Airborne Leak Detection

Prediction of Gas Transport Through Soil and Atmosphere

Kamal K. Botros, Claire Ennis (NOVA Chemicals)

Joe Zhou, Brad Watson (TransCanada Pipelines)

October 3, 2008

TransCanada
In business to deliver

NOVA Chemicals

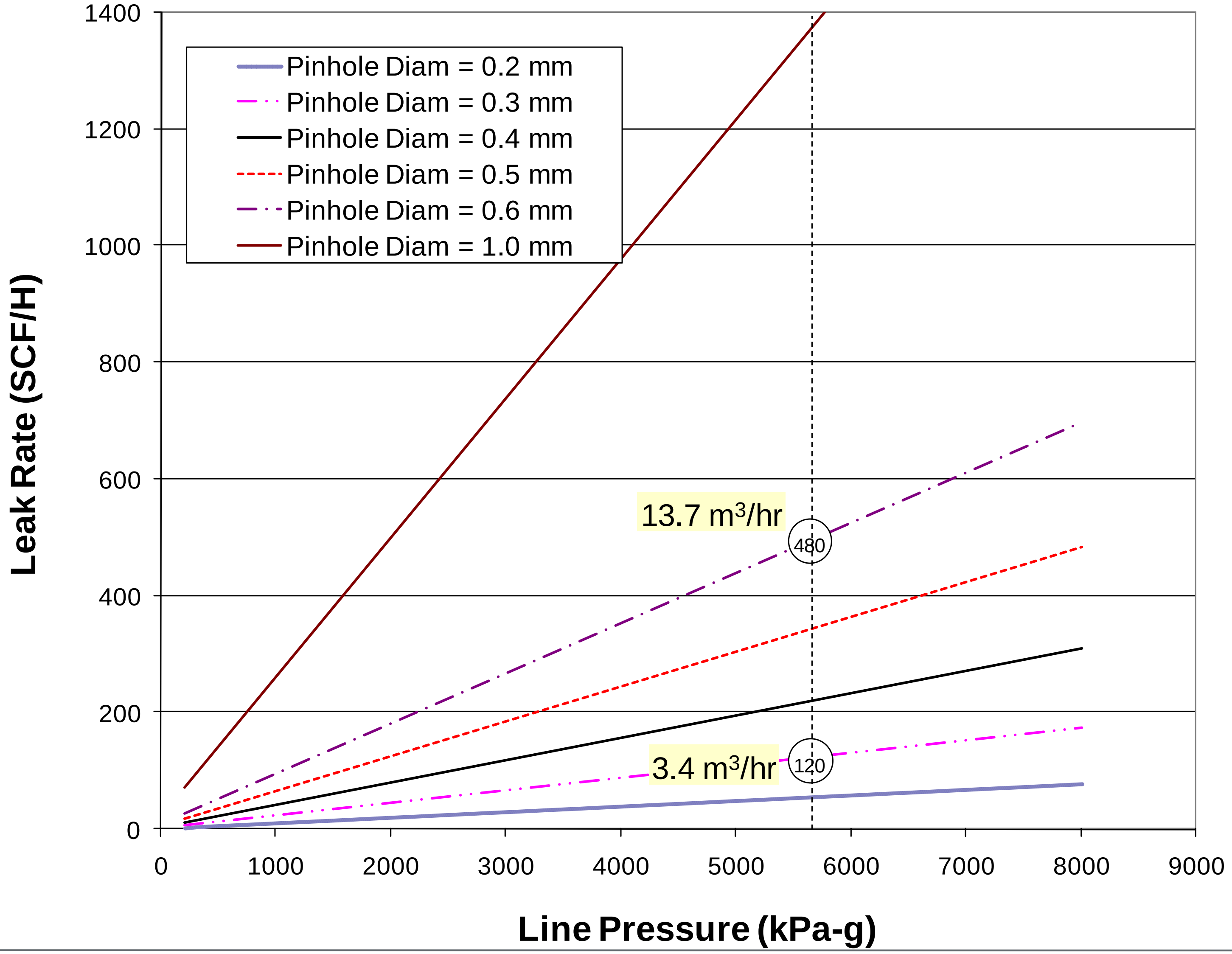
Outline

1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. Diffusive Gas Transport Mechanism
5. Simulation of Gas Transport (Atmosphere)
6. Field Test
7. Concluding Remarks

Motivation

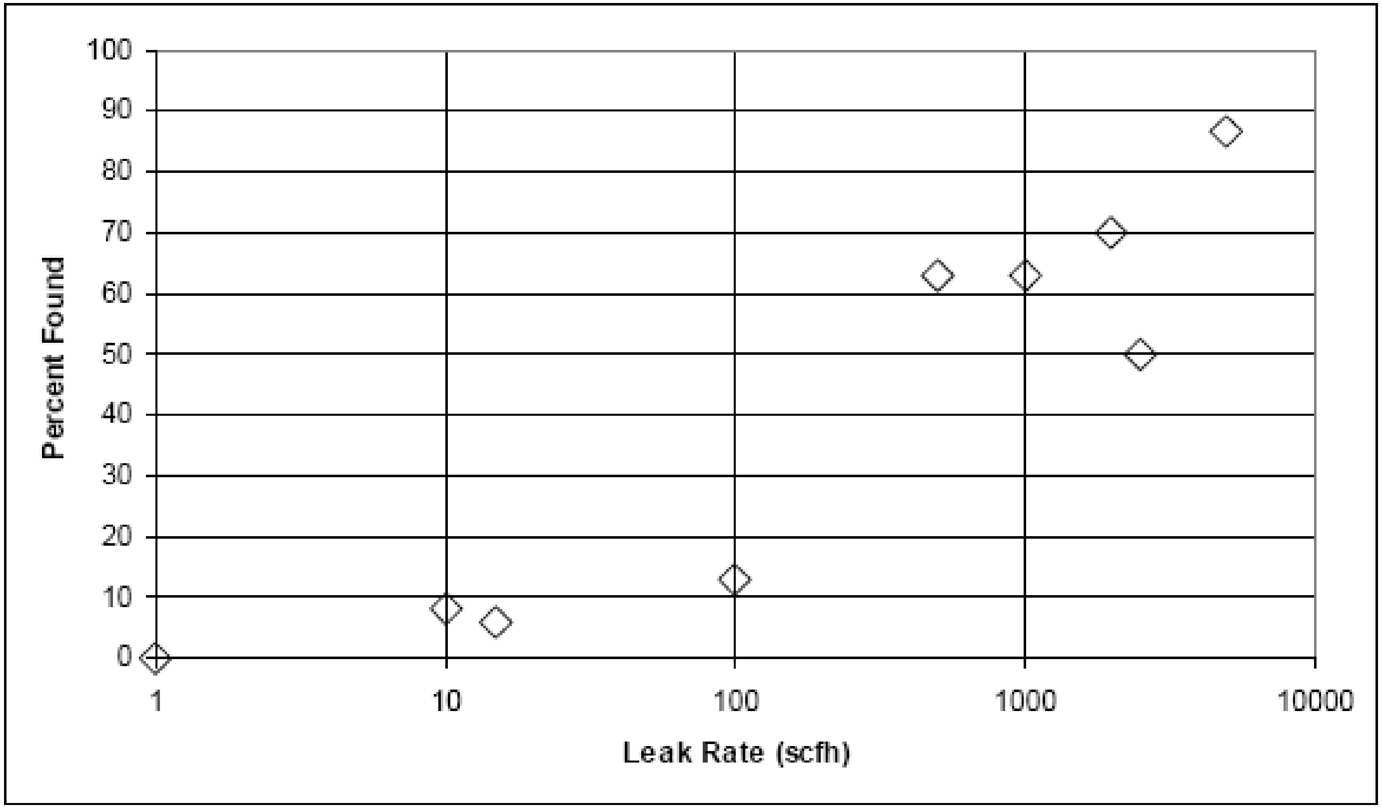
- Hydrotesting of newly constructed pipelines is required as per CSA Z662-07 Section 8.
- Cold weather construction challenges include: water freezing, availability of water, mixing water with methanol, and associated environmental concerns.

Leak Rates



Leak Rate (SCF/H)
1400
1200
1000
800
600
400
200
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Line Pressure (kPa-g)
Pinhole Diam = 0.2 mm
Pinhole Diam = 0.3 mm
Pinhole Diam = 0.4 mm
Pinhole Diam = 0.5 mm
Pinhole Diam = 0.6 mm
Pinhole Diam = 1.0 mm
13.7 m^3/hr
480
3.4 m^3/hr
120

DOE Round-Robin Test (2004)



Ref: Buckingham, J.C., Grimley, T.A., Burkey, R.C., "Field Testing of Remote Sensor Gas Leak Detection Systems," Southwest Research Institute®, Final Report for Department of Energy, Rocky Mountain Oilfield Testing Center, December 2004.

Section

1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. Diffusive Gas Transport Mechanism
5. Simulation of Gas Transport (Atmosphere)
6. Field Test
7. Concluding Remarks

Technology Classifications

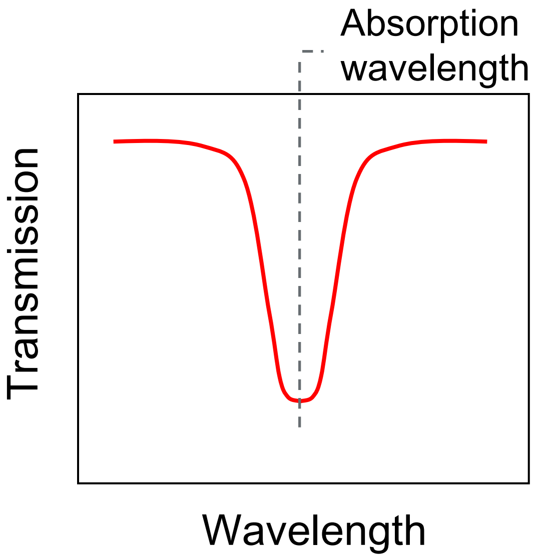
Extractive sample-based technologies:

- Combustible Gas Indicators (CGI): catalytic combustion of gas sample
- Flame Ionization Detectors (FID): senses increase in ions in a hydrogen-burning flame, detects all combustible gases

Optical-based technologies:

- Passive
- Active (TDLA & DIAL)

