005), the Resident and Recreational Fisher (adult and child) are assumed to be exposed through this pathway at the selected residence location.

5.7.1. Total Indirect COPC Intake by Resident Child

Under current HHRA guidance (USEPA, 2005), the Resident and Resident Child are exposed (via indirect pathways) to COPCs through the ingestion of soil, drinking water (where applicable), and homegrown produce. The total daily intake of COPCs via all indirect pathways is described by the following equation [See Table C-1-6 from USEPA, 2005]:

$$I_{tot} = I_{soil} + I_{dw} + I_{plants} \quad \text{[Equation 5-42]}$$

where:

I_{tot}	=	Total indirect daily COPC intake (mg/d);
I_{soil}	=	Daily intake of COPC from ingestion of soil (mg/d);
I_{dw}	=	Daily intake of COPC from ingestion of drinking water (mg/d); and
I_{plants}	=	Daily intake of COPC from ingestion of produce (mg/d).

The total indirect daily intake of COPCs in the Resident and Resident Child resulting from the incidental ingestion of soil, the ingestion of drinking water and the ingestion of homegrown plants is summarized in Tables 5-50. As discussed earlier, exposure to COPCs through the ingestion of drinking water is not considered to be a complete exposure pathway in the HBPW HHRA. Therefore, I_{dw} is set equal to zero.

5.7.2. Total Indirect COPC Intake by the Recreational Fisher and Recreational Fisher Child

Under current guidance (USEPA, 2005), the Recreational Fisher and Recreational Fisher Child are exposed (via indirect pathways) to COPCs through the ingestion of soil, drinking water (where applicable), homegrown produce, and fish. The total daily intake via all indirect pathways is described by the following equation [See Table C-1-6 from USEPA, 2005]:

$$I_{tot} = I_{soil} + I_{dw} + I_{plants} + I_{fish}$$

[Equation 5-43]

where:

I_{tot}	=	Total indirect daily COPC intake (mg/d);
I_{soil}	=	Daily intake of COPC from ingestion of soil (mg/d);
I_{dw}	=	Daily intake of COPC from ingestion of drinking water (mg/d);
I_{plants}	=	Daily intake of COPC from ingestion of produce (mg/d); and
I_{fish}	=	Daily intake of COPC from ingestion of fish (mg/d).

The total indirect daily intake of COPCs in the Recreational Fisher and Recreational Fisher Child resulting from the incidental ingestion of soil, the ingestion of drinking water, the ingestion of homegrown plants and the ingestion of fish is summarized in Tables 5-51 and 5-52, respectively. As discussed earlier, exposure to COPCs through the ingestion of drinking water is not considered to be a complete exposure pathway in the HBPW HHRA. Therefore, I_{dw} is set equal to zero.

5.8 Quantification of Residential Lead Exposure

Exposures to lead are evaluated in a different manner than that just described for mercury. In order to evaluate potential health effects from lead, USEPA developed the integrated exposure uptake biokinetic (IEUBK) model, which utilizes four interrelated modules to estimate blood lead levels in children exposed to lead-contaminated media (USEPA, 1994). These modules include:

- Exposure Component. Uses lead concentrations in environmental media to calculate the amount of lead entering a child's body. The exposure component uses media-specific consumption rates and lead concentrations to estimate media-specific intake rates.
- Uptake Component. Uses lead intake into the lungs and digestive tract and considers absorption of lead to calculate the amount of lead that enters a child's bloodstream.
- Biokinetic Component. Considers the transfer of lead between blood and other body tissues, or elimination of lead from the body in determining a blood lead concentrations.
- Probability Distribution Component. Shows the probability of a certain outcome (e.g., a blood lead concentration greater than a level of concern in an exposed child based on the model parameters).

In the revised HBPW risk assessment, IEUBKwin (Version 1-Build 263) has been used to evaluate the potential human health impacts from lead emissions (USEPA, 2005). The IEUBK model is an integrated approach for evaluating multiple lead exposures and, as lead is a naturally-occurring metal, it is important to understand the extent of background lead exposures prior to evaluating the potential impact of replacing Boiler Unit 3 with Boiler Unit 10. As described in the following sections, the contribution of background exposures to blood lead levels was evaluated as the first step. Then, the fate and transport algorithms, described in the previous sections, were used to estimate the change in lead concentrations in environmental media within the selected residential location resulting from the combined emissions from Boiler Units 4, 5 and 10 following boiler replacement. Where site-specific media lead concentrations are not available, either area/region-specific values or model default values have been used; default media consumption rates have been used throughout.

5.8.1. Air Input Data for IEUBK

Default values have been used for the IEUBK operating parameters linked to inhalation exposures (Table 5-53), including time spent outdoors (i.e., 1 to 4 hr/day), ventilation rates (i.e., 2 to 7 m³/day), indoor air lead concentration as a percent of outdoor air concentration (i.e., 30-percent), and percent of inhaled lead absorbed from the lungs (i.e., 32-percent) (USEPA, 2002).

Background Lead Concentrations

Where site-specific air data are not available, USEPA (2002) recommends using a default air concentration of 0.1 µg/m³, however, regional air monitoring data collected at Grand Rapids, MI, indicate that ambient air concentrations of lead are probably less than 0.01 µg/m³ (MDEQ, 2005a). An air lead concentration of 0.01 µg/m³ was selected as the background air input value for the IEUBK model.

Lead Concentrations Following Boiler Replacement

The modeled airborne lead concentration within the selected residential location has been chosen as an input for the IEUBK model (see Table 5-1). That level is based on the AERMOD outputs, as described in Section 5.5.1. An air lead concentration of $0.01 \mu\text{g}/\text{m}^3$ was selected as the air input value for the IEUBK model, based on an incremental air lead concentration of $0.0003 \mu\text{g}/\text{m}^3$ at the residential location combined with the $0.01 \mu\text{g}/\text{m}^3$ background value (Table 5-54).

5.8.2. Soil and Dust Input Data for IEUBK

Default values have been used for the IEUBK operating parameters linked to soil/dust ingestion exposures (Table 5-53), including soil/dust ingestion rates (i.e., 0.085 to 0.135 g/d), soil ingestion as a percentage of total soil/dust ingestion (i.e., 45-percent), and percent of ingested soil/dust lead absorbed from the gut (i.e., 30-percent) (USEPA, 2002).

Background Lead Concentrations

Where site-specific data are not available, USEPA (2002) recommends a default soil lead concentration of 200 mg/kg, however, the MDEQ AQD has recommended using a soil lead concentration of 21.0 mg/kg as the appropriate background soil level for the current study area. That value represents the average background surface soil concentration (plus 1 standard deviation) under MDEQ's Residential and Commercial I Part 201 Generic Cleanup Criteria and Screening Levels for soils.

The selection of an input value for background lead concentrations in indoor dust is complicated. In many urban settings deteriorating lead-based paint can yield dust with high levels of lead; that is not believed to be case here. By default, the IEUBK model defaults to 'Multiple Source Analysis' because it assumes that site-specific dust concentrations are not measured. That is the case in the HBPW assessment, as algorithms to model the concentrations of chemicals in dust are not included in USEPA's 2005 risk assessment guidance. If there are no other sources contributing to indoor dust lead (such as lead-based paint), the guidance indicates that a default ratio (i.e., 0.70) can be used to relate indoor dust lead to outdoor soil lead (USEPA, 2002); that would yield a background dust lead concentration of 14.7 mg/kg. A second data entry is the contribution of airborne lead to dust lead through deposition; the current default value is an additive increment of 100 mg/kg in house dust for each $\mu\text{g} \text{ lead}/\text{m}^3$ air; based on a background air lead concentration of $0.01 \mu\text{g}/\text{m}^3$ this represents an increment of 1 mg/kg.

A second option for the consideration of lead in house dust is to use a default dust lead value of 200 mg/kg, which is believed to be representative of homes with lead paint, although that lead paint is believed to be in good condition. Both options for the consideration of background dust lead concentrations have been evaluated in the HBPW risk assessment. Background soil and dust lead concentrations considered in the HBPW assessment are summarized in Table 5-54.

Lead Concentrations Following Boiler Replacement

The modeled surface soil lead concentration within the selected residential location was chosen as an input for the IEUBK model (see Table 5-5). Surface soil concentrations, calculated as described in Section 5.5.2, consider contributions from both wet and dry deposition of airborne lead. It should be noted that the current HHRA guidance (USEPA, 2005) recommends using a mixing depth of 2 cm for surface soil; this represents a change from previous guidance that recommended a mixing depth of 1 cm (USEPA, 1998a). A soil lead concentration of 21.7 mg/kg was selected as the soil input value for the IEUBK model, based on an incremental soil lead concentration of 0.72 mg/kg at the residential location combined with the 21.0 mg/kg background value (Table 5-54).

Due to the uncertainty associated with the availability of lead-based paint in the Holland area, the two different options for evaluating lead dust concentrations, described above, were modeled. Under the first option, the dust lead concentration was estimated to be 16.2 mg/kg. That value was based on the default relationship between soil lead and dust lead (i.e., 0.70×21.7 mg/kg) and the deposition of airborne lead (i.e., 1 mg/kg contribution to dust based on $0.01 \mu\text{g lead}/\text{m}^3$). Under the second option, the dust lead concentration was assumed to be 200 mg/kg. Dust lead concentrations considered in the HBPW assessment are summarized in Table 5-54.

5.8.3. Dietary Input Data for IEUBK

Default values have been used for the IEUBK operating parameters linked to dietary exposures (Table 5-53), including the gastrointestinal absorption of dietary lead (i.e., 50-percent) (USEPA, 2002).

Background Lead Concentrations

The model provides an opportunity to include information on that portion of the total lead intake that enters the body through the consumption of food. As complete area-specific data describing either the concentration of lead in the various dietary sources or consumption patterns are not available, default dietary data found in the

guidance (USEPA, 2002) have been used. These default values include dietary lead intake as a function of age (i.e., 5.53 to 7.00 µg Pb/day).

Lead Concentrations Following Boiler Replacement

Modeled dietary intakes of lead in the HHRA, resulting from the consumption of homegrown plants and locally caught fish (i.e., 0.14 µg/d), appear to represent a minimal incremental impact on the default dietary intake range; nonetheless, it was added to the default dietary lead intake for each age group (see Table 5-54).

5.8.4. Drinking Water Input Data for IEUBK

The drinking water input data are divided into two sections: water consumption rates and environmental concentrations. Table 5-53 summarizes those IEUBK operating parameters linked to drinking water exposures. Default values have been used for age-related water consumption rates (i.e., 0.20 to 0.59 L/d) and percent of ingested water lead absorbed from the gut (i.e., 50-percent) (USEPA, 2002).

Background Lead Concentrations

When entering a water lead concentration, the user has two options: either to use one concentration for all drinking water sources (Option 1), or to use source-dependent values (Option 2). Option 1 was selected for the HBPW assessment; however, the levels of lead measured in the Holland drinking water supply are lower than the default value (i.e., 4 µg/L) found in the guidance (USEPA, 2002). For 2002, the Holland Board of Public Works reported a 90th percentile lead concentration of 2 µg/L in drinking water (HBPW, 2003); that conservative value has been selected for input in the IEUBK (Table 5-54).

Lead Concentrations Following Boiler Replacement

Area drinking water will not be impacted by lead emissions from the boiler units. However, as the IEUBK model does consider the consumption of drinking water as a potential source of lead, the background concentration (i.e., 2 µg/L) has been used (see Table 5-54).

5.8.5. Maternal Input Data for IEUBK

Although IEUBK allows the user to consider the impact of lead transferred from the mother to the fetus *in utero*, the information needed to modify this exposure pathway are limited. Therefore, as shown in table 5-53, the default value (i.e., maternal blood lead level at childbirth = 2.5 µg/dL) was used without modification (USEPA, 2002).

5.8.6. Alternative Source Input Data for IEUBK

IEUBK allows the user to input lead concentrations from sources that are not covered under other input categories. Examples would include the direct ingestion of lead-based paint and the use of cosmetics or home remedies. For the HBPW assessment, no alternate sources of lead have been considered.

6.0 TOXICITY ASSESSMENT

The purpose of the toxicity assessment portion of the revised HHRA is to present sources of toxicity data for the emissions constituents. Toxicity is defined as the ability of a chemical to induce adverse effects at some dosage in biological systems. The purpose of the toxicity assessment is two-fold:

- To identify the adverse health effects that may arise from direct or indirect exposure of humans to the emissions constituents (hazard assessment); and
- To provide an estimate of the quantitative relationship between the magnitude and duration of exposure and the probability or severity of adverse effects (dose-response assessment).

Typically, both carcinogenic and non-carcinogenic health effects are evaluated quantitatively for exposures in the HHRA. The endpoints for these two types of effects are assessed differently because the mechanisms by which COPCs cause cancer are assumed to be fundamentally different from the processes that cause non-carcinogenic effects. The principal difference reflects the assumption that non-carcinogenic effects exhibit a threshold dose below which no adverse effects occur, whereas USEPA assumes no such threshold exists for carcinogenic effects.

As used here, the term carcinogen refers to any COPC for which there is sufficient evidence that exposure may result in continuing uncontrolled cell division (i.e., cancer) in humans or animals. Conversely, the term non-carcinogen refers to any COPC for which the carcinogenic evidence is negative or insufficient. These definitions are under continual review by USEPA and are subject to change as new information becomes available and the weight-of-evidence is modified. Because exposure to some COPCs may result in both carcinogenic and non-carcinogenic effects, both endpoints associated with such a constituent are evaluated quantitatively in the HHRA, when sufficient toxicity data are available.

As noted previously, the current HHRA guidance classifies both lead and mercury as non-carcinogens (USEPA, 2005). Therefore, there will be no further discussion on the evaluation of carcinogenic endpoints in this section.

6.1 Assessment of Non-carcinogens

For evaluating non-carcinogenic effects, USEPA defines acceptable exposure levels as those levels to which the human population, including sensitive subgroups, may be exposed without adverse effects during a lifetime or part of a lifetime, incorporating an adequate margin of safety (USEPA, 1989). The potential for non-carcinogenic health effects is usually assessed by comparing the estimated average daily intake (i.e.,

exposure dosage) to a reference dose (RfD). USEPA develops the RfD by identifying the no-observed-adverse-effect level (NOAEL) or lowest-observed-adverse-effect level (LOAEL) in the scientific literature. NOAELs and LOAELs may be derived from either human epidemiological studies or animal studies; however, because human data are often lacking, these levels are usually derived from laboratory animal studies in which relatively high doses are administered.

