Key Factors for Successful DPVE Remediation at Hydrocarbon-Impacted Sites

by

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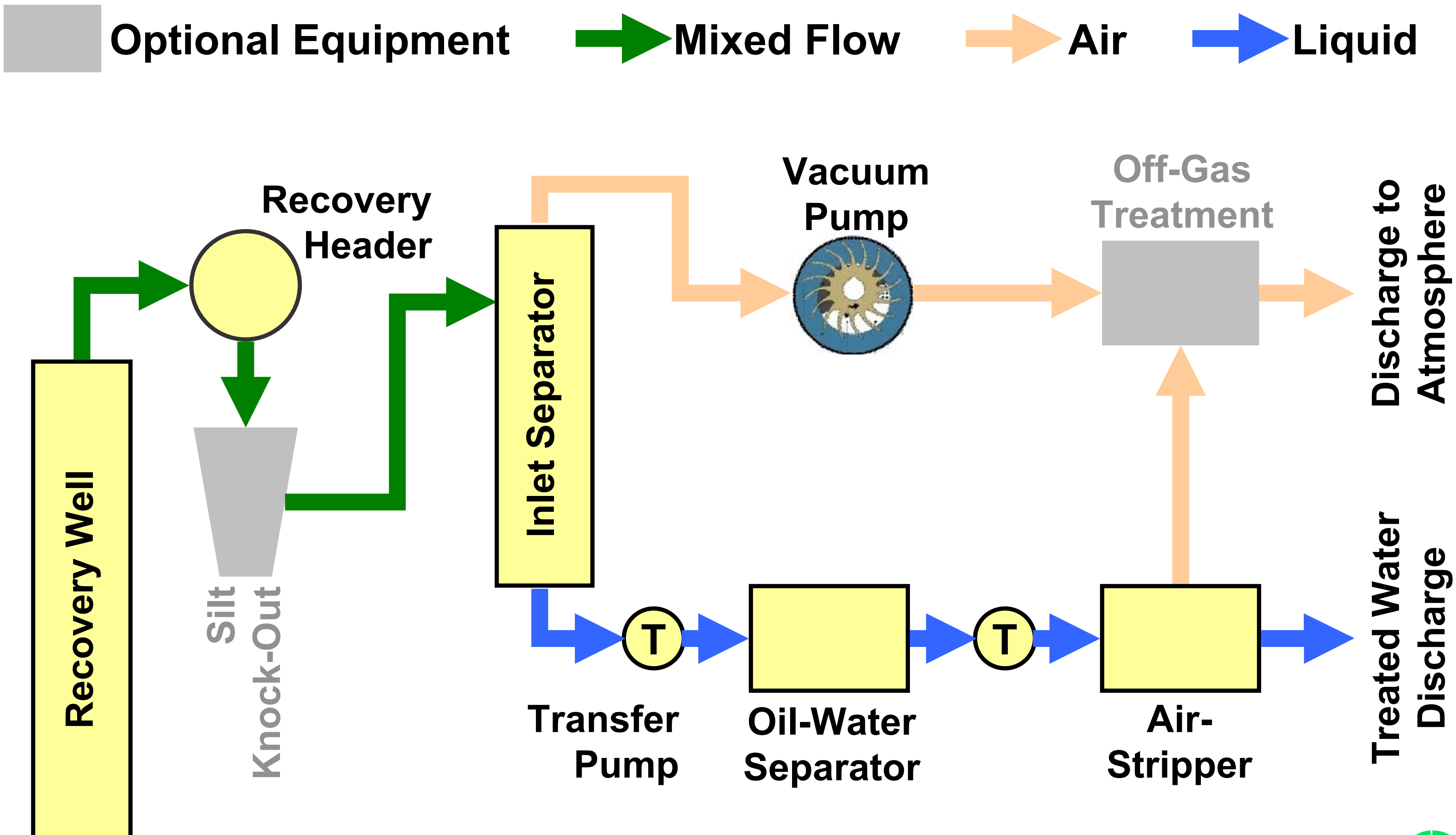
OUTLINE

- What is DPVE?
- Why DPVE?
- How to design it?
- How should it be operated?
- How well would it work?

What is DPVE?

- ◆ DPVE ≡ Dual Phase Vacuum Extraction
  - *in situ* remediation technology
  - Can remove both liquid and vapour/gas phases
  - Can extract water from depths > 30’
- ◆ Forms of DPVE
  - Both phases extracted from the same well
  - Separate air and liquid extraction wells (VEGE)

DPVE System: Typical Components



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Why DPVE?