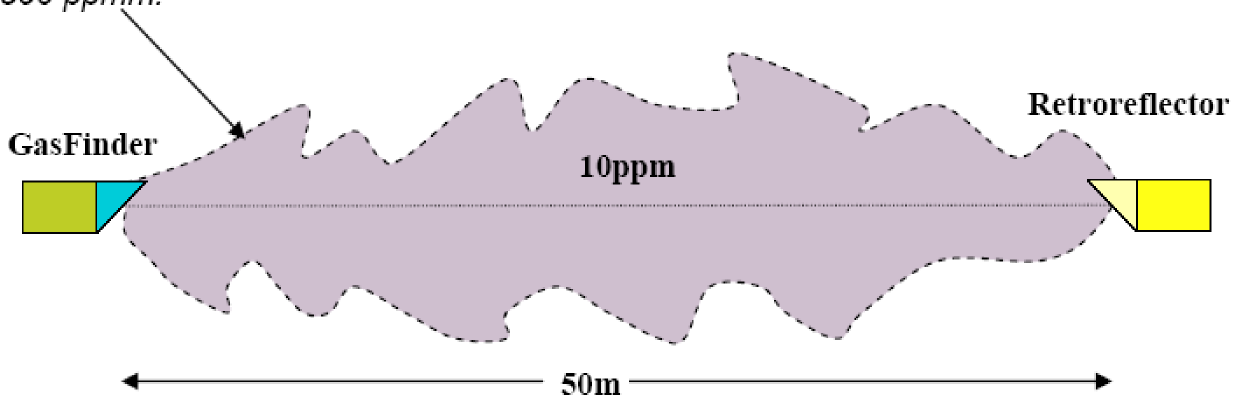
Beer-Lambert's law: $\log_{10}(I_o/I) = A$



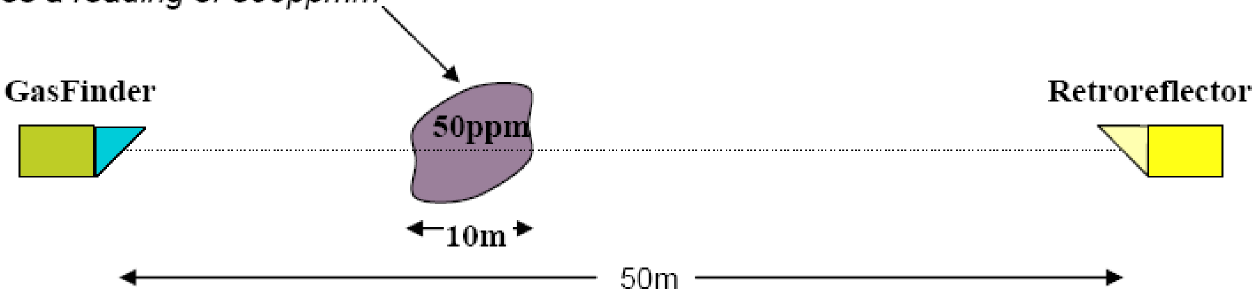
Concentration Path Length

$$\text{Concentration Path Length} = CPL = \frac{\int C\,dL}{L}$$

A uniform background concentration of 10 ppm over 50m gives a reading of 500 ppmm.



A concentrated cloud of 50 ppm,10m in diameter, in a background of 0 ppm also gives a reading of 500ppmm

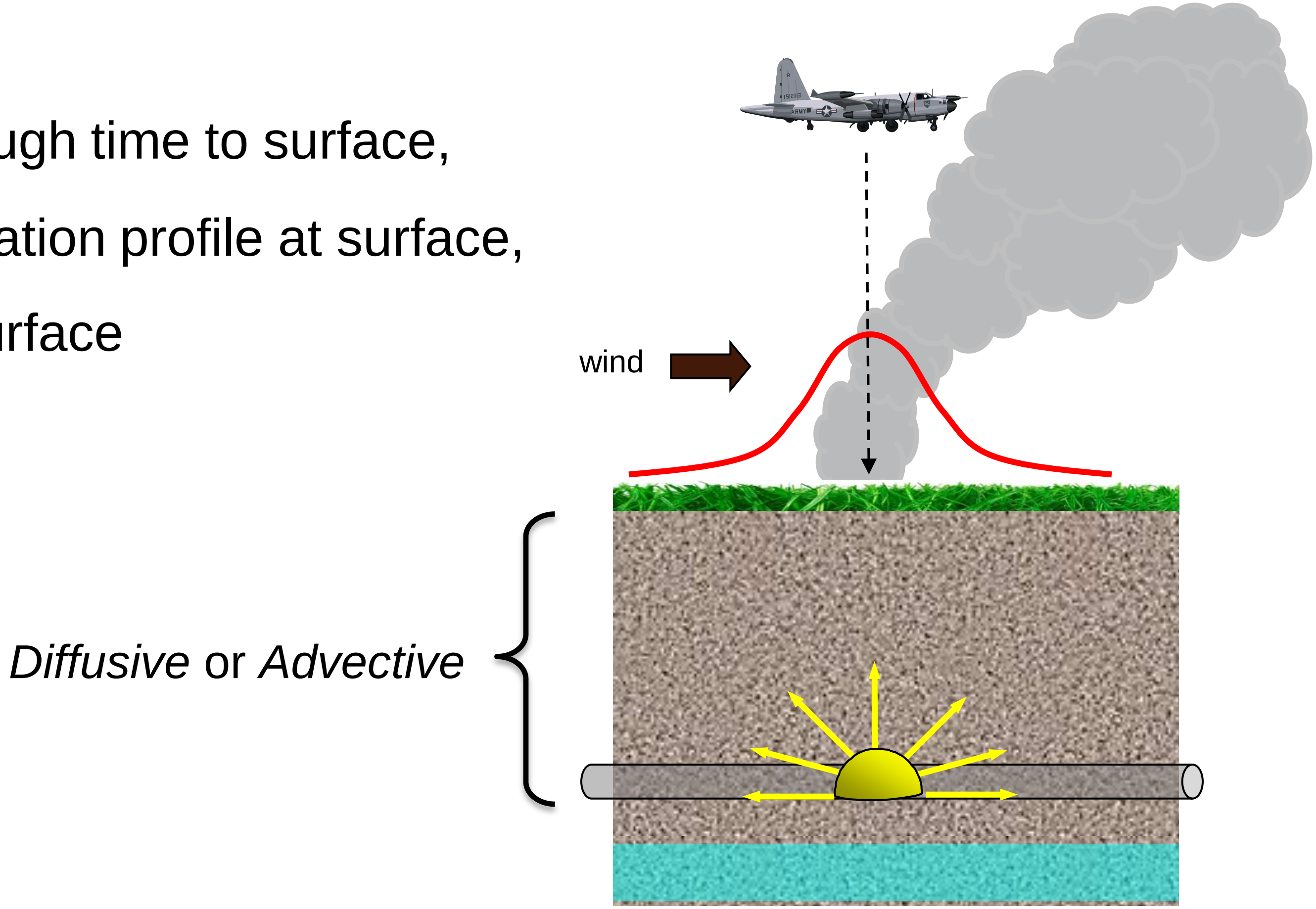


Courtesy of Boreal Laser Inc. 2003

Approach

Determine:

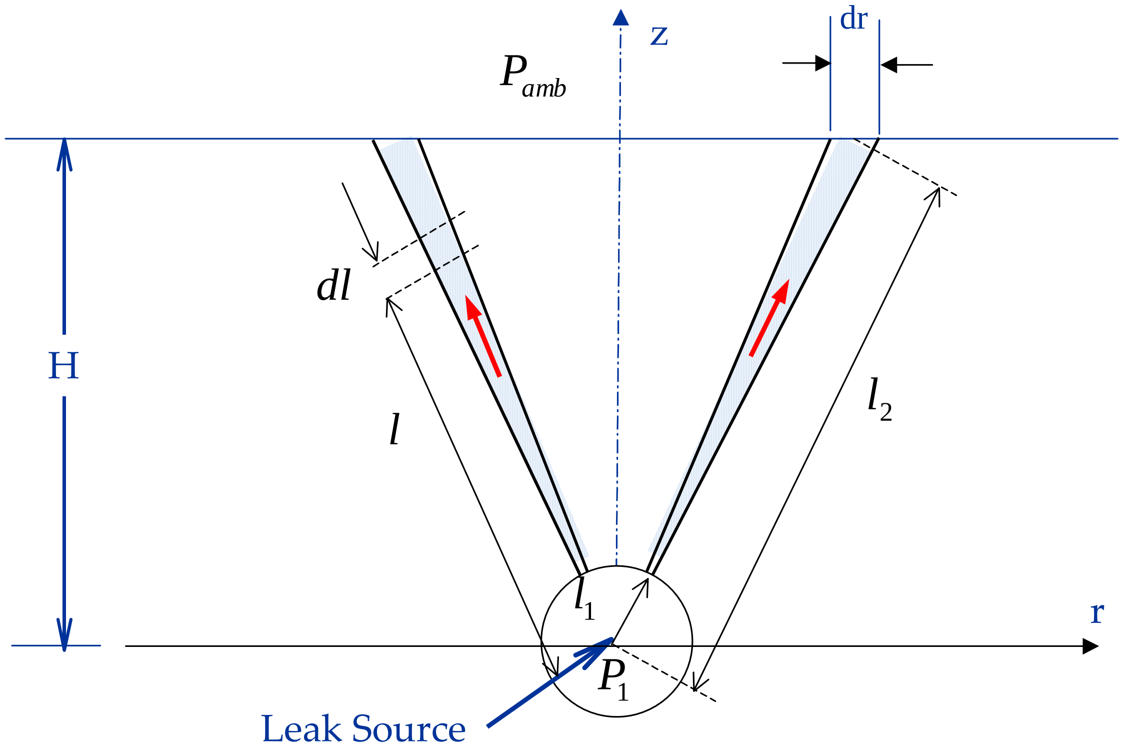
- a) Breakthough time to surface,
- b) Concentration profile at surface,
- c) Flux at surface



Section

1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. Diffusive Gas Transport Mechanism
5. Simulation of Gas Transport (Atmosphere)
6. Field Test
7. Concluding Remarks

