JOHNSON AND ETTINGER MODEL FACT SHEET

Introduction

This fact sheet provides an overview of a Microsoft Excel–based spreadsheet tool for implementation of the Johnson and Ettinger (J&E) vapor intrusion model (Johnson and Ettinger 1991). As noted in the recent **Summary of State Vapor Intrusion Practices (Appendix A)**, the U.S. Environmental Protection Agency (USEPA) spreadsheet version of the J&E model is the most commonly used screening-level model for estimating chemical concentrations in indoor air. With input of the concentrations in a subsurface vapor source (soil vapor or groundwater), the model estimates the associated indoor air concentrations. The USEPA J&E model is a one-dimensional deterministic model with single-point inputs and outputs. It is based on the basic principles of contaminant fate and transport, contaminant partitioning between media, and the physical and chemical properties of the contaminants themselves. The model incorporates both diffusion and advection as mechanisms of transport of subsurface soil vapor into the indoor air environment. Diffusion is the dominant mechanism for vapor transport within the vadose zone. Once the soil vapor enters into the "building zone of influence," the soil vapor migrates into the building through foundation cracks by diffusion and advection due to the indoor–outdoor building pressure differential. The distance of the building zone of influence is usually less than a few feet. The J&E model does not account for the degradation of biodegradable compounds (e.g., many petroleum hydrocarbons), and biodegradation models such as BioVapor (**BioVapor Model Fact Sheet**; **Appendix H**) may be used in those cases.

The Excel-based J&E model was initially developed by the USEPA in 1995 and included additional risk calculations as well as default parameter values for model inputs. The Excel spreadsheet has gone through several revisions by USEPA and state agencies (e.g., California Department of Toxic Substances Control [DTSC]) since its initial release. In 2017, USEPA released an updated Excel workbook (Version 6.0; (Version 6.0; USEPA 2017) with several enhancements from previous versions, including additions for evaluation of multiple chemicals simultaneously, evaluation of model uncertainties, and description of rate-limiting steps / key parameters influencing vapor intrusion for the specified model scenario and inputs. The updated workbook also displays a plot to compare the modeled soil vapor concentration profile with measured concentrations by depth. Several programming errors were subsequently identified in the 2017 USEPA spreadsheet tool, which limited its use. Recently, California DTSC released a modified J&E model spreadsheet to address the programming errors and to include options for an alternate capillary fringe model (for a groundwater source) and use of California-specific toxicity values and building parameters (DTSC 2024).

Model Assumptions and Limitations

The J&E model is a one-dimensional analytical solution to convective and diffusive vapor transport into indoor spaces and provides an estimated attenuation factor that relates the vapor concentration in the indoor space to the vapor concentration at the source of contamination. It uses the conservation-of-mass principle and is based on the following key assumptions (USEPA 2017):

- Steady state conditions exist.
- An infinite source of contamination exists.
- Air mixing in the building is uniform.
- Biodegradation of soil vapor does not occur.

- Contaminants are homogeneously distributed laterally beneath the building.
- Contaminant vapors enter a building primarily through cracks in the foundation and walls.
- Buildings are constructed on slabs or with basements and/or closed crawl spaces.
- Ventilation rates and soil vapor flow into the building are assumed to remain constant.

The USEPA J&E model is most suitable under homogeneous site conditions with uniform building construction features. Conversely, the model cannot evaluate the following conditions:

- Significant preferential pathways
- Substantial lateral transport of soil vapor
- Fractured-bedrock conditions
- Very shallow groundwater or wet basements
- Large buildings with localized sources of vapors beneath them
- Contaminant transport through bulk foundation materials (e.g., concrete)

A detailed list of relevant assumptions and the associated implications and field interpretation is presented in Table 4 of the USEPA User's Guide (USEPA 2017).

