United States Environmental Protection Agency

Evaluation of the BioVapor Model

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INTRODUCTION

BioVapor

BioVapor is a one-dimensional model for improving understanding of the impacts of petroleum products on indoor air concentrations. The model includes a steady-state vapor source, diffusion-dominated soil vapor transport, a homogeneous soil layer, and transport across a building foundation and subsequent mixing in indoor air (GSI, 2010). The soil layer is divided into an aerobic zone which is supplied with oxygen from the atmosphere and an anaerobic zone where biodegradation of petroleum hydrocarbons consumes all available oxygen. BioVapor accounts for multiple constituents of gasoline and native respiration to recognize that oxygen is used to degrade all species present, not just the target compound. The model is limited, however, in that it does not account for geometric effects, heterogeneous formations or transient fluxes.

The Nature of Environmental Models

All mechanistic environmental models consist of two parts: relationships between variables which are based on principles of transport and transformation and empirical data which characterize the relationships. A familiar example is Darcy's Law which relates the flow of ground water to the negative of the head gradient. The proportionality constant between these two is the hydraulic conductivity which can range over 13 orders of magnitude in natural systems. Knowing Darcy's Law isn't enough to determine the ground water flow rate; the value of the coefficient must also be known (Figure 1, Table 1).

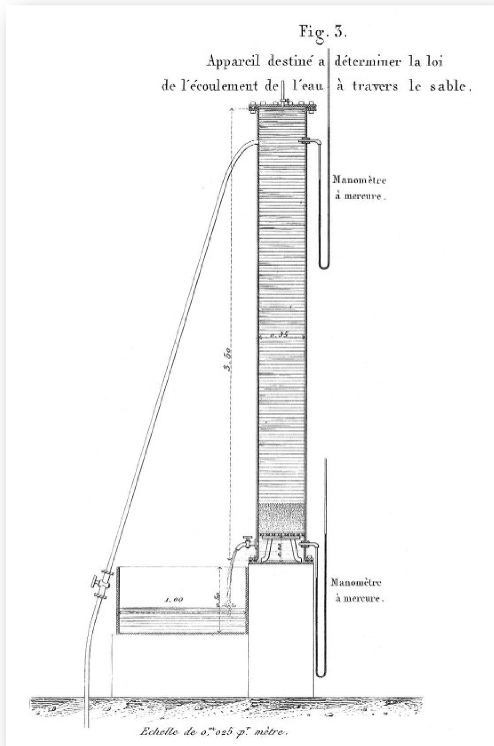

Figure 1. Darcy's original apparatus.

Table 1. Illustrative values of hydraulic conductivity.

Material	Value (m/d)
Gravel	10^{2} to 10^{4}
Sand	10^{-1} to 10^{3}
Clay	10^{-8} to 10^{-3}
Sandstone	10^{-5} to 10
Basalt	10^{-6} to 10^{-2}

Subsurface model inputs are typically uncertain. Site characterization typically provides a relatively small number of measured parameter values which do not definitively represent the geologic variability normally present in the subsurface. Naomi Oreskes from the University of California at San Diego (Oreskes, 2003) suggests that weather forecasts are good examples of the use of models and observed data, because the forecast is presented with uncertainty. Further, as consumers, we accept the forecast with that uncertainty (Figure 2).

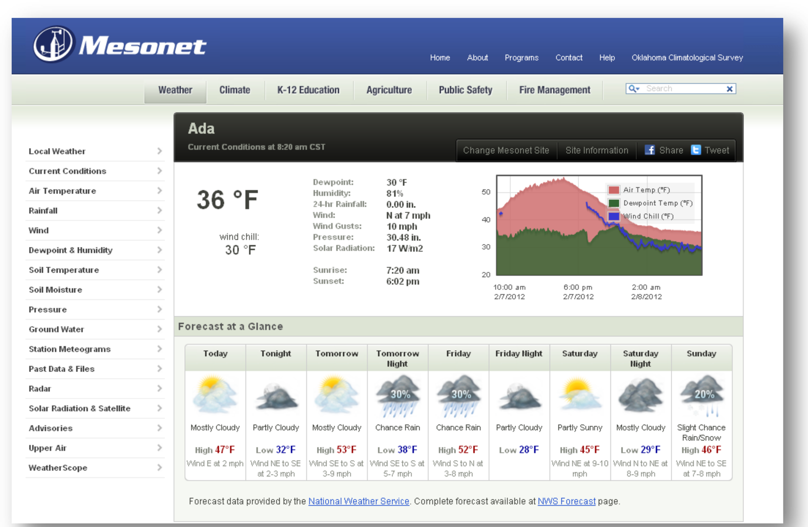

Figure 2. Weather forecast example.