Advective Flow Model



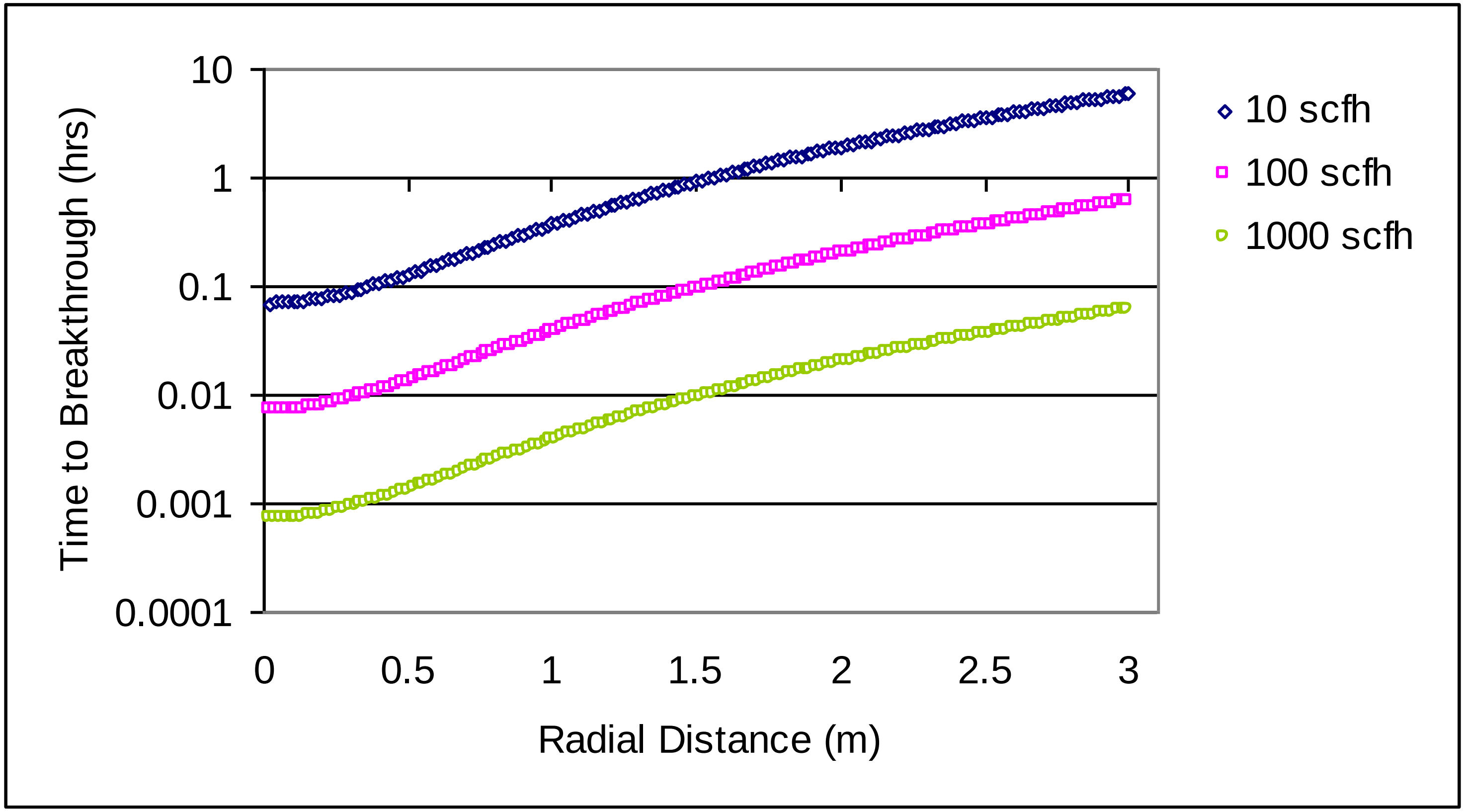
Known:

- Total mass flux (leak rate)
- Soil properties

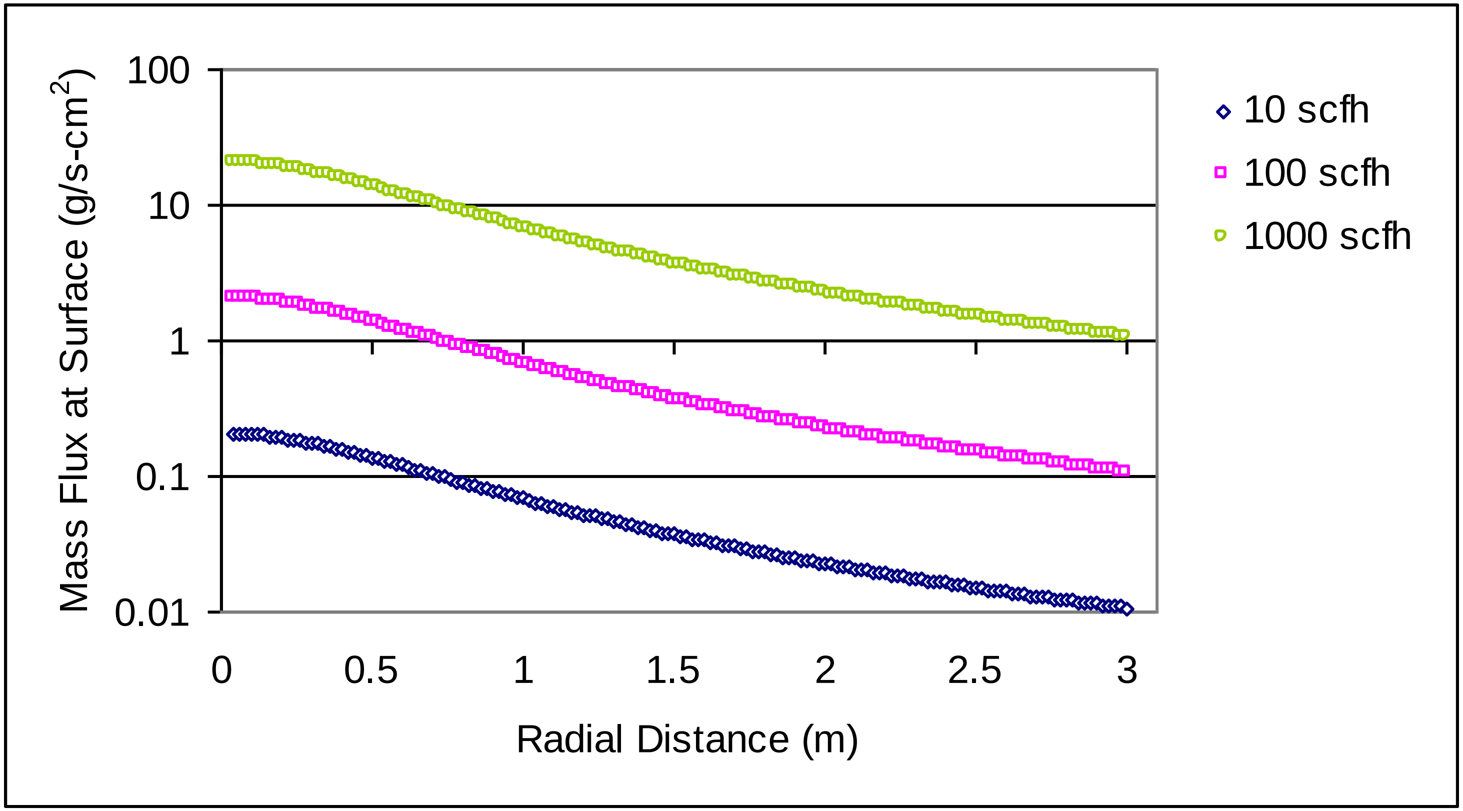
Unknown:

- dP
- Mass flux profile
- Time to reach surface
- Surface velocity

Time to Breakthrough (Depth = 0.7 m)



Mass Flux at Surface (Depth = 0.7 m)



Péclet Number

$$Pe \equiv \frac{Advective\ flow\ velocity}{Diffusive\ flow\ velocity} = \frac{v^{o} d}{D_{eff}}$$

Where

v^{o} = Flow velocity (actual)
d = Characteristic length (soil particle diameter)
D_{eff} = Effective diffusion coefficient of gaseous methane in air

Pe No. ↓ = More diffusive

Pe No. ↑ = More advective

Threshold
Pe = 0.02

Section

1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. **Diffusive Gas Transport Mechanism**
5. Simulation of Gas Transport (Atmosphere)
6. Field Test
7. Concluding Remarks

Diffusive Model Governing Equation

The transport model is based on Fick's 2nd Law:

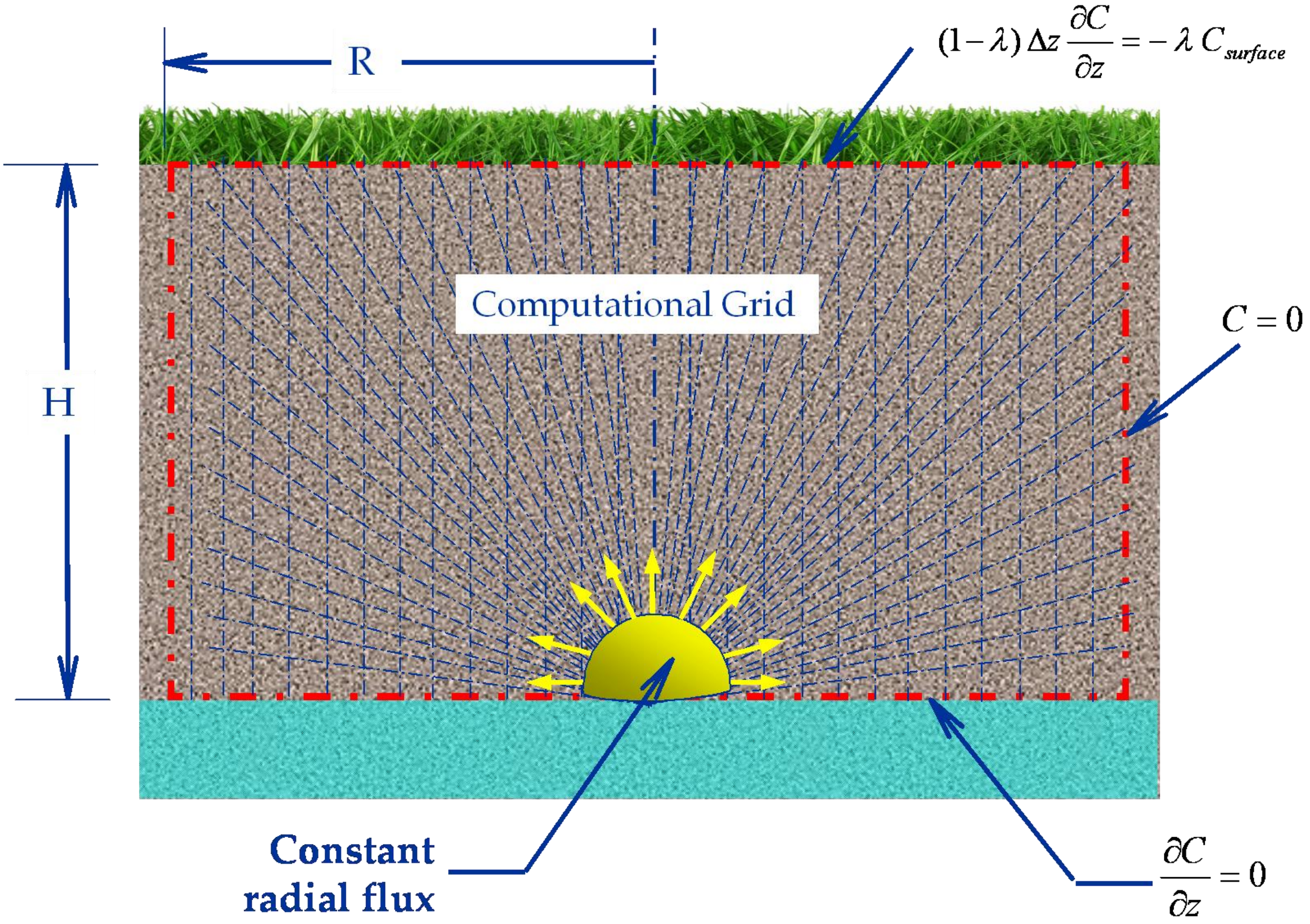
$$\frac{\partial C}{\partial t} = D \nabla^2 C$$