Uncertainty factors (UFs) are then applied to the NOAELs and LOAELs to compensate for the data limitations inherent in the experiments, in addition to uncertainties associated with extrapolating high-dose animal data to the relatively low-dose environmental exposure situations in humans. RfDs are expressed in units of mg/kg-day. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily intake to humans (including sensitive subgroups) that should not result in an appreciable risk of deleterious effects. USEPA assigns a qualitative level of confidence (i.e., low, medium, or high) to the study used to derive the toxicity value, database, and RfD.

RfDs are developed for specific exposure routes (i.e., oral, inhalation, etc.). USEPA frequently provides non-carcinogenic toxicity criteria for inhalation exposure as reference air concentrations (RfCs) rather than RfDs. RfCs are derived using the same principles as those for oral RfDs; however, the analysis of inhalation exposures is more complex because of the dynamics of the respiratory system and its diversity across species, and differences in the physicochemical properties of constituents (USEPA, 1989). RfCs are expressed as a concentration in air (in milligrams per cubic meter [mg/m^3]) for continuous 24-hour-per-day exposure.

RfDs are used as reference points for assessing the likelihood that potential adverse health effects would be associated with site-related exposures. Usually, adverse health effects are unlikely to be associated with exposures that are less than the RfD; the likelihood of adverse health effects in a human population increases as the predicted exposures exceed the RfD. However, it is not possible to state definitively that all exposures above the RfD will result in adverse effects.

6.2 Chronic Toxicity Values

In December 2003, the Office of Superfund Remediation and Technology Innovation distributed OSWER Directive 9285.7-53 (USEPA, 2004) updating the hierarchy of sources of human toxicity values. This hierarchy, recommended in the current HHRA guidance (USEPA, 2005), includes the following sources, in order of Agency preference:

- Chronic Toxicity Benchmarks from USEPA's Integrated Risk Information System (IRIS) computer database (USEPA, 2008);
- Provisional Peer-reviewed Toxicity values (PPRTVs) (USEPA, 2004); and
- Other Peer-reviewed Toxicity Values
 - CalEPA chronic Reference Exposure Levels and Unit Risk estimates (CalEPA, 2008)
 - ATSDR chronic Minimum Risk Levels (MRLs) (ATSDR, 2008)
 - Health Effects Assessment Summary Tables (HEAST) (USEPA, 1997b)

Table 6-1 summarizes the chronic toxicity factors selected for use in the revised HBPW HHRA. There are several issues of interest to discuss relative to the selected values. There is no RfD value listed for elemental mercury. Even though there is no value listed in the IRIS database, the oral ingestion of elemental mercury is not considered in the USEPA HHRA guidance (USEPA, 2005); inhalation is the only exposure pathway evaluated. Conversely, there is no RfC available for methylmercury; the inhalation exposure pathway is not considered to be a human health concern compared to the oral exposure pathway. As discussed in several previous sections, USEPA has not developed a RfD or RfC for lead due to the apparent absence of threshold behavior in evaluated dose-response assessments.

6.3 Lead Assessment

Oral and inhalation reference doses (RfDs) and concentrations (RfCs) have not been developed for lead, as available dose-response relationships correlating toxic effects with increasing exposure dose have failed to demonstrate the existence of threshold behavior. As a result, direct and indirect effects of lead cannot be evaluated in the same manner as other non-carcinogenic COPCs (i.e., mercury).

As described earlier, the integrated exposure uptake biokinetic (IEUBK) model lead model provides an opportunity to evaluate the potential for lead to produce adverse impacts on exposed children. The model is based on a set of coupled first-order differential equations that describe changes in various body compartments of the growing child (i.e., birth to 84 months), in response to changes in lead concentration and intake from various sources (USEPA, 1994). The model uses site-specific data on lead concentrations in air, water, soil, and household dust and average daily intake of lead from diet and from directly ingested paint chips, to estimate blood lead concentrations in children of different ages. In fact, the model estimates a plausible distribution of blood lead concentrations centered on a geometric mean blood lead concentration. From this distribution, the model estimates the risk (i.e., probability) that a child's blood lead concentration will

exceed a user-defined level of concern. The Centers for Disease Control (CDC) have established 10 micrograms of lead per deciliter of blood (i.e., $\mu\text{g}/\text{dL}$) as their level of concern (CDC 1991).

7.0 RISK CHARACTERIZATION

7.1 Introduction

Different processes are used to characterize potential risks resulting from exposure to emitted lead and mercury. Generally, the risk characterization for mercury follows the methodology described by USEPA (2005) and those methods are designed to be health-protective and tend to overestimate, rather than underestimate, risk. For lead, the fate and transport methodology described by USEPA (2005) has been used to provide an understanding of media lead concentrations and human exposures. However, because no toxicity criteria exist for lead, an alternate approach (i.e., IEUBK) must be used to evaluate the potential for adverse impacts to occur in exposed individuals.

7.2 Risk Characterization Approach

As the various forms of mercury are considered to be non-carcinogenic, the potential for adverse effects is assessed by comparing a COPC-specific average daily dose (ADD) to its RfD or by comparing its concentration in air [C_a] to a RfC. This comparison is made by calculating the ratio of the estimated ADD to the corresponding RfD (or C_a to the corresponding RfC) to yield a hazard quotient (HQ).

For oral (i.e., indirect) exposures to non-carcinogenic COPCs the HQ is calculated using the following equations [i.e., See Table C-1-8 from USEPA, 2005]:

$$HQ_i = \frac{ADD}{RfD}$$

[Equation 6-1]

where:

HQ_i = Hazard quotient for indirect exposure to COPC_i (unitless);
ADD = Average daily dose (mg/kg-d); and
RfD = Reference dose (mg/kg-d)

where

$$ADD_i = \frac{I_i \cdot EF \cdot ED}{AT_{NC} \cdot UCF}$$

[Equation 6-2]

where:

ADD_i = Average daily dose (mg/kg-d);
I_i = Daily intake of COPC_i via exposure to impacted medium (mg/kg-d);
EF = Exposure frequency (d/yr);
ED = Exposure duration (yr);

AT_{NC} = Averaging time, non-carcinogens (equal to ED) (yr); and
UCF = Units conversion factor (d/yr).

As a receptor might be exposed to multiple COPCs with non-carcinogenic health effects, USEPA recommends calculating the total chronic hazard from all COPCs for each exposure pathway. The total chronic hazard attributable to all COPCs through a single exposure pathway is known as the hazard index (HI), calculated using the following equation [i.e., See Table C-1-11 from USEPA, 2005]:

$$HI = \sum_i HQ_i$$

[Equation 6-3]

where:

HI = Hazard index for indirect exposure (unitless) and
HQ_i = Hazard quotient for indirect exposure for COPC_i (unitless);

A parallel approach is used to evaluate the potential non-carcinogenic health effects resulting from inhalation (i.e., direct) exposure to airborne COPCs.

$$HQ_{inh(i)} = \frac{EC \cdot UCF}{RfC}$$

[Equation 6-4]

where:

HQ_{inh(i)} = Hazard quotient for inhalation of COPC_i (unitless);
EC = Exposure concentration (µg/m³);
UCF = Units conversion factor (mg/µg); and
RfC = Reference concentration (mg/m³).

where:

$$EC = \frac{C_a \cdot EF \cdot ED}{AT \cdot UCF}$$

[Equation 6-5]

where:

EC = Exposure concentration (µg/m³);
C_a = COPC air concentration (µg/m³);
EF = Exposure frequency (d/yr);
ED = Exposure duration (yr);
AT_{NC} = Averaging time, non-carcinogens (equal to ED) (yr); and
UCF = Units conversion factor (d/yr).

$$HI_{inh} = \sum_i HQ_{inh(i)}$$

[Equation 6-6]

where:

HI_{inh} = Hazard index for direct inhalation (unitless) and
 $HQ_{inh(i)}$ = Hazard quotient for direct inhalation for COPC_i (unitless);

According to the HHRA guidance (USEPA, 2005), the Agency considers it reasonable to estimate a given receptor's total non-carcinogenic hazard as the sum of the HI's for each of the individual exposure pathways (and COPCs). This value is calculated using the following equation [i.e., See Table C-1-10 from USEPA, 2005]:

$$Total\ Hazard\ Index = \sum_j HI_j$$

[Equation 6-7]

where:

HI_j = Hazard index for exposure pathway *j* (unitless)

It is important to note from a risk communication perspective that an HQ (or HI) is not a mathematical probability that health effects will occur. Although an HQ greater than 1 is usually regarded as a regulatory benchmark by USEPA, risk assessors regard RfDs as relatively "soft" estimates, whose bounds of uncertainty can span an order of magnitude. While exposures somewhat higher than the RfD are associated with an increased possibility of adverse effects, considerable uncertainty is associated with that possibility.

As discussed above, HIs for different exposure pathways are summed to yield a cumulative HI that accounts for exposure by a given receptor across multiple COPCs and exposure pathways. In the absence of data to the contrary, USEPA assumes dose- and effect-additivity for non-carcinogenic effects (USEPA 2005). However, there is an exception to this additivity approach. The HHRA guidance states that additivity of HIs should be restricted to COPCs which act on common target organs (USEPA, 2005). In other words, it would be inappropriate to combine the HI from a COPC which acts primarily on the skin with the HI from a COPC that acts primarily on the liver. As segregation of the HI based on major health effects and target organs or systems is typically only undertaken when the total HI exceeds the benchmark target level and the individual COPC-specific HI values are less than the benchmark target level, this approach was not considered necessary in the current HHRA.

7.3 Characterization of Risks from Mercury Emissions

7.3.1. Indirect Exposure to Mercury Emissions

In the revised HBPW HHRA, indirect exposure of the Resident Child to emitted mercury is limited to the incidental ingestion of surface soil and the ingestion of homegrown plants and vegetables. In addition to those same indirect exposures, the Recreational Fisher and Recreational Fisher Child are also assumed to be exposed to emitted mercury through the ingestion of fish caught in Lake Macatawa.

Resident Child

Table 7-1 summarizes the hazard indices (HIs) in the Resident Child resulting from indirect exposure to emitted mercury. Note that the total mercury intake (I_{tot}) in mg/d is converted to an average daily dose (ADD) which reflects both the default body weight of the Resident Child (i.e., 15 kg) and the default exposure frequency (EF) of 350 d/yr. When the ADD for each COPC is compared against its RfD, the resulting HI_{ind} for divalent mercury and methylmercury are 0.0004 and 0.00006, respectively; both values are well-below USEPA's level of concern (i.e., $HI \leq 0.25$). Under the current HHRA guidance (USEPA, 2005), elemental mercury emissions do not participate in indirect exposures; contact with elemental mercury is assumed to occur only through direct (inhalation) exposure.

Recreational Fisher

Table 7-2 summarizes the hazard indices (HIs) in the Recreational Fisher resulting from indirect exposure to emitted mercury. It is important to remember that the Recreational Fisher is assumed to live at the same location as the Resident Child, resulting in exposure to the same mercury concentrations in soil and homegrown plants and vegetables. As noted above, the Recreational Fisher is also exposed to mercury through the ingestion of fish. Several values in Table 7-2 reflect the differences in the way USEPA and MDEQ model the movement of mercury from surface water into fish tissue. Under the USEPA approach, the daily intake of methylmercury is approximately 2.5-times that predicted under the MDEQ approach, resulting in a higher HI_{ind} . The HI_{ind} s for divalent mercury and methylmercury are 0.00009 and 0.02, respectively; both values are well-below USEPA's level of concern (i.e., $HI \leq 0.25$). Under the MDEQ approach, the HI_{ind} estimated for methylmercury is 0.007.

Recreational Fisher Child

Table 7-3 summarizes the hazard indices (HIs) in the Recreational Fisher Child resulting from indirect exposure to emitted mercury. It is important to remember that the Recreational Fisher Child differs from the Resident Child only through the consumption of locally caught fish. Again, several values in Table 7-3 reflect

the differences in the way USEPA and MDEQ model the movement of mercury from surface water into fish tissue. Under the USEPA approach, the daily intake of methylmercury is approximately 2.5-times that predicted under the MDEQ approach, resulting in a higher HI_{ind} . The HI_{ind} s for divalent mercury and methylmercury are 0.0004 and 0.01, respectively; both values are well-below USEPA's level of concern (i.e., $HI \leq 0.25$). Under the MDEQ approach, the HI_{ind} for methylmercury is 0.005.

7.3.2. Direct Exposure to Mercury Emissions

The characterization of risk from direct (inhalation) exposures to mercury is based on a comparison of modeled mercury air concentrations at locations of interest against a risk-based reference concentration (i.e., RfC). As the Resident Child, Recreational Fisher and Recreational Fisher Child are all assumed to be located at the same residential location, the modeled air concentrations of COPCs will be the same for each receptor group. Tables 7-4, 7-5 and 7-6 show the adjusted exposure concentrations for the three receptor groups, reflecting the exposure frequency (d/yr), exposure duration (yr) and averaging time (yr). It is important to note that, although the adjusted exposure concentrations are the same for divalent mercury and elemental mercury, divalent mercury exists in both the vapor and particle bound phases while elemental mercury exists completely in the vapor phase. The HQ_{Dir} for divalent mercury and elemental mercury are 0.0001 and 0.00003, respectively, for all three receptor groups (Table 7-7); both values are well-below USEPA's level of concern (i.e., $HI \leq 0.25$).

7.3.3. Combined Exposure to Mercury Emissions

Table 7-8 shows the combined hazard indices resulting from incremental exposure to emitted mercury. Values are summed across pathways and COPCs for each receptor group. The values shown for the Recreational Fisher and Recreational Fisher Child reflect use of the USEPA approach to estimate fish mercury concentrations; that approach is more conservative than the MDEQ approach. The highest combined HI was determined for the Recreational Fisher (0.02) followed by the Recreational Fisher Child (0.01) and Resident Child (0.0006). This pattern is not surprising given the consumption of fish by the two Fisher groups. Again, the combined HI estimates for all three receptor groups indicate that the incremental mercury impacts should not present a human health concern.