Similar ideas are expressed in the BioVapor User's Guide:

"Some required or optional model inputs parameters such as oxygen concentration below the building foundation and baseline soil oxygen respiration rate are not commonly measured during site investigation. …the user should conduct a sensitivity analysis in order to evaluate the effect of input parameter value uncertainty on the model results"

"…the user should consider the uncertainty associated with the model inputs, …"

"…along with the potential effects of spatial and temporal variability."

PARAMETER VARIABILITY IN BIOVAPOR SIMULATIONS

A set of simulations was constructed based on a hot source defined by DeVaull (2007) in Table 2. The source was placed at various depths below the foundation and other parameters were varied as in Table 3. In each of the following examples profiles of oxygen are plotted alongside benzene profiles.

Table 2. Hot source definition from DeVaull (2007).

Benzene, 10800	EC >5-6 aliphatic 553000
Toluene, 14700	EC >6-7 aliphatic 78200
Ethyl benzene, 980	EC >7-8 aliphatic 11600
Xylenes, 3760	EC >8-9 aliphatic 2360
EC >8-9 Aromatic, 117	
EC >9-10 Aromatic, 1140	
EC >10-11 Aromatic, 12.5	
Napthalene, 1.4	

Table 3. Base case and parameter variations.

Parameter	Values	Base Case
Source	Table 1 and 1/100 of values	Hot Source
Depth	10 cm to 2000 cm	100 cm
Oxygen at foundation	0.02 mg/m³ to 0.28 mg/m³	0.20 mg/m³
Degradation rates (aromatics)	0.79/hr to 0.0079/hr	0.79/hr
Degradation rates (aliphatics)	71/hr and 7.1/hr	71/hr
Moisture Content Porosity = 0.35	0.05 to 0.02	0.20
Air Exchange Rate	0.1/hr, to 1.5/hr	0.25/hr