The mass flux is:

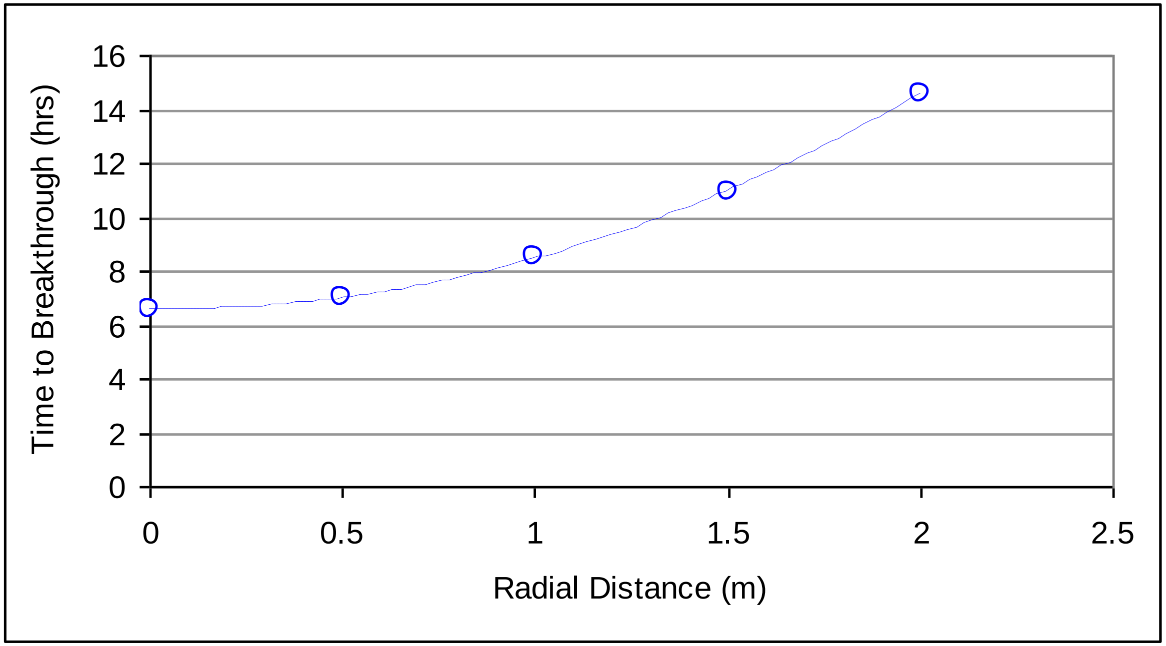
$$J = -D \nabla C$$

This was solved through numerical simulation in R-UNSAT.

Boundary Conditions



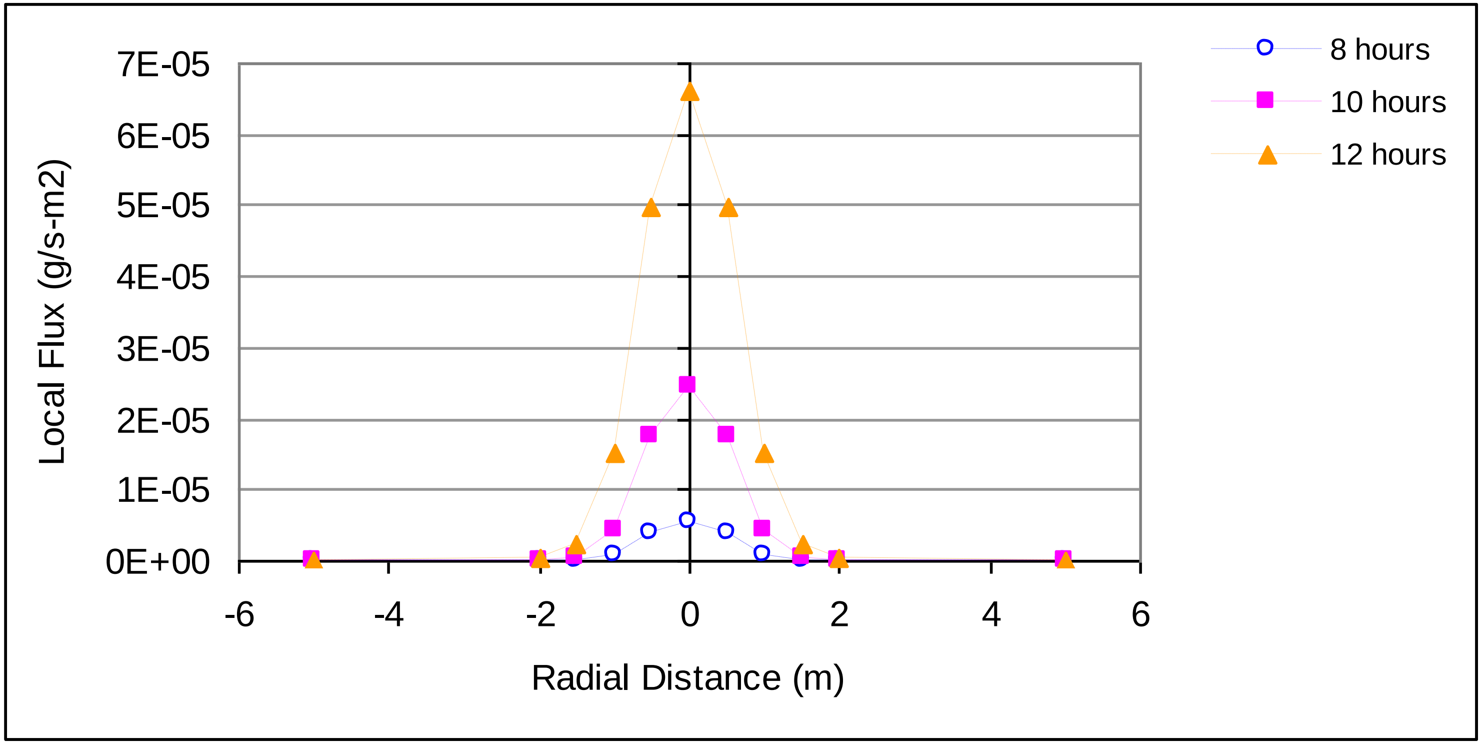
Diffusive Model Breakthrough Times



Breakthrough time is the time at which methane concentrations are greater than the atmospheric value of 1.75 ppm.

Depth = 2 m, Q = 10 scfh, Porosity = 0.35

Mass Flux at Surface



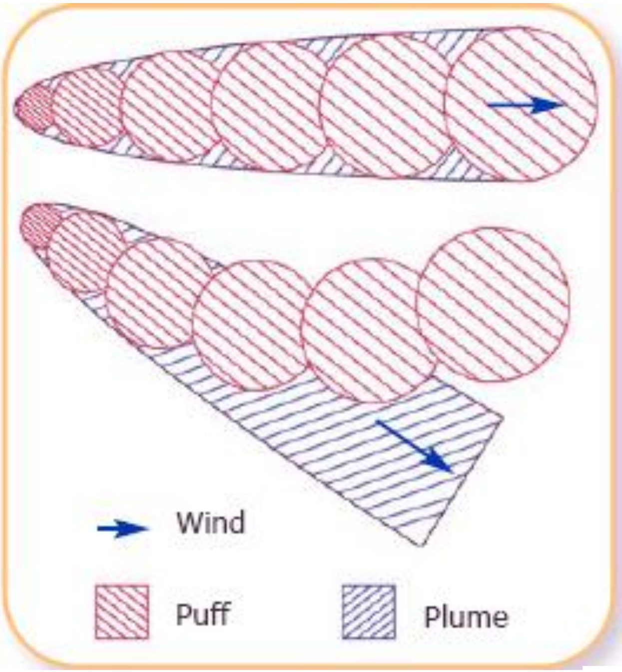
Depth = 2 m, Q = 10 scfh, Porosity = 0.35.

