In Situ Aeration-Based Remediation Technologies

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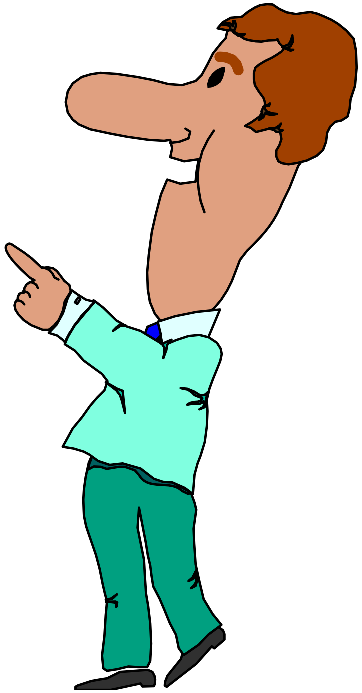
Aeration-Based Technologies

- In Situ Soil Vapor Extraction (SVE)
- Bioventing
- In Situ Air Sparging (IAS)
- Aerobic Biobarriers
- O_2 Delivery for Aerobic Biodegradation



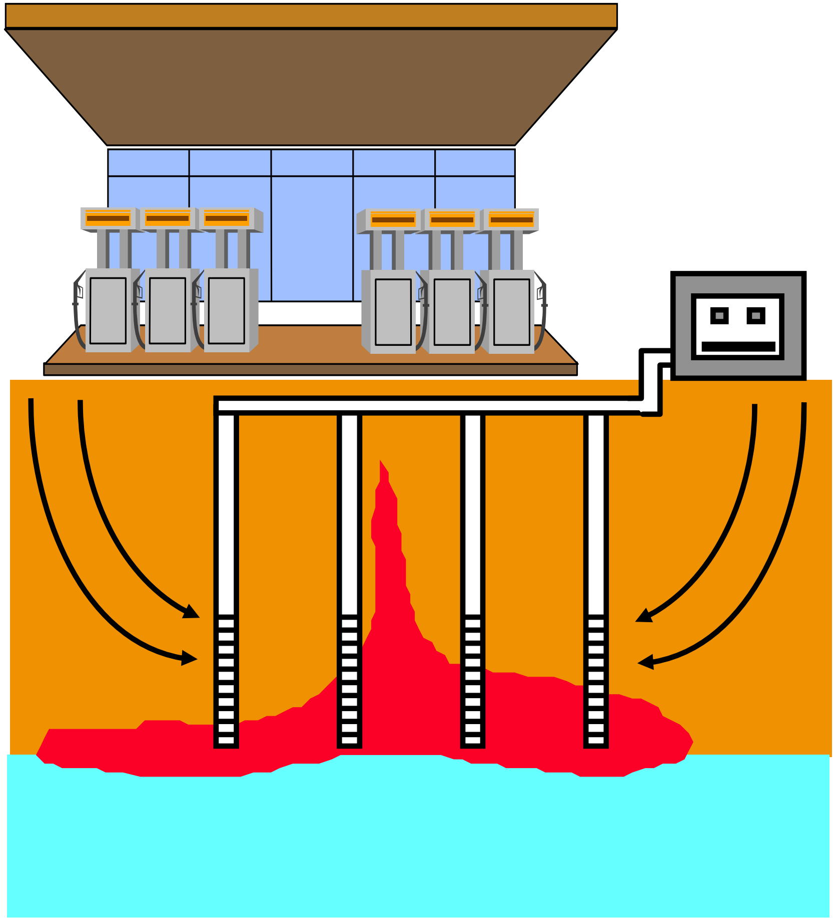
All of these involve vapor delivery and/or extraction and all rely to some extent on volatilization and aerobic biodegradation

Aeration-Based Technologies

- What are they?
- What are they used for?
- Why would I want to use them?
- When would I not use them?
- What will the typical consultant do (to) for me?
- How do I know if it's working?
- What do I need to know to apply these technologies most cost-effectively?

Soil Vapor Extraction - What is it?