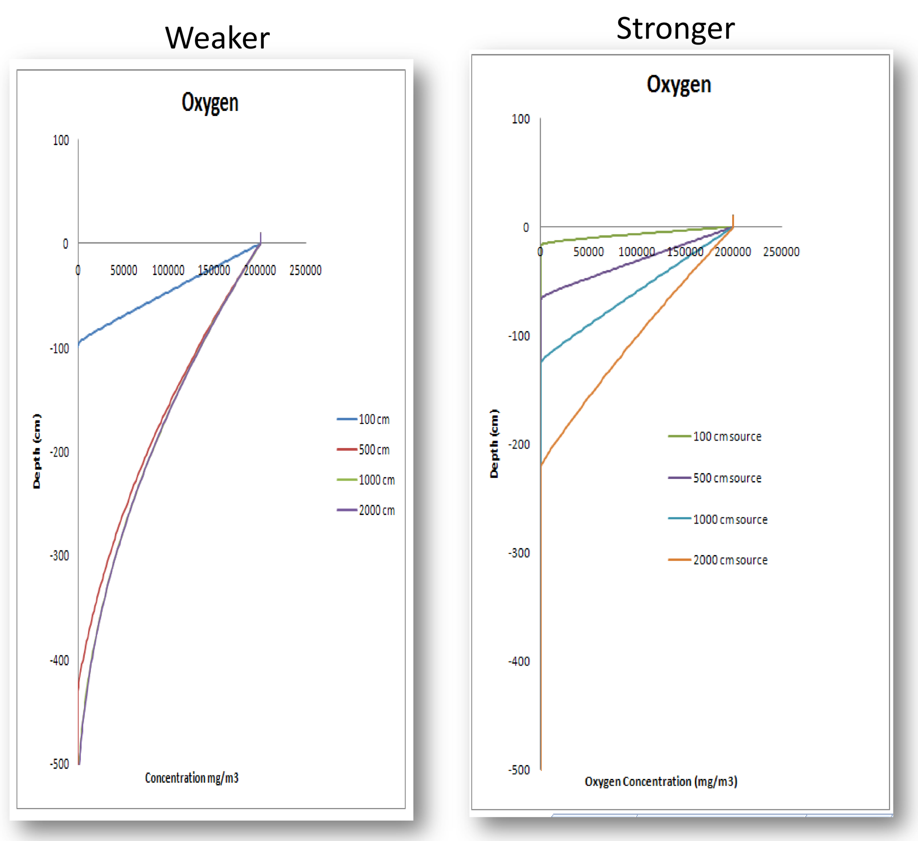

Figure 3. Oxygen profiles for the weaker (left) and stronger (right) sources. Oxygen penetrates deeper into the weaker source case because a lower demand is exerted from degradation. Within each figure deeper oxygen penetration occurs with increasing depth of the source.

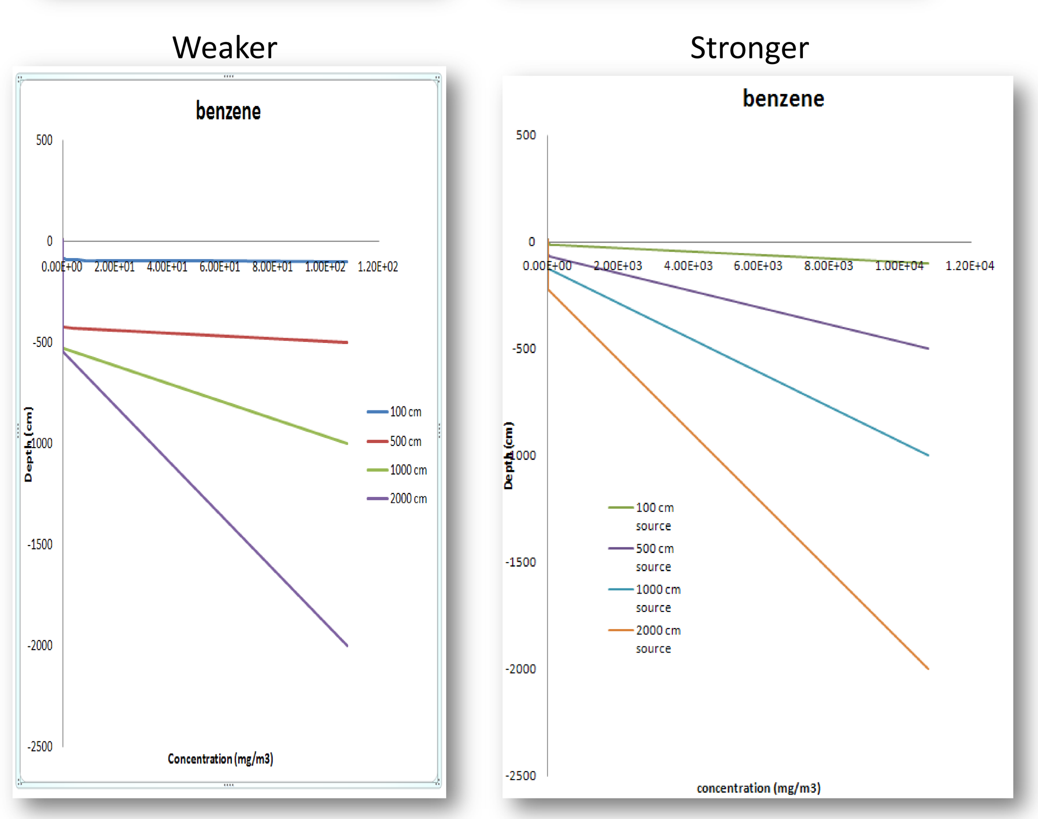

Figure 4. Benzene profiles for the weaker (left) and stronger (right) sources. Very low concentrations result for the weak source.