- Can remove LNAPL, groundwater and soil air at the same time
- Aims at lowering the water table and exposing the smear zone for air flow
  - At the same potential gradient, it is more efficient to move air than water in a soil (by volume)

Rules of Thumb for Effective Application

- 10^{-5} cm/s < K_w < 10^{-3} cm/s
- LNAPL Henry's coefficient > 0.08 at 20 ºC
- Kinematic viscosity of LNAPL < 10 cSt (10 mm^2/s)
- LNAPL thickness > 15 cm

(from USACE, 1999. Multi-Phase Extraction – EM1110-1-4010)

Implementation of a DPVE System

- Development of a conceptual site model
- Numerical modelling
- Pilot testing
- Equipment selection
- System installation

Conceptual Site Model…1

- Definition
  - A realistic but simplified representation of known site conditions
  - “synthesizes and crystallizes what is already known about a site that is pertinent to decision-making”
    (US EPA Triad Resource Center)

Conceptual Site Model…2

- **Determine contaminants of concern**
  - Physical and chemical properties:
    - » Density
    - » Viscosity
    - » Surface tension
    - » Henry's coefficient
  - C-Scan of LNAPL – carbon range
  - Source zone
  - Areal / vertical distribution

Conceptual Site Model…3

- Establish remediation end-points
- Establish realistic end-points for DPVE
  - A secondary remedial technology is often more cost-effective for final “polishing”.

Conceptual Site Model…4

- Hydrogeology
  - Stratigraphy – soil type, thickness, grain size
  - Hydraulic conductivities and air permeability – saturated and unsaturated; vertical and horizontal
  - Potentiometric surface – saturated thickness; seasonal variations, confined or unconfined flow

Conceptual Site Model…5

- Tools, for example:
  - Spreadsheet / database (data analysis)
  - SURFER (contouring)
  - VOXLER (3D data visualization)
  - SADA (spatial analysis and decision assistance software) - “free”

Numerical Modelling…1

- **Objectives – to estimate:**
  - Vacuum and drawdown influence based on CSM data
  - Flow & transport:
    - » volumetric air and water flow rates
    - » Remediation time frames for LNAPL removal and subsequent reduction of dissolved and residual concentrations

Numerical Modelling…2

- **Tools:**
  - Analytical closed-form solutions - spreadsheets
  - Numerical simulators:
    - » Mostly commercial computer codes
    - » Capable of handling multiphase flow, e.g. BIOSLURP, VISUAL MODFLOW with MODFLOW SURFACT, TMVOC

Pilot Test – Parameters

- Radius of air and water influence – pressure measurements need to be barometric compensated; appropriate definition of influence
- Pump performance
- Chemical composition of extracted groundwater and off-gas

Pilot Test – Equipment

- Can be carried out using separate air and water tests
- Measure extent of vacuum and drawdown influence – need to know barometric pressure variation
- Usually 3 different modes of operation: air, slurping, water extraction

DPVE System Specifications - 1

- Size: pump based on air and water flow requirements – use pump curves to specify flow rate and operating vacuum
- Choose: variable speed drive vs. constant speed drive
- Determine: electrical power supply – volts and amps

DPVE System Specifications - 2

- Locate recovery wells based on ROI - important to overlap
- Screen wells to cover impacted zone
- Layout header system – mindful of friction loss, heat-tracing, insulation and protection from traffic load

DPVE System Specifications - 3

- See if water pre-treatment is required – usually because of silt load
- Provide appropriate treatment for discharge water and off-gas
- Set up list of deliverables and acceptance criteria for suppliers

System Implementation …1

- **Recovery well**
  - At least 3” diameter
  - Screened over impacted zone
  - Equipped with adjustable drop tube
  - May be compressed-air assisted

System Implementation …2

- Header
  - Frictional loss $\propto$ (diameter)^5 - use at least 3" diameter pipes
  - Avoid sharp (>90º) bends – use 2 - 45º elbows
  - Heat-tracing & insulation

System Implementation …3

- **System Delivery & Commissioning**
  - Need a formal acceptance procedure to ensure system has been built according to specifications
  - List of deliverables

System Implementation …4

◆ Other considerations

- Sound abatement
- Silt knock-out on intake line
- Oil knock-out on exhaust air line
- Off-gas treatment