7.4 Characterization of Risks from Lead Emissions

As described in Section 6.3 (Lead Assessment), USEPA-verified RfDs are not available for lead. Consequently, the approach used to characterize the potential adverse health effects associated with lead exposure differs from that used to evaluate other COPCs. In the HBPW HHRA, site-specific and default

exposure data have been used as inputs for USEPA's IEUBK model. The model output consists of a best estimate of a plausible range of blood lead concentrations for a hypothetical child under the specific exposure conditions established within the HHRA. The range of values is centered on the geometric mean blood lead concentration expected for a typical child with this exposure scenario. The portion of the upper tail of the probability distribution exceeding some chosen blood lead concentration (i.e., typically 10 µg/dL) provides an estimate of the risk of exceeding that level for a typical child of that age residing in the same household and with the same exposure history (USEPA, 2002). IEUBK was run for the age range of 0 to 84 months using a 15-minute time step for the numerical iteration.

7.4.1. Results of IEUBK Modeling

As described previously, the goal of the revised HBPW risk assessment was to determine the potential human health impact of combined emissions from Boiler Units 4, 5 and 10. For consideration of the impact of lead emissions, four different scenarios were evaluated using the IEUBK model. These scenarios included:

- Background conditions assuming no lead-based paint in homes [i.e., lead in interior dust results from two sources: soil being tracked into homes and deposition of airborne lead];
- Background conditions assuming lead-based paint in good condition in homes [i.e., default interior dust lead value of 200 mg/kg];
- Impact of Boiler emissions assuming no lead-based paint in homes; and
- Impact of Boiler emissions assuming lead-based paint in good condition in homes.

The results are presented in graphical form in Figures 7-1 through 7-4 and summarized in Table 7-9. It is important to note that the IEUBK model outputs represent a distribution of predicted blood lead levels rather than a single value. Based on the input parameters described in Section 5.8, the IEUBK model predicted a background geometric mean blood lead concentration of 1.54 µg/dL in children living in homes that were free of lead-based paint; only 0.003 percent of those children would be expected to exceed the CDC's health-based level of concern (i.e., 10 µg/dL). If those homes contained lead-based paint in good condition, a background geometric mean blood lead concentration of 2.67 µg/dL could be expected; approximately 0.25 percent of exposed children would be expected to exceed CDC's health-based level of concern.

When the impact of post-modification Boiler emissions was evaluated in children living in homes with no lead-based paint, the IEUBK model predicted that geometric mean blood levels would only increase from 1.54 µg/dL to 1.57 µg/dL, an increase of 2.0 percent. The percentage of children with blood levels exceeding CDC's health-based level of concern would only be expected to increase from 0.003 to 0.004. A similar

pattern was predicted for children living in homes with lead-based paint in good condition. The IEUBK model predicted that geometric mean blood levels would only increase from 2.67 µg/dL to 2.70 µg/dL, an increase of 1.0 percent. The percentage of children with blood levels exceeding CDC's health-based level of concern would only be expected to increase from 0.25 to 0.27. None of these changes should be a cause for concern.

8.0 UNCERTAINTY ANALYSIS

8.1 Introduction

The purpose of this section is to highlight the primary sources of uncertainty within each component of the HHRA and to qualitatively identify the potential impact of such uncertainty on the ultimate characterization of risk. In this manner, the uncertainty assessment provides a context for understanding the risk characterization results with respect to the true nature of the predicted risks; such an approach allows the predicted risks to be placed in the proper perspective and provides the risk manager and the general public with a more balanced picture. The HHRA process, as prescribed in the HHRA guidance developed by the Office of Solid Waste (OSW), is conservative by design (USEPA, 2005). In consciously requiring that risk be overestimated, regulatory agencies can be assured that the actual risks resulting from operation of a combustor unit will not be underestimated.

8.2 Stack Emission Estimates

Stack emission rates for lead and mercury from existing Units 4 and 5 were based upon actual stack test data conducted by NTH. Lead emission estimates for Boiler Unit 10 were based upon proximate coal analysis data for the grade of coal to be burned in the CFB and the mine from where the coal will be obtained. A control factor (i.e., 99%) was then applied to calculate the expected lead emissions based upon the combustion design features of the CFB (i.e., limestone injection and add-on control technology including fabric filter, SNCR, and activated carbon injection). Mercury emission estimates for Boiler Unit 10 were determined from a rigorous case-by-case Maximum Achievable Control Technology (MACT) determination. The MACT analysis was based upon a review of available test data from similar sources and an estimate of the maximum control of mercury that could be obtained by the unit's air quality control system (AQCS). Since the permit will limit the emissions mercury and lead on a maximum potential basis, the emission estimates used in the HHRA are conservative (i.e., actual stack emissions of lead and mercury should be lower than those evaluated in the HHRA).

8.3 Air Modeling of Stack Emissions

The air impacts from lead and mercury emissions were predicted using a computer model (i.e., AERMOD) developed by USEPA. AERMOD is a state-of-the-science modeling system developed to replace an earlier regulatory model (i.e., ISC). It has been promulgated as the guideline model for use in both state and federal PSD applications where an assessment of both ambient impacts and secondary impacts are required.

The location of the NWS station used as a source of the meteorological data can introduce considerable uncertainty into the air modeling activity; it is not unusual for the nearest NWS station to be more than 50-100 miles from the combustor being modeled. To reduce this uncertainty, MDEQ has processed meteorological data sets for 56 stations across MI, including the Tulip City Airport in Holland, MI. As the Tulip City Airport is approximately 3 miles from HBPW facility, there should be a high degree of confidence that the meteorological data used in the air modeling actually reflect conditions within the study area.

Deposition modeling requires information on the size distribution of emitted particles. The particle size distribution used in the air modeling was based upon data from USEPA's Compilation of Air Pollutant Emission Factors (AP-42) for coal combustion with a fabric filter (Boiler Unit 10) and ESP (Boiler Units 4 and 5) for control of particulate matter. As the most current agency-approved approaches have been used to estimate the particle size distribution, the associated uncertainty is probably quite low.

8.4 Fate and Transport Modeling

In the revised HBPW HHRA, multiple fate and transport pathways were evaluated to ensure compliance with USEPA HHRA guidance requirements. In addition to the relatively straightforward air modeling methodology used to predict ambient air concentrations and deposition fluxes at pre-selected receptor locations, a complex, interrelated series of algorithms was used to develop estimates of COPC exposure concentrations for the following indirect pathways:

- Incidental ingestion of surface (untilled) soil;
- Ingestion of homegrown vegetables raised on impacted soils (tilled); and
- Ingestion of fish obtained from impacted area surface water bodies

There are several examples in the current guidance where upper-bound exposure assumptions have been used so as not to underestimate risk. As an example, the default receptor scenario assumes that the adult resident spends 350 days out of every year at his/her home and that exposure to emitted chemicals at that location continues uninterrupted for 30 years. In reality, very few individuals are likely to spend that amount of time in their homes (USEPA, 1997a); such an exposure could be considered to be unrealistically-conservative, even though it is theoretically possible. A second example can be found in the evaluation of impacts from lead using the IEUBK model. One of the important input parameters for the model is the concentration of lead in house dust. As nothing was known about the presence of lead in the dust inside Holland residences, a default value (i.e., 200 mg/kg) was used in one of the exposure scenarios. Although

this value is appropriate to describe homes that have lead paint in good condition, it probably overestimates actual dust lead levels.

Another example of this conservatism can be seen in the Recreational Fisher scenario, where the assumption is made that 2.6 ounces of homegrown produce are consumed every day and this consumption rate is in place 350 days/year for 30 years. In reality, most families consume a diet that is a blend of homegrown food and food purchased locally (i.e., in supermarkets) but grown/raised outside the immediate area.

An evaluation of the area within 10-km of the James DeYoung Generating Plant produced no indication that surface water from that area is used as a significant source of drinking water. As it was impossible to contact every resident within that area to confirm this, there is a degree of uncertainty associated with our decision to exclude consumption of surface water as a complete exposure pathway in the HHRA. The knowledge that the City of Holland obtains its drinking water from Lake Michigan certainly reduces the degree of uncertainty associated with our decision to eliminate that exposure pathway.

8.5 Toxicity Assessment

USEPA has adopted a standardized approach for evaluating the various sources of uncertainty associated with the assessment of toxicity studies and their relevance to the chronic low level exposure scenarios typically encountered in combustor risk assessments. Through the introduction of various levels of conservatism, the agency has ensured that the various toxicity criteria generated for use in the HHRA process would not underestimate the true toxicity of a chemical.

Health criteria for chemicals exhibiting chronic non-carcinogenic effects are generally developed using the Reference Dose (RfD) or Reference Concentration (RfC). The RfD/RfC is the estimated level of daily exposure to the human population (including sensitive subpopulations) below which it is unlikely that appreciable risk of deleterious effects will result over a lifetime of exposure. It is assumed that when a no-observed-adverse-effect level (NOAEL) or lowest-observed-adverse-effect level (LOAEL) is selected as the basis for the RfD/RfC, toxic effects will be avoided.

USEPA usually bases the RfD/RfC for non-carcinogens on the most-sensitive animal species. The dose is then adjusted by the use of uncertainty factors and modifying factors to compensate for the various sources of uncertainty inherent in the underlying toxicity database. Commonly used uncertainty factors include the following:

- Uncertainty factor of 10 to account for intraspecies variability (i.e., sensitive individuals);
- Uncertainty factor of 10 to account for interspecies variability (i.e., mouse to man);
- Uncertainty factor of 10 to account for subchronic to chronic exposure adjustment (i.e., short-term to lifetime exposure); and
- Uncertainty factor of 10 to account for LOAEL to NOAEL adjustment.

Due to the conservative nature of this approach, the compounding effect of multiplying individual uncertainty factors together could result in RfD/RfC values which tend to overestimate the actual risk. The IRIS database also contains an evaluation of the quality of the data used to generate a RfD/RfC. In many cases the level of confidence in the study is classified as low.

8.6 Risk Characterization

The previous sections have provided a discussion of the uncertainties associated with each component of the risk assessment process. In order to address these uncertainties, current USEPA HHRA guidance require the use of conservative assumptions throughout the risk assessment process in order to err on the side of public health protection. The cumulative impact of applying conservative assumptions throughout the risk assessment is that the estimated risks are almost certain to overestimate the true risks.

The fate and transport modeling used to predict exposure concentrations in various media is anticipated to overestimate impacts. This starts with the conservatism built into the USEPA air models used to model impacts at particular geographic locations and continues through the multiple mathematical algorithms used to evaluate the step-by-step migration of chemicals through the various direct and indirect exposure pathways. Many of these algorithms are closely linked with other algorithms and the use of conservative, upper-bound, default exposure assumptions will actually result in an exposure scenario that is so conservative that it would be unlikely to occur.

The toxicity assessment incorporates uncertainty factors and modifying factors and assumes upper-bound dose-response relationships in order to account for the uncertainties inherent in extrapolating from toxicity studies conducted in laboratory animals using high exposure doses to the situation where humans are exposed at relatively low concentrations. An additional level of conservatism results from summing the risks independent of the target organ. The assumption that all chemicals act in a similar manner is a conservative over-simplification of how chemicals are known to produce toxicity and will tend to overestimate the actual risk.

In the final characterization of risk, all of the conservative assumptions applied in the emissions characterization, fate and transport modeling, exposure assessment, and toxicity assessment are compounded in the derivation of a numerical estimate of risk. As a consequence, the projected risks associated with anticipated boiler emissions are likely to have been overestimated. Even though application of the HHRA process indicates that the emissions from Boiler Units 4, 5 and 10 will not pose a human health risk to the surrounding community, actual risks should be even lower than demonstrated in this activity.

9.0 SUMMARY AND CONCLUSIONS

The Holland Board of Public Works (HBPW) is proposing to construct and install a new circulating fluidized bed (CFB) boiler (Boiler Unit 10) at the James DeYoung Generation Station located in Holland, Michigan. Boiler Unit 10 will be replacing existing Boiler Unit 3 at the facility. The Michigan Department of Environmental Quality (MDEQ) Air Quality Division (AQD) has requested that a human health risk assessment (HHRA) be conducted as part of the permitting process for the new boiler. The original HBPW HHRA focused on lead and mercury emissions and compared potential human health impacts associated with combined operation of Boiler Units 4, 5, and 10 (i.e., future configuration) against combined operation of Boiler Units 3, 4, and 5 (i.e., current configuration). In contrast, the current revision of the HHRA focuses only on post-modification emissions from Boiler Units 4, 5 and 10.

The HHRA has been based on current federal risk assessment guidance, titled Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (USEPA, 2005), although it has also incorporated several requirements from the AQD. The migration of lead and mercury from their release into the atmosphere at the HBPW facility up to their ultimate intake by receptors involves a series of complex modeling processes. USEPA's AERMOD was used to evaluate the atmospheric movement of emitted chemicals, resulting in air concentration and deposition flux estimates at over 9,000 predefined grid locations.

At the request of AQD, a subset of USEPA default receptor scenarios was evaluated in the HHRA for both direct and indirect exposures to lead and mercury. The default receptor scenarios included:

- Resident Child;
- Recreational Fisher; and
- Recreational Fisher Child.

Consistent with current USEPA guidance, all three receptors were assumed to live at the same residential location, identified through evaluation of air modeling outputs, consideration of existing zoning and examination of digitized aerial photographs. Potential exposure to emitted lead and mercury through inhalation, incidental ingestion of surface soil and ingestion of homegrown plants/vegetables was evaluated for all three default receptor scenarios at the selected residential location. In addition, the Recreational Fisher and Recreational Fisher Child were evaluated for exposure to lead and mercury through the ingestion of fish caught in Lake Macatawa.

The terrestrial and aquatic fate-and-transport of lead and mercury involve a complex series of linked algorithms developed by USEPA in the HHRA guidance. The first step involved estimating the concentration of lead and mercury in various exposure media, including: air, soil (both tilled and untilled), homegrown plants, surface water and fish. The second step involved estimating the daily intake of lead and mercury through exposure to those media. Once an exposure level has been estimated, USEPA methods were used to determine if that exposure was sufficiently high to pose a threat to human health. Potential impacts from the various mercury species are evaluated through comparison of exposure levels against either a reference dose (RfD) for ingestion or a reference concentration (RfC) for inhalation.

Potential impacts from lead exposure were evaluated in a different manner. In contrast to the various forms of mercury, lead is not believed to exhibit threshold behavior; as a consequence, USEPA has not developed a RfD or RfC. The AQD recommended that the potential health impacts from lead be evaluated using the Integrated Exposure Uptake Biokinetic (IEUBK) model which focuses on potential impacts on children during the first seven years of life. IEUBK integrates lead intake from multiple exposure pathways and then estimates a blood lead level. The Centers for Disease Control (CDC) have established a blood lead concentration of 10 µg/dL as their level of concern. According to the agency, children with blood lead concentrations less than that are “not considered to be lead poisoned”.

