

Screening-Level Health Risk Assessment

Hyperion Energy Center

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Union County, South Dakota



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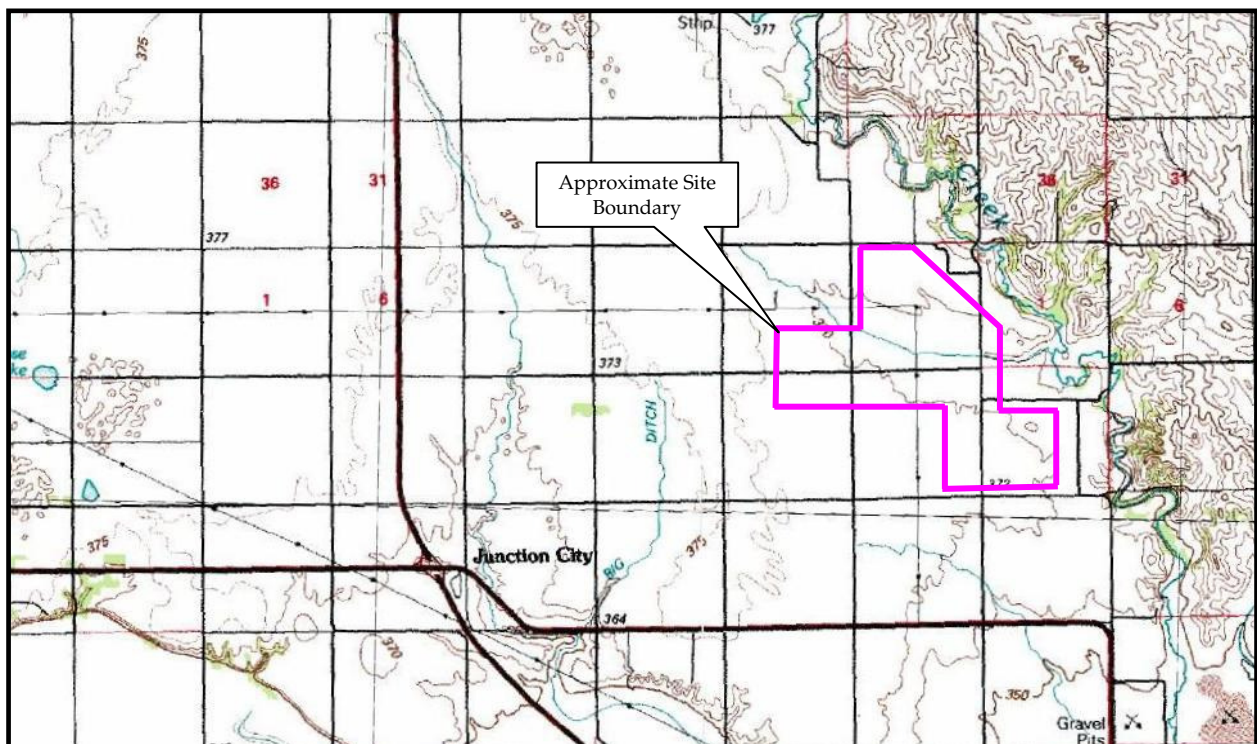
1.0

INTRODUCTION

Environmental Resources Management (ERM), in conjunction with RTP Environmental Associates (RTP), has prepared this Screening-Level Health Risk Assessment (hereafter, "the Assessment") for Hyperion Resources Inc. (Hyperion) in support of the proposed development of the Hyperion Energy Center (HEC) to be located in Union County, South Dakota (herein referred to as "the Project"). The Project includes a greenfield petroleum refinery and an integrated gasification combined cycle (IGCC) power plant.

The Project would be located in Union County, South Dakota, approximately 7 miles north-northwest of the Town of Elk Point, South Dakota and approximately 2 miles south of the Town of Spink, South Dakota. The site on which the facilities would be located ("the Site") covers approximately 3,300 acres, of which approximately 2,000 acres will be designated as an industrial zone and will contain all industrial activities for the Project (see Figure 1-1).

FIGURE 1-1: Site Location



(from Microsoft TerraServer Imagery, 1983)

1.1

OBJECTIVES AND APPROACH

The objective of the Assessment was to assess the potential risk to human health in the vicinity of the Site due to extended-term inhalation of facility emissions produced during Project operations. The approach for the Assessment was to use

the Human Exposure Model-3 Version 1.0.1 Modeling software (HEM-3) developed by the US Environmental Protection Agency (USEPA). HEM-3 focused on the inhalation exposure pathway, and considered chronic risks related to emissions of the key compounds associated with normal refinery/power plant operations. The Assessment did not consider acute health risks or other exposure pathways, and the assessed risk does not include any background risk levels from activities not related to the Project (e.g., effects from exposure to personal, residential, mechanical, or agricultural chemical products).

1.2 *SITE SETTING*

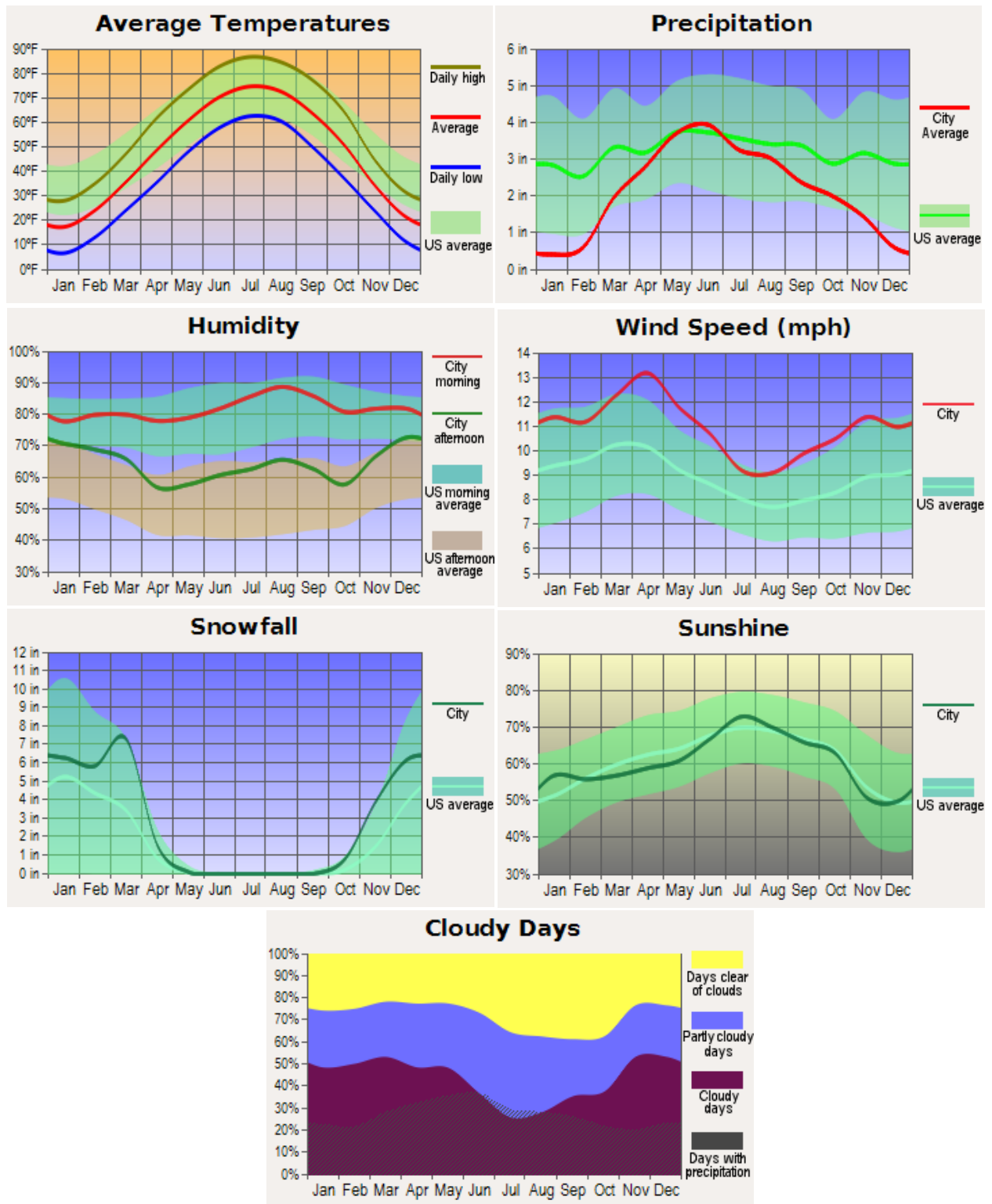
Elk point is a rural community with a population of 1,714 (U.S. Census 2000), estimated to be approximately 1,800 in 2005. Land use in the Site vicinity is primarily based on livestock production and agriculture. The principal crops grown commercially in Union County, South Dakota include soybeans, corn, wheat, oats, barley, sorghum, alfalfa, and apples. Crop land in the immediate vicinity of the Site is primarily employed in corn and soybean production. Other employment opportunities in the surrounding towns are primarily in public administration, education, service industries or equipment manufacturing.

The Site is located on the southernmost expression of the James River Lowland physiographic region of South Dakota. The area is described as a level to slightly level rolling plain. Elevation in the Site area ranges from approximately 1,231 to 1,188 feet above mean sea level (MSL) and the area slopes slightly to Brule Creek on the east. Bluffs of the Southern Plateau physiographic region rise on the east side of Brule Creek to elevations of approximately 1,360 ft MSL (see Figure 1-1).

Meteorological data from Elk Point, South Dakota is presented in Figure 1-2. Recorded ambient temperatures (2002-2007) ranged from 108.7 degrees Fahrenheit (°F) to -16.6 °F. The average annual precipitation for the area is 24 to 26 inches, although South Dakota experienced above average rainfall throughout the 1990s. Most of the precipitation occurs from March through November, with maximum monthly precipitation occurring in June. Typical wind speeds range between 9.0 and 13.5 miles per hour (mph), although sustained winds have been recorded at 33.0 mph and gusts as high as 42.7 mph have been recorded (Weather Underground, 2008)¹.

¹ Weather Underground, 2008; www.wunderground.com

FIGURE 1-2: Meteorological Data for Elk Point, South Dakota



(City-Data.com)

2.0 ASSESSMENT METHODOLOGY

This section describes the methodology utilized for the Assessment.

2.1 HEM-3 MODEL OVERVIEW

The Human Exposure Model (HEM) was developed by the USEPA for performing risk assessments for major point sources of air toxics. Recent guidance in the use of the model for petroleum refining sources has been provided by USEPA in draft form, and this guidance was used for the Assessment. HEM assesses the inhalation pathway of exposure and is designed to predict the risks associated with emitted compounds in the ambient air. HEM uses modeled ambient air concentrations, as surrogates for lifetime dose exposures, together with unit risk factors to produce estimates of cancer risk for the compounds modeled.

Two HEM forms are available: HEM-Screen and HEM-3. Data requirements are somewhat higher for HEM-3 compared to HEM-Screen; however, the results are typically more refined with HEM-3 because it provides more rigorous dispersion modeling options. Accordingly, HEM-3 was selected for the Assessment. The HEM-3 Manual is provided in Appendix A for reference.

HEM-3 incorporates two components. The first is an atmospheric dispersion model. HEM-3 has two options for dispersion modeling: the Industrial Source Complex (ISC) Model or the AMS/EPA Regulatory Model (AERMOD) dispersion model. Both incorporate local meteorological data. AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. AERMOD is the preferred model promulgated by the USEPA.

RTP selected the AERMOD option to conduct the dispersion modeling analysis for the HEC. AERMOD is the most appropriate model for calculating ambient concentrations to be used in assessing the potential for health risks near the HEC because of the model's ability to incorporate multiple sources and source types, the model's ability to incorporate building wake effects, and the model's ability to calculate concentrations within the cavity recirculation zone. It is also the model recommended for air quality studies by the South Dakota Department of Environment and Natural Resources (DENR).

The second component of HEM-3 is a human receptor (census) survey provided by U.S. Bureau of Census 2000 population data at the census block level. In conjunction with a library of compound toxicity data, HEM-3 can generate chronic (cancer) risk estimates.

Several key process data and information are required as input into the model, including stack height, exit velocity, emission rate, etc. Based on the inputs for source data and the meteorological data, the model estimates the magnitude and distribution of ambient air concentrations in the vicinity of each source. Ambient

air concentrations for selected chemicals predicted by AERMOD are used as exposure estimates for risk characterization. It is important to note that when estimating exposure, the model does not account for receptor-specific exposure durations or other activity patterns.

2.2 **CHRONIC RISK ASSESSMENT FUNDAMENTALS**

2.2.1 **Toxicants**

Toxicants are defined as any chemical or substance that can induce an adverse effect on a receptor organism. While toxicants are generally considered to be chemicals unnecessary for normal metabolism, it is important to note that toxicity may occur from exposure to substances otherwise deemed necessary to health including minerals, salts, vitamins, pharmaceutical drugs, and even water. The amount of the substance received by the receptor organism, the dose, determines the toxicity of the substance. Similarly, chemicals with no known function in the body may often display little toxicity, depending on the dose. This phenomenon may reflect the organism's ability to alter, remove, or tolerate the toxicant at low levels. This relationship between the dose and the observable response is termed the dose-response curve and is specific for each toxicant-receptor-exposure pathway combination. Human dose-response curves have been developed for many common or historically-used chemicals.

Toxicants may be classified by their target organs, use, source, effects, physical state, chemical nature, mechanisms of action, etc. For the Assessment, toxicants were classified by their chemical division into either inorganic or organic compounds. Organic compounds are those containing bonds between carbon and hydrogen atoms and this class is further divided by physiochemical properties into volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). By their nature, VOC molecules rapidly partition into the atmosphere at ambient temperatures. As such, they are considered to be of primary importance in inhalation risk assessments. Inorganic compounds (e.g., metals) may occur as either dissolved gases or particulate matter in the atmosphere and may also present inhalation risks.

For the purposes of this investigation, the terms *toxicant*, *toxic agent*, and *chemical of concern*, are used interchangeably in reference to regulated chemicals typically emitted into ambient air from petroleum refining and IGCC sources and having potential adverse inhalation effects on human receptors. The toxicants selected for this investigation were based on recent investigations by the USEPA and are discussed in Section 2.6.

2.2.2 **Fate and Transport**

The relationship between the sources and the final destinations of toxicants in the environment is a function of *fate and transport* properties and phenomena. Fate and transport scenarios can be exceedingly complex and may include meteorological factors (ambient temperature, solar radiation, humidity,

precipitation, wind), chemical factors (interactions with chemicals already present in the environment), media factors (physical and chemical nature of soils and waters), biological factors (bacteria, plant animal receptor species, trophic levels) and physical factors (gravity). Typically, modeling these systems is impractical or infeasible due to this complexity. Therefore, fate and transport models make assumptions to simplify the necessary calculations. At each level, assumptions are typically chosen based on which parameter value/scenario offers more protection to the receptor. This process results in a conservative model. In most cases, and by design, the process results in an overestimation of risk.

2.2.3 *Exposure Pathways*

Four chemical exposure routes are typically considered in human toxicology: inhalation, ingestion, dermal contact, and injection. The toxicity of a given chemical may vary widely depending on the exposure route employed. As a general rule, inhalation and injection of toxicants present greater risk since the toxicant has the potential to enter the bloodstream quickly and with little modification. However, ingestion is considered to be a pathway of importance as well. Because accidental injections of chemicals of concern are uncommon, risks associated with this pathway are typically not characterized.

2.2.4 *Dose and Duration*

The risk incurred due to a toxicant exposure is also dependent on the amount of toxicant involved and the duration of the exposure. The amount of toxicant to which the subject is exposed is referred to as the dose. Dose is typically measured in units of mass. Where mass units are difficult or impractical to measure, dose may also be presented as concentration of the toxicant in a given media (e.g., mg toxicant/L ingested water). Allowable exposure limits are typically presented as concentration limits in air, surface water, ground water, or soil.