System Operation …1

- ◆Pump needs TLC
- ◆Give TLC by:
  - Monitor operating parameters
  - Regular maintenance – e.g. remember

System Operation …2

- Iron fouling – air-stripper, recovery wells, discharge line, headers:
    - Acid treatment; jetting; replacement

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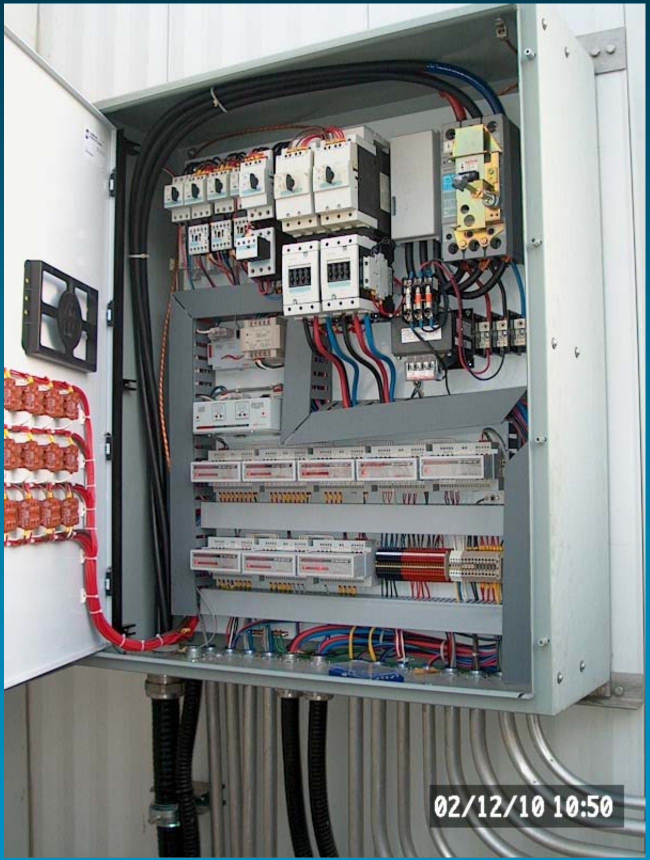
System Operation …3

- Periodic adjustment of drop-tubes to expose smear zone for air movement
  - $Q_{air} \cong 10 \times Q_{water}$ at 278 K (5 ºC)

System Operation …4

- Programmable logic control system for monitoring, data-logging and dialing out on alarm conditions



