APPENDIX E

Site-Wide Soil Gas Human Health Risk Assessment

Appendix E summarizes the approach used to identify site-specific values for several input parameters to be used in the Johnson and Ettinger (J&E) Soil Gas Model to evaluate vapor intrusion at the Tronox site. This information was originally submitted as a draft memorandum to NDEP on January 27, 2010. A revised memorandum and a supplemental documentation memorandum were submitted to NDEP on February 10, which were further discussed during teleconferences with NDEP and its consultants on February 17, 2010 and February 23, 2010. The specific input parameters addressed in this appendix include:

- Soil type
- Soil dry bulk density, soil total porosity, soil water-filled porosity
- Soil vapor permeability
- Average soil temperature
- Air exchange rate
- Enclosed space floor length and width
- Vapor flow rate into building

The rationale for each recommended value is described in the following sections.

<u>Soil Type</u>

Soil type was determined based on laboratory-measured grain size distributions of 15 samples collected across the Tronox site in 2009. These samples were all taken at 10 feet below ground surface (bgs), except for one sample at 15 feet bgs and one sample at 9 feet bgs. Figure E-1 shows the locations of these samples. Particle size analysis was performed for both coarser grains, according to ASTM D422, and finer grains, according to ASTM D4464M[1]. The weight percent of gravel, sand, silt, and clay in these samples was determined, as defined by the USDA. To classify the soil type, the normalized weight percent of sand, silt, and clay was plotted on the U.S. Soil Conservation Service Classification Chart provided in the J&E Model User's Guide (EPA 2004). The result is shown in Figure E-2. According to this classification, seven samples are "sand," seven samples are "loamy sand," and one sample is "sandy loam;" however, the 14 samples

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[1] The use of method ASTM D4464M is a change from the Sampling and Analysis Plan. For further information see Attachment 1: *Comparison of Analytical Methods for Fines Particle Size Distribution*.

classified as sand or loamy sand are clustered together along the boundary between these two soil types. Table E-1 summarizes these results. Figure E-3 shows the mean of all samples, which falls slightly inside the boundary of loamy sand. Removing the sandy loam sample from the mean gives a classification that is nearly directly on top of the loamy sand and sand boundary, as shown in Figure E-4. In addition, the soil classification was mapped for the various sample locations, shown in Figure E-1. Although it might appear that some regions of the site consist of sand and other regions consist of loamy sand, we believe that the entire site should be considered to be of a single soil type because the grain size distribution in Figure E-2 is very tightly clustered. While this cluster happens to cross the chart's boundary for sand and loamy sand, there are not two distinct clusters.

Soil Dry Bulk Density, Soil Total Porosity, Soil Water-Filled Porosity

Site-specific values for soil dry bulk density, soil total porosity, and soil water-filled porosity were estimated based on measurements from the same 15 soil samples collected in 2009 described above and an additional sample collected in 2008, although this later sample lacked laboratory data for total porosity. Soil dry bulk density was measured according to ASTM D2937, soil water filled porosity was measured according to ASTM D2216, and soil total porosity was calculated from the measured dry bulk density and specific gravity[2]. The results for these analyses are shown in Table E-2. The site-specific input values were taken as the arithmetic mean of the samples because of the uniform soil stratum identified in the above discussion.

Due to the variability associated with water-filled porosity, we conducted an additional evaluation of percent moisture data from every soil sampling location. Although these data are based on a less accurate test, averaged over all soil samples taken on the site, percent moisture should be close to the laboratory measured soil water-filled porosity if the 16 samples are representative of the site-wide water-filled porosity. Percent moisture was converted to a volumetric water content using a mean wet density from the 16 soil samples[3]. The result was that the laboratory-measured value for soil water-filled porosity matched up very well with the site-wide mean percent moisture data. Table E-3 shows this result as well as a breakdown of the data by month. Additionally, the majority of the soil samples were taken in the dry months between July and October, likely yielding a conservative value for water-filled porosity.

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[2] $total\ porosity = n = 1 - \frac{\rho_{bulk}}{\rho_{particle}}$

[3] For more detail see Attachment 2: *Supplemental Documentation Supporting Site-Specific Input Parameters for the Johnson & Ettinger Model.* .

Soil Vapor Permeability

The procedure used to calculate site-specific average soil vapor permeability comes from Section 2.8 of the J&E Model User's Guide (EPA 2004, pg. 26) and the steps are described briefly below. The results of these calculations are shown in Table E-4.

- The average of the value for Loamy Sand and Sand was used for parameters that are class averages by soil textural classification. These parameters are: saturated hydraulic conductivity (K_s), residual water content (Θ_r), and the van Genuchten shape parameter (M). Class average values for K_s are from Table 5 of the J&E Model User's Guide. Class average values for Θ_r and M are from Table 3 of the J&E Model User's guide.
- Intrinsic permeability (k_i) was calculated using Equation 29 in the J&E Model User's Guide (EPA 2004, pg. 28). The inputs are K_s, dynamic viscosity of water (.011 g/cm-s at 17°C), density of water (0.999 g/cm^3), and acceleration due to gravity (980.665 cm/s^2).
- Effective total fluid saturation (S_{te}) was calculated using Equation 28 in the J&E Model User's Guide (EPA 2004, pg. 28). The inputs are site-specific soil water-filled porosity (cm^3/cm^3), site-specific soil total porosity (cm^3/cm^3) and residual water content, Θ_r (cm^3/cm^3). Site-specific values are shown in Table A5-2.
- Relative air permeability (k_{rg}) was calculated using Equation 27 in the J&E Model User's Guide (EPA 2004, pg. 27). The inputs are S_{te}, calculated in the previous step, and the van Genuchten shape parameter, M.
- Effective air permeability, also called the soil vapor permeability, is calculated as the product of intrinsic permeability and the relative air permeability at the soil water-filled porosity according to the J&E Model User's Guide (EPA 2004):

$$k_v = k_{rg}(\theta_w) \times k_i$$

The resulting site-specific average value for k_v was found to be 3.65E-08 cm^2.

