

2. Appendix Y: Vapor Intrusion Modeling Requirements

(Appendix to Statewide health standard VI guidance in the *Technical Guidance Manual*)

DRAFT – FOR DISCUSSION PURPOSES ONLY

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The Department recommends the use of EPA’s Johnson & Ettinger model (U.S. EPA, 2004) for analyzing vapor intrusion under the Statewide health and site-specific standards. Remediators should use the Department’s versions of the model which are based on the advanced EPA version 3.1 spreadsheets. These versions are posted on the Department’s website, and they will be updated periodically with current toxicological parameter values when Ch. 250 MSCs are revised.

This section describes key assumptions and limitations of the J&E model, acceptable adjustments of default input values, and the use of alternative models for petroleum hydrocarbons.

2.1. Background

The Johnson & Ettinger (J&E) model solves for the transport of vapor-phase contaminants into a building above the source (Johnson and Ettinger, 1991; U.S. EPA, 2004). There are three spreadsheets for the different source types: groundwater, soil, and soil gas. The model calculates the vaporization of dissolved or adsorbed contaminants, the diffusion of these vapors toward the surface, their advection through the foundation or slab into the occupied space, and their dilution in indoor air. The calculations rely on five sets of parameters integral to this process and the inhalation risk assessment:

- source description (e.g., depth)
- chemical properties
- toxicological properties
- capillary and vadose zone properties (e.g., soil type)
- building characteristics (e.g., air exchange rate).

The J&E model is an approximation that is dependent on many parameters, not all of which are well known. It is not easily calibrated; therefore, the user should input conservative values to avoid underestimating inhalation risks. Users submitting J&E models to the Department must be familiar with EPA’s *User’s Guide* and must understand the model’s assumptions and limitations (U.S. EPA, 2004, Section 5).

Several studies have compared J&E model results to field data (Hers et al., 2003; Provoost et al., 2009, 2010) and to numerical analyses (Yao et al., 2011). This research indicates that J&E gives reasonable, conservative results in most cases, within about one order of magnitude. These studies reinforce the need to use J&E with caution because the model is highly sensitive to some parameters. It is essential to have adequate site data and a strong conceptual site model when modeling vapor intrusion.

The objective of vapor intrusion modeling is to determine if Act 2 standards are attained. Although the EPA spreadsheets can calculate screening values, models submitted to the

Department should not be used in this manner. Users must instead input contaminant concentrations on the “DATENTER” tab to calculate incremental risks. The Department versions give results in two forms.

- For Statewide health standard evaluations the user should compare the predicted indoor air concentration from the “RESULTS” tab to the SHS indoor air screening values (SV_{IA}) (Section II.B.6. Table 4).
- For site-specific standard risk assessments the user obtains the incremental carcinogenic and noncarcinogenic inhalation risks from the “RESULTS” tab, determines the cumulative risks for all SSS contaminants of concern, and compares the cumulative risks to the Act 2 thresholds (Title 25 Pa. Code Section 250.402(b)).

Input contaminant concentrations should generally be the maximum from recent data in the vicinity of current or potential future buildings. This data may have been collected for site characterization and/or the demonstration of attainment. The soil gas model should be used with near-source soil gas data.

2.2. Assumptions

Users are referred to EPA’s J&E *User’s Guide* for a complete description of the model (U.S. EPA, 2004). It has several critical assumptions and limitations that all users must be aware of.

- The source extent is horizontally and vertically infinite. Source mass does not diminish with time. These are conservative assumptions.
- No non-aqueous phase liquid (NAPL) is present.
- The solution is one-dimensional, meaning that lateral transport of vapors is ignored.
- Soil properties are homogeneous.
- There is no biodegradation of contaminant vapors in the vadose zone, a conservative assumption.
- There are no preferential pathways between the source and the building.
- The system is in steady state; that is, vapor transport is in equilibrium.
- The model does not account for the combined effects of multiple contaminants.
- The risk calculations do not account for mutagenic effects.

In addition, see U.S. EPA (2004) Sections 2.11 and 5.