Toxicologists usually divide exposure regimes into four categories: acute, subacute, subchronic, and chronic. For injection and dermal contact exposure scenarios, acute exposure is defined as exposure to a chemical for less than 24 hours with (typically) one dose applied. Acute exposure for inhalation is considered to be continuous exposure for less than 24 hours. Repeated exposure is divided into three categories: subacute, subchronic, and chronic. Subacute exposure refers to repeated exposure to a chemical for one month or less, subchronic for one to three months, and chronic for more than three months. For many agents, including benzene, the toxic effects that follow a single exposure can be significantly different from those produced by repeated exposures.²

2.2.5 *Metabolism*

The assessment of human risk due to such toxicants is further complicated by human physiology. In healthy individuals, many biochemical systems exist for

² Klaassen, Curtis D. ed.; Casarett & Doull's Toxicology: The Basic Science of Poisons, 5th ed.; McGraw-Hill, New York, 1996.

the removal or alteration of toxicants entering the body. Some chemicals of concern, particularly organic chemicals, can be biochemically altered in the receptor's body to form nontoxic or minimally toxic metabolites. The liver is of particular importance in this function for mammalian species. However, the level of enzyme-mediated biotransformation can vary widely from one individual to another. Furthermore, the toxicity of some chemicals may increase following such a biotransformation process. This occurrence is generally referred to as bioactivation. The rate of biotransformation can be affected by introduced chemicals, including those found in alcoholic drinks, cigarette smoke, and pharmaceutical drugs. These chemicals may stimulate or depress their own metabolic pathways or those of other chemicals. Other physical and biochemical mechanisms affecting the life-span of introduced chemical molecules in the mammalian body include metabolic non-transformation pathways, excretion, deposition, or physical removal (e.g., in the case of volatile chemicals, re-release to the atmosphere through exhalation).

2.2.6 *Endpoints*

In terms of toxicity, endpoints are any adverse effect desired to be investigated. They may include mortality, carcinogenesis (cancer), teratogenesis (developmental defects), behavioral or social changes, biochemical changes, etc. The Assessment focuses on the carcinogenesis (cancer) endpoint as a result of inhalation exposure to the modeled chemicals of concern.

2.2.7 *Probability and Risk*

Risk is expressed as the probability of the occurrence of a chosen endpoint in a given receptor population. This probability is based on the dose-response relationships for given exposure pathways and frequency/duration regimes. Dose-response data is typically sourced from empirical data derived from toxicology experiments. The accuracy of these data is a function of the quantity and quality of the research experiments. The effects of common toxicants in human receptors are generally well researched. By design, these investigations generally reflect differences in response by individuals in a population (due to genetics, randomness, etc.) and often may reflect differences in response based on age. However, they often cannot and do not reflect differences in response based on behavior, other environmental stimuli, prior exposures, interactions with other chemicals (synergistic or antagonistic, in vivo or ex vivo), etc. Well-vetted data from these experiments are incorporated into the chemical libraries of HEM-3.

The risk estimates generated by the model are expressed as fractions. For example, if the estimated risk of cirrhosis of the liver to an individual is reported as 1.0×10^{-7} , this means that the estimated probability of that individual developing cirrhosis due directly to the toxicant is one in 10,000,000. Loosely rephrased, out of 10,000,000 individuals exposed to the same toxicant at the same dose for the same duration, one individual is expected to develop cirrhosis as a result of toxicant exposure. It is important to note that once an event occurs, the probability of occurrence does not change for the remaining population. In the example above, if

one individual develops cirrhosis as a result of toxicant exposure, the probability of developing cirrhosis for each individual in the remaining population is still 1 in 10,000,000.

2.3 ***EXPOSURE PATHWAY SELECTION***

As discussed above, the Assessment focused on exposure to ambient air concentrations of compounds via inhalation. This approach was selected based on the fact that inhalation typically represents the key exposure route of concern for receptors located outside of an industrial facility generating air emissions. As previously discussed, inhalation exposure provides a relatively rapid conduit for chemicals of concern to enter the receptor's body systems as compared to exposure pathways such as ingestion or dermal adsorption. Additionally, the atmospheric transport/inhalation scenario typically has the potential to involve the largest surface area and therefore present exposure to the largest population. Finally, the atmospheric transport/inhalation scenario also complements the chemical, metabolic, and physical characteristics of the most closely studied and regulated chemicals that could be emitted from the HEC.

2.4 ***EXPOSURE DURATION SELECTION***

The exposure duration regime selected was a duration associated with chronic effects. This exposure regime is set by HEM-3 based on a site-specific typical dose (discussed in Section 2.5) applied 24 hours per day for a period of 70 years (assumed lifetime). The duration selected does not account for periodic migration from the affected area or for periodic reductions in doses/concentrations. Accordingly, these assumptions reflect the conservative nature of the model.

2.5 ***DOSE SELECTION***

Doses at discrete geographical census centroids are calculated by HEM-3 based on the respective emissions data for each source in the facility, distances from the sources to census centroids, and local meteorological and topographical data.

2.5.1 ***Emission Factors for Organic Compounds***

Combustion source emissions for organic compounds were developed using USEPA's Compilation of Air Pollutant Emission Factors Volume I (referred to as AP-42 emission factors). Because these AP-42 factors are generated from studies performed on a wide-range of combustion sources, these factors are expected to overestimate the emissions of organic compounds from combustion sources that only fire clean, gaseous fuels, such as proposed by Hyperion for the Project. This is because the AP-42 factors include test data from combustion sources that previously fired oil and/or solid fuels, the residuals of which are a primary source of most of the organic compounds. Table 2-1 summarizes the references utilized for organic compound emission factors for the various Project sources.

TABLE 2-1: References for Organic Compound Emission Factors

EMISSION SOURCE	REFERENCE
Process Heaters	AP-42 Table 1.4-3 emission factors for natural gas combustion in boilers times annual heat input
Sulfur Recovery Plant Thermal Oxidizer	
Gasifier Vents	
Combined Cycle Gas Turbines	Used AP-42 Table 1.4-3 boiler emission factors due to the effect of duct firing natural gas and use of oxidation catalyst for VOC and hazardous air pollutant (HAP) control
Diesel Engines	Diesel particulate equal to internal combustion engine particulate matter (PM) emissions
Storage Tanks	HAP emissions estimated using speciation from various Material Safety Data Sheet (MSDS) references
Product Loading Racks/Roads	Product loading VOC emissions in pounds per year speciated using speciation from various MSDS references
Equipment Leaks	VOC fugitive emission estimates speciated using EPA's SPECIATE Database
Cooling Tower	Proposed refinery National Emissions Standards for Hazardous Air Pollutants (NESHAP) for cooling towers (FR Vol. 72, No. 170; 9-4-2007 page 50723) of 10 lb/day per HAP times equipment leak HAP ratio
Wastewater Treatment Plant	From USEPA's Water 9 modeling of the Aeration Tanks at normal flow assuming upstream benzene, toluene, ethylbenzene and xylenes (BTEX) stripping

2.5.2 Emission Factors for Inorganic Compounds

Combustion source emissions for inorganic compounds³ were developed using emission limits found in USEPA's RACT/BACT/LAER (RBL) Clearinghouse Database. This reference was utilized because the USEPA's AP-42 emission factors are expected to grossly overestimate the emissions of metallic compounds from combustion sources that only fire clean, gaseous fuels, such as proposed by Hyperion for the Project. Specifically, the AP-42 factors include test data from combustion sources that previously fired oil and/or solid fuels, the residuals of which are the likely source of all metallic compounds. Other Project sources are not expected to contribute to inorganic compound emissions. Table 2-2 summarizes the references utilized for inorganic compound emission factors for the various Project sources.

³ Of the inorganic compounds that would be emitted from the Project sources, only metallic compounds have carcinogenic properties.

TABLE 2-2: References for Inorganic Compound Emission Factors

EMISSION SOURCE	REFERENCE
Process Heaters	Reviewed emission limits in USEPA’s RBL Clearinghouse Database for gas fired boilers, process heaters, and combustion turbines. No emission limits were identified, indicating that AP-42 emission factors are not used as a basis for setting metals limits for gas-fired sources
Sulfur Recovery Plant Thermal Oxidizer	
Gasifier Vents	
Combined Cycle Gas Turbines	Used emission limits/factors identified in USEPA’s RBL Clearinghouse Database for syngas-fired combustion turbines. Limits for only mercury and cadmium were identified.

2.5.3 Dose Pattern Modifications Due to Climatic Conditions

Meteorological data were used by HEM-3 to calculate dose at a given point under standard environmental conditions. One year (2004) of meteorological data was modeled in the analysis. Sequential hourly surface data from the National Weather Service (NWS) station in Sioux Falls, SD (WBAN No. 14944) and upper air data from the NWS station in Omaha, NE (WBAN No. 94980) were used in the model calculations.

2.6 TOXICANT SELECTION

2.6.1 Combined Toxicant Suite

The compounds selected for the Assessment were chosen based on research by the USEPA and professional knowledge of the chemical processes that will be employed in the Project facility. The following toxicants with potential carcinogenic properties were selected for the Assessment:

- Arsenic compounds
- Benzene
- Beryllium compounds
- Cadmium compounds
- Chromium (VI) compounds
- Chromium compounds
- Formaldehyde
- Naphthalene
- Nickel compounds
- Polycyclic organic matter
- 1,3-Butadiene

2.6.2 Benzene

In addition to assessing the risk due to inhalation of ambient concentrations of the combined toxicant suite described above, HEM-3 was also used to assess risk specific to benzene emissions (only).

Benzene is one of the key organic compounds associated with petroleum refining operations. Because it is a Class A Carcinogen, benzene is a closely studied and carefully regulated compound. Permissible exposure limits of benzene in

environmental media have been developed by the U.S. Occupational Safety and Health Administration (OSHA), USEPA and other state environmental regulatory agencies.

Benzene (C₆H₆) is the first member of a series of aromatic hydrocarbons recovered from refinery streams during catalytic reformation and other petroleum processes. Benzene is one of the world's major commodity chemicals. Its primary use (85% of production) is as an intermediate in the production of other chemicals, predominantly styrene (for styrofoam and other plastics), cumene (for various resins), and cyclohexane (for nylon and other synthetic fibers). Benzene is an important raw material for the manufacture of synthetic rubbers, gums, lubricants, dyes, pharmaceuticals, and agricultural chemicals. Benzene is a natural component of crude and refined petroleum. The mandatory decrease of lead alkyls in gasoline has led to an increase in the aromatic hydrocarbon content of gasoline to maintain high octane levels and antiknock properties. In the United States, gasoline typically contains less than 2% benzene by volume, but in other countries the benzene concentration may be as high as 5%.

Because of its lipophilic (*"oil/fat-loving"*) nature, benzene is an excellent solvent. Its use in paints, thinners, inks, adhesives, and rubbers, however, is decreasing and these uses now account for less than two percent (2%) of current benzene production. Benzene was also an important component of many industrial cleaning and degreasing formulations, but now has been replaced mostly by toluene, chlorinated solvents, or mineral spirits. Although benzene is no longer added in significant quantities to most commercial products, traces of it may still be present as a process contaminant.

Due in part to this wide variety of uses, there are many potential sources from which benzene can enter the environment. Benzene may enter the environment from production processes or storage associated with chemical manufacturing or gasoline industries, including petroleum refining, gasoline bulk-loading and discharging facilities and combustion engines (e.g., automobiles, lawn mowers, and snow blowers). Cigarette smoke is another common source of personal and environmental benzene exposure, representing about half of the benzene to which the general population is exposed. Gasoline use and storage significantly increases human exposure in residential environments. Each of these sources may release benzene to the atmosphere, soil, or ground water. Releases may be complex and involve more than one of these media.⁴

Once benzene is released into the atmosphere, it readily stays in gaseous form at ambient temperatures. Dispersion of molecules from their release point due to air movements is the most important factor in the reduction of benzene concentration in the air. In the absence of these movements (e.g., in confined spaces), benzene's

⁴ U.S. Department of Health and Human Services, Agency for Toxic Substances & Disease Registry, Division of Toxicology and Environmental Medicine. "Benzene Toxicity" Case Studies in Environmental Medicine, June 2000.

relatively greater density (compared to air) may cause it to pool in local depressions. Benzene molecules may also be scavenged from the air by precipitation (rain or snow). Benzene in the air may also be subject to photodegradation. Due to its lipophilic nature, benzene easily crosses phospholipid cell membranes. Depending on the circumstance, these molecules may either be disposed in the initially exposed cell or they may be transported throughout the organism.

The effects of chronic benzene exposure are different from those associated with acute exposures. Acute effects include central nervous system (CNS) depression resulting in disorientation, euphoria, giddiness, and confusion at lower concentrations and unconsciousness, paralysis, convulsion or respiratory or cardiovascular arrest at higher concentrations. The airborne benzene concentrations required to cause these acute effects are much higher than generally encountered in emissions from refining/power plant process, and are typically observed in only confined space applications. The acute effects of lower benzene concentrations are generally temporary and reversible.

The most significant effects of benzene exposure are considered to be those associated with chronic exposures. Chronic benzene exposures are associated with the risk of hematopoietic (*blood forming*) dysfunction. Current research indicates that this effect is mediated by the bioactivation of benzene molecules by cytochrome P450-dependent mixed function oxidases ('cytochrome P-450'). These enzymes initiate a multi-step biotransformation of benzene molecules into phenoxyl radicals. These molecules in turn bind to proteins and DNA in bone marrow cells and lead to the suppression or malfunction of hematopoiesis. In some cases, such genetic damage can result in mutation of the DNA. Some of these mutations may result in the subject cell becoming cancerous. As such, leukemia is an effect associated with chronic benzene exposure. However, in most cases, leukemia is not the first effect observed. Other potential initial hematopoietic effects include the onset of anemia, leucopenia, and/or thrombocytopenia. Continued exposure may result in the reduced production of all three cell lines, or aplastic anemia. Typically, subjects so diagnosed respond favorably to removal from exposure and treatment. Those developing aplastic anemia, however, frequently exhibit a preleukemic state and may then progress to acute myelogenous leukemia.

Several factors may affect the disposition of benzene in the body. Prior to their metabolism, the partitioning of benzene molecules in the body is a function of concentration gradients across semi-permeable membranes. As such, immediately upon moving from affected air spaces to unaffected air spaces, benzene will diffuse from the blood stream into the lungs and exit the body with exhalation. This process results in a dose reduction, although it is not easily quantified. Estimations of dose, then, that do not incorporate this reduction result in an overestimation of risk and thus add conservativeness to the risk estimates.

Conversely, as discussed, metabolism of molecules remaining in the cell is initiated by cytochrome P-450 enzymes. These enzymes also catalyze the

metabolism of many other common toxicants including ethanol (grain alcohol). As such, personal habits and previous exposures to other toxicants including household chemicals and pharmaceutical drugs may lead to increased levels of cytochrome P-450, which would result in the increased rate of biotransformation of benzene. Detoxification systems thus 'primed' may result in more significant effects due to benzene exposure. Little research data are available to support risk assessments of this occurrence.

2.7 *TOXICITY FACTOR SELECTION*

The toxicity factors for the combined toxicant suite were referenced from the HEM-3 unit risk library. Notably, alternate unit risk factors for benzene and arsenic were identified in widely-used regulatory databases. Specifically, USEPA's Integrated Risk Information System (IRIS) database listed a range of benzene unit risk factors from 2.2×10^{-6} to 7.8×10^{-6} (the upper end of the range is assumed in the HEM-3 unit risk library). Relative to the benzene unit risk factor, IRIS states that "...At present, the true cancer risk from exposure to benzene cannot be ascertained, even though dose-response data are used in the quantitative cancer risk analysis, because of uncertainties in the low-dose exposure scenarios and lack of clear understanding of the mode of action. A range of estimates of risk is recommended, each having equal scientific plausibility..." For arsenic, two separate sources were identified that provided a unit risk factor of 3.3×10^{-3} , whereas the HEM-3 unit risk library lists a unit risk factor of 4.3×10^{-3} .

While the use of higher unit risk factors would result in a more conservative analysis, the lower ends of the above ranges are considered to be scientifically valid numbers. Accordingly, the HEM-3 modeling was performed using both the higher-end numbers and the lower-end numbers.

2.8 *ENDPOINT SELECTION*

The Assessment focuses on the cancer risk pathway, and does not address the other potential endpoints for toxicants. The model provides a discrete cancer risk for a given endpoint by a given toxicant at the given dose.