Average Soil Temperature

The J&E Model User's Guide (EPA 2004) provides a figure of Average Shallow Groundwater Temperature in the United States that can be used to approximate average soil temperature. This figure gives an average groundwater temperature of 17°C in the Henderson, Nevada area. This value is essentially the same as the average air temperature of 19°C in Boulder City, Nevada (www.weatherbase.com).

Air Exchange Rate

EPA provides a recommended value for the air exchange rate for a residential building, but not a commercial building, in their J&E Model User's Guide (EPA 2004). The California Environmental Protection Agency (Cal-EPA) recommends a value of 1 per hour (1/hr) for commercial buildings based on the California Energy Commission's *Manual for Compliance with the 2001 Energy Efficiency Standards (for Nonresidential Buildings, High-Rise Residential Buildings and Hotels/Motels* (Cal-EPA 2005). The Michigan Department of Environmental Quality (MDEQ) recommends a value of 2/hr. The basis for this value is two-fold. First, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) *Draft BSR/ASHRAE Standard 62-1989R, Ventilation for Acceptable Indoor Air Quality* that suggests that system rates for total supply air in a general office will be approximately 1/hr. Second, natural ventilation, infiltration, and entrance and egress into and out of the building will increase air exchange rates above the approximate 1/hr provided by mechanical systems (Michigan Environmental Science Board 2001). For purposes of this HRA, the more conservative (i.e., health protective) value of 1/hr was used. To address the uncertainty in this input parameter, the estimated cancer risk estimates and non-cancer hazard indices were re-calculated using an air exchange rate of 2/hr as part of the Uncertainty Analysis (Section 6.3).

Enclosed Space Floor Length and Width

For purposes of evaluating vapor intrusion into existing buildings, site-specific data will be used for the enclosed space floor length and width. For purposes of evaluating future buildings, neither EPA nor Cal-EPA provides recommended values for these parameters. The MDEQ does provide a recommended default value for the size of a hypothetical commercial building of 4,000 square feet (ft^2) or 372 square meters (m^2) (Michigan Environmental Science Board 2001). This value is based on data provided in a 1994 U.S. Department of Energy (DOE) report entitled *Commercial Building Characteristics 1992*, which documents the results of a Commercial Buildings Energy Consumption Survey. The most recent survey was completed in 2003 and the results were presented in a 2006 report issued by the U.S. Energy Information Administration (U.S. EIA 2006). The data presented in this report are similar to that presented in the 1994 DOE report in that the majority of commercial buildings (other than malls) are between 1,000 $feet^2$ and 5,000 $feet^2$ in size and a single story, regardless of region of the country. In addition, the reported median square footage (the metric used by MDEQ) for different categories of commercial buildings nationwide ranges from 3,000 ft^2 to 7,000 ft^2. For purposes of this assessment we propose to use a value of 2000 square centimeters (cm^2) for both the floor length and width, which is approximately equal to the default value of 4000 ft^2 (372 m^2) recommended by MDEQ.

Vapor Flow Rate Into Building (Soil Gas Advection Rate)

The vapor flow rate into a building (Q_{soil}) is a controversial input parameter in the J&E Model. As originally conceived, this value was calculated using a "perimeter crack model" by Nazaroff based on various site-specific or default values related to soil vapor permeability, pressure differentials, and size of cracks; however, a wide range of values can be predicted because of the model's sensitivity to estimates of soil vapor permeability (EPA 2004). Consequently, EPA provides a recommended "default" value for vapor flow rate into residential buildings, but not commercial buildings, in their J&E Model User's Guide (EPA 2004). The recommended default value is 5 L/m, which is based on empirical data collected in residences; however, such data for commercial buildings are lacking. Cal-EPA has adopted EPA's recommended default value for Q_{soil} for residential buildings. For commercial buildings, Cal-EPA recommends scaling the default residential value based on the size of the commercial building (e.g., if the commercial building is twice the size as the default residential building, then the Q_{soil} value is doubled (Cal-EPA 2005). For purposes of this HRA, the scaled Q_{soil} value (4×5 L/m or 20 L/m because the default commercial building size described above is 4-times the default residential building size) was conservatively used. To assess the uncertainty in this input parameter, the estimated excess cancer risks and non-cancer hazard indices were re-calculated using a calculated Q_{soil} based on site-specific assumptions as originally conceived in the J&E model.

References

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U.S. EIA. 2006. 2003 Commercial Buildings Energy Consumption Survey. Detailed Tables. U.S. Energy Information Administration, Washington, DC. http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html (accessed January 13, 2010).

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