Assessing the Risk of Organic Contaminants at Off-Site Receptors

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Motivation

Does assessing risk due to groundwater contamination at the community level produce significantly different outcomes than assessing risk at the property level?
New Model Developed

Coupled Groundwater/Vapour Modelling

GW_VAP3D Simulates:

- Groundwater flow in heterogeneous aquifer
- Contaminant concentrations in groundwater
- Air velocity field in vadose zone
- Gaseous contaminant concentrations
- Indoor air concentrations in basements
Model Approach: Heterogeneity

Example Heterogeneous Permeability Field for Modelling
Approach – Summary

Monte Carlo Simulation

• Suites of simulations (50 realizations each) that account for heterogeneity without allowing results to be dominated by one particular aquifer configuration.
• Investigate sensitivity to the distribution of key transport features:
  — Hydraulic conductivity
  — Sorption
  — Degradation rate

Advantages :

• Flexible and straightforward
• Handles any degree of complexity
• Permits heterogeneity of parameters
• Produces sensitivity analysis of results
Conceptual Model and Model Domain

Source zone = (13x13x2) m

C = C₀ = 900 mg/L

House: 10 m x 10 m

Groundwater Flow

Control Plane  Control Plane  Control Plane
# Realistic Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Variance</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic conductivity (K)</td>
<td>3.1 - 30.3 m/d</td>
<td>0.3 -4.5</td>
<td>Wolf, 1988; Sudicky et al., 1986, 2010; Lemke et al., 2004; Rehfeldt et al., 1992; McNab, 2001.</td>
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<tr>
<td>Fraction of organic carbon (f_{oc})</td>
<td>0.01-0.5 (%)</td>
<td>0.5</td>
<td>MOE, 2011.</td>
</tr>
<tr>
<td>First-order decay coefficient (\lambda)</td>
<td>0.0-0.004 (d^{-1})</td>
<td>0.5</td>
<td>Wiedemeier et al., 1996; Patterson et al., 1993; Wiedemeier et al., 1995; Dobbins et al., 1992; Colberg and Young, 1995; Reinhard et al., 1991.</td>
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Evaluation at Control Planes

Control Plane \((cp)\)

\[\tilde{C}(x^{cp}, t)\]
Metrics

Simulation results (average of 50 realizations) represented by:

• Maximum, volume-averaged, and flux-averaged groundwater contaminant concentrations for all control planes

• Local groundwater concentrations beneath each house

• Indoor air contaminant concentration for each house

• Contaminant concentration in lake

• Probability of exceeding:
  Ontario drinking water standards
  Ontario indoor air concentration standards
Maximum GW Concentration Breakthrough Curves (zero degradation case)

At House No. 10

Ontario Drinking water standard = 5 µg/L

Groundwater standard = 3.2 µg/L (safe indoor air concentration)
Indoor Air Concentration Breakthrough curves (zero degradation case)

At House No. 10

Indoor air standard = 3.1 µg/m³
Probability of Exceedence Map: Groundwater (zero degradation case)
Probability of Exceedence Map: Indoor air (zero degradation case)

Plan View

Probability (%)
Maximum GW Concentration Breakthrough Curves (low mean degradation rate)

At House No. 10

Ontario Drinking water standard = 5 µg/L

Groundwater standard = 3.2 µg/L (safe indoor air concentration)

- Case 6 Heterogeneous K and λrxn (uncorrelated)
- Case 8 Heterogeneous K, λrxn and foc (uncorrelated)
- Case 11 Heterogeneous K and λrxn (positive correlated)
- Case 12 Heterogeneous K and λrxn (negative correlated)
Indoor Air Concentration Breakthrough Curves (low mean degradation rate)

At House No. 10

Indoor air standard = 3.1 µg/m$^3$
Probability of Exceedence Map: Groundwater (low mean degradation rate)
Probability of Exceedence Map: Indoor air (low mean degradation rate)

Plan View

Probability (%)

0 1 50
Summary and Conclusions

• State-of-the-art model developed that permits the risk of contaminated sites to be assessed in the community, considering both groundwater and indoor air receptors.

• For a spill of 577 drums of Benzene, prior to cleanup, the probability of exceeding allowable concentrations in GW and indoor air was 100% (i.e., independent of every statistical parameter considered).

• However, risk in the community was a strong function of location.
  • Directly downgradient a high risk.
  • Transverse to flow direction (~100-200 m) a variable risk (depends on heterogeneity).
  • Transverse to flow direction (~250 m) a low-to-no risk.
In locations where groundwater risk was small, significant indoor air risk was observed.

Natural attenuation, even at the lower bounds of published degradation rates, significantly reduces risk in the community (i.e. no risk after 1000 m even directly downgradient).
Acknowledgments

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