2.3. Parameter Adjustments

Key input parameters and allowable changes to these values are explained in this section. The Department’s conservative default model parameter values, as input on the “DATENTER” tab of the J&E spreadsheet, are given in Table Y-1. Most input values used are EPA’s defaults.

- **Depth below grade to source** (L_{WT} , L_t , L_s): The default value is 5 feet (150 cm). The user may enter the actual minimum depth based on the site characterization and/or monitoring. For groundwater it should be the seasonally high water table depth of the contaminated aquifer

(L_{WT}). For soil it should be the depth of the shallowest contaminated soil (L_t). (The model also permits a finite source calculation if the depth to the bottom of the contaminated soil is delineated (L_b).) For soil gas it is the depth of the top of the screen in the soil gas probe (L_s).

Where there is a basement, the source must be entirely below the foundation as J&E does not model lateral transport. Contaminated soil or groundwater must not be in contact with the foundation. J&E simulates vapor diffusion through homogeneous, isotropic porous media. Therefore, it cannot determine vapor migration through fractured bedrock. If the water table is below the bedrock interface, then the source depth should be input as the depth to bedrock. Soil must be present between the bedrock surface and the building foundation.

- **Soil/groundwater temperature (T_s):** The Department's default value for the average temperature is 11°C. This may only be changed if sufficient seasonal subsurface temperature data is collected at the site.
- **Soil type:** It is the user's responsibility to assess soil boring logs to select an appropriate soil type for input to the model. Field logging of borings must be performed by a qualified environmental professional. Where the soil is heterogeneous or there are different interpretations of the soil type, professional judgment must be used, but the best practice is to select the soil type with the greatest vapor intrusion potential. This may require sensitivity testing of the model. The default entry in the Department's model versions is a loamy sand as a conservative extreme.

EPA categorized soil using the U.S. Department of Agriculture's Soil Conservation Service (now the Natural Resources Conservation Service) soil types. Field logs using the Unified Soil Classification System (ASTM D 2487) must be interpreted in terms of the SCS classifications. A gradation analysis of soil samples is the best means to select the proper soil type in J&E (ASTM D 6913). Table Y-2 can also assist the user with this selection, and Figure Y-1 shows the SCS soil types in terms of the proportions of clay, silt, and sand.

- **Soil properties:** The Department has adopted the EPA default values for bulk soil density (ρ_b) and total porosity (n), which depend on the soil type. These values should not be altered unless properly collected samples have been analyzed for these parameters. The Department does not consider the EPA default water-filled porosity values (θ_w) to be sufficiently conservative because soil beneath buildings is relatively dry. The Department's default value is 0.1 or the residual saturation (θ_r), whichever is greater for the soil type. The user can change θ_w only based on lab analyses of the moisture content of properly collected soil samples collected under the building. The user may define up to three soil layers in the model if sufficient data has been obtained to support this option.
- **Fraction of organic carbon (f_{oc}):** The default value is 0.0025 from EPA and Title 25 Pa. Code Section 250.308(a). The user may change this value for soil modeling only if f_{oc} is measured for site soils by a laboratory.
- **Building foundation:** The default foundation type is slab-on-grade construction. This choice establishes the value of the depth below grade of the enclosed space floor (L_F) and the enclosed

space height (H_B). For slab-on-grade foundations the EPA defaults are $L_F = 15$ cm and $H_B = 244$ cm; for basements they are $L_F = 200$ cm and $H_B = 366$ cm. These values may be altered with supporting documentation for the site building.