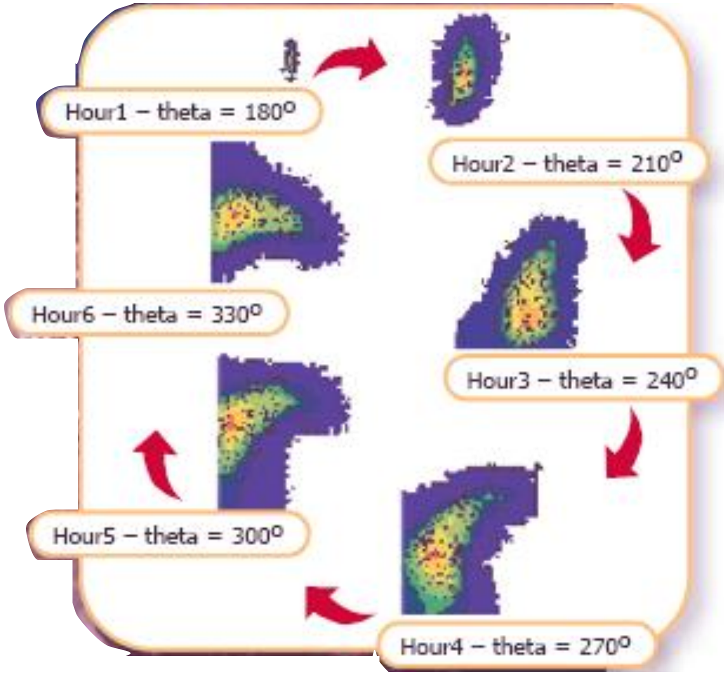
Section

1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. Diffusive Gas Transport Mechanism
5. **Simulation of Gas Transport (Atmosphere)**
6. Field Test
7. Concluding Remarks

Numerical Simulation: CALPUFF

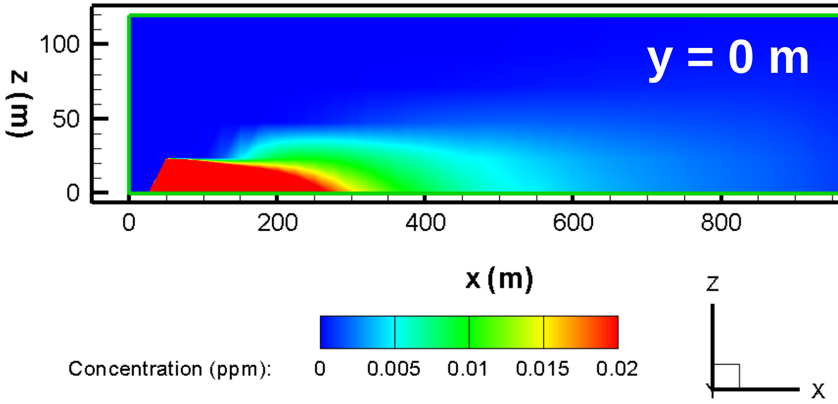
CALPUFF is a **non-steady-state** emissions modeling program developed by the US Environmental Protection Agency.

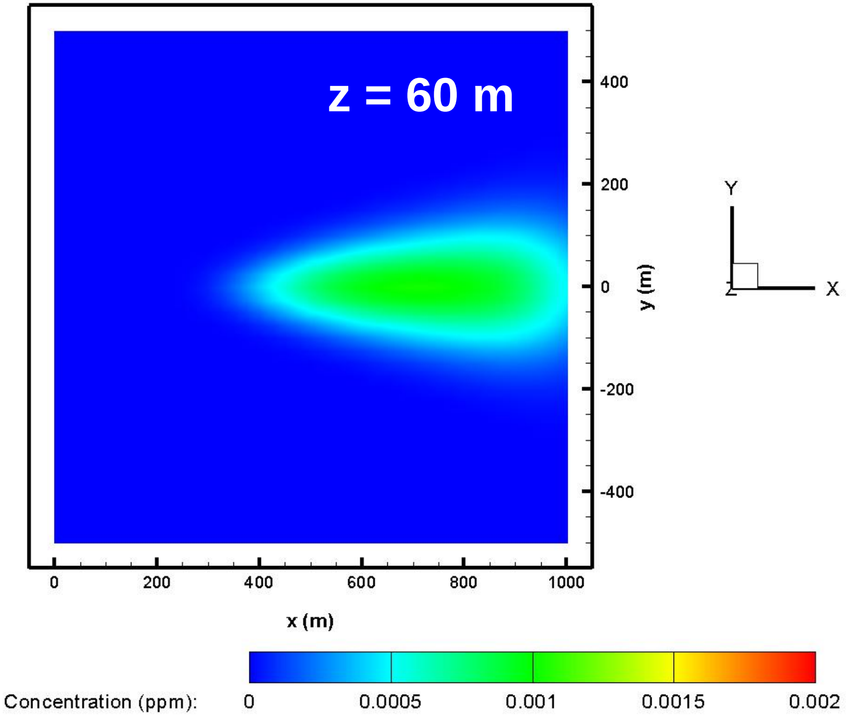




©1996-2007 Lakes Environmental Software

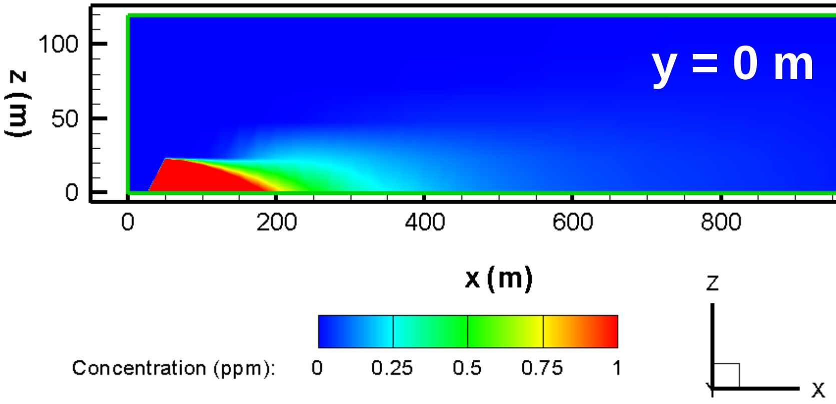
10 scfh leak, 3 hrs since initiation

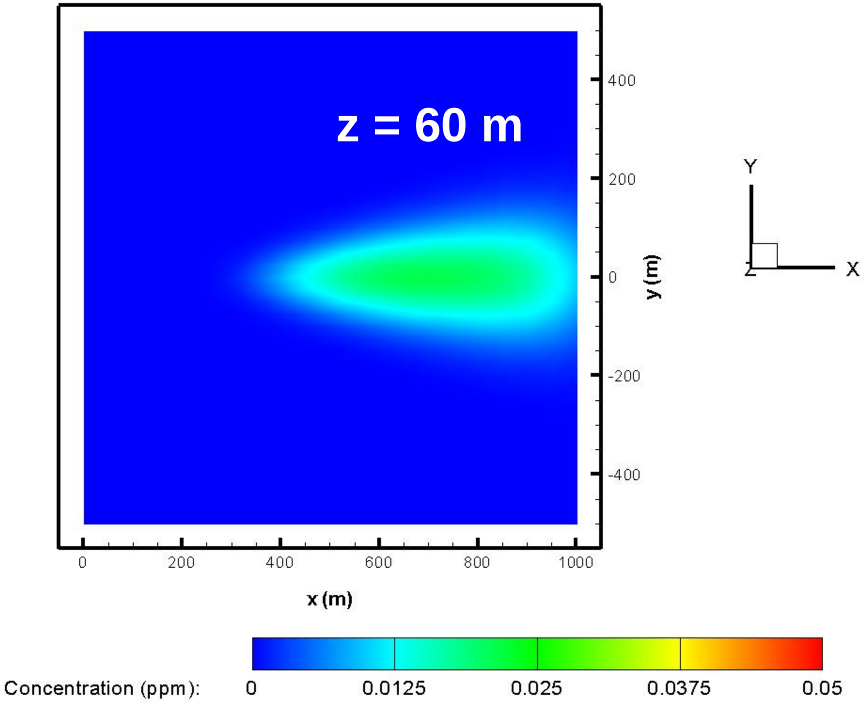




Depth = 0.7 m, Q = 10 scfh, Porosity = 0.35.

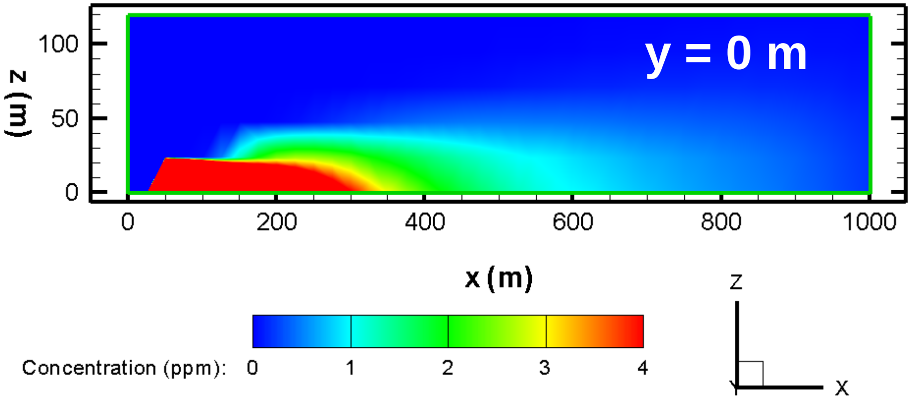
100 scfh leak, 1 hr since initiation

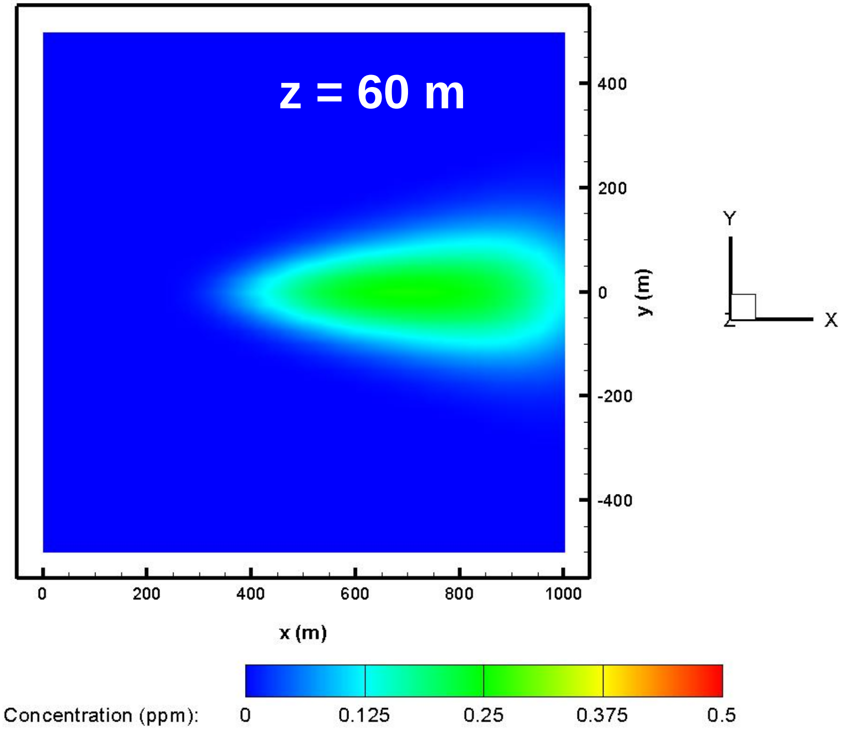




Depth = 0.7 m, Q = 100 scfh, Porosity = 0.35.