The HHRA results indicate that post-modification exposure to mercury emissions from Boiler Units 4, 5 and 10 should not pose a threat to individuals residing within the study area. Potential impacts from the various mercury species were quantified through generation of a hazard index (HI); direct and indirect exposure levels were compared against the appropriate toxicity criterion (RfD or RfC) and the resulting ratio values were summed across pathways and COPCs for each receptor group.

The highest combined HI was associated with the Recreational Fisher (0.02) followed by the Recreational Fisher Child (0.01) and Resident Child (0.0006). This pattern is not surprising given the consumption of fish by the two Fisher groups. Again, the combined HI estimates for all three receptor groups indicated that the incremental mercury impacts should not present a human health concern. Typically, a combined HI ≤ 1 indicates an exposure level that can be tolerated by all individuals, including sensitive subpopulations, throughout a lifetime without any adverse effects. As mercury exposures unrelated to operation of the HBPW facility can occur, USEPA (1998b) recommends an alternate target level (i.e., combined HI ≤ 0.25). For all three receptor scenarios, the combined HI was well below that target level.

Although the current revision of the HHRA evaluates anticipated combined emissions from Boiler Units 4, 5 and 10 it is important that these impacts be put in perspective. Combined mercury emissions from Boiler Units 3, 4 and 5 (the current facility configuration) were also evaluated (data not shown) and the highest combined HI values were again associated with the Recreational Fisher (0.02) and the Recreational Fisher Child (0.01). Although the replacement of Boiler Unit 3 with Boiler Unit 10 in the future configuration results in a modest increase in the HI from combined emissions for these receptor groups (i.e., less than 20 percent), the potential human health impacts are still anticipated to be well-below any level of regulatory concern.

The increases in media lead levels resulting from emissions from Boiler Units 4, 5 and 10 were added to region-specific background lead levels in those same media. The resulting media lead concentrations were evaluated using USEPA's IEUBK model, which integrates multiple exposure pathways and predicts blood lead levels in children. As there was uncertainty associated with the potential contribution of lead-based paint to dust levels in area homes, two different residential scenarios were evaluated.

In the first, the assumption was made that no lead-based paint was present; all lead in household dust was assumed to result from the tracking of soil into the homes and the deposition of airborne lead. The IEUBK-modeled geometric mean blood lead level under that background scenario was 1.54 µg/dL. Under the second scenario, the assumption was made that lead-based paint was present in area homes with the paint in good condition. USEPA believes that dust lead levels under that scenario could be as high as 200 mg/kg. The IEUBK-modeled geometric mean blood lead level under the second background scenario was 2.67 µg/dL. When the impact of combined lead emissions from Boiler Units 4, 5 and 10 was evaluated using the IEUBK model, the resulting geometric mean blood lead concentration under the first scenario (i.e., 1.57 µg/dL) represented an increase of only 2.0 percent; under the second scenario, the modeled geometric mean blood lead concentration (i.e., 2.70 µg/dL) represented an increase of only 1.0 percent. Under both scenarios, the incremental blood lead levels resulting from Boiler emissions were well below CDC's level of concern.

Given the level of conservatism inherent in USEPA's HHRA guidance, the results of the revised HBPW HHRA indicate that the impact of lead and mercury emissions resulting from the planned modification of the HBPW James DeYoung Generating Plant should not present a human health threat to individuals living in the surrounding area.

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James DeYoung Generating Plant
Holland, Michigan
October 2006 (Revised October 2008)

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APPENDIX A
IEUBK OUTPUT FILES

LEAD MODEL FOR WINDOWS Version 1.0

```

=====
Model Version: 1.0 Build 263
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Background [No Pb-Based Paint; Dust Pb from Tracked Soil]
=====
    
```

The time step used in this model run: 4 - Every 15 Minutes (96 times a day).

***** Air *****

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m ³ /day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m ³)
.5-1	1.000	2.000	32.000	0.010
1-2	2.000	3.000	32.000	0.010
2-3	3.000	5.000	32.000	0.010
3-4	4.000	5.000	32.000	0.010
4-5	4.000	5.000	32.000	0.010
5-6	4.000	7.000	32.000	0.010
6-7	4.000	7.000	32.000	0.010

***** Diet *****

Age	Diet Intake(ug/day)
.5-1	5.530
1-2	5.780
2-3	6.490
3-4	6.240
4-5	6.010
5-6	6.340
6-7	7.000

***** Drinking Water *****

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 2.000 ug Pb/L

***** Soil & Dust *****

Multiple Source Analysis Used

Average multiple source concentration: 15.700 ug/g

Mass fraction of outdoor soil to indoor dust conversion factor: 0.700

Outdoor airborne lead to indoor household dust lead concentration: 100.000

Use alternate indoor dust Pb sources? No

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	21.000	15.700
1-2	21.000	15.700
2-3	21.000	15.700
3-4	21.000	15.700
4-5	21.000	15.700
5-6	21.000	15.700
6-7	21.000	15.700

***** Alternate Intake *****

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

***** Maternal Contribution: Infant Model *****

Maternal Blood Concentration: 2.500 ug Pb/dL

 CALCULATED BLOOD LEAD AND LEAD UPTAKES:

Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.002	2.664	0.000	0.193
1-2	0.003	2.792	0.000	0.483
2-3	0.006	3.142	0.000	0.504
3-4	0.007	3.037	0.000	0.516
4-5	0.007	2.940	0.000	0.538
5-6	0.009	3.107	0.000	0.568
6-7	0.009	3.431	0.000	0.578

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	0.444	3.303	1.8
1-2	0.707	3.985	1.7
2-3	0.709	4.361	1.6
3-4	0.713	4.273	1.5
4-5	0.531	4.016	1.4
5-6	0.479	4.163	1.3
6-7	0.452	4.471	1.2

LEAD MODEL FOR WINDOWS Version 1.0

```

=====
Model Version: 1.0 Build 263
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: After [No Pb-based paint; Dust Pb from Tracked Soil]
=====

```

The time step used in this model run: 4 - Every 15 Minutes (96 times a day).

***** Air *****

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m ³ /day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m ³)
.5-1	1.000	2.000	32.000	0.010
1-2	2.000	3.000	32.000	0.010
2-3	3.000	5.000	32.000	0.010
3-4	4.000	5.000	32.000	0.010
4-5	4.000	5.000	32.000	0.010
5-6	4.000	7.000	32.000	0.010
6-7	4.000	7.000	32.000	0.010

***** Diet *****

Age	Diet Intake(ug/day)
.5-1	5.670
1-2	5.920
2-3	6.630
3-4	6.380
4-5	6.150
5-6	6.480
6-7	7.140

***** Drinking Water *****

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 2.000 ug Pb/L

***** Soil & Dust *****

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	21.720	16.230
1-2	21.720	16.230
2-3	21.720	16.230
3-4	21.720	16.230
4-5	21.720	16.230
5-6	21.720	16.230
6-7	21.720	16.230

***** Alternate Intake *****

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

***** Maternal Contribution: Infant Model *****

Maternal Blood Concentration: 2.500 ug Pb/dL

 CALCULATED BLOOD LEAD AND LEAD UPTAKES:

Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.002	2.728	0.000	0.192
1-2	0.003	2.857	0.000	0.483
2-3	0.006	3.208	0.000	0.503
3-4	0.007	3.103	0.000	0.516
4-5	0.007	3.007	0.000	0.538
5-6	0.009	3.174	0.000	0.568
6-7	0.009	3.499	0.000	0.578

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	0.459	3.382	1.9
1-2	0.731	4.074	1.8
2-3	0.733	4.450	1.6
3-4	0.737	4.363	1.5
4-5	0.549	4.100	1.4
5-6	0.495	4.247	1.3
6-7	0.467	4.554	1.3

LEAD MODEL FOR WINDOWS Version 1.0

```

=====
Model Version: 1.0 Build 263
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: Background [Pb-Based Paint Good Condition]
=====
    
```

The time step used in this model run: 4 - Every 15 Minutes (96 times a day).

***** Air *****

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m ³ /day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m ³)
.5-1	1.000	2.000	32.000	0.010
1-2	2.000	3.000	32.000	0.010
2-3	3.000	5.000	32.000	0.010
3-4	4.000	5.000	32.000	0.010
4-5	4.000	5.000	32.000	0.010
5-6	4.000	7.000	32.000	0.010
6-7	4.000	7.000	32.000	0.010

***** Diet *****

Age	Diet Intake(ug/day)
.5-1	5.530
1-2	5.780
2-3	6.490
3-4	6.240
4-5	6.010
5-6	6.340
6-7	7.000

***** Drinking Water *****

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 2.000 ug Pb/L

***** Soil & Dust *****

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	21.000	200.000
1-2	21.000	200.000
2-3	21.000	200.000
3-4	21.000	200.000
4-5	21.000	200.000
5-6	21.000	200.000
6-7	21.000	200.000

***** Alternate Intake *****

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

***** Maternal Contribution: Infant Model *****

Maternal Blood Concentration: 2.500 ug Pb/dL

 CALCULATED BLOOD LEAD AND LEAD UPTAKES:

Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.002	2.593	0.000	0.188
1-2	0.003	2.701	0.000	0.467
2-3	0.006	3.055	0.000	0.490
3-4	0.007	2.964	0.000	0.504
4-5	0.007	2.894	0.000	0.530
5-6	0.009	3.068	0.000	0.561
6-7	0.009	3.394	0.000	0.572

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	2.856	5.639	3.1
1-2	4.522	7.694	3.2
2-3	4.555	8.105	3.0
3-4	4.596	8.071	2.8
4-5	3.451	6.882	2.4
5-6	3.121	6.760	2.1
6-7	2.954	6.929	2.0

LEAD MODEL FOR WINDOWS Version 1.0

```

=====
Model Version: 1.0 Build 263
User Name:
Date:
Site Name:
Operable Unit:
Run Mode: After [Pb-Based Paint Good Condition]
=====
    
```

The time step used in this model run: 4 - Every 15 Minutes (96 times a day).

***** Air *****

Indoor Air Pb Concentration: 30.000 percent of outdoor.
Other Air Parameters:

Age	Time Outdoors (hours)	Ventilation Rate (m ³ /day)	Lung Absorption (%)	Outdoor Air Pb Conc (ug Pb/m ³)
.5-1	1.000	2.000	32.000	0.010
1-2	2.000	3.000	32.000	0.010
2-3	3.000	5.000	32.000	0.010
3-4	4.000	5.000	32.000	0.010
4-5	4.000	5.000	32.000	0.010
5-6	4.000	7.000	32.000	0.010
6-7	4.000	7.000	32.000	0.010

***** Diet *****

Age	Diet Intake(ug/day)
.5-1	5.670
1-2	5.920
2-3	6.630
3-4	6.380
4-5	6.150
5-6	6.480
6-7	7.140

***** Drinking Water *****

Water Consumption:

Age	Water (L/day)
.5-1	0.200
1-2	0.500
2-3	0.520
3-4	0.530
4-5	0.550
5-6	0.580
6-7	0.590

Drinking Water Concentration: 2.000 ug Pb/L

***** Soil & Dust *****

Age	Soil (ug Pb/g)	House Dust (ug Pb/g)
.5-1	21.720	200.000
1-2	21.720	200.000
2-3	21.720	200.000
3-4	21.720	200.000
4-5	21.720	200.000
5-6	21.720	200.000
6-7	21.720	200.000

***** Alternate Intake *****

Age	Alternate (ug Pb/day)
.5-1	0.000
1-2	0.000
2-3	0.000
3-4	0.000
4-5	0.000
5-6	0.000
6-7	0.000

***** Maternal Contribution: Infant Model *****

Maternal Blood Concentration: 2.500 ug Pb/dL

CALCULATED BLOOD LEAD AND LEAD UPTAKES:

Year	Air (ug/day)	Diet (ug/day)	Alternate (ug/day)	Water (ug/day)
.5-1	0.002	2.657	0.000	0.187
1-2	0.003	2.765	0.000	0.467
2-3	0.006	3.119	0.000	0.489
3-4	0.007	3.029	0.000	0.503
4-5	0.007	2.960	0.000	0.529
5-6	0.009	3.135	0.000	0.561
6-7	0.009	3.461	0.000	0.572

Year	Soil+Dust (ug/day)	Total (ug/day)	Blood (ug/dL)
.5-1	2.862	5.708	3.1
1-2	4.531	7.767	3.3
2-3	4.564	8.179	3.0
3-4	4.606	8.146	2.9
4-5	3.459	6.956	2.4
5-6	3.129	6.834	2.1
6-7	2.961	7.003	2.0

Table 3-1
Lead Emission Rates Evaluated in the HHRA

Boiler	Average Heat Input (MMBtu/hr)	Lead Emission Rate		
		(lb/MMBtu)	(lb/hr)	(g/s)
Before Modification (Past Actual Basis)				
Boiler Unit 3	102.6	1.76E-05	1.81E-03	2.27E-04
Boiler Unit 4	180.3	1.76E-05	3.17E-03	4.00E-04
Boiler Unit 5	225.5	1.76E-05	3.97E-03	5.00E-04
After Modification (Future Potential Basis)				
Boiler Unit 4	242.0	1.76E-05	4.26E-03	5.37E-04
Boiler Unit 5	319.0	1.76E-05	5.61E-03	7.07E-04
Boiler Unit 10	865.0	2.17E-05	1.88E-02	2.37E-03

Table 3-2
Speciated Mercury Emission Rates for Coal-Fired Boilers

Mercury Form	Symbol	% of Total Hg Emissions
Hg0 [Elemental Vapor]	Hg0	50%
Hg2 [Divalent Vapor]	Hg2	30%
HgP [Particle-bound Divalent Vapor]	HgP	20%
Totals		100%

Source: Mercury Study Report to Congress. [EPA-452/R-97-005] (USEPA, 1997a).