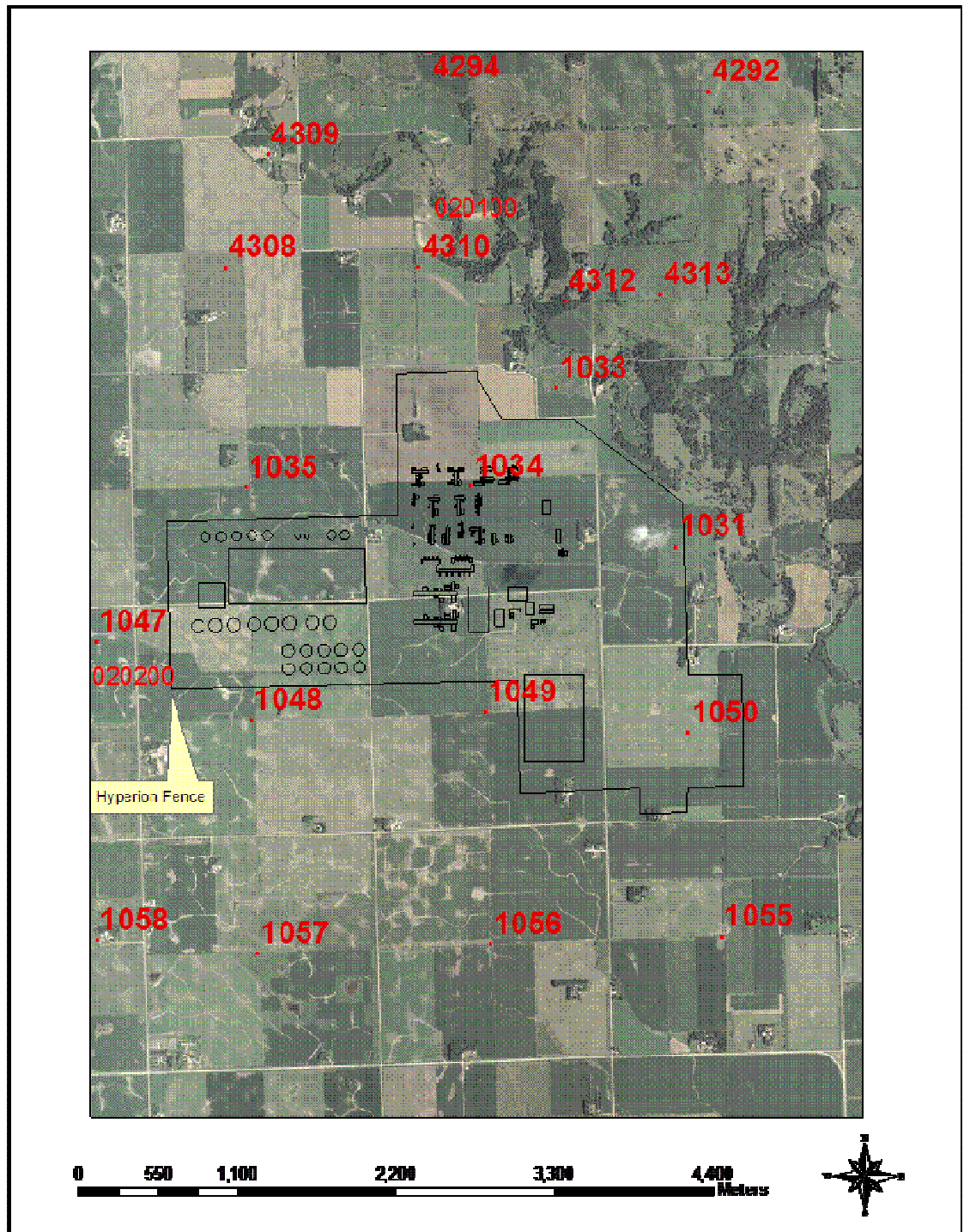
2.9 *MODEL RECEPTOR SELECTION*

The default model options in HEM-3 were selected. All census blocks within 50 kilometers of the Site were analyzed. Figure 2-1 shows the locations of census blocks in the vicinity of the Site (the dark red numbers are census block identification numbers). Notably, the analysis included census blocks that are within the proposed Site boundaries (i.e., locations that would not be inhabited following Project construction). The most notable of these census blocks is Census Block 1034, which is situated where the future location of a refinery process unit would be located. While inhabitants would not be present in these areas following construction of the Project, HEM-3 modeling was performed under two scenarios: 1) including these census blocks (representing an overestimation of the

risk); and 2) excluding these census blocks (representing a more realistic estimation of the risk).

Census blocks were modeled individually out to a distance of 5 kilometers from the Site. Beyond that distance, the model was allowed to interpolate concentrations using the model results from the receptor network. The receptor network consisted of 13 concentric circles with 16 radials. The default distances were used for each concentric circle. In addition, the default source-receptor overlap distance of 30 meters was also employed. AERMOD was run in rural dispersion model mode, with consideration of the influence of building downwash. No particulate deposition or plume depletion was modeled. To simplify the analysis, emissions were aggregated by source type and conservatively assumed to be emitted from a single stack that represented each source group. A total of 13 sources were modeled.

FIGURE 2-1: Locations of Census Blocks in Vicinity of Site



3.0

SUMMARY OF RESULTS

Tables 3-1 and 3-2 summarize the cancer risk estimates for the combined toxicant suite and benzene-only model scenarios described above:

TABLE 3-1: Cancer Risk Estimates – Combined Toxicant Suite

	Including Census Block 1034	Excluding Census Block 1034
Higher end of Unit Risk Factor Range for Benzene and Arsenic	9.41×10^{-7}	5.83×10^{-7}
Lower end of Unit Risk Factor Range for Benzene and Arsenic	5.28×10^{-7}	3.70×10^{-7}

TABLE 3-2: Cancer Risk Estimates – Benzene Only

	Including Census Block 1034
Higher end of Unit Risk Factor Range for Benzene	5.72×10^{-7}
Lower end of Unit Risk Factor Range for Benzene	1.61×10^{-7}

The combined toxicant suite cancer risk is the sum of the individual estimated risks of cancer development due to inhalation exposure (for an inhabitant in the center of the census block) for each of the modeled toxicants. The risk of any one toxicant leading to cancer development is, therefore, less than the total risk presented for each block.

As expected, the highest combined toxicant suite risk for cancer development was associated with the census block located within the proposed process area for the facility (i.e., Census Block 1034; see Figure 2-1). At this census block centroid (No. 1034), the combined toxicant suite risk of a receptor developing cancer due to long-term inhalation exposure to emissions from the HEC was estimated to range from 5.28×10^{-7} to 9.41×10^{-7} (i.e., from slightly greater than one in 1,900,000 to slightly greater than 1 in 1,100,000). In other terms, for the higher end of this range, if 1,100,000 individuals resided at this census block centroid location during plant operations and were present outside consistently for 24 hours per day for 70 years, one of these individuals would be statistically expected to contract toxicant-mediated cancer due (solely) to inhalation of emissions from the HEC.

Excluding Census Block 1034 (the location within the facility boundaries), the estimated risk range drops to 3.70×10^{-7} to 5.83×10^{-7} (i.e., slightly less than 1 in

2,700,000 to slightly less than 1 in 1,700,000). This scenario reflects a more realistic assessment of cancer risk, as it is a certainty that no individual would be residing at the location of Census Block 1034 during operations.

For the *benzene only* cancer risk estimates, HEM-3 was only able to provide results for all census blocks (i.e., it was not feasible to exclude Census Block 1034 from the modeling). The *benzene only* cancer risk estimates ranged from 1.61×10^{-7} to 5.72×10^{-7} (i.e., slightly less than 1 in 6,200,000 to slightly less than 1 in 1,700,000).

As a point of reference, in the September 2007 Federal Register providing the Proposed Rule for National Emission Standards for Hazardous Air Pollutants (NESHAP) from Petroleum Refineries, the USEPA includes the following objective from the Benzene NESHAP:

“...in protecting public health with an ample margin of safety, we strive to provide maximum feasible protection against risks to health from hazardous air pollutants by (a) Protecting the greatest number of persons possible to an individual lifetime risk level no higher than approximately 1-in-1 million and (2) limiting to no higher than approximately 1-in-10 thousand [i.e., 100-in-1 million] the estimated risk that a person living near a facility would have if he or she were exposed to the maximum pollutant concentrations for 70 years.”⁵

All of the cancer risk estimates presented above are below the low end of the range of acceptable risk numbers espoused by the USEPA (i.e., less than 1 in 1 million). In other words, the HEM-3 modeling indicates that the inhalation-based cancer risk estimates for receptors in the vicinity of the HEC would not exceed USEPA-advocated acceptability thresholds.

As an additional point of reference, according to statistics reported by the South Dakota Cancer Registry (SDCR) in their document *Cancer in South Dakota 2003* (December, 2006), Union County identified 115 new cancer cases in the three year period of 2001-2003. Over the same time period, the SDCR reported a 3-year population (i.e., the sum of the 2001, 2002 and 2003 annual populations) of 38,652 for Union County. This corresponds to an average annual reported cancer incidence rate of 2.9×10^{-3} (115 cases/38,652 individuals). This “baseline” rate (i.e., recorded cancer incidence in the absence of emissions by the proposed Project) is over 3,000 times higher than the conservatively high estimate of the Project-related rate predicted by the Assessment.

⁵ Federal Register Vol. 72, No. 170. September 4, 2007. Proposed Rule.

HEM-3 User's Guide
Appendix A

April 23, 2008
Project No. 0062074

Environmental Resources Management
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The HEM-3 User's Guide

HEM-3 Human Exposure Model
Version 1.1.0 (AERMOD version)

Draft

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1. Introduction

The Human Exposure Model-3 (HEM-3), Version 1.0.1 provides a streamlined, but at the same time rigorous tool for estimating ambient concentrations, human exposures and health risks that may result from air pollution emissions from a complex industrial facility, or a cluster of facilities located near one another. HEM-3 is designed to be used by EPA, states, local agencies, industry, and other stakeholders.

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1.1 Organization of the HEM-3 User's Guide

This User's Guide is organized into seven chapters:

Chapter 1	Provides a brief introduction to HEM-3, including the main features and requirements of the model.
Chapter 2	Provides instructions for installing HEM-3.
Chapter 3	Provides instructions for preparing the input data needed by HEM-3 and running the model.
Chapter 4	Describes the calculations performed by HEM-3.
Chapter 5	Describes the outputs produced by HEM-3.
Chapter 6	Describes the data libraries used by HEM-3.
Chapter 7	References.

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1.2 Main Features of HEM-3

HEM-3 performs three main operations: dispersion modeling, estimation of population exposure, and estimation of human health risks. In order to perform these calculations, HEM-3 draws on three data libraries, which are provided with the model. The first is a library of meteorological data for over 60 stations, which are used for dispersion calculations. A second library of Census block internal point locations and populations provides the basis of human exposure calculations (Census, 2000). This Census library also includes the elevation of each Census block, which can also be used in dispersion calculations, at the option of the model user. A third library of pollutant unit risk estimates and reference doses is used to calculate population risks. These risk factors and reference doses are based on the latest values recommended by EPA for hazardous air pollutants (HAP) and other toxic air pollutants (Smith and Murphy, 2003).

HEM-3 provides two options for dispersion modeling. The first is AERMOD, the state of the art air dispersion model developed under the auspices of the American Meteorological Society / [Environmental Protection Agency Regulatory Model Improvement Committee \(AERMIC\) \(EPA 2004a, EPA 2004b\)](#). The second option is the Industrial Source Complex - Short Term, Version 3 (ISCST3) model, which is one of EPA's alternate models for assessing pollutant concentrations from industrial facilities (EPA 1995a, EPA 1995b). Both of these dispersion

models handle a wide range of different source types which may be associated with an industrial source complex, including stack sources, area sources, and volume sources. HEM-3 runs AERMOD or ISCST3 as many times as is necessary to address the gaseous pollutants and particulate matter emitted from the target facility.

The model identifies all Census block locations within a given modeling domain, which can be specified by the user. The model's Census library includes locations and populations and elevations for all of the approximately 5.5 million Census blocks tabulated in the 2000 Census.

HEM-3 estimates cancer risks and noncancer adverse health effects due to inhalation exposure at Census block locations, and at other receptor locations that can be specified by the user. Cancer risks are computed using EPA's recommended unit risk estimates for Hazardous Air Pollutants (HAP) and other toxic air pollutants. The resulting estimates reflect the risk of developing cancer for an individual breathing the ambient air at a given receptor site 24-hours per day over a 70-year lifetime.

Noncancer health effects are quantified using hazard quotients and hazard indices for various target organs. The "hazard quotient" for a given chemical and receptor site is the ratio of the ambient concentration of the chemical to the level at which no adverse effects are expected. The "hazard index" for a given organ is the sum of hazard quotients for substances that affect that organ.

HEM-3 identifies receptor locations at which the predicted cancer risk and hazard indices are highest. For these locations, the model gives the concentrations of different chemicals and emission sources to overall cancer risks and hazard indices.

The model estimates the numbers of people exposed to various cancer risk levels and hazard index levels. In addition, HEM-3 estimates the average cancer risks, average hazard indices, and total incremental cancer risks for people living within different distances of the modeled emission sources.

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1.3 Differences Between HEM-3 and Previous Versions of HEM

HEM was originally developed as a screening tool for exposure assessment in the 1980's ([EPA, 1986](#)). This original model has also recently been upgraded to run in a Windows™ environment ([EPA, 2002](#)). HEM-3 is designed to be somewhat more rigorous than the original HEM. The main differences between HEM-3 and the original HEM are summarized below.

- ! HEM focuses mainly on cancer risks and exposures. HEM-3 estimates cancer risks and exposures, as well as acute and chronic noncancer hazard indices and exposures.
- ! HEM uses the ISC Long Term (ISCLT), while HEM-3 uses either AERMOD or ISCST3. Both AERMOD and ISCST3 are more rigorous than ISCLT, requiring more time to run.
- ! HEM uses a single location for all sources at a given industrial facility, while HEM-3 requires detailed location data for each emission source at the facility.
- ! HEM can estimate exposures for all facilities in a given industrial category in the same model run. HEM-3 is designed to be run for a single facility or a small cluster of facilities in close proximity to one another. HEM-3 can be run for larger groups of facilities, but

considerable time will be needed for these types of runs. In addition, a separate HEM-3 run is required for each meteorological station.

- ! HEM is designed to be run separately for each pollutant that is emitted. HEM-3 analyzes multiple pollutants concurrently.
- ! HEM-3 can take into account the impacts of pollutant deposition and plume depletion for both gaseous and particulate pollutants. These features are not included in HEM.
- ! HEM-3 can take into account the effects of terrain. This feature is not included in HEM.
- ! Both HEM and HEM-3 calculate risks for individual Census blocks, but the two models use different methods for the blocks closest to the facility. HEM models pollutant concentrations for a network of receptors (usually about 200) arranged in a polar array around the facility. Concentrations at Census blocks are then interpolated from this polar array. HEM-3 also uses a polar receptor array, but only interpolates risks for Census blocks that are far away from the facility. For Census blocks that are close to the facility, HEM-3 explicitly models concentrations and risks at the internal point given by the Census Bureau for each block. This internal point is commonly known as the centroid.

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1.4 Strengths and Limitations of HEM-3

HEM-3 performs detailed and rigorous analyses of acute and chronic air pollution risks for populations located near industrial emission sources. The HEM-3 model is designed to simplify the running of AERMOD or ISCST3 without sacrificing any of the strengths of those models. In keeping with this goal, the model allows the user to specify complex emission source configurations, including point sources for stacks, area and volume sources for fugitive emissions, and obliquely oriented area sources for roadways. As noted above, the model identifies all Census blocks located near the facility. The user can also specify the locations of individual houses, schools, plant boundaries, monitors, or other receptors to be modeled by HEM-3. The model can take into account the impacts of terrain, building wake effects, pollutant deposition, and plume depletion. It also analyzes multiple pollutants concurrently, with the capability to include particulate and gaseous pollutants in the same model run.

The framework of HEM-3 has some limitations. First, AERMOD and ISCST3, like all air pollutant dispersion models, are subject to uncertainties. Likewise, pollutant unit risk estimates and reference doses are subject to uncertainties. Another limitation is that HEM-3 estimates pollutant concentrations and risks for a Census block internal point, as defined by the Census Bureau. Values calculated for this internal point are not representative of the range of values over the entire block. Nor do they account for the movement of people from their home Census blocks to other Census blocks as a result of commuting or other daily activities. In addition, HEM-3 calculates outdoor concentrations of air pollutants. These do not account for indoor sources of pollution, or the reduction of outdoor pollution in indoor air.

HEM-3 performs a number of tests on user input data – such as emissions data and stack parameters – before using AERMOD or ISCST3 to calculate air pollution impacts. However, there are still some potential problems with input files that HEM-3 does not detect in these initial tests. Therefore, the model may sometimes run for an hour or more before detecting a problem

with the input data. To avoid this, the user should review the model input guidelines to make sure that the contents and format of input files meet these guidelines.

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1.5 Requirements for Running HEM-3

HEM-3 can be used on a Windows™-based personal computer running Windows-98™ or higher. Disk space requirements will depend on the number of Census and meteorological files that will be used. If HEM-3 will only be used to model plants in a single state, the model can be run with 20 megabytes of disk space. The model also will need a minimum of 132 megabytes of RAM.