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Some Experience to Share

- Pump types
- Time to remove LNAPL
- Successful clean-up

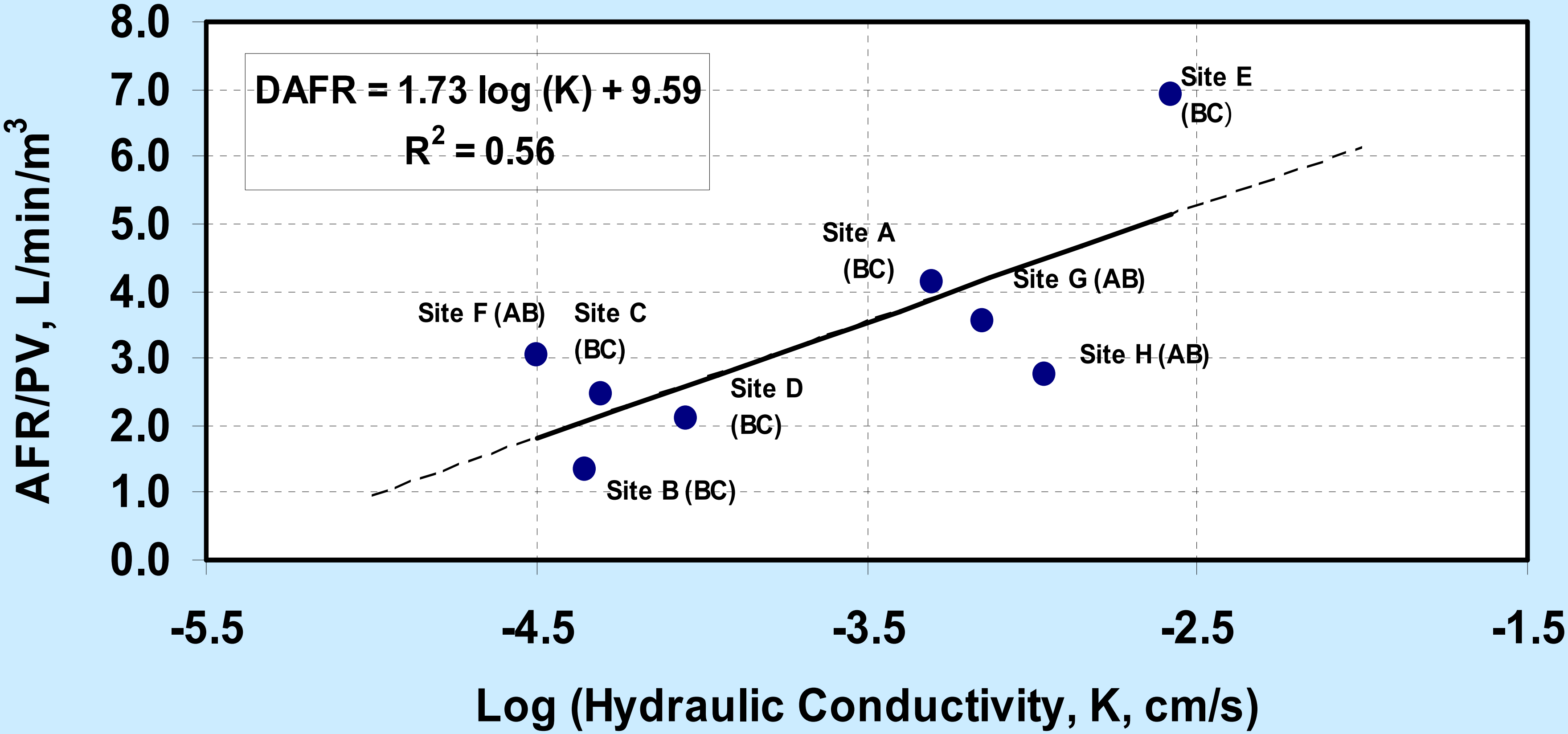
Pump Types - Comparison

	Liquid Ring	Rotary Claws
Uptime	80 to 89%	90% to 92%
Noise	Lower	Higher
Oil Blow-by	Yes	No
Temperature	High	Very High

Successful LNAPL Removal

Site	Soil Type	Time for Removal (months)	# Pore Vol. Exchanged
BC-A	Silty Sand (SS)	5.5	996
BC-B	Sandy Gravel	11.0	642
BC-C	SS & Gravel	7.0	752
BC-E	SS & Gravel	10.0	3034
AB-F	Sandy Silt	30.0	4003
AB-G	Silty Sand (SS)	9.5	1482
AB-H	Sand, some Silt	12.0	1459

Air Flow Rate Required for LNAPL Removal



Modified from Kallur et al. (2003)