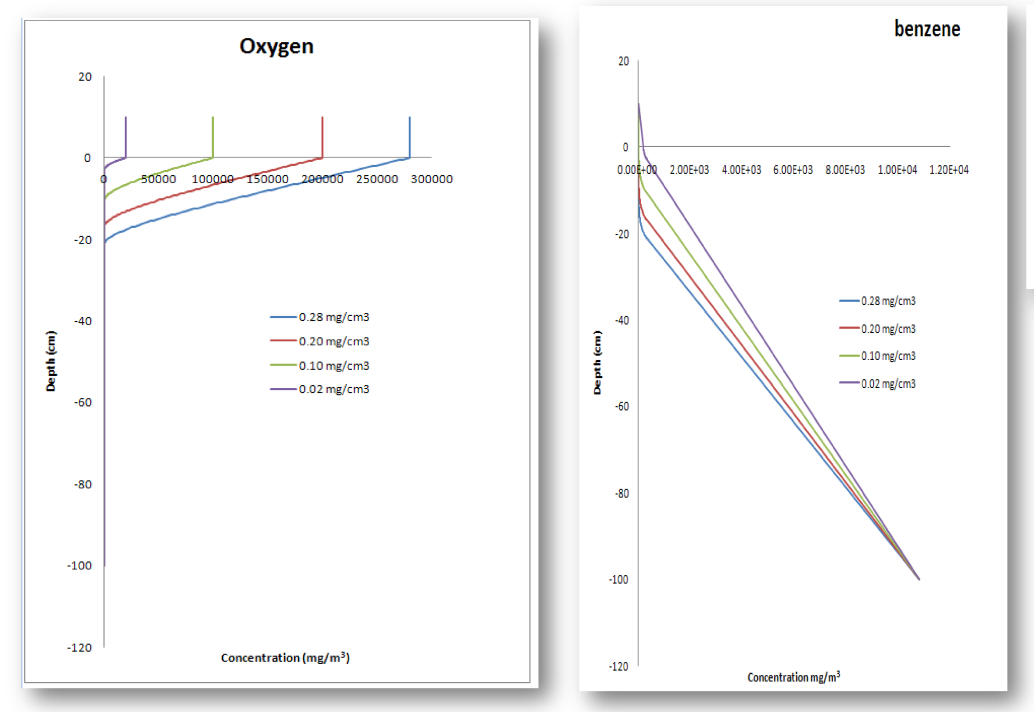

Figure 5. Stronger source with varying foundation oxygen concentration. Lower oxygen gives more intrusion.

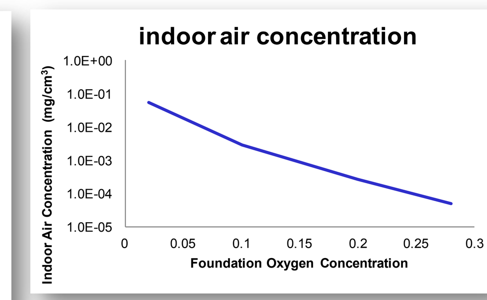

Figure 6. Indoor air concentration decreases as foundation oxygen concentration increases over 3 orders of magnitude.