Once installed, HEM-3 can be used to model risks and exposures for any location in the U.S., and for a wide range of emission source configurations. For each model analysis, emissions inputs and emission source locations must be provided in the form of Excel™ spreadsheet files. (If Excel™ is not available, another spreadsheet program such as Lotus-123™ can be used to prepare the tables; however, they must be saved in "XLS" format.) HEM-3 requires separate estimates of emission rates of each pollutant, from each emission point. The model also requires detailed information on each emission source, including location, height, emission velocity, emission temperature, and the configuration of fugitive emission sources. An optional spreadsheet file can also be used to provide the dimensions of buildings near emission sources, which will be used to compute building wake effects. When particulate emissions are being modeled, another optional spreadsheet file can be used to provide particle size information and deposition parameters. In addition to these input files, the user is also asked to design the model receptor network and to select other modeling options through a series of user input screens.

This manual is designed to provide all of the information that is needed to run HEM-3. However, some of the options for running HEM-3 draw on advanced features of AERMOD and ISCST3, such as the incorporation of building wake effects or plume depletion due to deposition. Users who are not already familiar with the AERMOD and ISCST3 dispersion models may need to refer to the manuals for those models in order to develop some of the inputs needed for HEM-3. This is particularly true for some of the more complex modeling options, such as plume depletion, building downwash, and complex source configurations. The AERMOD and ISCST3 manuals are available from the EPA modeling website, at www.epa.gov/scram001/dispersion_prefrec.htm#aermod and http://www.epa.gov/scram001/dispersion_alt.htm#isc3, respectively.

2. Installing HEM-3

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2.1 Downloading the HEM-3 Program

The HEM-3 model is available from the EPA Fate, Exposure, and Risk Analysis (FERA) Technology Transfer Network (http://www.epa.gov/ttn/fera/fera_download.html). The FERA website includes a link to install HEM-3, under section 3 “software available for download.” The user can click the HEM-3 link and select “run” to begin the installation program for HEM-3. The default location to install HEM-3 is “C:\Program Files\HEM3\.” The user can change this location by clicking the “Change...” button and indicating an alternate location. The basic files needed to run HEM-3 will be placed in the selected directory. A number of sub-directories will also be created. A screen called “Installing HEM3” is displayed while the files are being copied to the destination folder. When the install is complete, the window called “InstallShield Wizard Completed” appears.

To complete the installation of HEM-3, the user must also copy toxicity value files, meteorological data files, and Census data files. These files are discussed in the following sections.

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2.2 Obtaining Toxicity Value Data for HEM-3

HEM-3 uses a library of pollutant unit risk estimates and reference doses to calculate population risks. These risk factors and reference doses are based on the latest values recommended by EPA ([Smith and Murphy, 2003](#)), which are updated periodically. The user should check for updated versions of the HEM-3 pollutant library files on the HEM-3 web page. When these files become available, they should be copied into the “Reference” subdirectory under the HEM-3 directory that was selected during installation. The user should be sure to unzip the files and verify they are located in the specified directory when finished. (The default chemical reference subdirectory is “C:\Program Files\HEM3\Reference”).

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2.3 Obtaining Census Data

The user will need to obtain Census files and meteorological files for the region or regions that they are planning to model. These files are provided on the HEM-3 web page.

Census files should be obtained to cover the area (or areas) within 50 kilometers of facilities that will be modeled. The files are provided on a state-by-state basis. Two files are needed for each state, a database (dbf) file, and an index (cdx) file. Multiple states may be needed to model a particular facility (if the facility is located within 50 kilometers of a state boundary). If a state is affected by two different facilities, the files for that state need only be copied once. Files are not available for parts of states.

Once the user has identified the state Census files that are needed, these files must be unzipped and copied into the “Census” subdirectory under the HEM-3 directory that was selected during installation. The user should be sure to unzip the Census files and verify they are located in the specified directory when finished. (The default Census subdirectory is “C:\Program Files\HEM3\Census”).

2.4 Obtaining Meteorological Data

Meteorological files should also be obtained for the region or regions that will be modeled. Each meteorological file contains surface data and upper air data (see [Section 6.3](#)). The zip files for the meteorological files are named after the location of the surface observation site (the name of the nearest city and the state postal code). In some cases, multiple meteorological files are available for the same surface site, using different upper air observation sites. In these cases, the name of the upper air site is also included in the zip file name. Generally, the closest set of stations will be most representative of the meteorology in the modeling domain. However, there are a number of situations where a different combination of meteorological stations will be more representative. For instance, if the modeling domain is located on the Gulf of Mexico, a surface station near the Gulf should be selected, even if there is a closer inland station. It must be noted that two of the meteorological files on the HEM-3 website (Galveston and Houston-Hobby) are missing the precipitation data necessary to calculate wet deposition and depletion. These files can be used to calculate air concentrations, but cannot be used to compute the effects of wet depletion (as a result of rainfall or frozen precipitation).

Once the user has identified the meteorological files that are needed, these files are copied into the "MetData" subdirectory under the HEM-3 directory that was selected during installation. The user should be sure to unzip the meteorological files and verify they are located in the specified directory when finished. (The default meteorological subdirectory is "C:\Program Files\HEM3\MetData".) For ISCST3, the unzipped meteorological files will have file extension of "ALL." For AERMOD, two files are needed for each meteorological station, with file extensions of "PFL" and "SFC."

3. Running HEM-3

This section is divided into three subsections. Section 3.1 discusses the preparation of input files for HEM-3. Section 3.2 discusses the selection of model options. Section 3.3 provides guidance on the modeling of multiple facilities.

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3.1 Preparing Input Files

HEM-3 requires a series of Excel™ spreadsheet files to specify the emissions and configuration of the facility (or facilities) that are to be modeled. (If Excel™ is not available, then another spreadsheet program such as Lotus-123™ can be used to prepare the files. However, they must be saved in "XLS" format.)

At a minimum, two files are needed:

- ! a pollutant emission file
- ! an emission location file

If particulate deposition or plume depletion are to be considered, then HEM-3 will require another input file to specify the particle size distribution and scavenging parameters for various size ranges. Another optional file can be used to specify building dimensions if building wake effects are to be modeled. This option should be used if any of the emission sources are located near buildings or other obstructions which would produce wake effects. Finally, another optional input file can be used to provide the locations of houses, schools, or other sites near the emission source. HEM-3 will prompt the user to provide the input file names in a series of input screens.

Inputting directly from spreadsheets allows the user to avoid retyping the emission rates and other parameters that have been calculated. However, this method of input also has its drawbacks. Notably, HEM-3 will not run successfully unless the input files are formatted exactly as specified in the format guidelines. Section 3.1.1 describes general rules that will help the user avoid common mistakes. Template input files are provided to make formatting easier. (These files are located in the default "C:\Program Files\HEM3\Input" subdirectory.) Sections 3.1.2 through 3.1.6 provide detailed guidance on how to prepare the input files, and on when the optional files are needed. Template file names are also provided.

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3.1.1 General rules for input files

- ! A separate Excel™ workbook is needed for each input file.
- ! Each Excel™ workbook should contain only the one input file worksheet.
- ! Columns should match exactly with the format specified for the input file. The user can do this by using the template input files and substituting actual data for the template data. (Extra lines of template data must be deleted).
- ! Columns must not be inserted between the data columns. Even if they are hidden in the spreadsheet program, HEM-3 will read these extra columns as data.
- ! There should be one header line at the top of each file.
- ! Text should not be included in numerical data fields (for instance "<0.001"). HEM-3 may read these fields as 0's or may accept only a portion of the number.

- ! When latitudes and longitudes are used, they should be in decimal degrees. (The model will also accept Universal Transverse Mercator coordinates.)
- ! The units used for parameters such as emission rates and stack parameters should match the units given in file format guidelines (for example: meters/second, meters, etc.).

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3.1.2 Input file for source locations

Tables 1 and 2 give the format guidelines for the source location input file, and a sample input table. A template input file is also provided ("C:\Program Files\HEM3\Inputs\Template_emission_location_file.xls").

HEM-3 can model the ambient impacts of multiple emission sources at a single facility or at a cluster of neighboring facilities. The source location file should include one record for each individual source (stack, area source, or volume source) that is to be modeled. This record provides information on the location, size, height, and configuration for each source. (Emissions data are provided in a separate file.)

The "Source ID" is a key parameter of the source location file, because it will be used to match the locations to other input files, such as the emission file. The Source ID is restricted to 8 characters (or fewer), which must be letters or numbers. Spaces cannot be used at the beginning or in the middle of the Source ID, nor can the Source ID include "-" or other typographic characters.

Each Source ID must be distinct. Different sources should be given different ID's even if they have the same location. In addition, HEM-3 cannot tell the difference between upper and lower case characters. So "ABC" and "abc" would be treated as the same Source ID.

If a cluster of facilities is to be modeled, the first few characters of the Source ID can be used to distinguish among the different facilities. For instance, the Source IDs can begin with "F1" for the first plant, "F2" for the second plant, and so on. This will help in the interpretation of model results for the facilities making up the cluster.

Locations can be entered in terms of Universal Transverse Mercator (UTM) coordinates, or latitude and longitude. The "coordinate system" field must be completed for each source record, in order to specify which coordinates have been used ("U" for UTM, or "L" for latitude/longitude). If UTM coordinates are used, the UTM zone must be specified (in each emission source record). If UTM coordinates are used, HEM-3 will ask the user to indicate whether the coordinates are based on the 1927 or the 1983 North American Datum (NAD). This information is needed in order to accurately calculate the distances between the emission sources and Census blocks (which are specified by latitude and longitude). The difference between UTM coordinates calculated using the 1927 and 1983 projection systems will vary from location to location, but can be as large as 100 meters (m).

The source type field is used to indicate whether the emission source is a point source (P), an area source (A), or a volume source (V). If the source is a point source, such as a stack or vent, the source location file must also include the source height, diameter, exit velocity, and emission release temperature.

Table 1. Format Guidelines for the Source Location File

Field	Type	Length and decimal places	Source types*	Description or comment
Source ID	Character	8	all	Unique alphanumeric string up to 8 characters. No spaces or typographical symbols. Must contain at least one letter.
Coordinate system	Character	1	all	U = UTM, L = latitude / longitude
X-coordinate	Numeric	15,6	all	UTM east coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the center of point or volume sources, or the southwest corner of area sources
Y-coordinate	Numeric	15,6	all	UTM north coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the center of point or volume sources, or the southwest corner of area sources
UTM zone	Numeric	2,0	all	UTM zone if coordinate system = U (blank if coordinate system = L)
Source type	Character	1	all	P = point, A = area, V = volume
X-dimension	Numeric	7,0	A	Length in the easterly (or southeasterly) direction for area sources (m)
Y-dimension	Numeric	7,0	A	Length in the northerly (or northeasterly) direction for area sources (m)
Angle	Numeric	5,2	A	Angle of rotation (area sources only)
Lateral	Numeric	7,0	V	Horizontal dimension of volume source (meters)
Vertical	Numeric	7,0	V	Vertical dimension of volume source (meters)
Release height	Numeric	5,0	A, V	Release height (above ground) for area and volume sources (meters)
Stack height	Numeric	5,0	P	Stack release height above ground (meters)
Diameter	Numeric	5,1	P	Diameter of stack for point sources (meters)
Velocity	Numeric	7,2	P	Velocity at which emissions are coming from the stack (m/s) for point sources
Temperature	Numeric	4,0	P	Temperature of emissions for point sources (K)
Elevation	Numeric	6,0	all	Elevation of the ground above sea level at the source location (meters). Only required when using elevated terrain.
Hill height	Numeric	6,0	all	Needed for AERMOD only. Controlling hill height for the emission source location (meters). Defined as the highest elevation which is above a 10% grade from the source. (Used for flow calculations within AERMOD.)

*Source types for which the parameter is needed: A = area, P = point, V = volume.

Table 2. Sample Input File for Emission Source Locations

Source ID	Location type - U= UTM, L= lat/ lon	Longitude (dec.) or UTM E (m) ¹	Latitude (dec.) or UTM N (m) ¹	UTM zone	Source type- P=point, A=area, V= volume	Length in x direction - A sources (m)	Length in y direction - A sources (m)	Angle - A sources (deg)	Horizontal dimension - V sources (m)	Vertical dimension - V sources (m)	Release height - A or V sources (m) ²
Z6C00ROT	U	559966	4400652	16	P						...
Z6FARRFN	U	559880	4400565	16	A	130	120	0			2.0 ...

continued

Stack height - sources (m)	Stack diameter - P sources (m)	Exit velocity - P sources (m/sec)	Exit temperature - P sources (deg K)	Elevation (m)	Hill height (m) ³
...	50.3	2.82	21	244	300
...				244	300

¹Use the center of the source for point and volume sources and the southwest corner for area sources.

²Use the top of the source for point and area sources and the vertical center for volume sources.

³Needed only if AERMOD is selected.

An area source represents a rectangular area from which emissions are released at ambient temperature and with negligible velocity. Area sources can be at ground level, or at a height above ground level. The default orientation for area sources is with one axis in the north-south direction, but these sources can be rotated using the “angle” parameter, which specifies the rotation of the source from north (in the clockwise direction). This feature allows the simulation of emissions from a roadway, using a long, narrow area source. The location coordinates (UTM or latitude and longitude) should reflect the southwest corner of the area source. The x-dimension should reflect the length of the source in the easterly direction, or in the southeasterly direction if the source is rotated. The y-dimension should reflect the length in the northerly direction, or the northeasterly direction if the source is rotated.

Unlike AERMOD and ISCST3 where 360 degree rotation is allowed, the angle parameter for HEM3 area sources must be between 0 and 90 degrees. This angle can be used to cover any possible orientation by switching the x and y dimensions. For instance, to model a road segment running from southwest to northeast, use the y-dimension to specify the road length, the x-dimension to specify the road width. To model a road segment running from northwest to southeast, use the x-dimension to specify road length and the y-dimension to specify road width.

Volume sources are specified by a horizontal dimension, a vertical dimension, and a height. Emissions from a volume source are assumed to be released at ambient temperature and with zero velocity. Both the height and the source location coordinates (UTM or latitude and longitude) should reflect the center of the source.

If terrain impacts are to be considered, the elevation above sea level should be specified for each emission source. If no elevation data are entered for any emission sources (and if check the elevation option is selected), then HEM-3 will estimate an elevation for the emission sources based on the elevations of nearby Census blocks.

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3.1.3 Input file for emissions

Tables 3 and 4 give the format guidelines for the emissions input file, and a sample input table. An electronic version of the template input file is also provided in the default directory (“C:\Program Files\HEM3\Inputs\Template_HAP_emission_file.xls”).

The emissions file should contain one record for each combination of emission source and chemical. Each Source ID used in this file must match with a corresponding record in the source location file.

Each chemical name used in this file must match with one of the chemical names in the HEM-3 chemical library, hap_library.xls, that is located in the reference subfolder. (“C:\Program Files\HEM3\Reference\hap_library.xls”) Pollutants can be added to the chemical library by the user if needed.

The emission values should be expressed in terms of tons per year. The smallest value that can be modeled is 1E-15. If deposition or plume depletion are to be included in the model run, then HEM-3 will need the breakdown of emissions between vapor and particulate matter. The fraction emitted as particulate must be included for each emission record (each combination of source and chemical). A separate file will also be needed to specify particle sizes and scavenging coefficients. If deposition and depletion are not being considered, the particulate fraction column in the emissions input file can be left blank.

Table 3. Format Guidelines for the Emissions File

Field	Type	Length and decimal places	Description or comment
Source ID	Character	8	Must match Source ID's used in the <u>emission location</u> file
Pollutant	Character	50	Chemical name of the emitted pollutant. Must match a pollutant name in the <u>chemical library</u> . See "C:\Program Files\HEM3\Reference\HAP_library.xls" file
Emissions	Numeric	20,15	tons/year
Fraction emitted as particulate matter (%)	Numeric	7,3	%, Optional if not modeling depletion or deposition (blank if depletion and deposition are not being modeled)

Table 4. Sample Input File for Emissions

Source ID	Chemical name	Emissions (tons/year)	Fraction particulate (%)
Z6C00ROT	Antimony compounds	1.2E-001	100.0
Z6C00ROT	Chromium (VI) compounds	3.2E-004	100.0
Z6C00ROT	Mercury (elemental)	4.2E-002	50.0
Z6C00ROT	Dibenzofuran	1.1E-001	90.0
Z6C00ROT	Xylenes (mixed)	1.3E+000	0.0
Z6C00ROT	Benz(a)anthracene	7.3E-006	11.9
Z6C00ROT	Benzo(a)pyrene	2.5E-008	23.9
Z6C00ROT	Benzo(b)fluoranthene	2.8E-006	17.8
Z6C00ROT	Benzo(k)fluoranthene	4.6E-007	85.1
Z6C00ROT	Chrysene	3.2E-005	52.3
Z6C00ROT	Dibenz(a,h)anthracene	3.6E-008	99.3
Z6C00ROT	Indeno(1,2,3-cd)pyrene	1.1E-007	98.9
Z6FARRFN	Chromium (VI) compounds	3.8E-005	100.0
Z6FARRFN	Mercury (elemental)	3.6E-004	50.0
Z6FARRFN	Nickel compounds	4.8E-003	100.0
Z6FARRFN	Selenium compounds	2.1E-004	100.0

3.1.4 Additional requirements for source location and emissions input files when gaseous deposition or depletion is selected in the AERMOD mode

To be added

3.1.5 Input file for particle sizes and scavenging coefficients

If particulate matter deposition and plume depletion are to be modeled, HEM-3 will need information on the particle size distribution, and scavenging coefficients for different particle sizes. A separate input file is used to provide this information. This file should include a separate record for each particle size range emitted by each emission source. Each record must include an average particle diameter for the size range, the percentage that the size range represents in terms of the total mass of particulate matter from the given emission source, the average density of particles in the size range, and scavenging coefficients for the size range in rain and frozen precipitation. The mass percentages must total to 100 for each emission source.