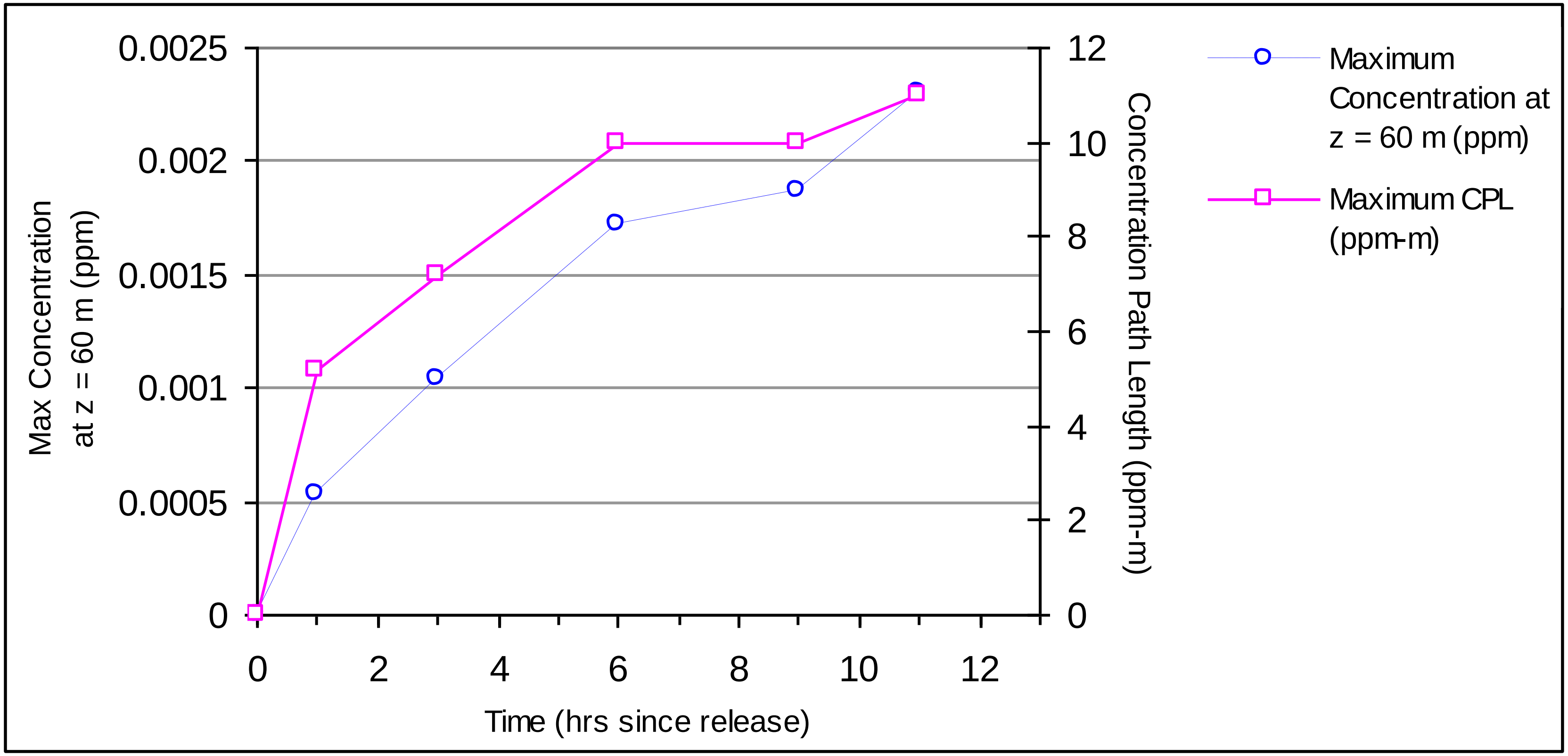
1,000 scfh leak, 0.5 hr since initiation





Depth = 0.7 m, Q = 1,000 scfh, Porosity = 0.35.

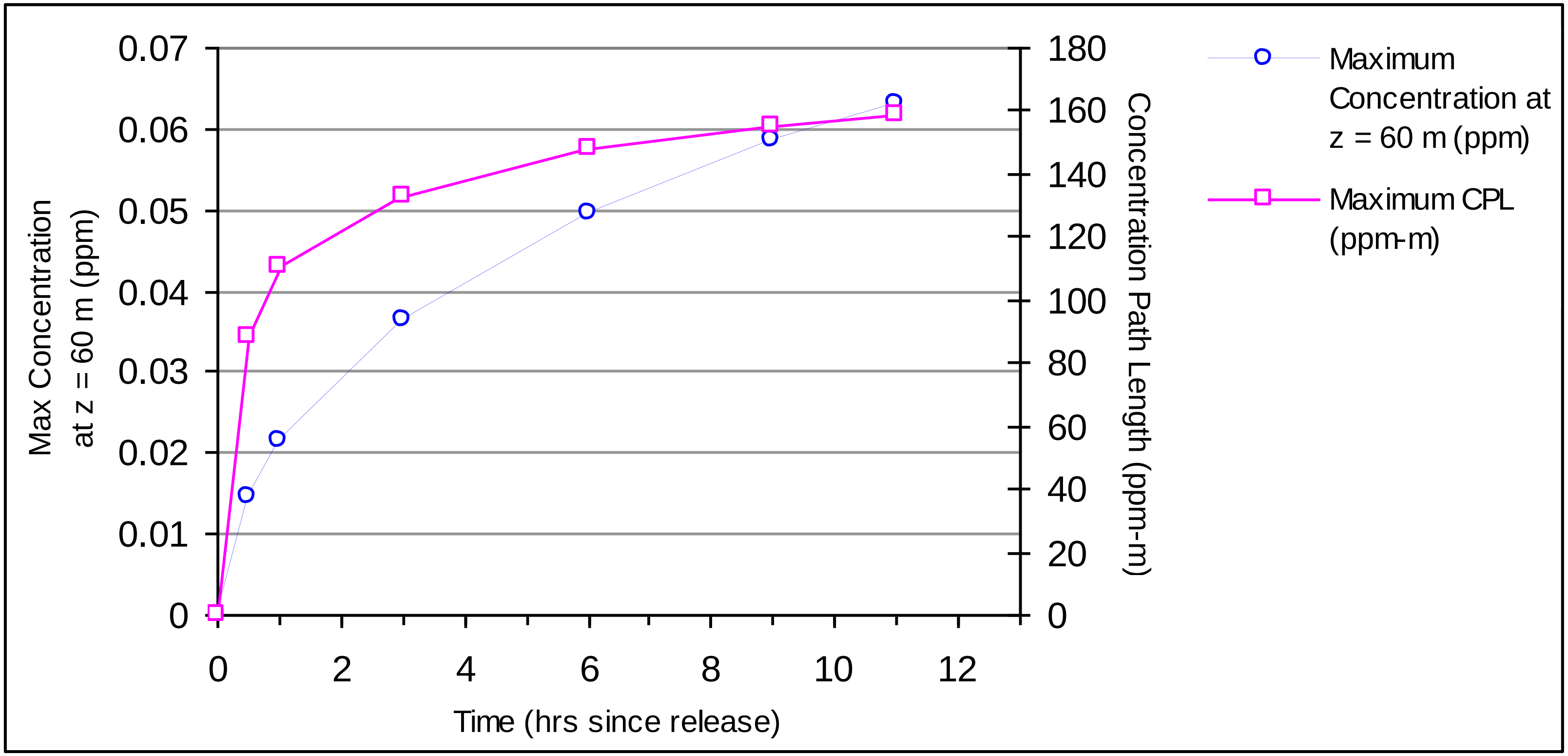
Maximum Local Concentration and CPL
Q = 10 scfh



Local concentration taken at z = 60 m.
CPL from x = 0-1,000m and z = 0-400m.

Depth = 0.7 m, Q = 10 scfh, Porosity = 0.35.

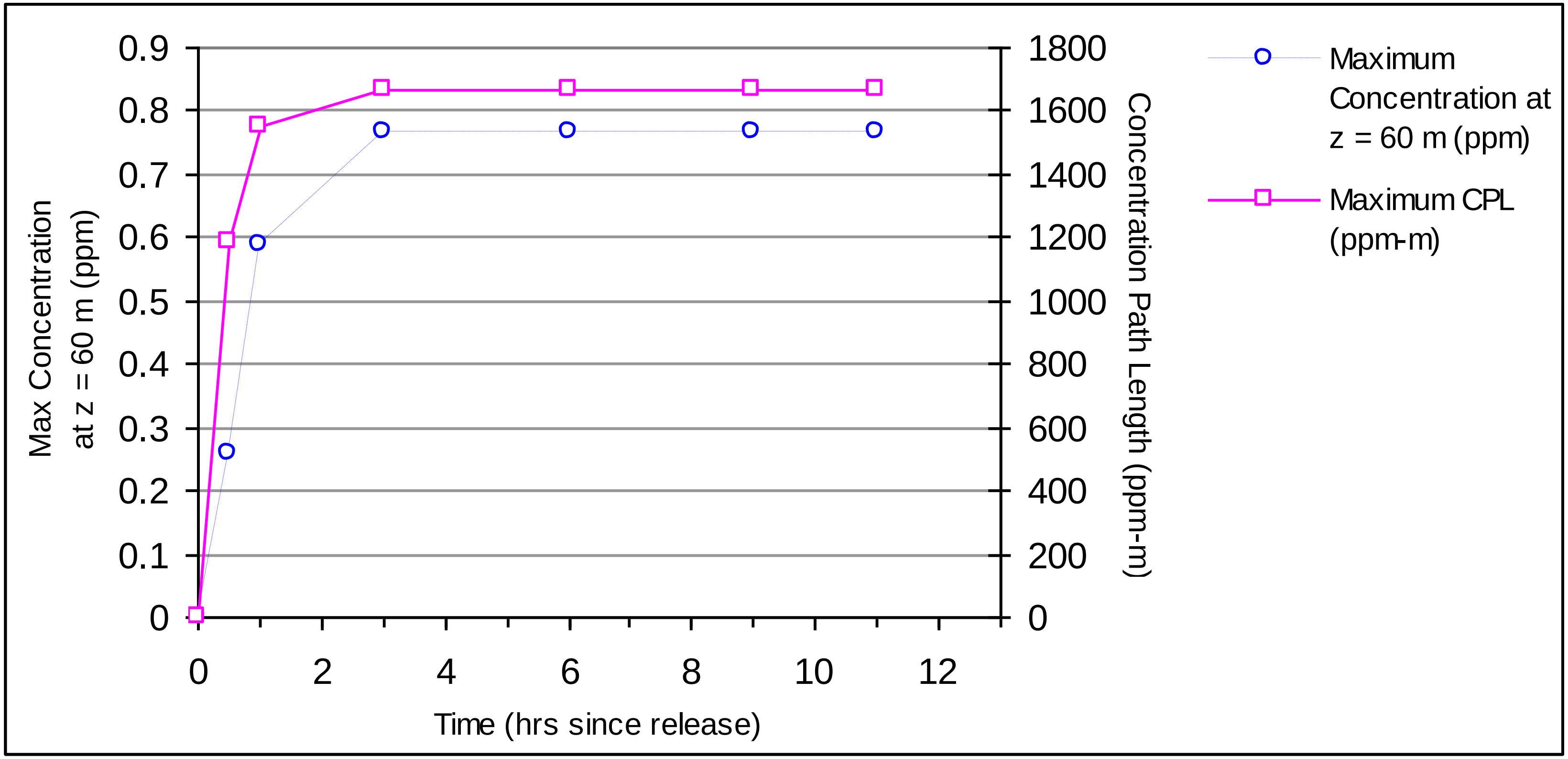
Maximum Local Concentration and CPL
Q = 100 scfh



Local concentration taken at z = 60 m.
CPL from x = 0-1,000m and z = 0-400m.