Table 3-3
Mercury Emission Rates Evaluated in the HHRA

Boiler	Potential Heat Input (MMBtu/hr)	Total Mercury Emission Rate			
		(lb/MMBtu)	(lb/hr)	(g/s)	
Boiler Unit 3 ¹	126.5	1.89E-06	2.39E-04	3.01E-05	
Boiler Unit 4 ^{1,2}	242.0	2.47E-06	5.98E-04	7.53E-05	
Boiler Unit 5 ^{1,2}	319.0	9.86E-07	3.15E-04	3.96E-05	
New Unit 10 ²	865.0	7.03E-07	6.08E-04	7.67E-05	
Form of Mercury (Hg)	Partitioning Percentage (Wt-%)	Unit 3 ¹ (g/s)	Unit 4 ^{1,2} (g/s)	Unit 5 ^{1,2} (g/s)	Unit 10 ² (g/s)
Hg0 (Elemental Vapor)	50.0%	1.51E-05	3.77E-05	1.98E-05	3.83E-05
Hg2 (Divalent Vapor)	30.0%	9.04E-06	2.26E-05	1.19E-05	2.30E-05
HgP (Particle-bound Divalent Vapor)	20.0%	6.03E-06	1.51E-05	7.93E-06	1.53E-05

¹ Source included in 'before' modification model run.

² Source included in post-modification model run.

Table 4-1
 Representative Plot File Generated Following AERMOD Run

UTMX	UTMY	AVERAGE CONC	TOTAL DEPO	DRY DEPO	WET DEPO	ZELEV	ZHILL	ZFLAG	AVE	GRP	NUM YRS	NET ID
564790.9	4727858	0.00799	6.41006	6.13867	0.27140	176.78	216.71	0	ANNUAL	ALL	1	
565090.9	4727858	0.00812	6.62949	6.30201	0.32747	197.27	216.41	0	ANNUAL	ALL	1	
--	--	--	--	--	--	--	--	--	--	--	--	
565690.9	4727858	0.00950	8.14442	7.59997	0.54448	205.33	224.03	0	ANNUAL	ALL	1	
565990.9	4727858	0.01001	8.88733	8.24375	0.64356	192.02	192.02	0	ANNUAL	ALL	1	

Table 5-1
AERMOD Modeled Residential COPC Impacts

Chemical	Air Concentration ($\mu\text{g}/\text{m}^3$)	Dry Deposition ($\text{g}/\text{m}^2\text{-yr}$)	Wet Deposition ($\text{g}/\text{m}^2\text{-yr}$)
Candidate Residential Area [Zone C1]			
Hg2 [Divalent Mercury-Vapor Phase]	6.38E-06	5.66E-06	1.90E-07
HgP [Divalent Mercury-Particle Bound Phase]	4.27E-06	1.18E-06	1.20E-07
Hg0 [Elemental Mercury-Vapor Phase]	1.07E-05	n/a	n/a
Lead	2.67E-04	8.80E-04	3.34E-05

n/a Parameters not involved in evaluation of elemental mercury impacts.

Table 5-2
Terrestrial and Atmospheric Fate and Transport Parameters Considered in the HHRA

Parameter	Symbol	Units	Value	Source
Ambient Air Temperature	T	K	282.4	Average for Holland, MI [NOAA, 2006]
Average Annual Evapotranspiration	E	cm/yr	70.7	Calculated: Based on 75% of Precipitation
Average Annual Irrigation	I	cm/yr	19.8	Calculated: Geraghty, 1973.
Average Annual Precipitation	P	cm/yr	94.3	Average for Grand Rapids, MI [NRCC, 2006]
Average Annual Runoff	RO	cm/yr	12.7	Calculated: Geraghty, 1973.
Average Annual Wind Speed	W	m/s	4.4	Average for Grand Rapids, MI [1986-1990]
Density of Air	ρ_a	g/cm ³	0.0012	Default: HHRA Guidance [USEPA, 2005]
Soil Mixing Depth - Tilled Soil	$Z_{s(\text{tilled})}$	cm	20	Default: HHRA Guidance [USEPA, 2005]
Soil Mixing Depth - Untilled Soil	$Z_{s(\text{untilled})}$	cm	2	Default: HHRA Guidance [USEPA, 2005]
Soil Particle Density	ρ_s	g/cm ³	2.7	Default: HHRA Guidance [USEPA, 2005]
Time Unit Correction Factor	UCF _{yr}	d/yr	365	Default: HHRA Guidance [USEPA, 2005]
Total Deposition Time (i.e., Facility Operating Life)	tD	yr	30	Default: HHRA Guidance [USEPA, 2005]
Universal Gas Constant	R _{Gas}	atm-m ³ /mol-K	8.205E-05	Default: HHRA Guidance [USEPA, 2005]
Viscosity of Air	μ_a	g/cm-s	1.810E-04	Default: HHRA Guidance [USEPA, 2005]

Geraghty, 1973: [Water Atlas of the United States](#)

NOAA, 2006: [Annual Climatological Survey](http://hurricane.ncdc.noaa.gov/ancsum/ACS)[http://hurricane.ncdc.noaa.gov/ancsum/ACS]

NRCC, 2006: Northeast Regional Climate Center [http://www.nrcc.cornell.edu/ccd/nrmpcp.html]

USEPA, 2005: [Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities](#) Office of Solid Waste.

Table 5-3
COPC Concentrations in Residential Air

Chemical	C _v ($\mu\text{g}/\text{m}^3$)	C _{pSA} ($\mu\text{g}/\text{m}^3$)	C _{pM} ($\mu\text{g}/\text{m}^3$)	C _p ($\mu\text{g}/\text{m}^3$)	Ca ($\mu\text{g}/\text{m}^3$)
Mercury (Divalent)	6.38E-06	4.27E-06	0.00E+00	4.27E-06	1.1E-05
Mercury (Methyl)					
Mercury (Elemental)	1.07E-05	0.00E+00	0.00E+00	0.00E+00	1.1E-05
Lead	0.00E+00	0.00E+00	2.67E-04	2.67E-04	2.7E-04

Table 5-4
COPC Concentrations in Residential Soil - Deposition Term

Chemical	Dydv (g/m ² -yr)	Dyvw (g/m ² -yr)	Dydp _{SA} (g/m ² -yr)	Dydp _M (g/m ² -yr)	Dydp (g/m ² -yr)	Dywp _{SA} (g/m ² -yr)	Dywp _M (g/m ² -yr)	Dywp (g/m ² -yr)	BD (g/cm ³)	Z _{s(untilled)} (cm)	Z _{s(tilled)} (cm)	Ds _{untilled} (mg/kg-yr)	Ds _{tilled} (mg/kg-yr)
Mercury (Divalent)	5.66E-06	1.90E-07	1.18E-06	0.00E+00	1.18E-06	1.20E-07	0.00E+00	1.20E-07	1.5	2	20	2.3E-04	2.3E-05
Mercury (Methyl)												4.8E-06	4.8E-07
Mercury (Elemental)													
Lead	0.00E+00	0.00E+00	0.00E+00	8.80E-04	8.80E-04	0.00E+00	3.34E-05	3.34E-05	1.5	2	20	3.0E-02	3.0E-03

Table 5-5
COPC Concentrations in Residential Soil

Chemical	tD (yr)	Untilled			Tilled		
		DS _{untilled} (mg/kg-yr)	KS _{untilled} (yr ⁻¹)	CS _{untilled} (mg/kg)	DS _{tilled} (mg/kg-yr)	KS _{tilled} (yr ⁻¹)	CS _{tilled} (mg/kg)
Mercury (Divalent)	30	2.3E-04	2.5E-04	7.0E-03	2.3E-05	2.5E-05	7.0E-04
Mercury (Methyl)	30	4.8E-06	2.3E-03	1.4E-04	4.8E-07	2.1E-04	1.4E-05
Mercury (Elemental)							
Lead	30	3.0E-02	1.6E-02	7.2E-01	3.0E-03	1.6E-03	8.9E-02

Table 5-6
Residential Soil Loss Constants

Chemical	$k_{sl_{untilled}}$ (yr^{-1})	$k_{se_{untilled}}$ (yr^{-1})	$k_{sr_{untilled}}$ (yr^{-1})	k_{sg} (yr^{-1})	$k_{sv_{untilled}}$ (yr^{-1})	$k_{s_{untilled}}$ (yr^{-1})	$k_{sl_{tilled}}$ (yr^{-1})	$k_{se_{tilled}}$ (yr^{-1})	$k_{sr_{tilled}}$ (yr^{-1})	k_{sg} (yr^{-1})	$k_{sv_{tilled}}$ (yr^{-1})	$k_{s_{tilled}}$ (yr^{-1})
Mercury (Divalent)	1.8E-04	0.0E+00	7.3E-05	0.0E+00	3.1E-08	2.5E-04	1.8E-05	0.0E+00	7.3E-06	0.0E+00	3.1E-10	2.5E-05
Mercury (Methyl)	1.5E-03	0.0E+00	6.0E-04	0.0E+00	2.0E-04	2.3E-03	1.5E-04	0.0E+00	6.0E-05	0.0E+00	2.0E-06	2.1E-04
Mercury (Elemental)												
Lead	1.1E-02	0.0E+00	4.7E-03	0.0E+00	0.0E+00	1.6E-02	1.1E-03	0.0E+00	4.7E-04	0.0E+00	0.0E+00	1.6E-03

Table 5-7
Soil Loss Constant Due to Leaching

Chemical	P (cm/yr)	I (cm/yr)	RO (cm/yr)	E _v (cm/yr)	θ _{sw} (mL/cm ³)	Z _{s(untilled)} (cm)	Z _{s(tilled)} (cm)	BD (g/cm ³)	Kd _s (cm ³ /g)	ksl _{untilled} (yr ⁻¹)	ksl _{tilled} (yr ⁻¹)
Mercury (Divalent)	94.3	19.8	12.7	70.7	0.20	2	20	1.5	5.8E+04	1.8E-04	1.8E-05
Mercury (Methyl)	94.3	19.8	12.7	70.7	0.20	2	20	1.5	7.0E+03	1.5E-03	1.5E-04
Mercury (Elemental)											
Lead	94.3	19.8	12.7	70.7	0.20	2	20	1.5	9.0E+02	1.1E-02	1.1E-03

Table 5-8
Soil Loss Constant Due to Runoff

Chemical	RO (cm/yr)	Z _{s(untilled)} (cm)	Z _{s(tilled)} (cm)	θ _{sw} (mL/cm ³)	K _{d_s} (cm ³ /g)	BD (g/ml)	k _{sr_{untilled}} (yr ⁻¹)	k _{sr_{tilled}} (yr ⁻¹)
Mercury (Divalent)	12.7	2	20	0.20	5.8E+04	1.5	7.3E-05	7.3E-06
Mercury (Methyl)	12.7	2	20	0.20	7.0E+03	1.5	6.0E-04	6.0E-05
Mercury (Elemental)								
Lead	12.7	2	20	0.20	9.0E+02	1.5	4.7E-03	4.7E-04

Table 5-9
Soil Loss Constant Due to Volatilization

Chemical	K_{ds} (cm^3/g)	D_a (cm^2/s)	Z_{untilled} (cm)	$Z_{\text{s(tilled)}}$ (cm)	H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	R_{Gas} ($\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$)	T (K)	BD (g/cm^3)	θ_{sw} (mL/cm^3)	ρ_s (g/cm^3)	$k_{\text{svuntilled}}$ (y^{-1})	k_{svtilled} (y^{-1})
Mercury (Divalent)	5.8E+04	4.5E-02	2	20	7.1E-10	8.2E-05	282	1.5	0.20	2.7	3.1E-08	3.1E-10
Mercury (Methyl)	7.0E+03	5.3E-02	2	20	4.7E-07	8.2E-05	282	1.5	0.20	2.7	2.0E-04	2.0E-06
Mercury (Elemental)												
Lead	9.0E+02	7.7E-02	2	20	0.0E+00	8.2E-05	282	1.5	0.20	2.7	0.0E+00	0.0E+00

Table 5-10
COPC Concentrations in Above-Ground Plants Due to Particle Deposition

Chemical	Dydp _{SA} (g/m ² -yr)	Dydp _M (g/m ² -yr)	Dydp (g/m ² -yr)	Fw ()	Dywp _{SA} (g/m ² -yr)	Dywp _M (g/m ² -yr)	Dywp (g/m ² -yr)	Rp ()	kp (yr ⁻¹)	Tp (yr)	Yp (kg/m ²)	Pd (mg/kg)
Mercury (Divalent)	1.18E-06	0.00E+00	1.18E-06	0.6	1.20E-07	0.00E+00	1.20E-07	0.39	18.0	0.16	2.24	8.9E-06
Mercury (Methyl)												2.5E-06
Mercury (Elemental)												
Lead	0.00E+00	8.80E-04	8.80E-04	0.6	0.00E+00	3.34E-05	3.34E-05	0.39	18.0	0.16	2.24	8.2E-03

Table 5-11
COPC Concentrations in Above-Ground Plants Due to Air-to-Plant Transfer

Chemical	C _{yv} (μg/m ³)	B _{vag} [(mg/kg)/(μg/g)]	ρ _a (g/m ³)	V _{Gag} ()	P _v (mg/kg)
Mercury (Divalent)	6.38E-06	1.80E+03	1.2E+03	1.00	7.5E-06
Mercury (Methyl)					2.1E-06
Mercury (Elemental)					
Lead	0.00E+00	0.0E+00	1.2E+03	1.00	0.0E+00

Table 5-12
COPC Concentrations in Above-Ground Plants Due to Root Uptake

Chemical	$C_{S_{filled}}$ (mg/kg)	Br [(mg/kg)/(mg/kg)]	Pr (mg/kg)
Mercury (Divalent)	7.0E-04	1.4E-02	9.8E-06
Mercury (Methyl)	1.4E-05	2.9E-02	4.1E-07
Mercury (Elemental)			
Lead	8.9E-02	1.4E-02	1.2E-03

Table 5-13
COPC Concentrations in Below-Ground Plants Due to Root Uptake

Chemical	C _s _{tilled} (mg/kg)	RCF ()	K _d _s (L/kg)	Br _{root} ()	VG _{root} ()	Pr _{bg} (mg/kg)
Mercury (Divalent)	7.0E-04	0.0E+00	5.8E+04	3.6E-02	1.00	2.5E-05
Mercury (Methyl)	1.4E-05	0.0E+00	7.0E+03	9.9E-02	1.00	1.4E-06
Mercury (Elemental)						
Lead	8.9E-02	0.0E+00	9.0E+02	9.0E-03	1.00	8.0E-04

Table 5-14
AERMOD Modeled COPC Impacts on Lake Macatawa

Chemical	Water Body		Watershed	
	Air Concentration ($\mu\text{g}/\text{m}^3$)	Total Deposition ($\text{g}/\text{m}^2\text{-yr}$)	Air Concentration ($\mu\text{g}/\text{m}^3$)	Total Deposition ($\text{g}/\text{m}^2\text{-yr}$)
Hg2 [Divalent Mercury-Vapor Phase]	7.43E-07	4.89E-07	n/a	1.54E-07
HgP [Divalent Mercury-Particle Bound Phase]	n/a	9.51E-08	n/a	2.55E-08
Lead	n/a	1.53E-04	n/a	3.76E-05

n/a Parameter not used in algorithms involved in modeling surface water impacts.