Rain scavenging coefficients can be estimated from the correlation curve shown in [Figure 1](#), developed by Jindal and Heinold (1991). This correlation curve relates the coefficient to aerodynamic particulate diameter. The frozen precipitation scavenging coefficient can be estimated by dividing the wet scavenging coefficient by 3.0 ([Scire et al., 1990](#)).

Information must be provided for each of the sources listed in the [source location file](#) that emits particulate matter (as specified in the particulate fraction column of the [emissions input file](#)). Particulate information must be specified separately for each source that emits particulate matter. If the particle size and deposition information is the same for all emissions at the plant, then the information must be repeated for each emission source.

Tables 5 and 6 give format requirements for the particulate matter information file, and a sample input table. A template file is also provided ("C:\Program Files\HEM3\Inputs\Template_particle_data.xls").

Table 5. Format Guidelines for the Particulate Matter Information File

Field	Type	Length and decimal places	Description or comment
Source ID	Character	8	Must match Source ID's used in the <u>emission location</u> file
Average particle diameter	Numeric	5,2	units = μm
Mass fraction (%)	Numeric	5,1	Must add up to 100% for each Source ID
Average particle density	Numeric	5,2	units = g/cm^3
Rain scavenging coefficient (1/s-mm-h)	Numeric	7,5	Can be estimated using the correlation curve shown in <u>Figure 1</u>
Frozen precipitation scavenging coefficient (1/s-mm-h)	Numeric	7,5	Can be estimated by dividing the rain scavenging coefficient by 3

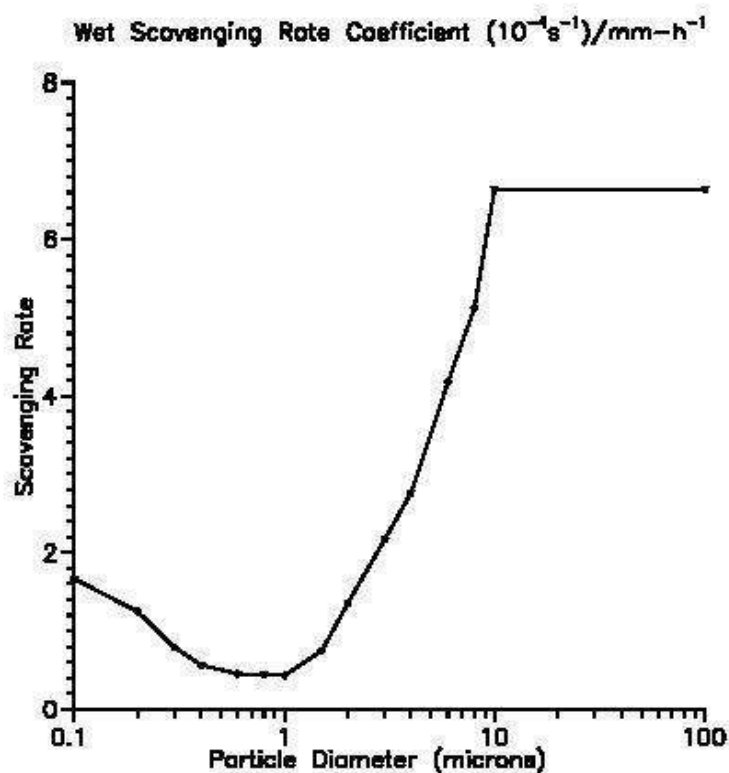


Figure 1. Wet Scavenging Coefficient as a Function of Particle Size.

Table 6. Sample Input File for Particulate Matter Deposition Information

Source ID	Particle diameter (µm)	Mass fraction (%)	Particle density (g/cm ³)	Liquid precipitation scavenging coefficient (1/s-mm-h)	Frozen precipitation scavenging coefficient (1/s-mm-h)
Z6C00ROT	0.5	72	1	0.00005	0.00002
Z6C00ROT	1.5	8	1	0.00007	0.00002
Z6C00ROT	2.5	4	1	0.00019	0.00006
Z6C00ROT	4.0	4	1	0.00033	0.00011
Z6C00ROT	10.0	12	1	0.00067	0.00022
Z6C01RMA	0.5	72	1	0.00005	0.00002
Z6C01RMA	1.5	8	1	0.00007	0.00002
Z6C01RMA	2.5	4	1	0.00019	0.00006
Z6C01RMA	4.0	4	1	0.00033	0.00011
Z6C01RMA	10.0	12	1	0.00067	0.00022

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3.1.6 Input file for building downwash

Under the regulatory option of AERMOD or ISCST3, the effects of building downwash should be taken into account when a building is close enough to impact dispersion from an emission source. Building downwash will affect the predictions of AERMOD or ISCST3 when:

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

It should be noted that a building may impact emissions from multiple sources. In order to model the impact of building downwash, HEM-3 requires information on the configuration of the building when viewed from different wind directions. The following parameters are needed for both the AERMOD and ISCST3 versions of HEM-3:

- ! height (keyword=BUILDHGT)
- ! projected width perpendicular to the direction of flow (keyword=BUILDWID)

These parameters must be provided for 36 wind directions, at increments of 10 degrees (compass bearing). For the AERMOD version, three additional parameters are needed (again for 36 wind directions):

- ! length in the direction of flow (keyword=, BUILDLEN)
- ! distance from the stack to the center of the upwind face of the building parallel to the direction of flow (keyword=XBADJ)
- ! distance from the stack to the center of the upwind face of the building perpendicular to the direction of flow (keyword=YBADJ)

All of these parameters can be calculated using EPA's Building Profile Input Program (BPIP). BPIP is available at http://www.epa.gov/scram001/dispersion_related.htm.

Building dimensions are entered using a building downwash information file. Tables 7 and 8 give format requirements for the building downwash file, and a sample input table. A template input file is also provided ("C:\Program Files\HEM3\Inputs\Template_bldg_dimensions.xls").

Table 7. Format Guidelines for the Building Downwash File

Field	Type	Length and decimal places	Description or comment
Keyword	Character	6	Specifies which values are given in this record, as follows: BUILDHGT = building height BUILDWID = projected width perpendicular to the direction of flow BUILDLEN ^a = length in the direction of flow XBADJ ^a = along-flow distance from the stack to the upwind face of the building YBADJ ^a = across-flow distance from the stack to the upwind face of the building
Source ID	Character	8	Must match Source ID's used in the <u>emission location</u> file
Value 1	Numeric	6,2	Dimension or distance (depending on the Keyword parameter) viewed from a compass bearing of 10 degrees from the emission release point
Value 2	Numeric	6,2	Dimension or distance at a bearing of 20 degrees
Value n (n = 3 thru 35)	Numeric	6,2	Dimension or distance at a bearing of nx10
Value 36	Numeric	6,2	Dimension or distance at a bearing of 360 degrees

^a Not needed for the ISCST3 version of HEM-3.

Table 8. Sample Input File for Building Downwash

Keyword	Source ID	Value 1 (10°)	Value 2 (20°)	Value 3 (30°)	...	Value 36 (360°)
BUILDHGT	Z6C00ROT	16.8	16.8	16.8	...	16.8
BUILDWID	Z6C00ROT	107.2	111.1	108.7	...	100.0
BUILDLLEN ^a	Z6C00ROT	66.6	81.2	93.3	...	50.0
XBADJ ^a	Z6C00ROT	50.8	53.2	57.7	...	50.0
YBADJ ^a	Z6C00ROT	8.9	17.1	25.0	...	0.0

^a Not needed for the ISCST3 version of HEM-3.

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3.1.7 Input file for user-defined receptors

HEM-3 will calculate ambient impacts and resultant cancer risks and noncancer hazard indices for all Census blocks within the defined modeling domain. The user can also specify additional receptor sites to be modeled, such as schools or ambient monitors. The locations of these sites are specified in the user-defined receptor file. Use a separate record to indicate the location of each user-specified receptor. If terrain effects are to be modeled, the elevation above sea level must also be provided for each user-specified receptor.

A “receptor type code” must also be specified to indicate the type of receptor. A code of “P” represents populated sites, “B” represents plant boundary sites, and “M” represents ambient monitors. A code of “P” should be used for any receptor that is to be considered in the calculation of maximum individual risk. These receptors could include houses, schools, businesses, or other populated locations.

Tables 9 and 10 give format requirements for the user-defined receptor file, and a sample input table. A template input file is also provided (“C:\Program Files\HEM3\Inputs\Template_user_receptors.xls”).

Table 9. Format Guidelines for the User-Defined Receptor File

Field	Type	Length and decimal places	Description or comment
Coordinate system	Character	1	U = UTM, L = latitude / longitude
X-coordinate	Numeric	15,6	UTM easting coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the receptor
Y-coordinate	Numeric	15,6	UTM northing coordinate, in meters (if coordinate system = U) or decimal latitude (if coordinate system = L) of the receptor
Elevation	Numeric	6,0	Height of receptor above sea level (meters)
Receptor type code	Character	1	P = school, house, or other populated site; B = plant boundary; M = monitor
Hill height	Numeric	6,0	Needed for AERMOD only. Controlling hill height for the receptor location (meters). Defined as the maximum elevation above a 10% grade from the receptor location.

Table 10. Sample Input File for User-Defined Receptors

Location type	Latitude or UTM east (m)	Longitude or UTM north (m)	UTM zone	Elevation (m)	Type of receptor	Hill height (m)*
U	560000	441010	16	244	P	300
U	560005	441000	16	244	M	300

*Needed for AERMOD only.

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3.2 Selecting Model Options

Once the input files have been prepared for the modeling application, the HEM-3 program can be started. The program is started by double clicking on the HEM-3 icon on your desktop or clicking on the HEM3.exe file in Windows Explorer™. The model will display a series of screens which will require the user to select various options and to provide some additional information. These selections are discussed below.

3.2.1 Selecting the type of model run

The first input screen that requires user input will ask whether AERMOD or ISCST3 will be used for atmospheric dispersion modeling. EPA's modeling guidance indicates that either of the two models may be used for air toxics applications (EPA, 2005). AERMOD represents the the state-of-the-art, and is recommended by EPA for most industrial source modeling applications. However, the deposition and depletion algorithms of AERMOD are currently in draft form (2006). In addition, ISCST3 may require less input data and less model run time for some applications.

The first input screen also requires the user to specify some general options for the model run. HEM-3 can be used to estimate *chronic* health risks, *acute* health risks, or both. If the acute option is selected along with either the plume deposition or depletion option, HEM-3 will require more time to run. The exact run time will depend on the particular source configuration and modeling domain, but the combination of acute calculations and plume depletion will generally increase run times from a few minutes to over an hour. Plume depletion has more of an effect on ambient concentrations farther from the plant than it does closer to the plant where the maximum impact generally occurs. Therefore if plume depletion option is being included in the model run, it may save time to make two separate runs. One would calculate chronic effects and include plume depletion; and the second would calculate acute effects without depletion.

Chronic health risks are estimated based on long-term average concentrations, as predicted by AERMOD or ISCST3. The timeframe of this average is determined by the number of years covered by the meteorological data file selected for the model run. This is generally five years. Acute adverse health effects are calculated from the maximum short term ambient concentrations predicted by AERMOD or ISCST3. The user may elect one of four options for the timeframe of the short term average: 1-hour, 6-hour, 8-hour, and 24-hour.

The user will need to specify whether HEM-3 ISCST3 should use *urban* or *rural* dispersion coefficients for the model run. EPA provides guidance on whether to select urban or rural dispersion coefficients in its AERMOD and ISCST3 [modeling guidance](#). In general, the urban option should be used if (1) the land use is classified as urban for more than 50% of the land within a 3 kilometer radius of the emission source, or (2) the population density within 3 a kilometer radius is greater than 750 people per square kilometer. Of these two criteria, the land use criterion is considered to be the more definitive. If AERMOD is being used as the dispersion model and urban dispersion characteristics are chosen, the user is also asked to specify the population of the urban area surrounding the emission source.

The user will also need to specify whether HEM-3 will take into the account the impacts of *terrain elevations* in calculating air concentrations. Elevated terrain around the facility can cause local impacts to increase, although the impact should be different in each set of sources and elevations. The elevation option should be selected if the height of receptors around the facility may exceed the height of any stacks at the facility. When this option is selected, the source location file must be populated with elevations for each source. EPA's Guideline on Air Quality Models (also published as Appendix W of 40 CFR Part 51) (EPA, 2005) should be consulted for more explicit directions on when the use of terrain elevations is recommended. The Guideline is available at <http://www.epa.gov/scram001/dispersionindex.htm>.

3.2.2 Specifying file names for emissions and source locations

The second user input screen will ask for the names of and path to the emission file, and the source location file to be used in the current model run. This input screen also asks whether the UTM coordinates supplied in the source location file are based on the 1927 NAD or the 1983 NAD (if any UTM coordinates are used). Ignore this selection if all coordinates are in latitude and longitude.

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3.2.3 Specifying options for deposition and plume depletion

The third user screen allows the user to specify whether the model will take into account the impacts of deposition and plume depletion. These processes reduce the ambient impacts from the emission source by removing pollutants from the plume. HEM-3 can consider deposition and depletion for particulate matter, gaseous pollutants, or both.

If the user opts to model deposition and depletion of particulate matter, HEM-3 will require a particulate matter input file containing particle size information and appropriate scavenging [coefficients](#). [HEM-3 will prompt the user to specify the name of and the path to the particulate matter input file.](#) If deposition and depletion of gaseous pollutants are to be modeled, HEM-3 will allow the user to specify gas scavenging coefficients for rain and for frozen precipitation. The default values for gas scavenging coefficients are currently set at levels equal to scavenging coefficients for very fine particulate matter ([Figure 1](#)).

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3.2.4 Optional inputs and outputs

The fourth input screen allows the user to specify whether HEM-3 will model the effects of building downwash. Section 3.1.5 summarizes situations where building downwash should be taken into account. If the building downwash option is selected, HEM-3 will prompt the user for the name of the building dimension file ([see Section 3.1.5](#)).

This input screen is used to determine whether HEM-3 will produce a number of optional output files giving detailed model predictions. The first option is to provide estimated incremental concentrations for each modeled chemical from each emission source, and at each receptor. If this option is selected, HEM-3 will produce three detailed output files. The second option is to produce file giving a detailed histogram of the estimated numbers of people exposed to different levels of maximum individual cancer risk. (These optional output files are described in Section 5.7.)

The user can also change the annual average emissions multiplier for acute calculations to account for the high end of the short-term variations in emissions. The default multiplier is 10, which means that the hourly-average emission rate used in calculating acute adverse health impacts is assumed to be ten times the annual-average emission rate.

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3.2.5 Defining the modeling domain

The fifth user input screen allows the user to define the modeling domain by specifying the following information.

Outside radius. The modeling domain input screen allows the user to specify the outside radius of the modeling domain, or the area for which ambient impacts are to be modeled. This distance is usually 30 to 50 kilometers. The center of this area is generally the geographical center of the facility (or facilities) being modeled, but this location can be adjusted in a later input screen.

Inside radius. An inside radius for the modeling domain can also be specified, but generally this radius should be set to 0. HEM-3 provides the option of changing this value in case it becomes necessary to divide a modeling job in order to make more efficient use of computer resources. For instance, one run could be used to model all receptors from 0 to 10,000 meters from a facility, and a second run could be used for receptors located between 10,000 and 50,000 meters from the same facility. In this case, the maximum individual risk would be the maximum value for the two runs, and the population exposure to any given risk level would be the sum of population exposures for the two runs.

Distance for individual modeling of Census blocks. The modeling domain input screen will also ask the user to specify the cutoff distance for individual modeling of Census blocks. Within this radius, each block will be modeled explicitly as a receptor using AERMOD or ISCST3. Outside of this radius, Census blocks will not be modeled individually, but ambient impacts will instead be interpolated using dispersion modeling results for a polar receptor network, described below. Larger values for this cutoff distance will require more time to model, because the number of Census block receptors will be higher. However, this cutoff value should be set at a large enough distance so that at the maximum individual risk receptor will be modeled individually. This distance will vary depending on the configuration of the source, but it generally is between 1500 and 2000 meters.