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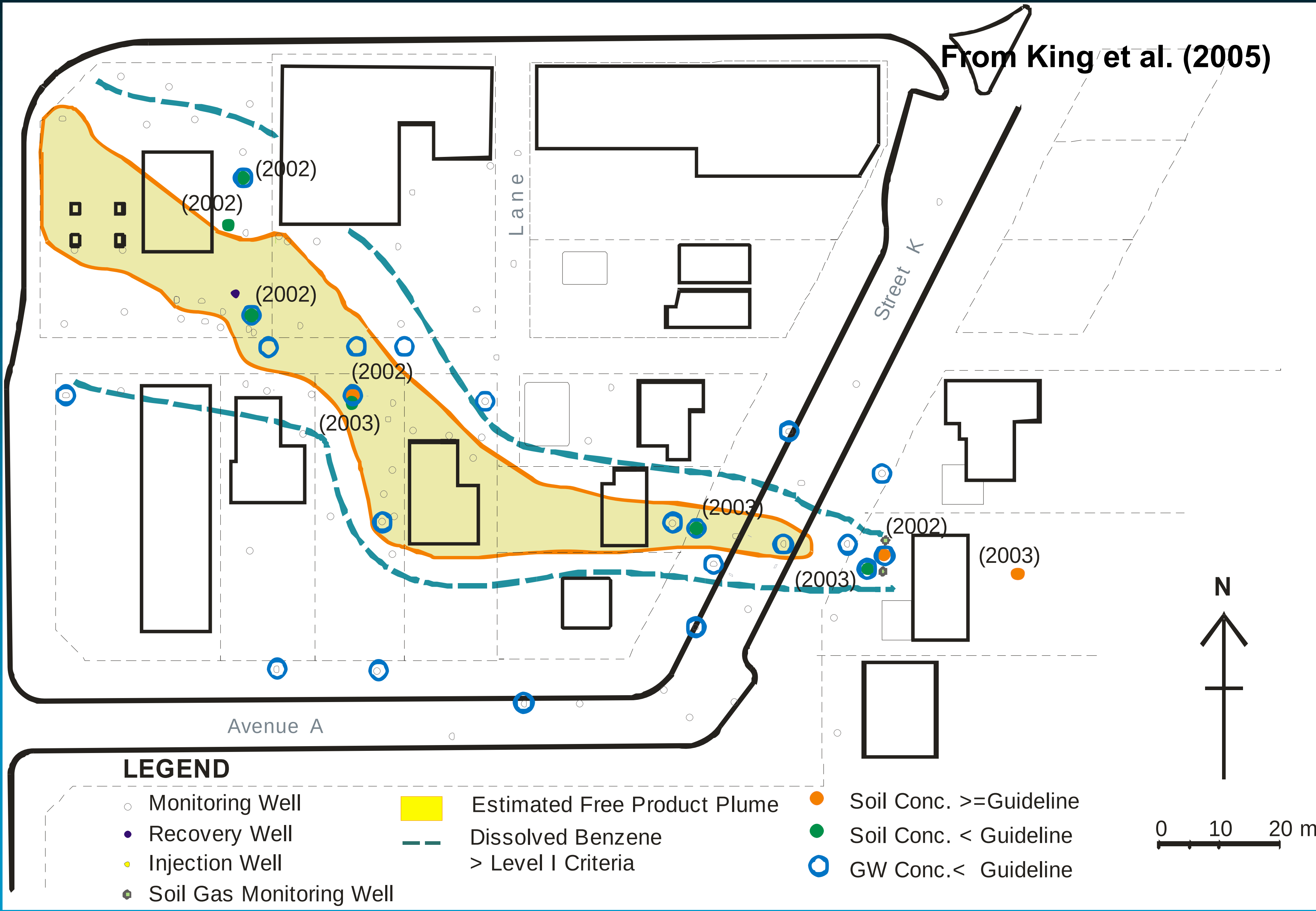
Reductions in Soil & GW Conc.



Summary

- DPVE aims at exposing the smear zone for air movement
- DPVE can be a viable in situ remediation option for gasoline-impacted sites if:
  - $3x10^{-5} \leq K_w$ [cm/s] $\leq 3x10^{-3}$
  - Average saturated thickness > 2 m
  - However, may not be very effective for > F2
- Needs care and attention in its design and operation

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Thanks to ….

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  - Andrew, Chad, Jeff, Ken, Martin, Mike, Todd…, especially Brent
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Thank you!

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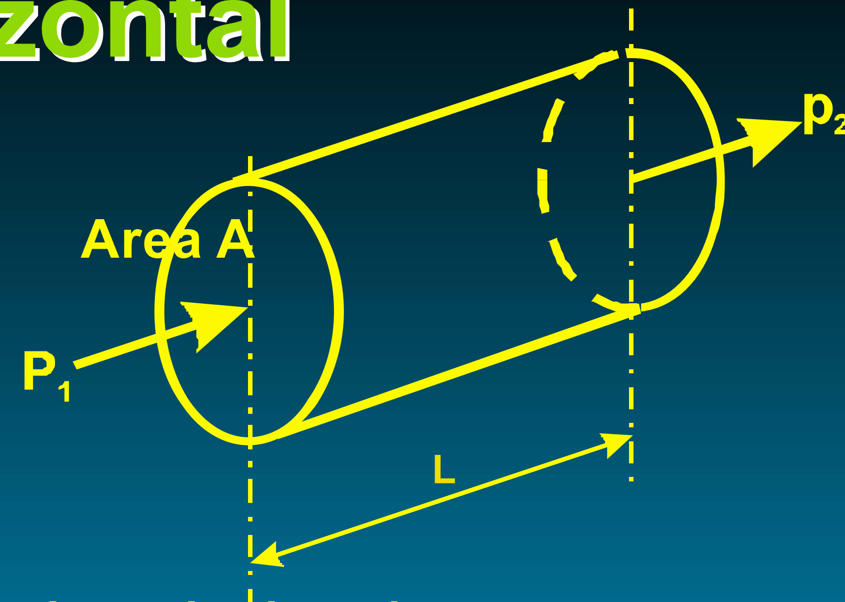
Darcy's Law for Horizontal Fluid Flow