- **In situ soil vapor extraction (SVE) involves extracting vapors from the subsurface via wells screened across the vadose zone.**
- **The vapor flow (not the vacuum) promotes volatilization by sweeping contaminant vapors to the extraction wells.**
- **Vapors are treated above-ground or directly discharged to the atmosphere.**
- **Vapor treatment costs can dominate the economics in some areas.**



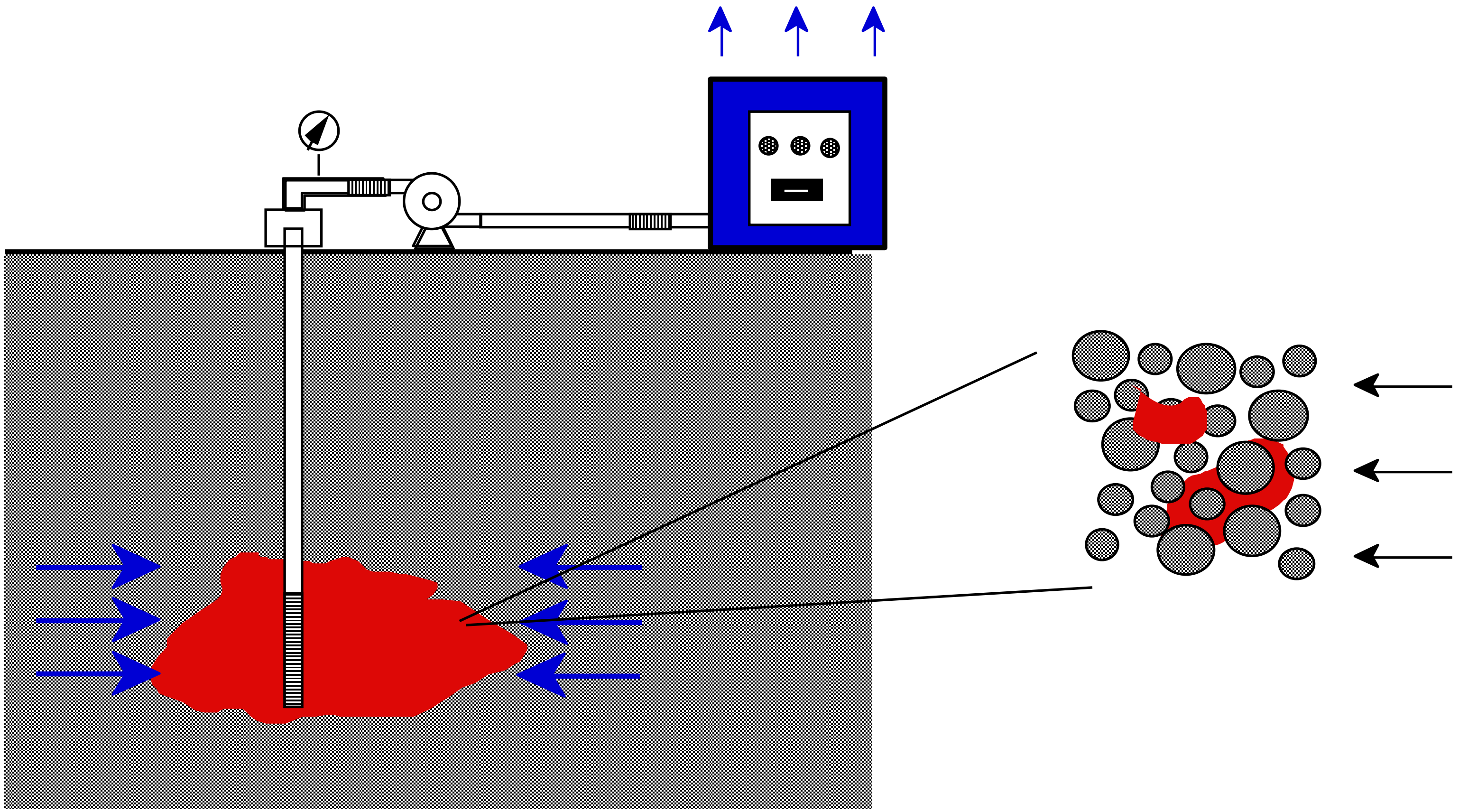
What is it Used For?

In situ soil vapor extraction (SVE) systems are commonly used to remediate vadose zone soils impacted with:

- **Petroleum fuels (gasoline, aviation fuel, etc.)**
- **Chlorinated solvents (dry cleaner sites, etc.)**

SVE is also used in combination with other technologies like in situ air sparging and in situ thermal heating to access chemicals below the water table, trapped in tighter soils, or of lower volatility.