Table 5-15
Aquatic Fate-and-Transport Parameters Considered in the HHRA

Parameter	Symbol	Units	Value	Source
Average Volumetric Flow Through Waterbody	Vfx	m ³ /yr	1.29E+08	Calculated: Based on Gaging Data
Bed Sediment Concentration	BS	g/cm ³	1	Default: HHRA Guidance [USEPA, 2005]
Bed Sediment Porosity	θ _{bs}	L _{water} /L	0.6	Default: HHRA Guidance [USEPA, 2005]
Current Velocity	u	m/s	0.03	Calculated: From Vfx & Channel Cross Sectional Area
Density of Water	ρ _w	g/cm ³	1	Default: HHRA Guidance [USEPA, 2005]
Depth of Upper Benthic Layer	d _b	m	0.03	Default: HHRA Guidance [USEPA, 2005]
Depth of Water Column	d _w	m	2.97	Calculated: ArcGIS from Navigation Chart
Drag Coefficient	C _d	()	0.0011	Default: HHRA Guidance [USEPA, 2005]
Empirical Intercept Coefficient	a	()	1.05	Calculated: HHRA Guidance [USEPA, 2005] Table B-4-14
Empirical Slope Coefficient	b	()	0.125	Default: HHRA Guidance [USEPA, 2005]
Fraction Organic Carbon in Bottom Sediment	OC _{sed}	()	0.04	Default: HHRA Guidance [USEPA, 2005]
Soil Bulk Density	BD	g/cm ³	1.5	Default: HHRA Guidance [USEPA, 2005]
Soil Enrichment Ratio (Organics)	ER	()	3	Default: HHRA Guidance [USEPA, 2005]
Soil Enrichment Ratio (Metals)	ER	()	1	Default: HHRA Guidance [USEPA, 2005]
Suspended Solids Deposition Rate	D _{ss}	m/yr	1825	Default: HHRA Guidance [USEPA, 2005]
Temperature Correction Factor - Surface Water	θ	()	1.026	Default: HHRA Guidance [USEPA, 2005]
Total Suspended Solids	TSS	mg/L	29.35	Calculated: From MDEQ Data
USLE Cover Management Factor	C	()	0.1	Default: HHRA Guidance [USEPA, 2005]
USLE Erodibility Factor	K	ton/acre	0.27	Calculated: State Average [MDEQ, 2006a]
USLE Length-slope Factor	LS	()	1.5	Default: HHRA Guidance [USEPA, 2005]
USLE Rainfall Factor	RF	yr ⁻¹	100	Default: Ottawa County [MDEQ, 2006a]
USLE Supporting Practice Factor	P	()	1	Default: HHRA Guidance [USEPA, 2005]
Viscous Sublayer Thickness-Dimensionless	λ ₂	()	4	Default: HHRA Guidance [USEPA, 2005]
Viscosity of Water	μ _w	g/cm-s	0.0169	Default: HHRA Guidance [USEPA, 2005]
Volumetric Soil Water Content	θ _{sw}	cm ³ /cm ³	0.2	Default: HHRA Guidance [USEPA, 2005]
Von Karman's Constant	k	()	0.4	Default: HHRA Guidance [USEPA, 2005]
Water Body Area	WA _w	m ²	8.27E+06	Calculated: ArcGIS from DOQQ
Waterbody Temperature	T _k	K	282.4	Estimated: From Air Temperature
Watershed Area	WA _L	m ²	4.26E+08	Calculated: ArcGIS from DOQQ
Watershed Area, Impervious	WA _I	m ²	2.56E+07	Calculated: ArcGIS from DOQQ

MDEQ, 2006a: Soil Erosion and Sediment Control Training Manual, MDEQ Water Bureau.

USEPA, 2005: Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, Office of Solid Waste.

Table 5-16
COPC Concentrations in Watershed Soils - Deposition Term

Chemical	Watershed				BD (g/cm ³)	Z _{untilled} (cm)	D _{s_{wshed}} (mg/kg-yr)
	Dytwv (g/m ² -yr)	Dytwp _{SA} (g/m ² -yr)	Dytwp _M (g/m ² -yr)	Dytwp (g/m ² -yr)			
Mercury (Divalent)	1.54E-07	2.55E-08	0.00E+00	2.55E-08	1.5	2	5.9E-06
Mercury (Methyl)							1.2E-07
Mercury (Elemental)							
Lead	0.00E+00	0.00E+00	3.76E-05	3.76E-05	1.5	2	1.3E-03

Table 5-17
COPC Concentrations in Watershed Soils

Chemical	Ds (mg/kg-yr)	$k_{S_{untilled}}$ (yr^{-1})	tD (yr)	$C_{S_{wshed}}$ (mg/kg)
Mercury (Divalent)	5.9E-06	2.9E-03	30	1.7E-04
Mercury (Methyl)	1.2E-07	1.0E-02	30	3.1E-06
Mercury (Elemental)				
Lead	1.3E-03	1.9E-02	30	2.9E-02

Table 5-18
Watershed Soil Loss Constant Due to Leaching

Chemical	K _d (ml/g)	P (cm/yr)	I (cm/yr)	RO (cm/yr)	E _v (cm/yr)	Z _{untilled} (cm)	θ _{sw} ()	BD (g/ml)	k _{sl} _{wshed} (yr ⁻¹)
Mercury (Divalent)	5.8E+04	94.31	19.8	12.7	70.7	2	0.2	1.5	1.8E-04
Mercury (Methyl)	7.0E+03	94.31	19.8	12.7	70.7	2	0.2	1.5	1.5E-03
Mercury (Elemental)									
Lead	9.0E+02	94.31	19.8	12.7	70.7	2	0.2	1.5	1.1E-02

Table 5-19
Watershed Soil Loss Constant Due to Volatilization

Chemical	K_{ds} (cm ³ /g)	D_a (cm ² /s)	$Z_{untilled}$ (cm)	H (atm-m ³ /mol)	R_{Gas} (atm-m ³ /mol-K)	T (K)	BD (g/cm ³)	θ_{sw} (mL/cm ³)	ρ_s (g/cm ³)	$k_{SV_{wshed}}$ (y ⁻¹)
Mercury (Divalent)	5.8E+04	4.5E-02	2	7.1E-10	8.2E-05	282	1.5	0.20	2.7	3.1E-08
Mercury (Methyl)	7.0E+03	5.3E-02	2	4.7E-07	8.2E-05	282	1.5	0.20	2.7	2.0E-04
Mercury (Elemental)										
Lead	9.0E+02	7.7E-02	2	0.0E+00	8.2E-05	282	1.5	0.20	2.7	0.0E+00

Table 5-20
Watershed Soil Loss Constant Due to Runoff

Chemical	K_d_s (cm^3/g)	RO (cm/yr)	θ_{sw} (mL/cm^3)	Z_{untilled} (cm)	BD (g/cm^3)	ksr_{wshed} (yr^{-1})
Mercury (Divalent)	5.8E+04	12.7	0.2	2	1.5	7.3E-05
Mercury (Methyl)	7.0E+03	12.7	0.2	2	1.5	6.0E-04
Mercury (Elemental)						
Lead	9.0E+02	12.7	0.2	2	1.5	4.7E-03

Table 5-21
Watershed Soil Loss Constant Due to Erosion

Chemical	Kd_s (cm^3/g)	X_e ($kg/m^2\text{-yr}$)	SD ($\text{}$)	ER ($\text{}$)	Z_{untilled} (cm)	BD (g/cm^3)	θ_{sw} (mL/cm^3)	kse_{wshed} (yr^{-1})
Mercury (Divalent)	5.8E+04	0.91	0.09	1.0	2	1.5	0.2	2.7E-03
Mercury (Methyl)	7.0E+03	0.91	0.09	3.0	2	1.5	0.2	8.0E-03
Mercury (Elemental)								
Lead	9.0E+02	0.91	0.09	1.0	2	1.5	0.2	2.7E-03

Table 5-22
Watershed Soil Loss Constants

Chemical	$k_{sl_{wshed}}$ (yr^{-1})	$k_{se_{wshed}}$ (yr^{-1})	$k_{sf_{wshed}}$ (yr^{-1})	$k_{sg_{wshed}}$ (yr^{-1})	$k_{sv_{wshed}}$ (yr^{-1})	$k_{s_{wshed}}$ (yr^{-1})
Mercury (Divalent)	1.8E-04	2.7E-03	7.3E-05	0.0E+00	3.1E-08	2.9E-03
Mercury (Methyl)	1.5E-03	8.0E-03	6.0E-04	0.0E+00	2.0E-04	1.0E-02
Mercury (Elemental)						
Lead	1.1E-02	2.7E-03	4.7E-03	0.0E+00	0.0E+00	1.9E-02

Table 5-23
 Deposition Loading of COPCs to Lake Macatawa

Chemical	Water Body				A _w (m ²)	L _{Dep} (g/yr)
	Dytwv (g/m ² -yr)	Dytwp _{SA} (g/m ² -yr)	Dytwp _M (g/m ² -yr)	Dytwp (g/m ² -yr)		
Mercury (Divalent)	4.89E-07	9.51E-08	0.00E+00	9.51E-08	8.27E+06	4.8E+00
Mercury (Methyl)						0.0E+00
Mercury (Elemental)						
Lead	0.00E+00	0.00E+00	1.53E-04	1.53E-04	8.27E+06	1.3E+03

Table 5-24
Diffusion Loading of COPCs to Lake Macatawa

Chemical	K_v (m/yr)	C_{yw} ($\mu\text{g}/\text{m}^3$)	A_w (m^2)	H ($\text{atm}\cdot\text{m}^3/\text{mol}$)	R ($\text{atm}\cdot\text{m}^3/\text{mol}\cdot\text{K}$)	T_{wk} (K)	L_{Dif} (g/yr)
Mercury (Divalent)	8.52E-04	7.43E-07	8.27E+06	7.1E-10	8.21E-05	282.4	1.7E-01
Mercury (Methyl)							
Mercury (Elemental)							
Lead	0.00E+00	0.00E+00	8.27E+06	0.0E+00	8.21E-05	282.4	0.0E+00

Table 5-25
 Impervious Runoff Loading of COPCs to Lake Macatawa

Chemical	Watershed				A _I (m ²)	L _{RI} (g/yr)
	Dytwv (g/m ² -yr)	Dytwp _{SA} (g/m ² -yr)	Dytwp _M (g/m ² -yr)	Dytwp (g/m ² -yr)		
Mercury (Divalent)	1.54E-07	2.55E-08	0.00E+00	2.55E-08	2.56E+07	4.6E+00
Mercury (Methyl)						0.0E+00
Mercury (Elemental)						
Lead	0.00E+00	0.00E+00	3.76E-05	3.76E-05	2.56E+07	9.6E+02

Table 5-26
Pervious Runoff Loading of COPCs to Lake Macatawa

Chemical	$C_{S_{wshed}}$ (mg/kg)	RO (cm/yr)	BD (g/cm ³)	K_{ds} (L/kg)	A_L (m ²)	A_I (m ²)	θ_{sw} ()	UCF (cm ² -kg/m ² -mg)	L_R (g/yr)
Mercury (Divalent)	1.7E-04	12.7	1.5	5.8E+04	4.26E+08	2.56E+07	0.2	0.01	1.5E-01
Mercury (Methyl)	3.1E-06	12.7	1.5	7.0E+03	4.26E+08	2.56E+07	0.2	0.01	2.2E-02
Mercury (Elemental)									
Lead	2.9E-02	12.7	1.5	9.0E+02	4.26E+08	2.56E+07	0.2	0.01	1.6E+03

Table 5-27
Erosion Loading of COPCs to Lake Macatawa

Chemical	$C_{S_{wshed}}$ (mg/kg)	X_e (kg/m ² -yr)	A_L (m ²)	A_I (m ²)	SD (λ)	ER (λ)	K_{d_s} (L/kg)	θ_{sw} (λ)	BD (g/cm ³)	UCF (mg/g)	L_E (g/yr)
Mercury (Divalent)	1.7E-04	0.91	4.26E+08	2.56E+07	0.09	1.0	5.8E+04	0.2	1.5	0.001	5.4E+00
Mercury (Methyl)	3.1E-06	0.91	4.26E+08	2.56E+07	0.09	3.0	7.0E+03	0.2	1.5	0.001	3.0E-01
Mercury (Elemental)											
Lead	2.9E-02	0.91	4.26E+08	2.56E+07	0.09	1.0	9.0E+02	0.2	1.5	0.001	9.2E+02

Table 5-28
 Universal Soil Loss Equation and Sediment Delivery Ratio

RF (yr ⁻¹)	K (ton/acre)	LS ()	C ()	PF ()	X _e (kg/m ² -yr)	A _L (m ²)	b ()	a ()	SD ()
100.0	0.27	1.5	0.1	1.0	0.91	4.26E+08	0.125	1.1	0.09

Table 5-29
Total Loading of COPCs to Lake Macatawa

Chemical	L_{Dep} (g/yr)	L_I (g/yr)	L_{RI} (g/yr)	L_R (g/yr)	L_E (g/yr)	L_{Dif} (g/yr)	L_T (g/yr)
Mercury (Divalent)	4.8E+00	0.0E+00	4.6E+00	1.5E-01	5.4E+00	1.7E-01	1.5E+01
Mercury (Methyl)	0.0E+00	0.0E+00	0.0E+00	2.2E-02	3.0E-01	0.0E+00	3.2E-01
Mercury (Elemental)							
Lead	1.3E+03	0.0E+00	9.6E+02	1.6E+03	9.2E+02	0.0E+00	4.8E+03