Overlap distance. The user can also specify a distance within which sources and receptors will be considered to be overlapping. This feature is provided in order to address the situation where Census blocks are very close to a facility and have complex shapes. In such cases, the centroid of a Census block may be much closer to the facility than the nearest actual dwelling. (In fact, if a Census block surrounds a portion of the facility, the centroid of the block will be on plant property.) The default value for the overlap distance is set to 30 meters, or approximately equal to the width of a narrow buffer and a roadway. If a receptor falls within this distance, HEM-3 will not calculate risks based on the location of that receptor, but will instead assume that the risks associated with the receptor are the same as the highest predicted value for any receptor that does not overlap plant property (even if it is not a population receptor).

Polar receptor network. As noted above, a polar receptor network will be used to interpolate risk values for Census blocks outside of the individual block modeling distance. The user can specify the minimum radius for the polar network, the number of concentric circles which will be analyzed, and the number of radial directions to be included. The inner radius of the polar network should be the minimum distance from the facility center that is generally outside of plant property. (For complex plant shapes, it is sometimes useful to specify an inner ring that encroaches on facility property in some directions.) A typical run would include 13 concentric rings and 12 or 16 radial directions. HEM-3 will distribute the radial directions evenly around the plant. For instance, if 16 directions are chosen, receptors will be modeled at compass bearings of 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5, 180, 202.5, 225, 247.5, 270, 292.5, 315, and 337.5. The selection of specific ring distances is discussed in Section 3.2.7.

3.2.6 Checking the HEM-3 inputs

After the modeling domain input screen, the input verification screen will ask the user to verify all of the choices that have been made. To change a selection, check the appropriate box and then click "OK." The selected parameter can then be edited.

3.2.7 Changing the suggested model ring distances

HEM-3 will suggest a list of polar ring distances based on the number of rings that have been specified in the modeling domain input screen. This suggested list will be a logarithmic progression of distances starting at the inner ring distance and ending at the outer radius of the modeling domain. The ring distance input screen allows the user to alter the suggested ring distances to fit the specific size and surroundings of the facility (or facilities) that are being modeled.

The polar grid receptors are used primarily for interpolating risks at Census blocks outside of the modeling cutoff distance. However, it is also important to include some rings close to the facility. HEM-3 generally estimates maximum individual risks and hazard indices using concentrations calculated at Census blocks. However, HEM-3 will default to the next most impacted receptor if a Census block is located within the "overlap distance" (specified by the user, see Section 3.2.5) of any of the emission sources. This next most impacted receptor can be either a Census block or a polar grid receptor. The polar receptors are also included in the calculation of maximum offsite impacts, which can be used in determining analyzing the risks of short-term exposure.

The user should place the nearest polar receptor ring as close as possible to the facility boundary. For irregularly shaped facilities, the user should also specify a set of boundary receptors with the user-defined receptor file (see Section 3.1.6).

3.2.8 Checking the facility location and the domain center

The location check screen provides a number of options for viewing the facility location in relation to other nearby geographic features. The user can view the location on a Geographic Information System (GIS) map, an aerial photograph, or a topographical map. HEM-3 calculates the geographic center using the combination of all emission sources listed in the source location file. To generate the GIS map, HEM-3 provides the location of the modeled facility to EPA's EnviroMapper website. The aerial photograph and the topographic map are generated by calling the Terraserver™ website, operated by Microsoft.

HEM-3 allows the user to use the geographic center of the emission sources as the center for the modeling domain, or to specify different coordinates to meet the needs of the analysis. The center of the modeling domain will be used in interpolating risks at Census blocks outside the modeling cutoff distance. In addition, HEM-3 will calculate the total population and average risks within various distances from the modeling domain center. It may be desirable to change the domain center if the facility includes an outlying emission source, such as a storage tank farm or a ship-loading facility. In that case, the default condition of HEM-3 would be to place the domain center midway between the main process operation and the outlying source. In this

case, the domain center can be moved closer to the main process operation, especially if the outlying facility is a small source of emissions.

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3.2.9 Selecting a meteorological station

The meteorological station input screen allows the user to select an appropriate meteorological input file for the modeling domain. HEM-3 includes a library of processed meteorological data covering over 120 sites for AERMOD, and over 80 sites for ISCST3. The meteorological input files include upper air data and surface data as discussed in [Section 6.3](#). HEM-3 calculates the distances from all of the surface and upper air stations to the center of the modeling domain. The meteorological input screen then ranks the available files according to their proximity to the modeling domain.

Generally, the closest set of stations will be most representative of the meteorology in the modeling domain. However, there are a number of situations where a different combination of meteorological stations will be more representative. For instance, if the modeling domain is located on the Gulf of Mexico, a surface station near the Gulf should be selected, even if there is a closer inland station. HEM-3 also allows the user to provide a meteorological data file for the specific facility location. (This file must be preprocessed and formatted for AERMOD or ISCST3, as discussed in [Section 6.3](#), and placed in the “C:\Program Files\HEM3\Metdata” subdirectory). If the user does not specify a particular set of surface and upper air station, the closest available set of stations will be selected.

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3.2.10 Changing the chemical unit risk estimates and health benchmarks

The user can edit the chemical library by editing the Excel™ spreadsheet files which have been downloaded from the HEM-3 webpage – entitled “HAP_library.xls” and “Target_organisms.xls”. New chemicals can also be added to the library.

When adding new chemical names to the library, the user should make sure to use the same spelling that has been used in the [emissions input file](#). The CAS number and HAP number fields in the chemical library are optional. If a cancer unit risk factor is not specified for a new chemical, then the cancer unit risk factor will be assumed to be 0 and cancer risks will not be evaluated for that chemical. Similarly, if a noncancer reference dose is not specified for a new chemical, HEM3 will not calculate adverse health effects.

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3.2.11 Checking the facility configuration and nearby receptors

After the user has checked the location of the facility and specified the modeling domain, HEM-3 identifies the Census blocks within the modeling domain. The model then produces a plot showing the source configuration and the locations of the nearest Census block receptors.

If any of the receptors overlap the facility as defined in [Section 3.2.5](#) under overlap, HEM-3 will not calculate risks based on the location of that receptor, but will instead assume that the risks associated with the receptor are the same as the highest predicted value for any receptor that does not overlap plant property. Therefore, the user should enter a series of boundary receptors to make sure that the maximum risks for the overlapping receptors are properly characterized.

3.3 Modeling Multiple Facilities

HEM-3 can be used to analyze the impacts of a single industrial facility or a cluster of facilities located near one another. The main factor limiting the number of facilities that can be modeled is the time that will be required to run AERMOD or ISCST3. This required runtime will be roughly proportional to the product of the number of emission source locations and the number of receptors that are modeled. The number of receptors modeled includes the polar receptor network, all of the Census blocks that are modeled individually (see [Distance for individual modeling of Census blocks](#) under Section 3.1.5), and any receptor locations defined by the user (see [Section 3.1.6](#)).

It should be noted that the cutoff distance for individual modeling of Census blocks applies to *all* emission source locations, not just to the center of the modeling domain. This feature of HEM-3 is designed to ensure that calculated maximum individual risks and hazard indices will be based on actual dispersion model results, rather than interpolation. As a consequence of this feature, the number of individually modeled Census blocks will depend on how close the facilities are to one another. For instance, if a model cutoff distance of 2 kilometers is chosen for a cluster of two facilities located 100 meters apart, the number of individually modeled Census blocks will not be much larger than if only one facility was modeled. However, the number of individually modeled Census blocks will likely double if the facilities are 2 kilometers apart. (The exact numbers will depend on the population density in the modeling domain.)

The interpolations performed in HEM-3 will become less accurate as distances increase between the modeled facilities. This will primarily affect exposure calculations, such as the number of people estimated to be exposed to different risk levels. The accuracy of maximum individual risks and maximum hazard indices will generally be unaffected, since these values are not interpolated unless the selected cutoff distance is too small. (HEM-3 will show a warning message when this occurs.)

The HEM-3 output files allow the user to distinguish the contributions of different emission sources to the maximum individual risk or maximum hazard indices (see [Sections 5.1 and 5.2](#)). When a cluster of facilities is modeled, the first few characters of the Source ID can be used to distinguish among the different facilities. For instance, "F1" for the first plant, "F2" for the second plant, and so on. This will help in the interpretation of model results for the facilities making up the cluster.

It should be noted that the location of the maximum individual risk for a cluster of facilities may be different from the location of the maximum individual risk for any single facility in the cluster. Therefore, it may be desirable to model the facilities in the cluster separately as well as together.

4. Calculations Performed by HEM-3

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4.1 Dispersion Modeling

HEM-3 carries out dispersion modeling by running either the AERMOD or the ISCST3 dispersion model. Section 3 has described a number of options that the user of HEM-3 can specify for the running of the dispersion models, for instance whether to incorporate deposition and depletion, and whether to use urban or rural dispersion parameters. This section describes the options which are implemented automatically by HEM-3. In addition, we describe the dilution factor methodology, which is used in HEM-3 for modeling multiple pollutants.

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4.1.1 Regulatory default option

HEM-3 uses the regulatory default options when running AERMOD or ISCST3. These options include the following:

- ! Use stack-tip downwash (except for Schulman-Scire downwash)
- ! Use buoyancy-induced dispersion (except for Schulman-Scire downwash)
- ! Do not use gradual plume rise (except for building downwash)
- ! Use the calms processing routines
- ! Use upper-bound concentration estimates for sources influenced by building downwash from super-squat buildings
- ! Use default wind profile exponents
- ! Use default vertical potential temperature gradients.

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4.1.2 Toxics option

HEM-3 invokes the “toxics” option when AERMOD is selected, or also when modeling chronic risks using ISCST3. In AERMOD, the toxics option expedites the modeling of area and volume sources by reducing the requirements for uniformity of emissions over the extent of the sources. The toxics option of ISCST3 also reduces the number of meteorological data processed by the model, so that the model processes every 13th hour of data. This option is considered suitable for modeling chronic risks, since the ISCST3 meteorological data files contain 5 years of data. The toxics option is not used to model acute risks in ISCST3, since they are based on the maximum hourly concentration.

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4.1.3 Dilution factors

To save time when analyzing the impacts of multiple pollutants, HEM-3 does not model each pollutant separately. Instead, AERMOD or ISCST3 is used to compute a series of dilution factors, specific to each emission source and receptor. The dilution factor for a particular emission source and receptor is defined as the predicted ambient impact from the given source and at the given receptor, divided by the emission rate from the given source.

If the user chooses not to analyze deposition or depletion, then the dilution factor does not vary from pollutant to pollutant. If deposition or depletion is selected, HEM-3 will compute separate dilution factors for gaseous and particulate pollutants. In addition, different particle sizes,

densities, and particle scavenging coefficients can be specified for each particulate matter emission source. Since the ISCST3 version of HEM-3 does not take into account dry gas deposition, the deposition properties of different gaseous toxic pollutants are assumed to be similar. In the AERMOD version, the user can only specify one gaseous pollutant per emission source ID. Multiple source ID's can be created using the same locations and stack parameters in order to accommodate different pollutants.

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4.2 Estimating Risks and Hazard Indices

HEM-3 estimates total cancer risks and hazard indices for all Census block locations in the modeling domain, all user-defined receptors, and all points in the polar receptor network. [Section 4.2.1](#) describes methods used to calculate cancer risks and hazard indices for receptors that are explicitly modeled using AERMOD or ISCST3. [Section 4.2.2](#) describes the interpolation approach used to estimate cancer risks and hazard indices at Census blocks that are not explicitly modeled.

Based on the results for Census blocks and other receptors, HEM-3 estimates the maximum individual risk and maximum hazard indices for populated receptors ([Section 4.2.3](#)); as well as the maximum impacts for all offsite receptors, including unpopulated locations ([Section 4.2.4](#)). For these locations, the model calculates the contributions of individual chemicals and emission sources to cancer risks and hazard indices ([Section 4.2.5](#)).

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4.2.1 Inner Census blocks and other modeled receptors

HEM-3 calculates cancer risks and target-organ-specific hazard indices for three types of discrete receptors. These are (1) Census blocks within the user-defined [distance cutoff for modeling of individual blocks](#), (2) all [user-defined receptors](#), and (3) the [user-defined polar receptor network](#).

As noted in the previous section on [dilution factors](#), HEM-3 combines pollutants into two categories – gases and particulates – for the purposes of dispersion modeling. In order to conserve computer memory capacity, the model retains these categories to calculate cancer risks and noncancer hazard indices. The following algorithms are used.

For cancer risk:

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

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

For noncancer hazard indices:

$$HI_T = \sum_{i,j} HI_{i,j}$$

$$HI_{i,j} = DF_{i,j} \times CF \times \sum_k [E_{i,k} / RC_k]$$

where:

- CR_T = total cancer risk at a given receptor (probability for one person)
- ∑_{i,j} = the sum over all sources i and pollutant types j (particulate or gas)
- CR_{i,j} = cancer risk at the given receptor for source i and pollutant type j

- $DF_{i,j}$ = dilution factor $[(\mu\text{g}/\text{m}^3) / (\text{g}/\text{sec})]$ at the given receptor for source i and pollutant type j
 CF = conversion factor, $0.02877 [(\text{g}/\text{sec}) / (\text{ton}/\text{year})]$
 \sum_k = sum over all pollutants k within pollutant group j (particulate or gas)
 $E_{i,k}$ = emissions of pollutant k from source i
 URE_k = cancer unit risk factor for pollutant k
 HI_T = total organ-specific hazard index at a given receptor and for a given organ
 $HI_{i,j}$ = organ-specific hazard index at the given receptor for source i and pollutant type j
 RC_k = noncancer health effect reference concentration for pollutant k

The above equations are equivalent to the following simpler equations:

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

$$HI_T = \sum_{i,k} AC_{i,k} / RC_k$$

where:

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

However, these simpler equations would require that all pollutants be modeled individually in AERMOD or ISCST3, and that risk calculations be performed separately for each pollutant.

If the cancer unit risk factor is not available for a given chemical, then that chemical is not included in the calculation of cancer risk. Likewise, if the noncancer reference concentration is not available for a given chemical, that chemical is not included in the calculation of hazard indices. Note also that separate reference concentrations are used for acute and chronic hazard indices.

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4.2.2 Outer Census blocks

For Census blocks outside of the user-defined distance cutoff for individual block modeling, [HEM-3 estimates cancer risks and hazard indices by interpolation from the polar receptor network](#). Impacts at the polar grid receptors are estimated using AERMOD or ISCST3 modeling results and the algorithms described in section 4.2.1. If the terrain elevation option is selected, then an elevation is estimated for each polar receptor. This is done by assigning a sector to each polar receptor, and taking the highest elevation of any Census block within that sector. If a sector contains no Census blocks, then an elevation is selected based on the nearest Census block of the neighboring sectors.

The impacts at each outer Census block are interpolated from the four nearest polar grid receptors. The interpolation is linear in the angular direction, and logarithmic in the radial direction, as summarized in the following equations:

$$I_{a,r} = I_{1,r} + (I_{2,r} - I_{1,r}) \times (a - A1) / (A2 - A1)$$

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

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

where:

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

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4.2.3 Maximum individual risks and hazard indices

HEM-3 evaluates the predicted impacts for all populated receptors in order to identify the locations of the maximum individual cancer risk and the highest hazard indices for various target organs. For these calculations, populated receptors include all Census block locations, and any user-defined receptors that are designated as type-P (population-oriented). In general, type-P receptors should include houses near the facility boundary, as well as nearby schools, public places, or other populated sites.

It should be noted that the maximum cancer risk may occur at a different location than the maximum hazard index for a given organ. Likewise, the location of the maximum hazard index for one organ will not necessarily be the same as the location for a different organ. HEM-3 performs a separate evaluation of the maximum impact location for each health effect.

The model also tests for instances where Census blocks or other type-P receptors appear to be located on plant property. This is done by calculating the distance between each receptor and each emission source. These distances are compared with an overlap distance, which can be specified by the user. If a population-oriented receptor is located within the overlap distance, then the calculated results for this receptor are not used to estimate the maximum individual cancer risk or maximum hazard indices for populated areas. Instead, the impacts at the overlapping receptor are assumed to be equal to the maximum impacts for any receptors that do not overlap plant property. This could include both populated and unpopulated receptors, as long as they do not overlap plant property.

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4.2.4 Maximum offsite impacts

In addition to evaluating the maximum cancer risks and hazard indices for populated receptors, HEM-3 also evaluates maximum offsite impacts for all receptors. All Census blocks, all user-defined receptors (populated and unpopulated), and all points on the polar receptor network are included in the evaluation of maximum offsite impacts, except for those receptors that are found to be overlapping emission sources.