Factors Affecting Performance



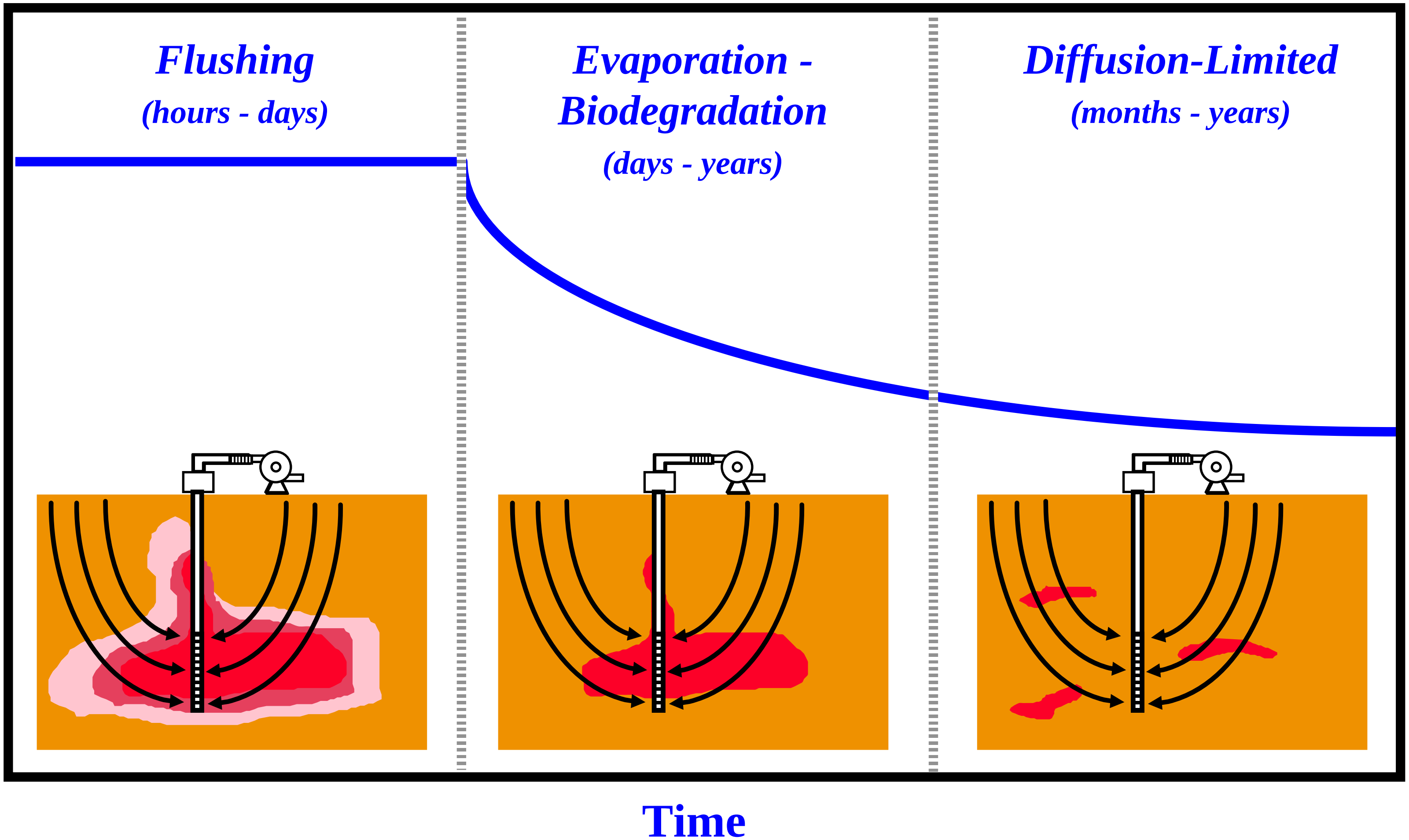
- Vapor Flow
- Chemical Partitioning
- Contaminant/Soil Distribution
- Mass Transfer Considerations
- Biodegradation/Chemical Reaction?