- **Building dimensions** (L_B, W_B): The EPA default residential floor space area is 1080 ft^2 (100 m^2) for a 10- by 10-m home. Site-specific analyses may use the actual (or planned) building dimensions.
- **Floor thickness** (L_{crack}): The EPA default value is 10 cm. This may be changed by the user if the actual slab thickness is known.
- **Air exchange rate** (ER): Air exchange rates exhibit a large range for different buildings and seasons. EPA's residential default value was 0.25 hr^{-1} . The Department adopts the current 10th percentile figure of 0.18 hr^{-1} (U.S. EPA, 2011, Ch. 19). The measured range in a study of 100 office buildings was approximately 0.2–4.5 per hour (Persily and Gorfain, 2009). A 10th percentile nonresidential value is 0.60 hr^{-1} (U.S. EPA, 2011, Ch. 19). The user should input these 10th-percentile values for residential and nonresidential buildings. The actual air exchange rate of an existing or planned building may be input to a site-specific model if it has been measured or is documented in the HVAC system design and settings.
- **Vapor flow rate** (Q_{soil}): The soil gas flow rate into buildings is highly uncertain, and it depends on the material in contact with the foundation, the arrangement of cracks and other foundation openings, the pressure differential, and other factors. The EPA default value is 5 L/min based on tracer gas studies at five sites summarized by Hers *et al.* (2003). In the absence of better information on this parameter, the Department requires at least 5 L/min for site-specific modeling, and this input field should generally not be blank. If the user changes the building dimensions (L_B and W_B) then the value of Q_{soil} should be scaled correspondingly. Assuming foundation perimeter cracks, the scale factor is the ratio of the building perimeters. The default perimeter for the 10- by 10-m building is 40 m (130 ft). For example, if the building dimensions are 50 ft by 100 ft, the perimeter is 300 ft, the scale factor is 2.3, and $Q_{\text{soil}} = 11.5 \text{ L/min}$.

The J&E model will calculate an estimated Q_{soil} rate if this field is left blank. The calculation will depend on the permeability of the soil in contact with the foundation. Most buildings are assumed to have a relatively coarse-grained material beneath the foundation, and the 5 L/min value is appropriate. If the user has detailed knowledge of the native soil type that is present beneath and in contact with the foundation, this soil type may be entered in the "Soil stratum A SCS soil type (used to estimate soil vapor permeability)" field and the Q_{soil} field may be left blank. The report must justify this step with descriptions of soil samples collected from beneath the foundation and described by an environmental professional.

A third option is to enter a soil vapor permeability and allow the model to calculate Q_{soil} . This is permitted only if the user performs vapor permeability testing of the soil in contact with the foundation.

- **Pressure differential (ΔP):** The pressure differential only affects the model calculation of Q_{soil} . EPA's default residential value is 4 Pa (40 g/cm-s²). The ventilation system design of commercial buildings typically results in less under-pressurization than in homes (Hers *et al.*, 2001). The Department allows a value of 2 Pa (20 g/cm-s²) for the nonresidential modeling. If the remediator can document the actual or planned ventilation system design for a building, that information may be used in a site-specific model.
- **Crack width (w):** The crack width only affects the model calculation of Q_{soil} . EPA's default value is 0.1 cm. This value may be changed only with a documented study of the foundation cracks in the modeled building.

Chemical, physical, and toxicological properties for substances with vapor intrusion potential are found in the "VLOOKUP" tab of the J&E spreadsheet. The Department's default values are listed in Table X-5. The user should not change these parameters, with rare exceptions described below.

- **Organic carbon partition coefficient (K_{oc}):** The default values are from Title 25 Pa. Code Ch. 250, Appendix A, Table 5A. The values may be changed only if the user undertakes laboratory testing of soil samples collected at the site.
- **Toxicity parameters (IUR , RfC_i):** The inhalation unit risk (or unit risk factor, URF) and the inhalation reference concentration are from Title 25 Pa. Code Ch. 250, Appendix A, Table 5A. They must be used for Statewide health standard modeling. For a site-specific standard risk assessment, the user should determine if there is more recent toxicity information available. Current values should be substituted for the Ch. 250 values.

Exposure factors are entered on the "DATENTER" tab of the J&E spreadsheet for site-specific standard risk assessments. The default values are listed in Table Y-3. Residential factors should not be changed. The user may adjust nonresidential factors based on conditions at the site. For instance, the daily exposure time could depend on the workplace shift length. EPA currently recommends a residential exposure duration of 26 yr (U.S. EPA, 2014), and this may be changed under the site-specific standard. (Model-predicted indoor air concentrations for the Statewide health standard do not depend on the exposure factors on the "DATENTER" tab.)

EPA's J&E spreadsheets do not allow for the input of the exposure time (ET). All calculations are performed for a fixed ET = 24 hr/day. For nonresidential models the user may make a proportional adjustment to the exposure frequency (EF). For example, to calculate risks for ET = 8 hr/day, the user should enter EF = 83 day/yr. Any such adjustments must be explained in the report.