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4.2.5 Contributions of different chemicals and emission sources

HEM-3 calculates the contributions of different chemicals and emission sources to cancer risks and hazard indices at the receptors where impacts are highest, both for populated receptors

and for all offsite receptors. As noted in Section 4.2.1, HEM-3 conserves computer disk space by grouping chemicals together when calculating total risks and hazard indices for the large number of receptors that are typically included in an overall modeling domain. Thus, the contributions of individual chemicals and emission sources are not computed for all receptors. However, HEM-3 retains the information needed to determine the contributions of individual chemicals and emission sources at the receptors where impacts are highest. These contributions are calculated using the following equations:

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

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

$$HQ_{i,k,m} = AC_{i,k,m} / RC_k$$

where:

- $AC_{i,k,m}$ = predicted ambient concentration for chemical k, from source i, at receptor m
- $E_{i,k}$ = emissions of pollutant k from source i
- $DF_{i,j,m}$ = the dilution factor for source i, receptor m, and pollutant group j, which includes pollutant k
- CF = conversion factor, 0.02877 [(g/sec) / (ton/year)]
- $CR_{i,k,m}$ = estimated cancer risk from source i, and pollutant k, at receptor m
- URE_k = cancer unit risk factor for pollutant k
- $HQ_{i,k,m}$ = organ-specific hazard quotient as a result of emissions of pollutant k, from source i, at receptor m
- RC_k = noncancer health effect reference concentration for pollutant k

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4.3 Population Exposures, Average Impacts and Total Risks

Using the predicted impacts for Census blocks, HEM-3 estimates the populations exposed to various cancer risk levels and hazard index levels. This is done by adding up the populations for receptors that have predicted cancer risks or hazard indices above the given threshold.

The model also calculates the average cancer risks, average hazard indices, and total cancer risks for Census blocks located within various distances of the emission sources. The following equations are used:

$$MCR_d = \sum_m [CR_m \times P_m] / \sum_m P_m$$

$$MHI_d = \sum_m [HI_m \times P_m] / \sum_m P_m$$

$$TCR_d = \sum_m [CR_m \times P_m] / LT$$

where:

- MCR_d = the population-weighted average cancer risk for the population located within distance d of the center of the modeling domain
- \sum_m = the sum over all Census blocks m within distance d
- CR_m = the total lifetime cancer risk (from all modeled pollutants and emission sources) at Census block m

- P_m = the population at Census block m
- MHI_d = the population-weighted average hazard index (for a particular organ) for the population located within distance d
- HI_m = the total hazard index for the given organ (from all modeled pollutants and emission sources) at Census block m
- TCR_d = the estimated total annual cancer risk (cancers/year) to the population living within distance d
- LT = the average lifetime used to develop the cancer unit risk factor, 70 years

HEM-3 also estimates the contributions of different chemicals and emission sources to total cancer risks for the overall modeling domain. The following equations are used:

$$TCR_{i,j} = \sum_m \left[\left(\sum_k E_{i,k} \times URE_k \right) \times DF_{i,j,m} \times CF / LT \right]$$

$$TCR_{i,k} = TCR_{i,j} \times E_{i,k} \times URE_k / \left(\sum_k E_{i,k} \times URE_k \right)$$

where:

- $TCR_{i,j}$ = the estimated total annual cancer risk (cancers/year) to the population in the modeling domain due to emissions from pollutant type j (1= particulate, 2=gas) and emission source i
- \sum_m = the sum over all Census blocks m in the modeling domain
- \sum_k = the sum over all pollutants k, within pollutant type j
- $E_{i,k}$ = emissions of pollutant k from source i (tons/year)
- URE_k = unit risk factor for pollutant k
- $DF_{i,j,m}$ = dilution factor at receptor m, for emissions of pollutant type j (which includes pollutant k), from source i
- CF = conversion factor, 0.02877 [(g/sec) / (ton/year)]
- $TCR_{i,k}$ = the estimated total annual cancer risk (cancers/year) to the population in the modeling domain due to emissions of pollutant k (in pollutant type j) from emission source i

5. Outputs of HEM-3

After running the dispersion model and completing the necessary risk and exposure calculations, HEM-3 displays a series of output tables. All of these tables are also copied to spreadsheets in Excel™ format in an output subdirectory specified by the user. (If Excel™ is not available, these files can also be read by another spreadsheet program, such as Lotus-123™.) HEM-3 also produces a number of more detailed database and spreadsheet files which can be used for more in-depth analyses, such as GIS analysis or analyses of demographic data. The following sections describe the output tables and files produced by HEM-3.

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5.1 Maximum Individual Risks

The maximum individual risk screen displays a table showing the highest cancer risks and hazard indices (HI) predicted for any populated receptor that does not overlap plant property. If any populated receptor is located within the minimum overlap distance, then it is assumed that either the source location or the receptor location is inappropriate. (A block centroid may be inappropriate as a receptor location if the block partially encompasses an emission source, such as at a corner of the plant.) When an overlap condition occurs, the calculated results for the overlapping receptor are not used. Instead, the maximum cancer risk and hazard indices are assumed to be equal to the maximum impacts for any receptor that does not overlap plant property. This could include both populated and unpopulated receptors, as long as they do not overlap plant property. When this occurs, a warning message is displayed. The user should check the coordinates in the source location input file, and also define a set of plant boundary receptors in the user-defined receptor file.

A separate line is displayed for each health effect: cancer risk; chronic hazard indices for the respiratory system, the liver, the neurological system, developmental effects, the reproductive system, the kidney, the ocular system, the endocrine system, the hematological system, the immunological system, the skeletal system, the spleen, the thyroid, and whole body effects. Table 11 shows the fields displayed on the maximum individual risk screen.

Cancer risks are computed using EPA's recommended unit risk estimates for HAPs and other toxic air pollutants. The resulting estimates reflect the risk of developing cancer for an individual breathing the ambient air at a given receptor site over a 70-year lifetime. Noncancer health effects are quantified using hazard quotients and hazard indices for various target organs. The "hazard quotient" for a given chemical and receptor site ratio of the ambient concentration of the chemical to the level at which no adverse effects are expected. The "hazard index" for a given organ is the sum of hazard quotients for substances that affect that organ.

Data will only be displayed if the maximum cancer risk or hazard index is greater than 0. The user can view the contribution of different chemicals to the maximum cancer risk, or to any of the hazard indices by highlighting the appropriate line and then clicking the "details by pollutant" button. The pollutant contributions to the maximum cancer risk will be displayed in order of highest impact. Likewise, the contribution of different emission sources can be viewed by highlighting the appropriate line and clicking the "details by source" button.

Table 11. Fields Included in the Maximum Individual Risk and Maximum Offsite Impact Displays

Field	Description
Parameter name	cancer risk, respiratory HI, liver HI, neurological HI, etc.
Value	maximum individual cancer risk or maximum hazard index
Population	at the location of the maximum cancer risk or hazard index, if it is a Census block
Distance	from the center of the modeling domain
Angle	from north
Elevation	above sea level
Receptor type	C = Census block, P = user-defined population receptor, G = polar grid receptor, B = boundary, M = monitor
Notes	An entry in this field will generally mean that the modeling analysis should be rerun. This field will provide advice on how to change model input files or other specifications.
County FIPS code	if the receptor is a Census block
Census block identifier	for linking to demographic data (if the receptor is a Census block)
UTM east coordinate	meters
UTM north coordinate	meters
Latitude	decimal
Longitude	decimal

The user can also highlight any of the receptor lines and click the “GIS map” button to view an EnviroMapper GIS map centered on the receptor location. The “source map” button will display the locations of the maximum cancer risk and maximum total chronic hazard index receptors in comparison to the locations of emission sources.

Click the “Next” button to move to the next results screen.

HEM-3 automatically produces an Excel™ file entitled “maximum_indiv_risks.xls” which includes all of the data tabulated on this screen. The file also breaks down the contributions of gaseous and particulate emissions for any chemicals that are emitted in both forms. Table 12 shows the fields included in the chemical and source contribution file “Risk_breakdown.xls” file.

**Table 12. Fields Included in the Chemical and Source Contribution File
(Risk_breakdown.xls)**

Field	Description
Site type	maximum individual risk, or maximum offsite impact
Parameter name	cancer risk, total chronic HI, respiratory HI, liver HI, neurological HI, etc.
Source ID	maximum individual cancer risk or maximum hazard index
Pollutant	chemical name
Pollutant type	P = particulate, V = vapor
Angle	from north
Value	cancer risk or hazard quotient (HQ)
Value_rnd	cancer risk or HQ rounded to two significant figures
Conc_ugm3	pollutant concentration ($\mu\text{g}/\text{m}^3$)
URE	unit risk estimate used to compute cancer risks for the pollutant
RFC	reference concentration used to compute hazard quotients for the pollutant ($\mu\text{g}/\text{m}^3$)

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5.2 Maximum Offsite Impacts

The maximum offsite impact screen displays a table showing the highest cancer risks and HI predicted at any receptor that does not overlap with the emission sources, whether the receptor is populated or unpopulated. The receptors included in this calculation include all Census blocks, all user-defined receptors (including boundary sites and ambient monitor sites), and all points in the polar receptor network, except for those receptors which overlap with emission sources.

The format is the same as in the Maximum Individual Risk output screen. A separate line is displayed for each health effect: cancer risk; chronic HI's for the respiratory system, CNS, cardiovascular system, blood, liver, kidney, and immune system; and total acute hazard index. Table 11 shows the fields displayed on the maximum individual risk screen. Data will only be displayed if the maximum cancer risk or hazard index is greater than 0.

The contribution of different chemicals to the maximum cancer risk, or to any of the hazard indices, can be viewed by highlighting the appropriate line and then clicking the "details by pollutant" button. Likewise, the user can view the contribution of different emission sources by highlighting the appropriate line and clicking the "details by source" button. In addition, the user can highlight any of the receptor lines and click the "GIS map" button to view an EnviroMapper GIS map centered on the receptor location.

Click the "next" button to move to the next results screen.

HEM-3 automatically produces an Excel™ file entitled “maximum_offsite_impact.xls” which includes all of the data tabulated on this screen. In addition, the chemical and source contribution file – entitled “Risk_breakdown.xls” – includes the contributions of individual chemicals and emission sources to the maximum cancer risk and maximum hazard indices. The file also breaks down the contributions of gaseous and particulate emissions for any chemicals that are emitted in both forms. Table 12 shows the fields included in the chemical and source contribution file.

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5.3 Domain-Wide Population Exposures

The domain wide population exposure screen presents two tables, which estimate the populations exposed to different cancer risk levels and to different hazard indices for noncancer effects. Tables 13 and 14 show sample population exposure tables for cancer, and for noncancer impacts, respectively. HEM-3 automatically creates two Excel™ files entitled “Cancer_risk_exposure.xls” and “Noncancer_risk_exposure.xls,” which contain the information given in Tables 13 and 14, respectively.

Table 13. Sample Output Table for Cancer Risk Exposure

Cancer risk level	Population
Greater than or equal to 1 in 1,000	0
Greater than or equal to 1 in 10,000	2
Greater than or equal to 1 in 20,000	101
Greater than or equal to 1 in 100,000	2,233
Greater than or equal to 1 in 1,000,000	263,631
Greater than or equal to 1 in 10,000,000	2,310,368

Table 14. Sample Output Table for Noncancer Risk Exposure

Estimated number of people exposed to hazard indices above
the noted levels

Level of total chronic hazard index	Total chronic	Respirat ory	Liver	Neuro- logical	Devel- opment al	Repro- ductive	...
Greater than or equal to 1 in 100	0	0	0	0	0	0	...
Greater than or equal to 1 in 50	0	0	0	0	0	0	...
Greater than or equal to 1 in 10	0	0	0	0	0	0	...
Greater than or equal to 1 in 1.0	0	0	0	0	0	0	...
Greater than or equal to 1 in 0.5	0	0	0	0	0	0	...
Greater than or equal to 1 in 0.2	0	0	0	0	0	0	...

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5.4 Cancer Risk by Distance

The distance-based and risk screen displays the average cancer risk and the estimated total potential annual cancer impact for the populations living within each of the ring distances specified for the polar receptor network. This screen also displays the total population for all of the Census blocks with geographic centroids inside each ring distance as shown in Table 15.

Table 15. Sample Output Table for Cancer Exposure at Different Distances

Distance (m)	Population	Average cancer risk to an individual	Total potential cancer impact (number of cases per year)
100	0	na	na
180	0	na	na
320	0	na	na
570	0	na	na
1,000	628	2.4 E -08	2.2 E -07
1,600	7,250	2.2 E -08	2.3 E -06
2,600	23,569	1.8 E -08	6.5 E -06
4,200	58,522	1.4 E -08	1.4 E -05
6,800	158,787	9.0 E -09	2.6 E -05
11,100	374,763	5.6 E -09	4.4 E -05
18,100	851,851	3.4 E -09	6.6 E -05
29,500	1,291,629	2.1 E -09	7.9 E -05
50,000	1,457,279	1.0 E -09	8.2 E -05

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5.5 Maximum Short Term Impacts

If the “acute” option is selected, HEM-3 will display two tables of maximum offsite short-term concentrations. Each table compares the maximum predicted pollutant concentrations with available short term benchmark levels. The first table is for population oriented receptors, including populated Census blocks and user-defined receptors that are population-oriented. The second is for all receptors – populated or unpopulated – including Census blocks, polar grid receptors, and user-defined receptors. Table 16 shows the fields included in these displays.

Table 16. Fields Included in the Maximum Offsite Short Term Concentration Displays

Field	Description
Pollutant	Chemical name
Maximum concentration	units = $\mu\text{g}/\text{m}^3$
Notes	An entry in this field will generally mean that the modeling analysis should be rerun. This field will provide advice on how to change model input files or other specifications.
AEGL-1, 1-hour	Acute Exposure Guideline Level 1 (AEGL-1) for a 1-hour exposure: the concentration above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, nonsensory effects (mg/m^3)
AEGL-1, 8-hour	See AEGL-1 above, but for an 8-hour exposure
AEGL-2, 1-hour	Concentration above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape for a 1-hour exposure (mg/m^3)
AEGL-2, 8-hour	See AEGL-2 above, but for an 8-hour exposure
ERPG-1	Emergency Response Planning Guideline 1 (ERPG-1): concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor (mg/m^3)
ERPG-2	Concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action (mg/m^3)
IDLH/10	Immediately Dangerous to Life or Health: concentration believed likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment, divided by a factor of 10 (mg/m^3)
MRL	Minimal Risk Level: daily human exposure that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure (mg/m^3)
REL	concentration below which no adverse health effects are anticipated, based on the most sensitive adverse health effect reported (mg/m^3)
TEEL_0	Temporary Emergency Exposure Limit 0 (TEEL) defined by the U.S. Department of Energy: the threshold concentration below which most people will experience no adverse health effects
TEEL_1	Maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or perceiving a clearly defined objectionable odor.
Block population	if the receptor is a Census block
Distance	from the center of the modeling domain (meters)
Angle	from north
Elevation	meters above sea level
County FIPS code	if the receptor is a Census block
Census block identifier	for linking to demographic data (if the receptor is a Census block)
UTM east coordinate	meters
UTM north coordinate	meters
Latitude	decimal
Longitude	decimal
Receptor type	C = Census block, P = user-defined population receptor, G = polar receptor grid point, B = boundary, M = monitor

The information listed in Table 16 is also output in two Excel™ files entitled “Acute_chem_pop.xls” and “Acute_chem_unpop.xls.xls.” A third file entitled “Acute_bkdn.xls,” gives the contribution of different emission sources to the predicted maximum pollutant concentrations.

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5.6 Additional Output Files

In addition to the Excel™ output files discussed above, HEM-3 produces four Dbase™-formatted output files that give total cancer risks and hazard indices for all of the modeled receptors and interpolated receptors in the modeling domain. These files are entitled:

- ! Block_summary_chronic.dbf
- ! Block_summary_acute.dbf
- ! Ring_summary_chronic.dbf
- ! Ring_summary_acute.dbf

The “chronic” files give the total estimated cancer risk at each receptor, as well as total and organ-specific hazard indices for chronic noncancer effects. The “acute” files give the total hazard index of acute noncancer effects at each receptor. The “block summary” files give results for the Census block locations, and the “ring summary” file provide give results for points in the polar receptor network.

In addition to cancer risk estimates and hazard indices, each file gives the latitude and longitude, and the UTM coordinates of each receptor. These are intended to facilitate detailed GIS analyses of HEM-3 results. The “block summary” files also give the county FIPS code, block identification number, and population of each Census block. This information is intended to facilitate studies linking HEM-3 results with Census information, such as demographic or economic data.