Table 5-30
Total Water Body Concentration of COPCs in Lake Macatawa

Chemical	L_T (g/yr)	Vf_x (m ³ /yr)	f_{wc} ()	d_{wc} (m)	d_{bs} (m)	k_{wt} (yr ⁻¹)	A_W (m ²)	C_{wtot} (mg/L)
Mercury (Divalent)	1.5E+01	1.29E+08	0.008	2.97	0.03	1.20E-01	8.27E+06	3.8E-06
Mercury (Methyl)	3.2E-01	1.29E+08	0.115	2.97	0.03	1.13E-01	8.27E+06	1.8E-08
Mercury (Elemental)								
Lead	4.8E+03	1.29E+08	0.101	2.97	0.03	1.09E-01	8.27E+06	3.0E-04

Table 5-31
 Fraction of COPCs in Lake Macatawa Water Column and Benthic Sediment

Chemical	K_{dsw} (L/kg)	TSS (mg/L)	d_{wc} (m)	d_{bs} (m)	d_z (m)	θ_{bs} (L _w /L)	K_{dbs} (L/kg)	C_{BS} (g/cm ³)	f_{bs} ()	f_{wc} ()
Mercury (Divalent)	1.0E+05	29.4	2.97	0.03	3.00	0.60	5.0E+04	1.0	0.992	0.008
Mercury (Methyl)	1.0E+05	29.4	2.97	0.03	3.00	0.60	3.0E+03	1.0	0.885	0.115
Mercury (Elemental)										
Lead	9.0E+02	29.4	2.97	0.03	3.00	0.60	9.0E+02	1.0	0.899	0.101

Table 5-32
Overall Total Water Body Dissipation Rate Constants for COPCs in Lake Macatawa

Chemical	f_{wc} ()	k_v (yr^{-1})	f_{bs} ()	k_b (yr^{-1})	k_{wt} (yr^{-1})
Mercury (Divalent)	0.008	7.2E-05	0.992	0.12	1.2E-01
Mercury (Methyl)	0.115	4.7E-02	0.885	0.12	1.1E-01
Mercury (Elemental)					
Lead	0.101	0.0E+00	0.899	0.12	1.1E-01

Table 5-33
Benthic Burial Rate Constant for COPCs in Lake Macatawa

X_e (kg/m ² -yr)	A_L (m ²)	SD ()	V_{f_x} (m ³ /yr)	TSS (mg/L)	A_W (m ²)	C_{BS} (kg/L)	d_{bs} (m)	k_b (yr ⁻¹)
0.91	4.26E+08	0.09	1.29E+08	29.4	8.27E+06	1.0	0.03	0.12

Table 5-34
Water Column Volatilization Loss Rate Constants for COPCs in Lake Macatawa

Chemical	K_v (m/yr)	d_w (m)	d_b (m)	d_z (m)	$K_{d_{sw}}$ (L/kg)	TSS (mg/L)	k_v (yr ⁻¹)
Mercury (Divalent)	8.52E-04	2.97	0.03	3	1.0E+05	29.4	7.2E-05
Mercury (Methyl)	5.59E-01	2.97	0.03	3	1.0E+05	29.4	4.7E-02
Mercury (Elemental)							
Lead	0.00E+00	2.97	0.03	3	9.0E+02	29.4	0.0E+00

Table 5-35
Overall Transfer Rates for COPCs in Lake Macatawa

Chemical	K_L (m/yr)	K_G (m/yr)	H (atm·m ³ /mol)	R (atm·m ³ /mol·K)	T_{wk} (K)	θ ()	K_V (m/yr)
Mercury (Divalent)	7.19E+01	3.7E+04	7.1E-10	8.205E-05	282.4	1.026	8.5E-04
Mercury (Methyl)	7.79E+01	3.7E+04	4.7E-07	8.205E-05	282.4	1.026	5.6E-01
Mercury (Elemental)							
Lead	9.77E+01	3.7E+04	0.0E+00	8.205E-05	282.4	1.026	0.0E+00

Table 5-36
Liquid Phase Transfer Coefficients for COPCs in Lake Macatawa

Chemical	D_w (cm^2/s)	u (m/s)	d_z (m)	C_d ($\text{}$)	W (m/s)	ρ_a (g/cm^3)	ρ_w (g/cm^3)	k ($\text{}$)	λ_z ($\text{}$)	μ_w ($\text{g}/\text{cm}\cdot\text{s}$)	K_L (m/yr)
Mercury (Divalent)	5.2E-06	0.03	3	1.1E-03	4.42	1.2E-03	1.0	0.4	4	1.69E-02	7.2E+01
Mercury (Methyl)	6.1E-06	0.03	3	1.1E-03	4.42	1.2E-03	1.0	0.4	4	1.69E-02	7.8E+01
Mercury (Elemental)											
Lead	9.6E-06	0.03	3	1.1E-03	4.42	1.2E-03	1.0	0.4	4	1.69E-02	9.8E+01

Table 5-37
Total Water Column Concentration of COPCs in Lake Macatawa

Chemical	f_{wc} ()	C_{wtot} (mg/L)	d_{wc} (m)	d_{bs} (m)	C_{wctot} (mg/L)
Mercury (Divalent)	0.008	3.8E-06	2.97	0.03	3.0E-08
Mercury (Methyl)	0.115	1.8E-08	2.97	0.03	2.1E-09
Mercury (Elemental)					
Lead	0.101	3.0E-04	2.97	0.03	3.1E-05

Table 5-38
Dissolved Water Concentration of COPCs in Lake Macatawa

Chemical	C_{wctot} (mg/L)	Kd_{sw} (L/kg)	TSS (mg/L)	C_{dw} (mg/L)
Mercury (Divalent)	3.0E-08	1.0E+05	29.4	6.4E-09
Mercury (Methyl)	2.1E-09	1.0E+05	29.4	1.7E-09
Mercury (Elemental)				
Lead	3.1E-05	9.0E+02	29.4	3.0E-05

Table 5-39
COPC Concentrations in Lake Macatawa Fish Tissue

Chemical	C _{dw} (mg/L)	BCF (L/kg)	BAF (L/kg)	C _{fish} BCF	C _{fish} BAF	C _{fish} (mg/kg)	C _{wctot} (mg/L)	C _{wctot} [Comb] (mg/L)	BAF (L/kg)	C _{fish} (mg/kg)
	USEPA Approach						MDEQ Approach			
Mercury (Divalent)	6.4E-09	0.00E+00	1.0E+00	0.0E+00	6.4E-09	6.4E-09	3.0E-08			
Mercury (Methyl)	1.7E-09	0.00E+00	5.6E+06	0.0E+00	9.2E-03	9.2E-03	2.1E-09	3.2E-08	1.1E+05	3.6E-03
Mercury (Elemental)										
Lead	3.0E-05	9.00E-02	0.0E+00	2.7E-06	0.0E+00	2.7E-06				2.7E-06

Table 5-40
Bioaccumulation Factors for Modeling Fish Tissue Concentrations of Mercury

Parameter	MDEQ Daily Fish Intake ¹ (g/d)	Fractional Intake ()	MDEQ BAF ² (L/kg)	TL-Adjusted MDEQ BAF (L/kg)	USEPA BAF ³ (L/kg)	TL-Adjusted USEPA BAF (L/kg)
Trophic Level 4	11.4	0.76	1.40E+05	1.06E+05	6.80E+06	5.17E+06
Trophic Level 3	3.6	0.24	2.79E+04	6.70E+03	1.60E+06	3.84E+05
Total	15.0	1.00		1.13E+05		5.55E+06

¹ Average for Michigan sports anglers and sports-caught fish.

² Per the MDEQ water quality standards derivation protocol [Bob Sills, Personal Communication]

³ Mercury Study Report to Congress [USEPA, 1997].

Table 5-41
Exposure Parameters Considered in the HHRA

Parameter ¹	Symbol	Units	Resident	Resident Child	Recreational Fisher	Fisher Child
Daily Consumption Rate of Soil	CR _{soil}	g/d	0.1	0.2	0.1	0.2
Fraction of Soil Contaminated	F _{soil}	()	1	1	1	1
Daily Consumption Rate of Fish (Recreational Fisher) ²	CR _{fish}	g FW/d	0	0	15	2.3
Daily Consumption Rate of Trophic Level 3 Fish ²	CR _{fish}	g FW/d	0	0	3.6	0.54
Daily Consumption Rate of Trophic Level 4 Fish ²	CR _{fish}	g FW/d	0	0	11.4	1.71
Fraction of Fish Contaminated ²	F _{fish}	()	1	1	1	1
Daily Consumption Rate (Above-Ground Produce)	CR _{ag}	g DW/d	22.4	11.55	22.4	11.55
Daily Consumption Rate (Below-Ground Produce)	CR _{bg}	g DW/d	9.8	3.45	9.8	3.45
Daily Consumption Rate (Prot. Above-Ground Produce)	CR _{pp}	g DW/d	42.7	22.5	42.7	22.5
Fraction of Produce Contaminated	F _{ag}	()	1	1	1	1
Exposure Frequency	EF	d/yr	350	350	350	350
Exposure Duration	ED	yr	30	6	30	6
Body Weight	BW	kg	70	15	70	15
Averaging Time (Non-Carcinogens)	AT _{nc}	yr	30	6	30	6

¹ Unless otherwise noted, values are from USEPA (2005).

² Fish consumption rates for adults recommended by Bob Sills, MDEQ AQD based on average value for recreational Michigan fishermen.

Table 5-42
 Daily Intake of COPCs Via Incidental Soil Ingestion
 Resident Child

Chemical	$C_{S_{untilled}}$ (mg/kg)	CR_{soil} (kg/d)	F_{soil} ()	I_{soil} (mg/d)
Mercury (Divalent)	7.0E-03	0.0002	1.0	1.4E-06
Mercury (Methyl)	1.4E-04	0.0002	1.0	2.8E-08
Mercury (Elemental)	0.0E+00	0.0002	1.0	0.0E+00
Lead	7.2E-01	0.0002	1.0	1.4E-04

Table 5-43
 Daily Intake of COPCs Via Incidental Soil Ingestion
 Recreational Fisher

Chemical	$C_{S_{untilled}}$ (mg/kg)	CR_{soil} (kg/d)	F_{soil} ()	I_{soil} (mg/d)
Mercury (Divalent)	7.0E-03	0.0001	1.0	7.0E-07
Mercury (Methyl)	1.4E-04	0.0001	1.0	1.4E-08
Mercury (Elemental)	0.0E+00	0.0001	1.0	0.0E+00
Lead	7.2E-01	0.0001	1.0	7.2E-05

Table 5-44
 Daily Intake of COPCs Via Incidental Soil Ingestion
 Recreational Fisher Child

Chemical	$C_{S_{untilled}}$ (mg/kg)	CR_{soil} (kg/d)	F_{soil} ()	I_{soil} (mg/d)
Mercury (Divalent)	7.0E-03	0.0002	1.0	1.4E-06
Mercury (Methyl)	1.4E-04	0.0002	1.0	2.8E-08
Mercury (Elemental)	0.0E+00	0.0002	1.0	0.0E+00
Lead	7.2E-01	0.0002	1.0	1.4E-04

Table 5-45
 Daily Intake of COPCs Via Ingestion of Homegrown Plants
 Resident Child

Chemical	Pd (mg/kg)	Pv (mg/kg)	Pr (mg/kg)	Pr _{bg} (mg/kg)	CR _{ag} (kg/d)	CR _{pp} (kg/d)	CR _{bg} (kg/d)	F _{veg} ()	I _{veg} (mg/d)
Mercury (Divalent)	8.9E-06	7.5E-06	9.8E-06	2.5E-05	0.01155	0.0225	0.00345	1.0	6.1E-07
Mercury (Methyl)	2.5E-06	2.1E-06	4.1E-07	1.4E-06	0.01155	0.0225	0.00345	1.0	7.2E-08
Mercury (Elemental)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.01155	0.0225	0.00345	1.0	0.0E+00
Lead	8.2E-03	0.0E+00	1.2E-03	8.0E-04	0.01155	0.0225	0.00345	1.0	1.4E-04

Table 5-46
 Daily Intake of COPCs Via Ingestion of Homegrown Plants
 Recreational Fisher

Chemical	Pd (mg/kg)	Pv (mg/kg)	Pr (mg/kg)	Pr _{bg} (mg/kg)	CR _{ag} (kg/d)	CR _{pp} (kg/d)	CR _{bg} (kg/d)	F _{veg} ()	I _{veg} (mg/d)
Mercury (Divalent)	8.9E-06	7.5E-06	9.8E-06	2.5E-05	0.0224	0.0427	0.0098	1.0	1.3E-06
Mercury (Methyl)	2.5E-06	2.1E-06	4.1E-07	1.4E-06	0.0224	0.0427	0.0098	1.0	1.4E-07
Mercury (Elemental)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0224	0.0427	0.0098	1.0	0.0E+00
Lead	8.2E-03	0.0E+00	1.2E-03	8.0E-04	0.0224	0.0427	0.0098	1.0	2.7E-04

Table 5-47
 Daily Intake of COPCs Via Ingestion of Homegrown Plants
 Recreational Fisher Child

Chemical	Pd (mg/kg)	Pv (mg/kg)	Pr (mg/kg)	Pr _{bg} (mg/kg)	CR _{ag} (kg/d)	CR _{pp} (kg/d)	CR _{bg} (kg/d)	F _{veg} ()	I _{veg} (mg/d)
Mercury (Divalent)	8.9E-06	7.5E-06	9.8E-06	2.5E-05	0.01155	0.0225	0.00345	1.0	6.1E-07
Mercury (Methyl)	2.5E-06	2.1E-06	4.1E-07	1.4E-06	0.01155	0.0225	0.00345	1.0	7.2E-08
Mercury (Elemental)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.01155	0.0225	0.00345	1.0	0.0E+00
Lead	8.2E-03	0.0E+00	1.2E-03	8.0E-04	0.01155	0.0225	0.00345	1.0	1.4E-04

Table 5-48
 Daily Intake of COPCs Via Ingestion of Fish
 Recreational Fisher

Chemical	$C_{\text{fish-USEPA}}$ (mg/kg)	$C_{\text{fish-MDEQ}}$ (mg/kg)	CR_{fish} (kg/d)	F_{fish} ()	$I_{\text{fish-USEPA}}$ (mg/d)	$I_{\text{fish-MDEQ}}$ (mg/d)
Mercury (Divalent)	6.4E-09	0.0E+00	0.015	1.0	9.6E-11	0.0E+00
Mercury (Methyl)	9.2E-03	3.6E-03	0.015	1.0	1.4E-04	5.4E-05
Mercury (Elemental)	0.0E+00	0.0E+00	0.015	1.0	0.0E+00	0.0E+00
Lead	2.7E-06	2.7E-06	0.015	1.0	4.1E-08	4.1E-08