2.4. Petroleum Hydrocarbons

The Department can accept the use of models that account for biodegradation when evaluating petroleum hydrocarbon vapor intrusion. An example is the American Petroleum Institute's BioVapor (API, 2010).

BioVapor has several additional parameters that must be assessed in the modeling. The user should test the model sensitivity to these values.

- **Oxygen boundary condition:** The user should normally select a constant air flow rate (Q_f), and this is typically set equal to the vapor flow rate through the foundation (e.g., $Q_{soil} = 5$ L/min). If site data is collected to determine vertical profiles of oxygen, carbon dioxide, and methane concentrations, then the user may estimate the depth of the aerobic zone for model input.
- **Baseline soil oxygen respiration rate:** The model scales this rate with the fraction of organic carbon (f_{oc}), which is not typically known for the site.
- **Biodegradation rate constants (k_w):** BioVapor selects default first-order, aqueous phase, aerobic decay rates. Actual degradation rates are extremely variable. Vertical profiling of contaminant concentrations in soil gas may allow the user to estimate the decay rates.

2.5. Attenuation Factor Risk Calculations

Site-specific standard risk assessments may also be performed with groundwater, soil, near-source soil gas, and sub-slab soil gas data by using conservative attenuation factors (α). An attenuation factor is the ratio between the contaminant concentration in indoor air and the equilibrium soil gas concentration in the medium ($\alpha \equiv C_{IA}/C_{SG}$). Therefore, conservative indoor air concentrations may be estimated using a measured or calculated soil gas concentration and an appropriate attenuation factor. Refer to Appendix X for the relevant equations and Table X-4 for the Department's default attenuation factors.

Other attenuation factors may be used with adequate justification for the site-specific standard. For instance, a tracer test could be used to determine a sub-slab attenuation factor (α_{SS}) for the building. The default attenuation factors may be scaled with actual air exchange rates (AER) for the building. The Department's default indoor air exchange rates are 0.18 hr^{-1} for residential properties and 0.60 hr^{-1} for nonresidential facilities. The adjusted attenuation factor (α') is the product of the default attenuation factor and the ratio of the default AER and the actual AER. For example, if a nonresidential building has a measured air exchange rate of 1.2 hr^{-1} , then the sub-slab attenuation factor may be reduced as follows:

$$\alpha'_{SS,NR} = \alpha_{SS,NR} \frac{0.60 \text{ hr}^{-1}}{1.2 \text{ hr}^{-1}} = (0.0078) \frac{0.60 \text{ hr}^{-1}}{1.2 \text{ hr}^{-1}} = 0.0039$$

2.6. References

American Petroleum Institute (API), 2010, *BioVapor Users Manual*, Washington, DC.

<http://www.api.org/environment-health-and-safety/clean-water/ground-water/vapor-intrusion/biovapor-form>

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Table Y-1. Adjustable Johnson & Ettinger model input parameters and default values

Parameter	Symbol	Residential	Nonresidential
Average soil/groundwater temperature (°C)	T _s	11	11
Depth below grade to bottom of enclosed space floor (cm)	L _F	15	15
Depth below grade to source (cm)	L _{WT} , L _t	150	150
Thickness of soil strata (cm)	h	150	150
Capillary and vadose zone USDA SCS soil types		SL*	SL*
Soil dry bulk density (g/cm ³)	ρ _b	1.62	1.62
Soil total porosity	n	0.390	0.390
Soil water-filled porosity	θ _w	0.1	0.1
Enclosed space floor thickness (cm)	L _{crack}	10	10
Soil–building pressure differential (g/cm-s ²)	ΔP	40	20
Enclosed space floor length (cm)	L _B	1000	1000
Enclosed space floor width (cm)	W _B	1000	1000
Enclosed space height (cm)	H _B	244	244
Floor–wall seam crack width (cm)	w	0.1	0.1
Indoor air exchange rate (hr ⁻¹)	ER	0.18	0.60
Average vapor flow rate into building (L/min)	Q _{soil}	5	5