Progression of Performance

Volatilization Removal Rate = Flowrate x Concentration

Aerobic Biodegradation Rate = 2 - 20 mg-TPH/kg-soil/d (gas, jet fuel, etc.)

(if O_2 > 2% v/v)



Technology Selection:

Screening Calculations

Flowrate Estimation → Q_{well}

↓

Maximum Vapor Concentration → C_{vapor}

↓

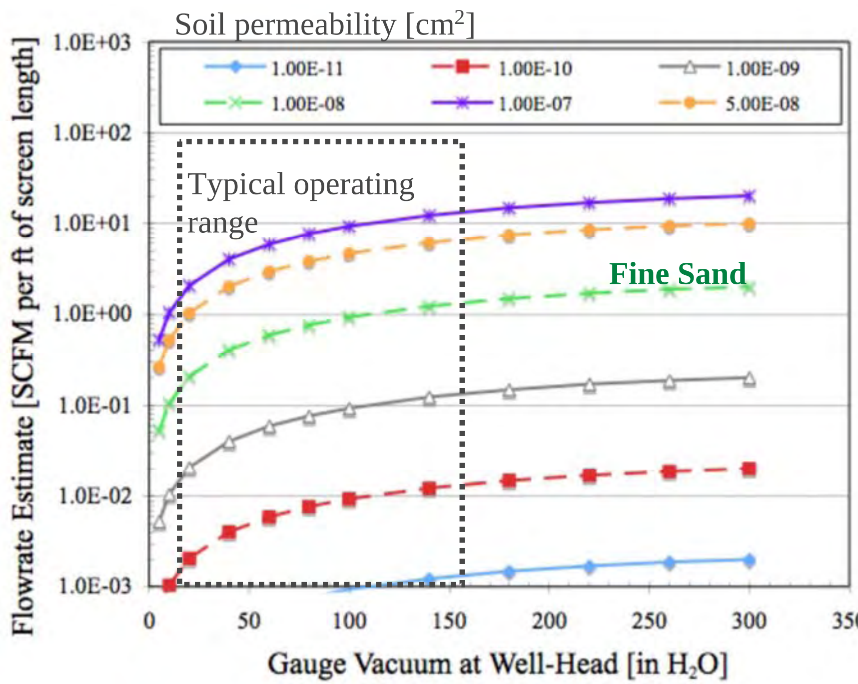
Maximum Removal Rate → $R = Q{*}C_{vapor}$

↓

Acceptable? → $t_{min} = \dfrac{M_{spill}}{Q{*}C_{vapor}}$

↓

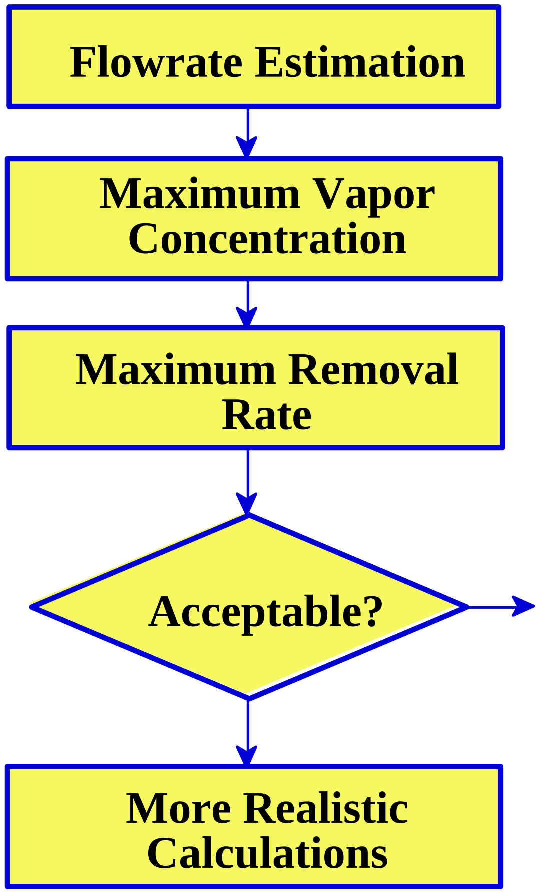
More Realistic Calculations → **Composition changes, mass transfer issues, etc.**



Johnson, P.C., C.C. Stanley, M.W. Kemblowski, D.L. Byers, and J.D. Colthart. 1990. A Practical Approach to the Design, Operation, and Monitoring of In Situ Soil-Venting Systems. Ground Water Monit. Rev.. 10 (2). 159 - 178.