Depth = 0.7 m, Q = 100 scfh, Porosity = 0.35.

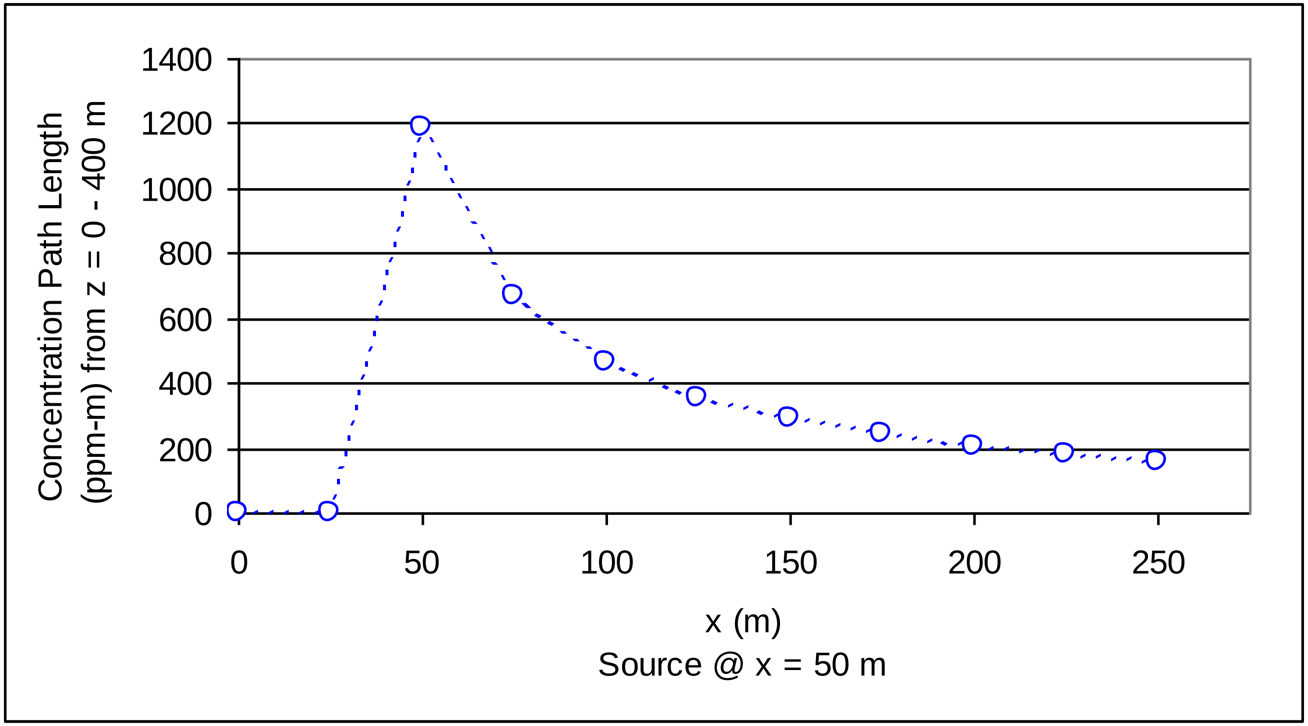
Maximum Local Concentration and CPL
Q = 1,000 scfh



Local concentration taken at z = 60 m.
CPL from x = 0-1,000m and z = 0-400m.

Depth = 0.7 m, Q = 1,000 scfh, Porosity = 0.35.

CPL Profile Along Plume Path

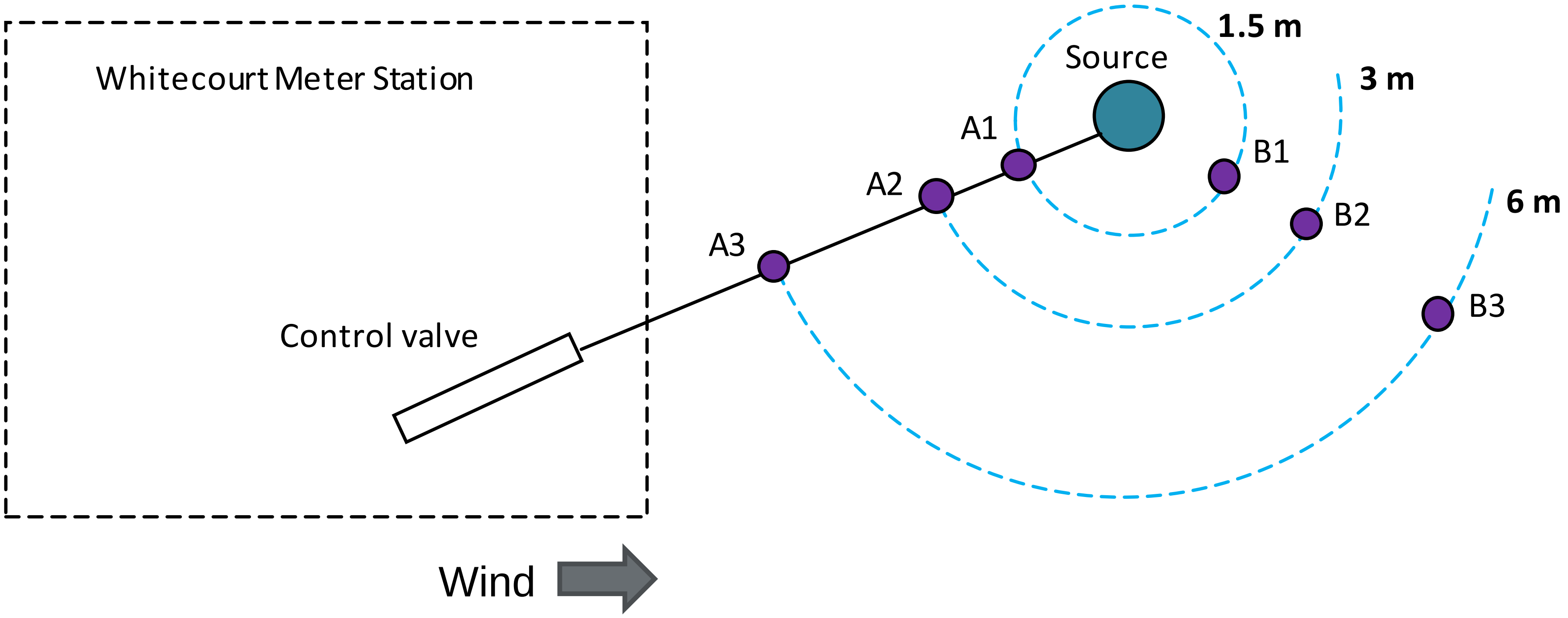


Depth = 0.7 m, Q = 1,000 scfh, Porosity = 0.35, 0.5 hrs of leakage.

Section

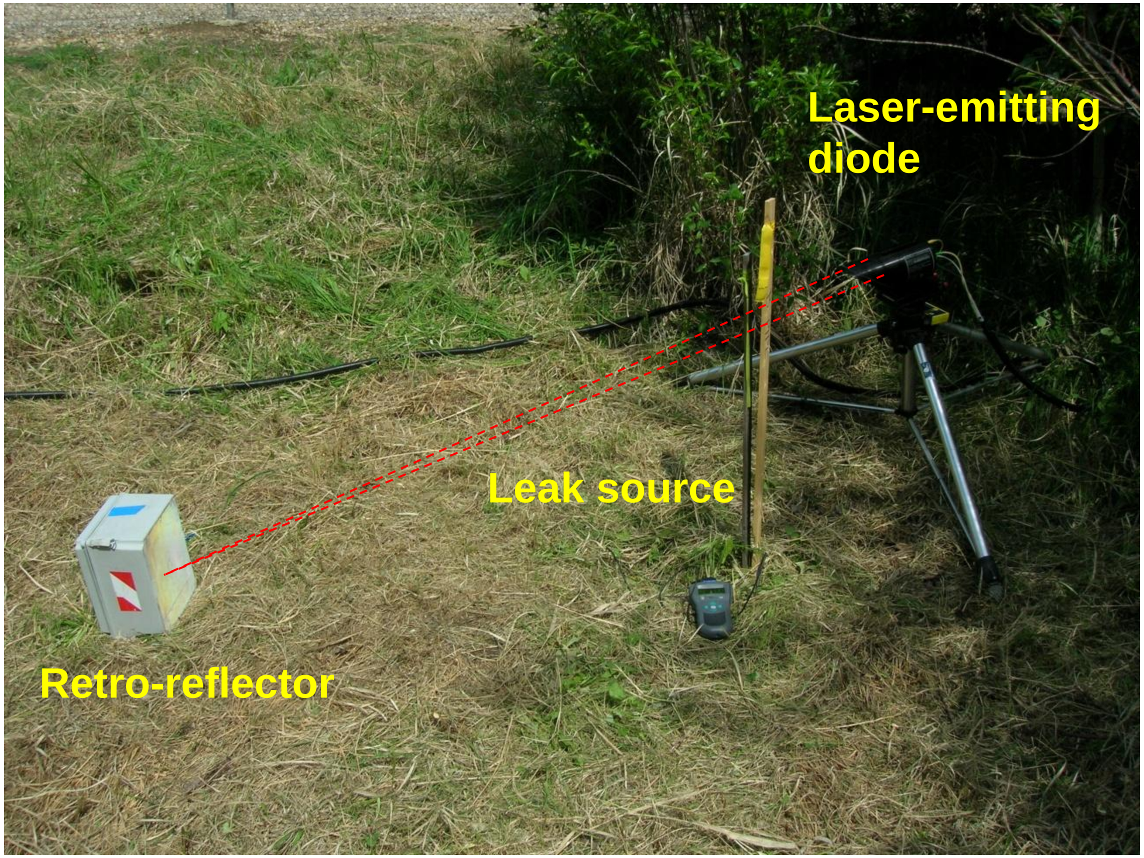
1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. Diffusive Gas Transport Mechanism
5. Simulation of Gas Transport (Atmosphere)
6. **Field Test**
7. Concluding Remarks

Field Test: Artificial Leak Site Schematic



Depth = 0.7 m, Q = 190 scfh, Porosity = 0.35.