* sandy loam

Table Y-2. Guidance for the selection of the J&E model soil type

Predominant Soil Types in Boring Logs	Recommended Soil Classification
• Sand or Gravel or Sand and Gravel, with less than about 12% fines, where “fines” are smaller than 0.075 mm in size.	Sand
• Sand or Silty Sand, with about 12% to 25% fines	Loamy Sand
• Silty Sand, with about 20% to 50% fines	Sandy Loam
• Silt and Sand or Silty Sand or Clayey, Silty Sand or Sandy Silt or Clayey, Sandy Silt, with about 45 to 75% fines	Loam
• Sandy Silt or Silt, with about 50 to 85% fines	Silt Loam

Source: U.S. EPA (2004, Table 11)

Table Y-3. J&E model default exposure factors

Symbol	Term	Residential	Nonresidential
AT _{nc}	Averaging Time for systemic toxicants (yr)	30	25
ET	Exposure Time (hr/day)	24	8
EF	Exposure Frequency (days/yr)	350	250
ED	Exposure Duration (yr)	30	25
AT _c	Averaging Time for carcinogens (yr)	70	70

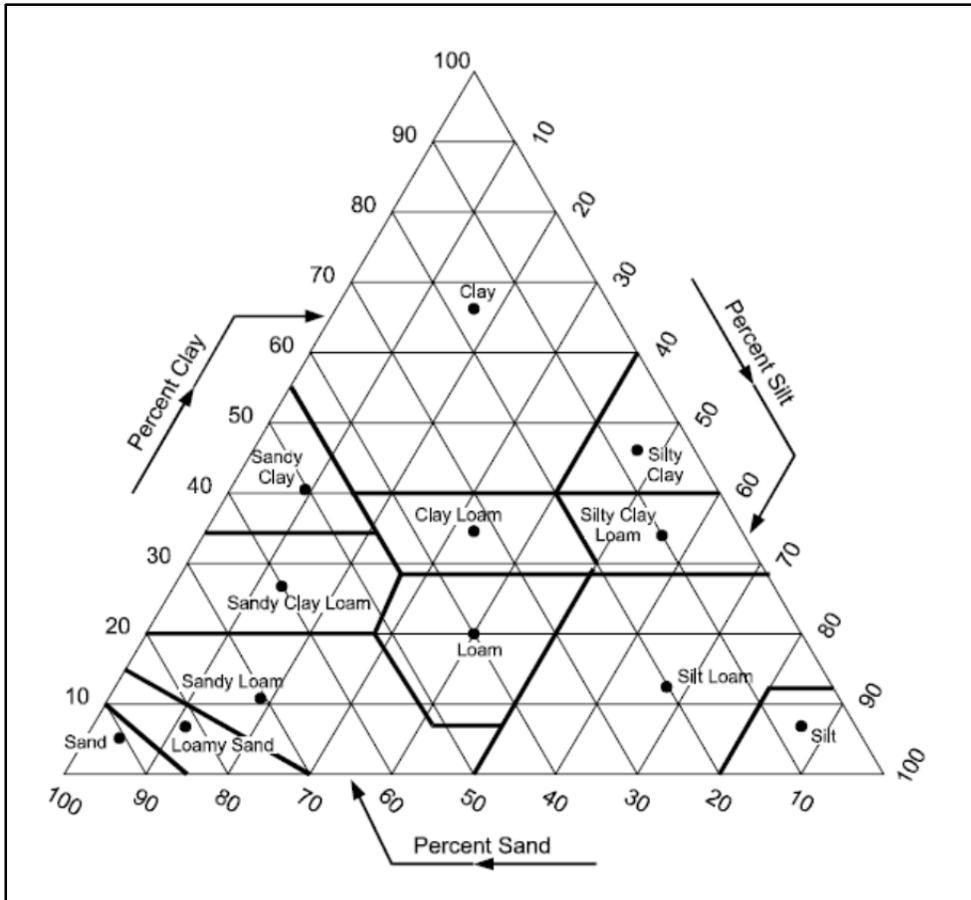


Figure Y-1. USDA SCS soil classification chart.