Table 5-49
 Daily Intake of COPCs Via Ingestion of Fish
 Recreational Fisher Child

Chemical	$C_{\text{fish-USEPA}}$ (mg/kg)	$C_{\text{fish-MDEQ}}$ (mg/kg)	CR_{fish} (kg/d)	F_{fish} ()	$I_{\text{fish-USEPA}}$ (mg/d)	$I_{\text{fish-MDEQ}}$ (mg/d)
Mercury (Divalent)	6.4E-09	0.0E+00	0.0023	1.0	1.5E-11	0.0E+00
Mercury (Methyl)	9.2E-03	3.6E-03	0.0023	1.0	2.1E-05	8.3E-06
Mercury (Elemental)	0.0E+00	0.0E+00	0.0023	1.0	0.0E+00	0.0E+00
Lead	2.7E-06	2.7E-06	0.0023	1.0	6.2E-09	6.2E-09

Table 5-50
 Combined Daily Intake of COPCs Via Indirect Exposure Pathways
 Resident Child

Chemical	I _{soil} (mg/d)	I _{veg} (mg/d)	I _{dw} (mg/d)	I _{tot} (mg/d)
Mercury (Divalent)	1.4E-06	6.1E-07	0.0E+00	2.0E-06
Mercury (Methyl)	2.8E-08	7.2E-08	0.0E+00	1.0E-07
Mercury (Elemental)	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Lead	1.4E-04	1.4E-04	0.0E+00	2.9E-04

Table 5-51
 Combined Daily Intake of COPCs Via Indirect Exposure Pathways
 Recreational Fisher

Chemical	I _{soil} (mg/d)	I _{veg} (mg/d)	I _{fish-EPA} (mg/d)	I _{fish-MDEQ} (mg/d)	I _{dw} (mg/d)	I _{tot-EPA} (mg/d)	I _{tot-MDEQ} (mg/d)
Mercury (Divalent)	7.0E-07	1.3E-06	9.6E-11	0.0E+00	0.0E+00	2.0E-06	2.0E-06
Mercury (Methyl)	1.4E-08	1.4E-07	1.4E-04	5.4E-05	0.0E+00	1.4E-04	5.4E-05
Mercury (Elemental)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Lead	7.2E-05	2.7E-04	4.1E-08	4.1E-08	0.0E+00	3.5E-04	3.5E-04

Table 5-52
 Combined Daily Intake of COPCs Via Indirect Exposure Pathways
 Recreational Fisher Child

Chemical	I _{soil} (mg/d)	I _{veg} (mg/d)	I _{fish-EPA} (mg/d)	I _{fish-MDEQ} (mg/d)	I _{dw} (mg/d)	I _{tot-EPA} (mg/d)	I _{tot-MDEQ} (mg/d)
Mercury (Divalent)	1.4E-06	6.1E-07	1.5E-11	0.0E+00	0.0E+00	2.0E-06	2.0E-06
Mercury (Methyl)	2.8E-08	7.2E-08	2.1E-05	8.2E-06	0.0E+00	2.1E-05	8.3E-06
Mercury (Elemental)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Lead	1.4E-04	1.4E-04	6.2E-09	6.2E-09	0.0E+00	2.9E-04	2.9E-04

¹ Consistent with agency guidance, hazard values are expressed to one significant figure [USEPA, 1989]

Table 5-53
IEUBK Operating Parameters Selected for the Assessment of Lead

Operating Parameter	Units	Selected Value(s)	Reference
Target Blood Lead	(µg/dL)	10	CDC, 1991
Time Spent Outdoors	(hr/d)	1-4	USEPA, 2002
Ventilation Rate	(m ³ /d)	2-7	USEPA, 2002
Indoor Air Concentration (% of Outdoor)	(%)	30	USEPA, 2002
Soil/dust Ingestion Rate	(mg/d)	85-135	USEPA, 2002
Soil Ingestion Rate (% of Soil/dust Ingestion)	(%)	45	USEPA, 2002
Gastrointestinal Absorption (Soil/Dust Lead)	(%)	30	USEPA, 2002
Gastrointestinal Absorption (Dietary Lead)	(%)	50	USEPA, 2002
Gastrointestinal Absorption (Drinking Water Lead)	(%)	50	USEPA, 2002
Age-Related Water Consumption Rates	(L/d)	0.20-0.59	USEPA, 2002

CDC, 1991 - Preventing Lead Poisoning in Young Children Centers for Disease Control.

USEPA, 2002 - User's Guide for the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK)

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Table 5-54
Media Concentrations Selected for the IEUBK Assessment of Lead

Selected Medium	Units	Parameter Value	Reference
Soil Lead			
Background	(mg/kg)	2.10E+01	MDEQ, 2006b
Modeled Increase	(mg/kg)	7.20E-01	HHRA Table 5-5
Indoor Dust Lead			
Background [Pb-Based Paint in Good Condition]	(mg/kg)	2.00E+02	USEPA, 2002
Background [No Pb-Based Paint and Tracked Soil Pb]	(mg/kg)	1.57E+01	0.70 x Soil Pb Plus Air Pb
Modeled Increase [Pb-Based Paint in Good Condition]	(mg/kg)	2.00E+02	USEPA, 2002
Modeled Increase [No Pb-Based Paint and Tracked Soil Pb]	(mg/kg)	1.62E+01	0.70 x Soil Pb Plus Air Pb
Air Lead			
Background	($\mu\text{g}/\text{m}^3$)	1.00E-02	MDEQ, 2005a
Modeled Increase	($\mu\text{g}/\text{m}^3$)	2.67E-04	HHRA Table 5-1
Drinking Water Lead			
Background	($\mu\text{g}/\text{L}$)	2.00E+00	HBPW, 2003
Modeled Increase	($\mu\text{g}/\text{L}$)	n/a	n/a
Dietary Lead			
Background	($\mu\text{g}/\text{d}$)	5.53-7.00	USEPA, 2002
Modeled Increase	($\mu\text{g}/\text{d}$)	0.14	HHRA Table 5-45
Maternal Blood Lead			
Background	($\mu\text{g}/\text{dL}$)	2.50E+00	USEPA, 2002
Modeled Increase	($\mu\text{g}/\text{dL}$)	n/a	n/a

HBPW, 2003 - [Annual Drinking Water Quality Report for 2003](#). Holland Board of Public Works.

MDEQ, 2005a - [Michigan's 2004 Annual Air Quality Report](#).

MDEQ, 2006b - [Table 2. Soil: Residential and Commercial I Part 201 Generic Cleanup Criteria and Screening Levels; Part 213 Tier 1 Risk-Based Screening Levels \(RBSLs\)](#).

USEPA, 2002 - [User's Guide for the Integrated Exposure Uptake Biokinetic Model for Lead in Children \(IEUBK\) Windows Version-32 Bit Version](#)

Table 6-1
Chronic Toxicity Criteria Used in HHRA

Chemical	RfD (mg/kg-d)	Reference	RfC (mg/m ³)	Reference
Divalent Mercury [Hg ⁺²]	3.0E-04	IRIS	9.0E-05	CalEPA
Methylmercury [MeHg]	1.0E-04	IRIS	---	
Elemental Mercury [Hg ⁰]	---		3.0E-04	IRIS
Lead [Pb]	---		---	

Source: On-line IRIS Database (USEPA, 2008)

Source: On-line chronic reference exposure level (REL) database (CalEPA, 2002)

Table 7-1
Hazard Indices Resulting from Indirect Exposure Pathways¹
Resident Child

Chemical	I _{tot} (mg/d)	EF (d/yr)	BW (kg)	UCF (d/yr)	ADD (mg/kg-d)	RfD (mg/kg-d)	HI _{ind} ()
Mercury (Divalent)	2.0E-06	350	15	365	1.3E-07	3.0E-04	4E-04
Mercury (Methyl)	1.0E-07	350	15	365	6.4E-09	1.0E-04	6E-05
Mercury (Elemental)	0.0E+00	350	15	365	0.0E+00		
Lead	2.9E-04	350	15	365	1.8E-05		

¹ Consistent with agency guidance, hazard values are expressed to one significant figure [USEPA, 1989]

Table 7-2
Hazard Indices Resulting from Indirect Exposure Pathways¹
Recreational Fisher

Chemical	I _{tot-EPA} (mg/d)	I _{tot-MDEQ} (mg/d)	EF (d/yr)	BW (kg)	UCF (d/yr)	ADD _{EPA} (mg/kg-d)	ADD _{MDEQ} (mg/kg-d)	RfD (mg/kg-d)	HI _{EPA} ()	HI _{MDEQ} ()
Mercury (Divalent)	2.0E-06	2.0E-06	350	70	365	2.7E-08	2.7E-08	3.0E-04	9E-05	9E-05
Mercury (Methyl)	1.4E-04	5.4E-05	350	70	365	1.9E-06	7.4E-07	1.0E-04	2E-02	7E-03
Mercury (Elemental)	0.0E+00	0.0E+00	350	70	365	0.0E+00	0.0E+00			
Lead	3.5E-04	3.5E-04	350	70	365	4.7E-06	4.7E-06			

¹ Consistent with agency guidance, hazard values are expressed to one significant figure [USEPA, 1989]

Table 7-3
Hazard Indices Resulting from Indirect Exposure Pathways¹
Recreational Fisher Child

Chemical	I _{tot-EPA} (mg/d)	I _{tot-MDEQ} (mg/d)	EF (d/yr)	BW (kg)	UCF (d/yr)	ADD _{EPA} (mg/kg-d)	ADD _{MDEQ} (mg/kg-d)	RfD (mg/kg-d)	HI _{EPA} ()	HI _{MDEQ} ()
Mercury (Divalent)	2.0E-06	2.0E-06	350	15	365	1.3E-07	1.3E-07	3.0E-04	4E-04	4E-04
Mercury (Methyl)	2.1E-05	8.4E-06	350	15	365	1.4E-06	5.3E-07	1.0E-04	1E-02	5E-03
Mercury (Elemental)	0.0E+00	0.0E+00	350	15	365	0.0E+00	0.0E+00			
Lead	2.9E-04	2.9E-04	350	15	365	1.8E-05	1.8E-05			

¹ Consistent with agency guidance, hazard values are expressed to one significant figure [USEPA, 1989]

Table 7-4
Average Inhalation Exposure Concentration
Resident Child

Chemical	C _{air} ($\mu\text{g}/\text{m}^3$)	EF (d/yr)	ED (yr)	AT (d)	UCF (d/yr)	EC ($\mu\text{g}/\text{m}^3$)
Mercury (Divalent)	1.1E-05	350	6	6	365	1.0E-05
Mercury (Methyl)	0.0E+00	350	6	6	365	0.0E+00
Mercury (Elemental)	1.1E-05	350	6	6	365	1.0E-05
Lead	2.7E-04	350	6	6	365	2.6E-04

Table 7-5
Average Inhalation Exposure Concentration
Recreational Fisher

Chemical	C_{air} ($\mu\text{g}/\text{m}^3$)	EF (d/yr)	ED (yr)	AT (d)	UCF (d/yr)	EC_{NCarc} ($\mu\text{g}/\text{m}^3$)
Mercury (Divalent)	1.1E-05	350	30	30	365	1.0E-05
Mercury (Methyl)	0.0E+00	350	30	30	365	0.0E+00
Mercury (Elemental)	1.1E-05	350	30	30	365	1.0E-05
Lead	2.7E-04	350	30	30	365	2.6E-04

Table 7-6
Average Inhalation Exposure Concentration
Recreational Fisher Child

Chemical	C _{air} ($\mu\text{g}/\text{m}^3$)	EF (d/yr)	ED (yr)	AT (d)	UCF (d/yr)	EC ($\mu\text{g}/\text{m}^3$)
Mercury (Divalent)	1.1E-05	350	6	6	365	1.0E-05
Mercury (Methyl)	0.0E+00	350	6	6	365	0.0E+00
Mercury (Elemental)	1.1E-05	350	6	6	365	1.0E-05
Lead	2.7E-04	350	6	6	365	2.6E-04

Table 7-7
Hazard Quotients Resulting from Direct Exposure Pathway
All Receptors

Chemical	C_{air} ($\mu\text{g}/\text{m}^3$)	EC ($\mu\text{g}/\text{m}^3$)	RfC (mg/m^3)	UCF ($\text{mg}/\mu\text{g}$)	HQ _i ()
Mercury (Divalent)	1.1E-05	1.0E-05	9.0E-05	0.001	1E-04
Mercury (Methyl)					
Mercury (Elemental)	1.1E-05	1.0E-05	3.0E-04	0.001	3E-05
Lead	2.7E-04	2.6E-04		0.001	

Table 7-8
 Combined Hazard Indices Resulting from Exposure to Emitted Mercury¹

Chemical	Resident Child			Recreational Fisher			Recreational Fisher Child		
	Indirect HI ()	Direct HQ ()	Total HI ()	Indirect HI ² ()	Direct HQ ()	Total HI ()	Indirect HI ² ()	Direct HQ ()	Total HI ()
Mercury (Divalent)	4E-4	1E-4	5E-4	9E-5	1E-4	2E-4	4E-4	1E-4	5E-4
Mercury (Methyl)	6E-5		6E-5	2E-2		2E-2	1E-2		1E-2
Mercury (Elemental)		3E-5	3E-5		3E-5	3E-5		3E-5	3E-5
Combined HI			6E-4			2E-2			1E-2

¹ Consistent with agency guidance, hazard values are expressed to one significant figure [USEPA, 1989].

² Indirect HI values for Recreational Fisher and Fisher Child are based on C_{fish} developed for the Lake Macatawa using HHRAP guidance [USEPA, 2005].

Table 7-9
IEUBK Predicted Blood Lead Levels Under Modeled Exposure Scenarios

Scenario	Description	Description of Lead Paint in Homes	Predicted Blood Lead Concentration ¹ (µg/dL)	Probability of Exceeding 10 µg/dL (%)
1	Background	None	1.536	0.003
2	Background	Lead Paint: Good Condition	2.672	0.249
3	Background + HBPW Emissions ²	None	1.567	0.004
4	Background + HBPW Emissions ²	Lead Paint: Good Condition	2.699	0.266

¹ Geometric mean blood lead concentration predicted by IEUBK.

² Post-modification emissions.