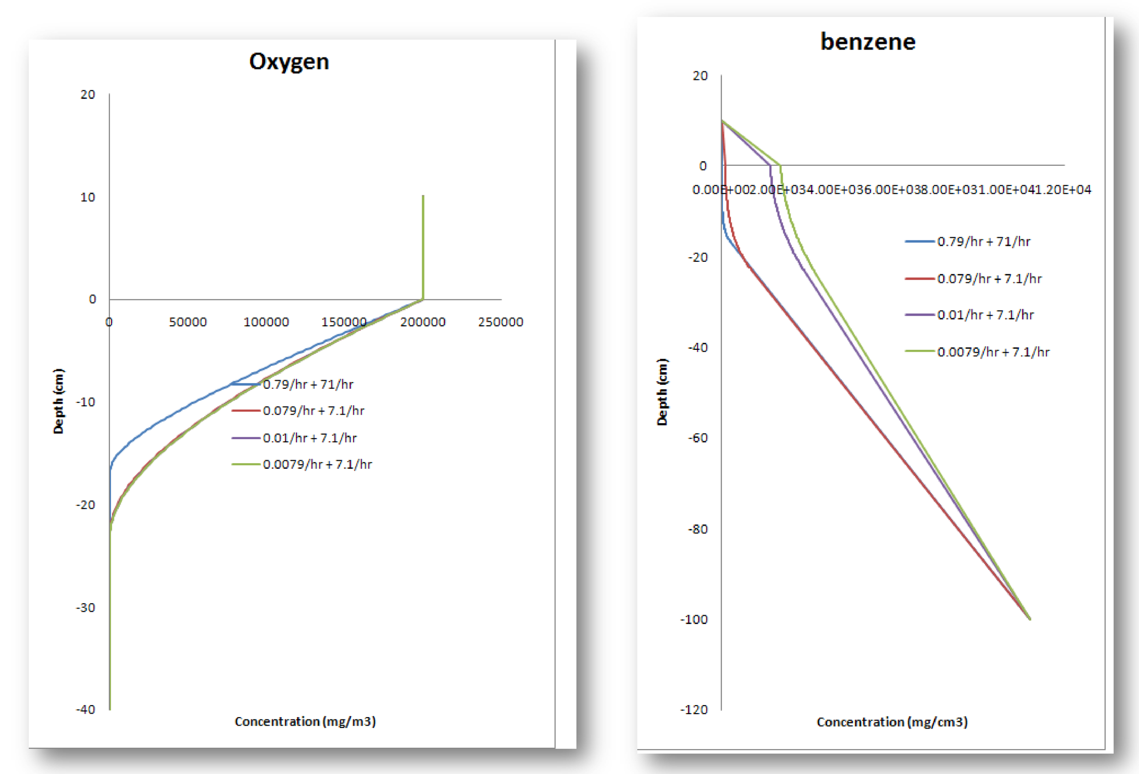

Figure 7. DuVaull (2007) estimated biodegradation rates as 0.79/hr for aromatics and 71/hr for aliphatics. These were varied from the base case over ranges indicated by the supporting data.

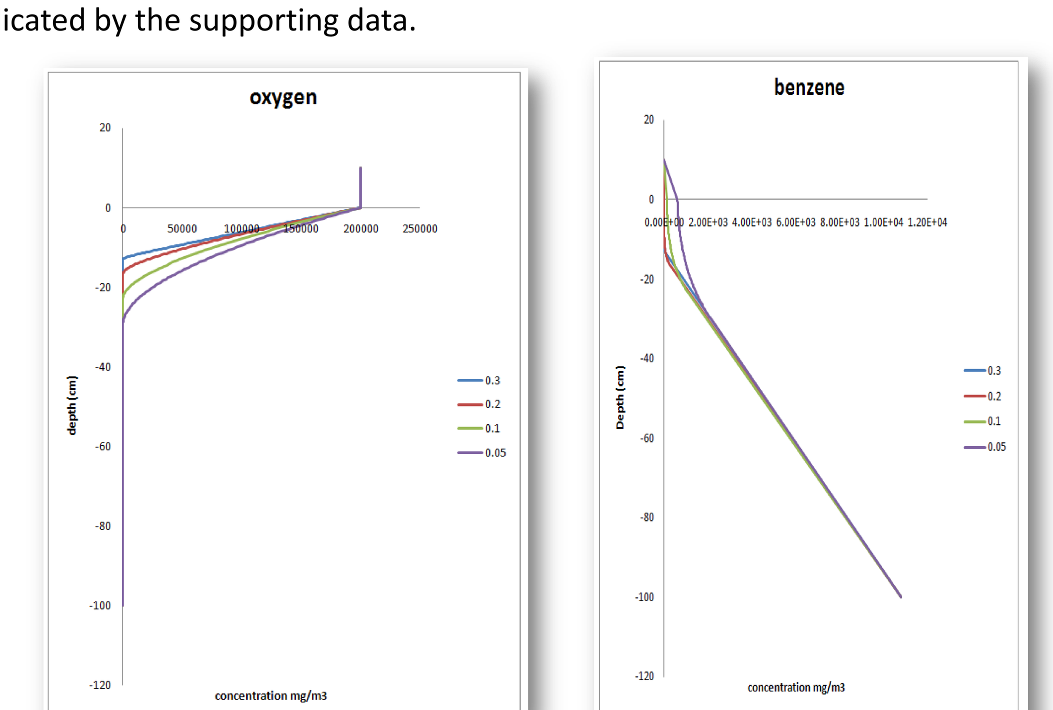

Figure 8. Analysis of the Johnson & Ettinger model showed that moisture content and air exchange rate were important parameters (Tillman and Weaver, 2006). Varying moisture content in Biovapor shows a small impact in the base case.