Model Inputs/Outputs

Inputs to the J&E model include chemical properties of the contaminant, saturated and unsaturated zone soil properties, and structural properties of the building. The latest USEPA and DTSC implementation in an Excel workbook also includes contaminant toxicity values and exposure parameters for estimating incremental cancer risks and hazard quotients based on soil vapor or groundwater concentrations as well as risk-based target concentrations given a user-defined target cancer risk and noncancer hazard level. **Table 1** provides a list of the various worksheets in the Excel workbook and their contents, and **Appendix I** includes the screenshots of key model inputs and outputs in the workbook. Detailed technical information and model instructions can be found in the user's guides for the model (DTSC 2024; USEPA 2017).

Table 2 lists key input parameters in the J&E model and their effects on predicted attenuation factor and indoor air concentration in most cases. The **Model Sensitivity Analysis Fact Sheet** provides additional information on how to assess the sensitivity and uncertainty of model input parameters on predicted model results.

Key J&E model outputs include chemical-specific attenuation factor, predicted indoor air concentration, predicted sub-slab vapor concentration, effective diffusion coefficients, critical parameters controlling vapor transport through soil and across building foundation, dominant mechanism for overall rate-limiting process, and a plot to compare the modeled soil vapor concentration profile with measured data by depth. **Figure 1** illustrates the first part of the "Model Output" section in the USEPA J&E model spreadsheet that presents the information on these outputs.

Table 1. Worksheets in the J&E model workbook.

Worksheet Title	Purpose	Content
README	Spreadsheet information*	Key spreadsheet information (e.g., contacts, content)
MODEL	Model input and output[†] (single chemical)	Primary model input worksheet
MEASURED_SOIL_GAS_CONC	Data entry and model output	Data entry and plot for comparison of measured and modeled soil vapor concentrations
MULTI_CHEM_INPUT	Model input (multiple chemicals)	Data entry to run J&E model for multiple chemicals
MULTI_CHEM_OUTPUT	Model output (multiple chemicals)	Model output for multiple chemical modeling
Converter	Data entry	Convert data entries from English to metric units
BLDG_DATA	Lookup table*	Lookup table of building parameters
CHEM_DATA	Lookup table*	Lookup table of chemical properties and toxicity values
EXPOSURE_DATA	Lookup table*	Lookup table of exposure parameters used for risk calculations
SOIL_DATA	Lookup table*	Lookup table of soil property parameters (e.g., porosity, moisture content)
ParametersSummary	Imported table*	Chemical properties table (from USEPA RSLs)
ToxSummary	Imported table*	Toxicity values table (from USEPA Regional Screening Levels and DTSC Human Health Risk Assessment Note 10)
SOIL_CV_DATA	Reference information*	Table of coefficients of variance for soil properties
Reference Sources	Reference information*	Reference list for default values, ranges, and coefficients of variance values
Version Notes	Spreadsheet information*	Summary of spreadsheet modifications and changes

*These worksheets contain spreadsheet information, references, and lookup tables that are used to populate defaults and ranges for model inputs and should not be modified by the user.

[†] Input cells are highlighted in yellow and output cells are highlighted in blue on the Model tab. Other model inputs (i.e., dotted outline cells) may also be modified on a site-specific basis.

Source: Modified from Table 1 in DTSC (2024).

Table 2. Key input parameters in J&E model.

Section	Input Parameter	Effect on Predicted Indoor Air Concentration (with Increase in Input Parameter Value)
Source Characteristics	Source medium (sub-slab soil vapor, exterior soil vapor, or groundwater)	Not applicable
	Source concentration	Increase
	Source depth	Decrease
	Average temperature	Increase (groundwater source only)
Contaminant Information	Chemical properties	Various
	Toxicity factors	No effect (for calculation of risk/hazard)
Building Characteristics	Building setting (residential vs. commercial)	Changes in default building parameters
	Foundation type (slab on grade, basement, or crawl space)	Changes in default building parameters
	Building volume (floor area × height)	Decrease
	Air exchange rate	Decrease
	$Q_{soil}/Q_{building}$*	Increase or little effect (advection is not a rate-limiting process)
Vadose Zone Characteristics†	Soil type‡	Changes in default soil properties
	Stratum thickness	Various (depending on soil type/properties)
	Soil total porosity	Increase
	Soil water-filled porosity	Decrease
	Soil bulk density	Decrease (due to decrease in total soil porosity)
Exposure Parameters	Target risk and hazard	No effect (for calculation of risk-based target concentrations)
	Exposure scenario (residential vs. commercial)	No effect (changes in default exposure parameters for risk calculations)