Field Test: Equipment



Field Measurements

Location	Time since leak initiation	Approximate concentration	Transport regime modeled	Predicted breakthrough time
Whitecourt Above source	10 s	Unknown (saturated equipment)	Advective	22 s
Whitecourt A1 (1.5 m upwind)	2 min	200 ppm_v [1]	Diffusive	1 hr 43 min
Whitecourt A2 (3 m upwind)	3 min	50 ppm_v [1]	Diffusive	> 5 hrs
Whitecourt A3 (6 m upwind)	4 min	10 ppm_v [1]	Diffusive	> 5 hrs
Blueridge Above source	18 s	900 ppm_v	Advective	1 min 51 s

Section

1. Motivation
2. Current Leak Detection Technologies
3. Advective Gas Transport Mechanism
4. Diffusive Gas Transport Mechanism
5. Simulation of Gas Transport (Atmosphere)
6. Field Test
7. Concluding Remarks

Concluding Remarks

Leak Rate	Wind Speed	Stability	Minimum Time to Steady State Plume
10 scfh	5 m/s	Slightly Unstable	**9 hrs**
1,000 scfh	5 m/s	Slightly Unstable	**3 hrs**

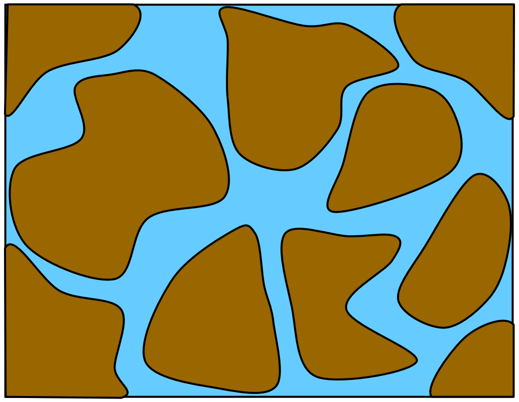
1. Numerical models are conservative.
2. Soil-transport model breakthough times agree within reason to measured results.
3. Flying altitude, meteorological conditions and technology requirements should be considered when determining ‘wait time’.

Acknowledgment

TransCanada:	Rachel Lee
NOVA Chemicals:	Chris Foy Michel Berghmans
Boreal Laser:	John Selby Hamish Adam Edwin Thornton
ITT:	Steve Stearns
Rosen Canada:	Daryl Ronsky

Supporting Information

Soil Properties



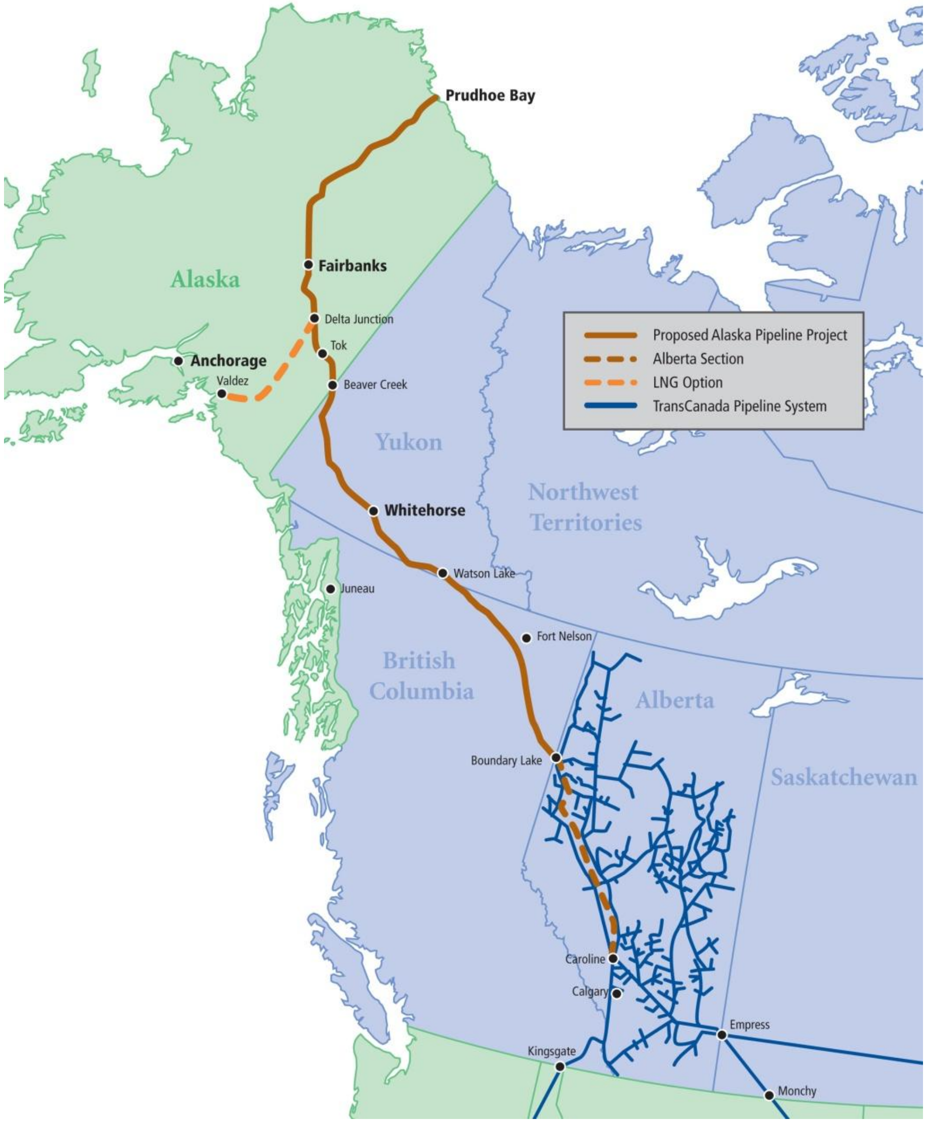
Porosity = 0.35 – 0.50

Moisture Content = 5%

Soil Temperature = 10°C

Ambient Pressure = 760 mm Hg

Alaska Pipeline



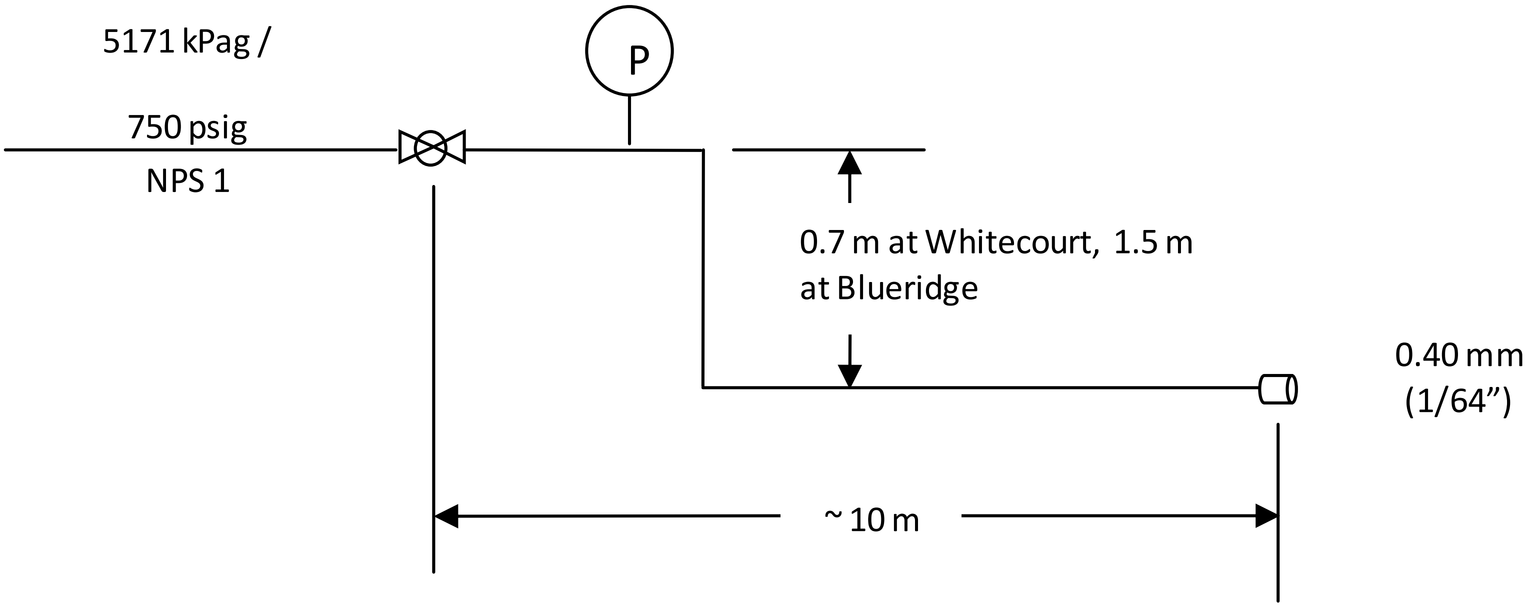
Modelling Properties

The following are additional parameters used in the simulation:

- e_a = 30%
- e_t = 35%
- d_e = 0.0015 mm
- Soil temperature = 0°C
- Ambient Pressure = 698 mm Hg
- V_x = 5 m/s at 10 m elevation above ground.
- Mixing height = 1000 m above ground.
- Stability class during test was assumed slightly unstable (Pasquill-Gifford Class C).
- Leak rates: 0.283, 2.83 and 28.3 m^3/hr (10, 100, and 1,000 scfh)

At these three rates and at 0.7 m depth, the gas transport mechanism through the soil was found to be predominantly advective as the *Pe*'s at *R* = 0 for these three rates were 0.3, 3 and 30, respectively.

Field Test Schematic



5171 kPag /

750 psig

NPS 1

0.7 m at Whitecourt, 1.5 m at Blueridge

0.40 mm (1/64”)

~ 10 m