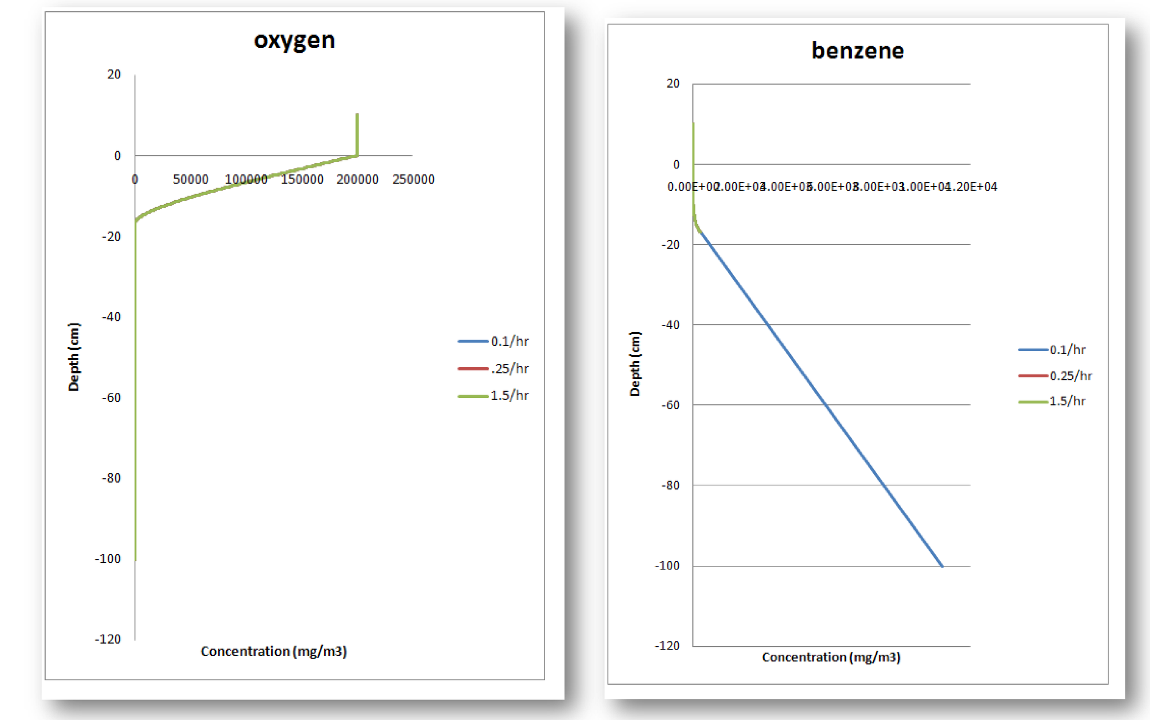

Figure 9. Air exchange rate appears to be unimportant for the BioVapor results. This will be the case when biodegradation removes the petroleum constituents before they are near the foundation.

CONCLUSIONS

BioVapor simulations are sensitive to choices of parameters. With a large capacity for biodegradation due to influx of oxygen, however, stronger sources near the base of the foundation are needed to produce significant impacts. As the source becomes weaker and the source drops lower from the foundation, the impacts become insignificant. Thus a measure of the strength of the source and its depth below the bottom of the foundation provide critical information showing no impact from petroleum vapor intrusion. Although the Johnson and Ettinger displays strong dependence on the air exchange rate, BioVapor does not, when the source attenuates prior to impacting the bottom of the foundation. Thus building parameters in general only become important for BioVapor when the source is strong and near the bottom of the building. Otherwise the model results are dominated by the strength and depth of the source, biodegradation rate and oxygen influx. Significant petroleum vapor intrusion is limited to cases of strong sources close to the bottom of the foundation.

REFERENCES

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Oreskes, Naomi, 2003, The role of quantitative models in science, in Models in Ecosystem Science, C.D. Canham and W.K. Lauenroth, eds. Princeton University Press, 13-31.

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