*The ratio of the average vapor flow rate into the building (Q_{soil}) and the building ventilation rate ($Q_{building}$) (see **Appendix I** for additional discussion).
† Up to three soil layers/strata can be entered, and the sum of individual layer thicknesses must equal the source depth entered in the Source Characteristics section.
‡ Twelve U.S. Department of Agriculture Soil Conservation Service Soil Textural Classifications (USEPA 2017).

Model Output Site Name/Run Number: DTSC J&E Case

Chemical Name: Trichloroethylene CAS No. 79-01-6

Range is based on the reasonable range of Qsoil/Qbuilding values, as reported in the literature.

Source to Indoor Air Attenuation Factor	Units	Symbol	Value	Range	Default	Default Range	Flag
Groundwater to indoor air attenuation coefficient	(-)	alpha	3.7E-04	8.5E-05 - 4.1E-04	3.7E-04	8.5E-05 - 4.1E-04	

Predicted Indoor Air Concentration	Units	Symbol	Value	Range	Default	Default Range	Flag
Indoor air concentration due to vapor intrusion	(ug/m3)	Cia	1.2E-01	2.7E-02 - 1.3E-01	1.2E-01	2.7E-02 - 1.3E-01	
	(ppbv)		2.2E-02	5.1E-03 - 2.5E-02	2.2E-02	5.1E-03 - 2.5E-02	

Predicted Vapor Conc. Beneath Foundation	Units	Symbol	Value	Range	Default	Default Range	Flag
Subslab vapor concentration	(ug/m3)	Css	3.9E+01	2.7E+00 - 2.7E+02	3.9E+01	2.7E+02 - 1.3E+03	
	(ppbv)		7.3E+00	4.9E-01 - 5.1E+01	7.3E+00	5.1E+01 - 2.5E+02	

Diffusive Transport Upward Through Vadose Zone	Units	Symbol	Value	Range	Default	Default Range	Flag
Effective diffusion coefficient through Stratum A	(cm2/sec)	DeffA	1.1E-02	-	1.1E-02	-	
Effective diffusion coefficient through Stratum B	(cm2/sec)	DeffB		-		-	
Effective diffusion coefficient through Stratum C	(cm2/sec)	DeffC		-		-	
Effective diffusion coefficient through capillary zone	(cm2/sec)	DeffCZ	4.4E-04	-	4.4E-04	-	
Effective diffusion coefficient through unsaturated zone	(cm2/sec)	DeffT	6.0E-03	-	6.0E-03	-	

Critical Parameters		Symbol	Value	Range	Default	Default Range	Flag
α for diffusive transport from source to building with dirt floor foundation	(-)	A_Param	4.2E-04	-	4.2E-04		
Pe (Peclet Number) for transport through the foundation (advection / diffusion)	(-)	B_Param	8.0E+01	2.7E+00 - 1.3E+03	8.0E+01	2.7E+00 - 1.3E+03	
α for convective transport from subslab to building	(-)	C_Param	3.0E-03	1.0E-04 - 5.0E-02	3.0E-03	1.0E-04 - 5.0E-02	

Interpretation

Advection is the dominant mechanism across the foundation.
Diffusion through soil and advection through foundation both control intrusion.

Critical Parameters

Hb, Ls, DeffT, ach, Qsoil_Qb

Non-Critical Parameters

Lf, DeffA, eta

The Soil Gas Profile Plot has been moved to "MEASURED_SOIL_GAS_CONC." tab for side-by-side comparison.