Technology Selection:

Key Concept



Removal by volatilization is related to the volume of vapor passed by the contaminant per unit initial contaminant mass **(not related to vacuum applied, except that it causes flow).**

For example, partitioning calculations suggest that:

> **>100 L-air is required per initial gram of weathered gasoline to achieve >90% removal under ideal conditions**
>
> **>2.5 L-air is required per initial gram of TCE to achieve >90% removal under ideal conditions**

Higher vapor volumes are needed when there are mass transfer issues (e.g., contaminants in low permeability lenses)

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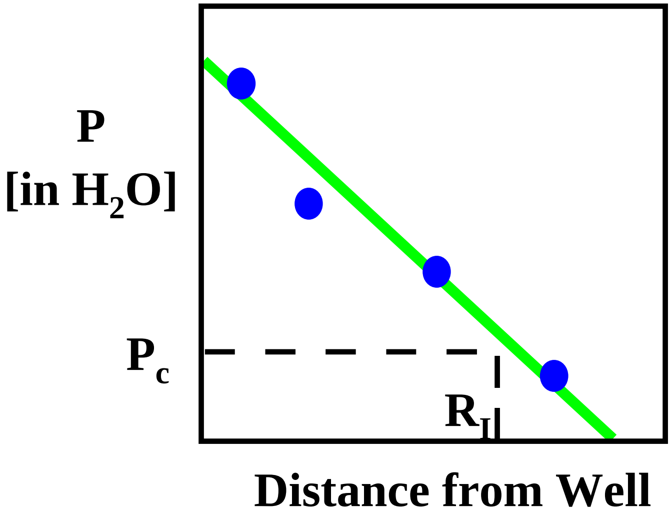
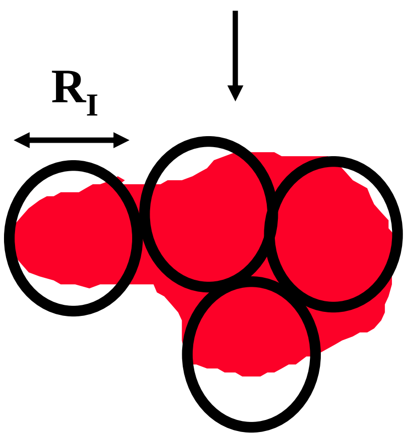
Pilot Testing and System Design

Conventional Approach

Pilot Test/Design Approach

1) Turn on blower
2) Measure flow rate
3) Measure P vs. R
4) Plot data and extract R_I
5) Space extraction wells so that R_I's encompass treatment zone



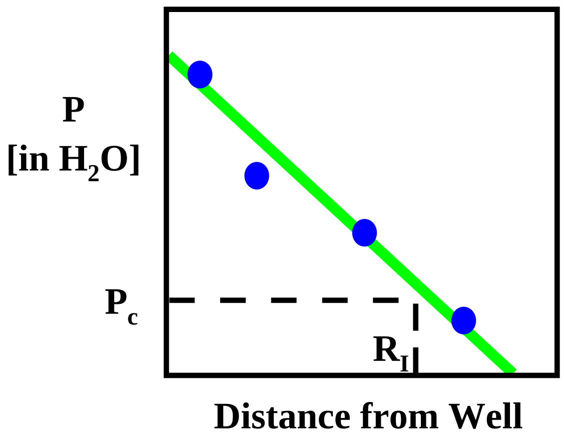


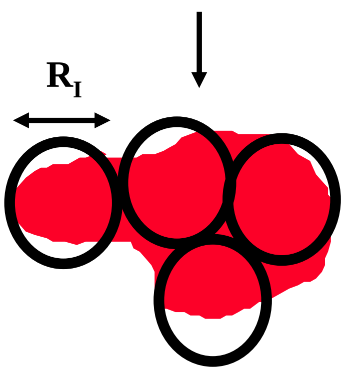
Johnson, P. C. and R. A. Ettinger. 1994. Some Considerations for the Design of In Situ Vapor Extraction Systems: Radius of Influence -vs- Radius of Remediation. Ground Water Monitoring and Remediation. 14 (3). 123 - 128.