For water:

$$Q_w = \frac{k}{\mu_w}\frac{(p_1 - p_2)}{L}A$$

For air (isothermal):

$$Q_a \cong \frac{k}{\mu_a}\frac{(p_1 - p_2)}{L}A$$

$\dot{m}$

μ: dynamic viscosity
ρ: density
k: intrinsic permeability of medium
K: fluid conductivity
m: mass
Q: volumetric flow rate

At 278 K (5 ºC):

$$\frac{Q_a}{Q_w} = \frac{\mu_w}{\mu_a} = \frac{1.52}{0.018} \cong 84; \quad \frac{K_a}{K_w} = \frac{\mu_w}{\mu_a}\frac{\rho_a}{\rho_w} = \frac{\dot{m}_a}{\dot{m}_w} \cong \frac{1}{9}$$

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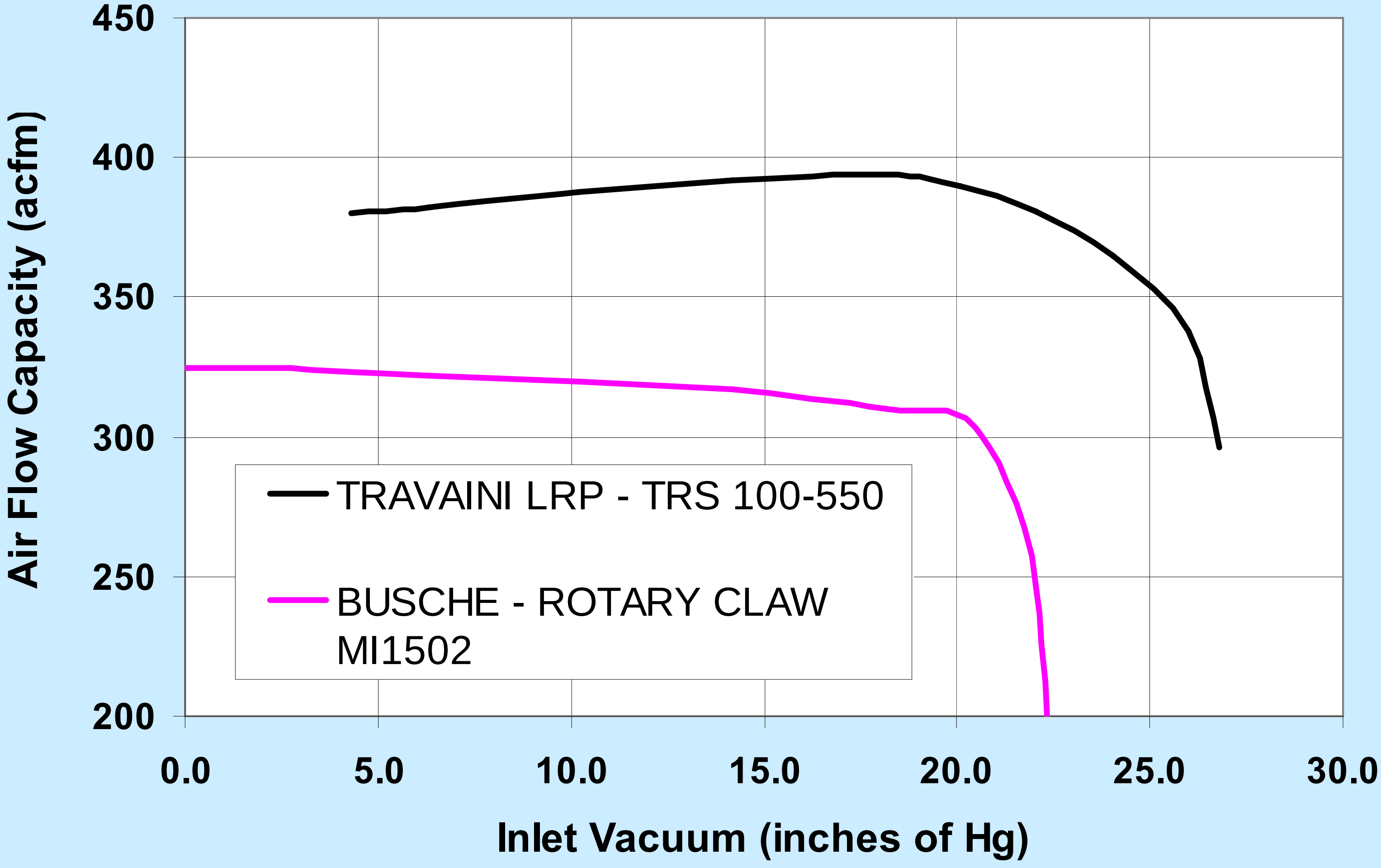
Typical Pump Curves