HEM-3 also provides a set of files designed to facilitate tracking and quality assurance of the model run. These files are described below:

- ! Input_selection_options.xls – lists the options and input file names specified in the user input screens
- ! Overlapping_source_receptors.xls – lists receptors that were identified as located within the user-specified overlap distance of an emission source
- ! Aermod.out or Isclog.out – the dispersion model log file showing inputs data, selected options, outputs, and warning or error messages
- ! Aermod1.out Isclog1.out – a second dispersion model log file produced in cases where both gases and particulate emissions are being modeled

Finally, HEM-3 can produce an four optional files, which provide mode detailed results. The user specifies whether these files should be produced under input screen #4. The names of the four optional files are as follows:

- ! Cancer_histogram.dbf
- ! All_inner_receptors.dbf

! All_outer_receptors.dbf
! All_polar_receptors.dbf

The cancer histogram file gives estimates of the numbers of people exposed to different cancer risk levels, similar to the cancer risk exposure Excel™ file (Table 13). However, the cancer histogram file includes many more risk levels than the Excel™ file – 10 exposure bins for each factor of ten change in estimated cancer risk.

The three “all receptors” files provide detailed model predictions for all of the receptors in the modeling domain. Each file gives the estimated incremental ambient concentration impact for all emission sources and for all chemicals included in the model analysis. The “all_inner_receptors” file addresses all of the Census block receptors inside the modeling cutoff distance, as well as all of the user-defined receptors. The “all_outer_receptors” file includes all of the Census block receptors that have been interpolated, that is all receptors located between the modeling cutoff distance and the outer edge of the modeling domain. The “all_polar_receptors” file provides detailed concentration estimates for the nodes of the polar receptor grid.

6. HEM-3 Data Libraries

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6.1 Chemical Health Effects Information

HEM-3 includes a library of available health effects data for HAPs. For each pollutant, the library includes the following parameters, where available:

- ! unit risk factor for cancer
- ! reference concentration for chronic noncancer health effects
- ! reference concentration for acute health effects
- ! target organs affected by the chemical

These parameters have been taken from EPA's database of recommended dose-response factors for HAPs ([Smith and Murphy, 2003](#)).

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6.2 Census and Elevation Data

The HEM3 Census library includes Census block identification codes, locations, populations, elevations, and controlling hill heights for all of the over 5 million Census blocks identified in the 2000 Census. The location coordinates reflect the internal point of the block, which is a point selected by the Census to be roughly in the center of the block. For complex shapes, the internal point may not be in the geographic center of the block. Locations and population data for Census blocks in the 50 states and Puerto Rico were extracted from the LandView® database ([Census, 2000](#)). Locations and populations for blocks in the Virgin Islands were obtained from the Census web site.

The elevation of each Census block in the continental U.S. and Hawaii was estimated by interpolating the elevation at the block's internal point from the U.S. Geological Service's 1:250,000 Digital Elevation Model (DEM) data ([USGS, 2003](#)). These data have a resolution of 3 arc seconds, or about 90 meters. The estimation of the elevation of each Census block in Alaska and the U.S. Virgin Islands was performed with analysis tools in the ArcGIS 9.1 software application. The point locations of the Census block centroids in Alaska and the Virgin Islands were overlaid with a raster layer of North American Digital Elevation Model elevations (in meters). Each Census block point was assigned an elevation value based on the closest point in the ArcGIS elevation raster file.

Controlling hill heights were determined with base on the algorithm used in AERMAP, the AERMOD terrain processor ([EPA 2004c](#)). These values are used for flow calculations within AERMOD. In order to save run time and resources, the HEM3 Census block elevation database was substituted for the DEM data generally used in AERMAP. As noted above, the Census block elevations were originally derived from the DEM database. To determine the controlling hill height for each Census block, a cone was projected away from the block location, representing a 10% elevation grade. The controlling hill height was selected based on the highest elevation above that 10% grade (in accordance with the AERMAP methodology). The distance cutoff for this calculation was 100 km. (This corresponds to an elevation difference, at a 10% grade, of 10,000 m, which considerably exceeds the maximum elevation difference in North America.)

6.3 Meteorological Data

AERMOD and ISCST3 both require surface and upper air meteorological data that meet specific format requirements. HEM-3 includes a library of preprocessed meteorological data for the each of these models, from National Weather Service (NWS) observation stations. The HEM-3 AERMOD meteorological library includes over 120 locations (Figure 1), while the HEM-3 ISCST3 meteorological library includes over 60 locations, shown in (Figure 2).

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6.3.1 Data preprocessed for AERMOD

Surface and upper air meteorological data for AERMOD were prepared using the AERMOD meteorological processor, AERMET. AERMET requires hourly surface weather observations and the full twice-daily upper air soundings (i.e., meteorological variables reported at all levels). The surface and upper air stations are paired to produce the required input data for AERMOD. To simplify processing and minimize the amount of quality assurance needed, the analysis was restricted to meteorological data collected prior to the installation of the Automated Surface Observation System (ASOS). The ASOS has previously been found to omit the ceiling height for a large percentage of the observations at a number of meteorological stations. Installation and operation of ASOS equipment began in 1992; therefore, data for 1991 were processed with AERMET. Data were retrieved from products available from the National Climatic Data Center (NCDC). The surface data for 1991 were retrieved from the Hourly United States Weather Observation (HUSWO) CD. Upper air soundings were obtained from the Radiosonde Data of North America CDs produced by NCDC and the Forecast Systems Laboratory (FSL).

The input to and output from AERMET were examined for indications of missing input data. The 1200 Greenwich Mean Time (GMT) sounding is required for AERMET to calculate the convective boundary layer height and several associated parameters. There were many isolated days in which the 1200 GMT sounding was missing for many of the stations. However there also were several stations for which there were two or more consecutive days of missing 1200 GMT soundings. To minimize the impact on the output from AERMET, upper air data from a representative upper air station were substituted for those periods for which the 1200 GMT sounding was missing for two or more consecutive days.

One of the important requirements of applying the AERMOD model is the specification of surface characteristics for use in processing the meteorological data using AERMET. Application of AERMET requires specification of the surface roughness length, the Bowen ratio (an indicator of surface moisture), and the albedo (an indicator of surface reflectivity). These surface characteristics are used by AERMET to calculate the level of shear-induced mechanical turbulence generated by flow over the surface and for the energy balance calculations used in the determination of the Monin-Obukhov stability parameter and the convective velocity scale. For this application, the following surface characteristics were used:

- ! Surface roughness length = 0.25 m. At the airport meteorological site, the surface roughness includes runways, terminal buildings and other airport structures. In addition, off-airport structures often are within 3 kilometers of the measurement site. This combination of land covers suggests a value of 0.2 – 0.3 meters is appropriate.
- ! Bowen ratio = 1.0. Representing an equal partition of the heat fluxes

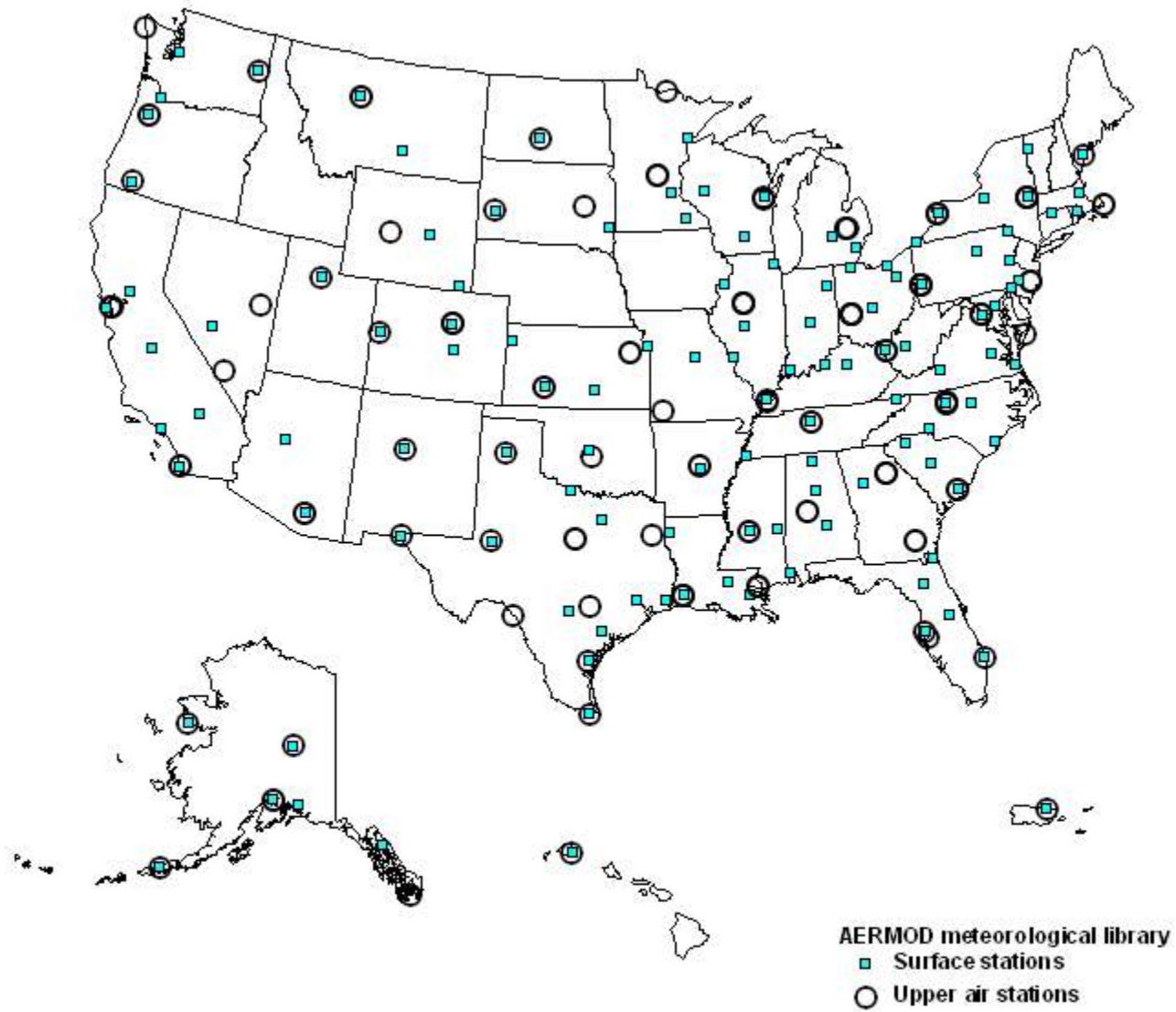


Figure 2. HEM-3 meteorological library for AERMOD.

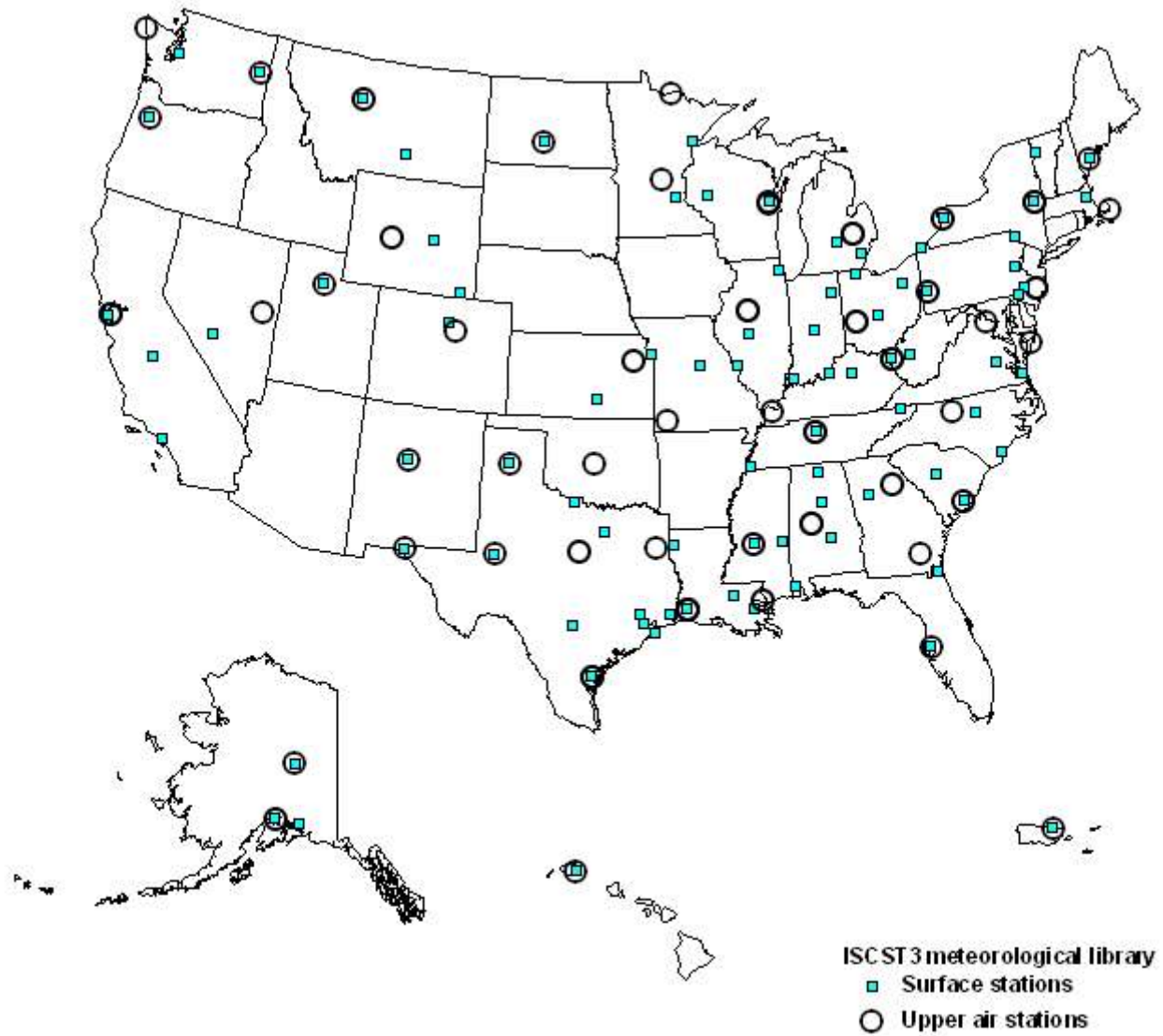


Figure 3. HEM-3 meteorological library for ISCST3.

- ! Albedo = 0.15. Representing conditions for all seasons, including winter without continuous snow cover.
- ! The file STNS.TXT located on the HUSWO CD was used for the anemometer heights required by AERMET. These heights are to the nearest meter and were deemed appropriate for use in this application.

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6.3.2 Data preprocessed for ISCST3

Surface data in the HEM-3 library have been obtained from two data sources. The first is a joint EPA/National Oceanic and Atmospheric Administration (NOAA) database of "Hourly United States Weather Observations," or HUSWO (EPA/NOAA). This database contains observations data from 1990-1995, the most recent compilation of the surface data needed in the required format. If previous years of data were required, this information was extracted from a joint NOAA/National Renewable Energy Laboratory (NREL) data product, "Solar and Meteorological Surface Observation Network," or SAMSON (NOAA/NREL). Upper air data were obtained from a databases produced by NOAA, "Radiosonde Data of North America."

Two preprocessor programs were used to produce meteorological files suitable for ISCST3. First, the Mixing Heights preprocessor was used to compute twice daily mixing heights from hourly surface observations and twice daily upper air soundings (EPA, 1998b). The PCRAMMET preprocessor was then used to calculate hourly values for atmospheric stability, to interpolate twice daily mixing heights to hourly values, and to calculate the parameters for dry and wet deposition processes (EPA, 1999). In addition to meteorological observations, PCRAMMET requires a number of properties representative of the meteorology site. These include: minimum Monin-Obukhov length, anemometer height, surface roughness length, noontime albedo, Bowen ratio, anthropogenic heat flux, and net radiation fraction absorbed by the ground. These properties were set using guidance provided in the PCRAMMET User's Guide. The output from PCRAMMET model becomes the input for meteorological data into ISCST3.

In some cases, the meteorological observation input files do not have values reported for every hour. Because ISCST3 requires that there be no missing values in certain required data fields, the missing data in those fields were filled using interpolation. However, if more than five consecutive required variables are missing, the year of data containing those missing variables cannot be used. In addition, if there is 10% or more of a required variable missing from one year of data, that year of data cannot be used. In general HEM-3 includes used the most recent data available, but in those cases, earlier years of data were used. In cases where there were not five years of good data available, another station was chosen for either the upper air data, the surface data, or both.

7. References

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