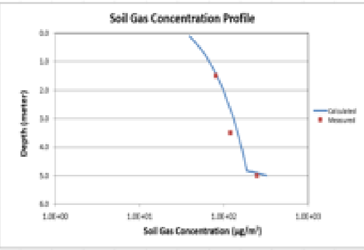

Figure 1. Model output in J&E model spreadsheet.

Source: USEPA (2017).

The rest of the Model Output section includes the calculations of cancer risk and noncancer hazard estimates (forward calculations) as well as the risk-based target concentrations (inverse or backward calculations). **Chapter 8** provides discussions on how these calculations are used for vapor intrusion data evaluation and risk assessment.

Considerations for Johnson and Ettinger Model Use

Prior to using the J&E model, a vapor intrusion (VI) conceptual site model (CSM) for the vapor intrusion pathway should be developed (see **Chapter 4** on construction of a robust VI CSM). For modeling purposes, the VI CSM should include the following items relevant to set up of the model (i.e., input parameters in **Table 2**) and interpretation of results (DTSC 2024; USEPA 2017):

- Source characteristics: media of concern (sub-slab soil vapor, exterior soil vapor, or groundwater), chemicals of concern and their concentrations, and sample depth
- Subsurface conditions: geology and stratigraphy, associated soil type(s)/properties (up to three horizontal layers), and depth to groundwater (for a groundwater source)
- Building characteristics: building/foundation type, building parameters (dimensions, air exchange rate, etc.), and other building conditions (e.g., if vapor conduits or preferential pathways exist)

Other site-specific conditions should also be considered as they may affect the applications of the J&E model. For example, paving and construction of buildings can cause a "capping effect," potentially resulting in the soil vapor directly beneath the floor higher than that adjacent to the building (USEPA 2012). The properties of asphalt or concrete slabs, and that of adjacent soil, may affect gas transport (both air/vapors), and potentially the vapor regime. Site development and transient conditions can also alter soil moisture (e.g., irrigation and water from broken water pipes) which will likely reduce vapor migration.

While the J&E model does not capture all complexities of a particular site and some scientific judgment is often required when selecting model inputs, appropriate modeling scenarios can be constructed to provide a conservative assessment of the vapor intrusion pathway in many cases. The model can be used to generate a range of outcomes by focusing on key model input parameters to assess the sensitivity and uncertainty in the model (see the **Model Sensitivity Analysis Fact Sheet**). In addition, a comparison of modeling results with empirical data is recommended to provide greater confidence in the modeling predictions. When suitably constructed and used together with other site-specific lines of evidence (see the **Multiple Lines of Evidence Fact Sheet**), mathematical modeling can be used in the data evaluation and risk assessment (**Chapter 8**) to support decision-making.

REFERENCES

DTSC. 2024. “User’s Guide — DTSC Implementation of the Johnson and Ettinger Model to Evaluate Vapor Intrusion into Buildings.” California Department of Toxic Substances Control, October. **https://dtsc.ca.gov/wp-content/uploads/sites/31/2024/11/DTSC-JEM-User-Guide_2024-October.pdf**.

Johnson, Paul C., and Robert A. Ettinger. 1991. “Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings.” *Environmental Science & Technology* 25 (8): 1445–52. **https://doi.org/10.1021/es00020a013**.

USEPA. 2012. "EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation, Factors for Chlorinated Volatile Organic Compounds and Residential Buildings." March 16. https://www.epa.gov/sites/default/files/2015-09/documents/oswer_2010_database_report_03-16-2012_final_witherratum_508.pdf.

USEPA. 2017. "Documentation for EPA's Implementation of the Johnson and Ettinger Model to Evaluate Site Specific Vapor Intrusion into Buildings Version 6.0." Office of Superfund Remediation and Technology Innovation. https://semspub.epa.gov/work/HQ/100000489.pdf.