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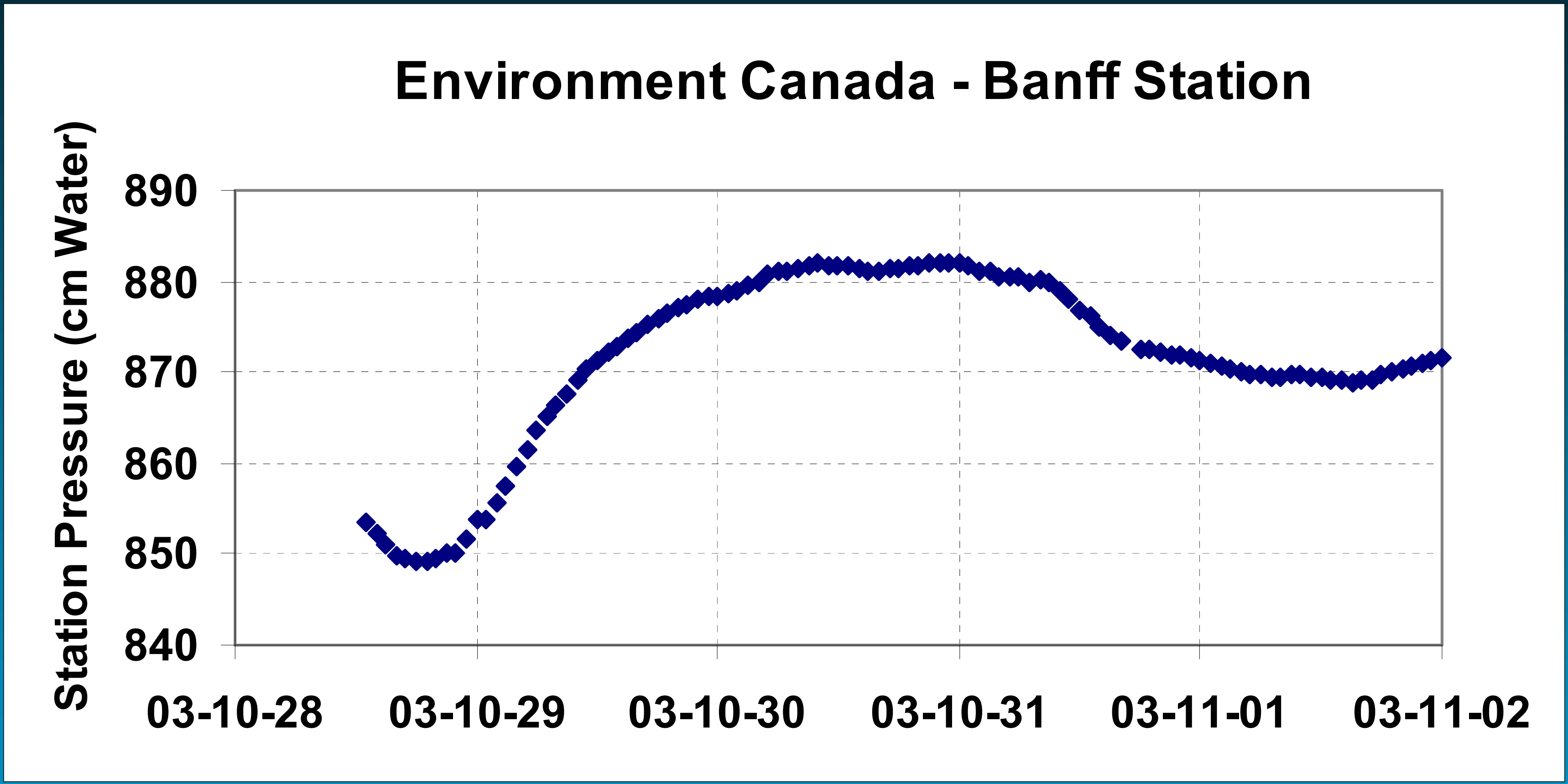

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