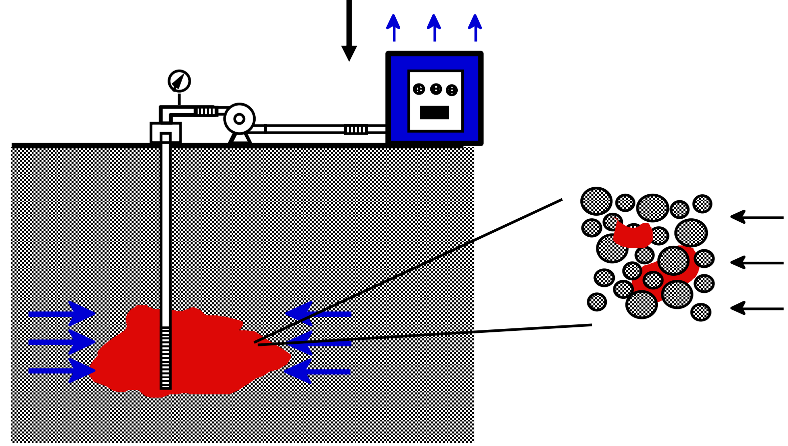
Pilot Testing and System Design

OK, but does this make sense??

This — **Has Nothing to do with this**





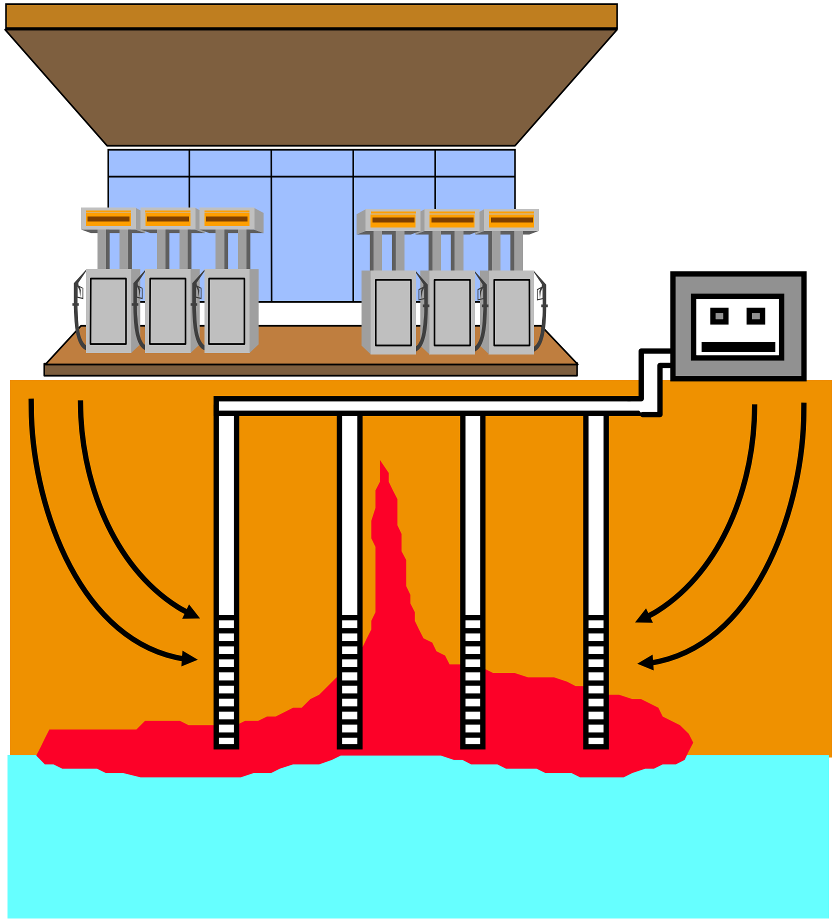


- Vapor Flow
- Chemical Partitioning
- Contaminant/Soil Distribution
- Other Loss Mechanisms
- Mass Transfer Considerations

System Design - What Should I Know?

The conventional pilot-test and "radius-of-influence" design approach at best insures vapor capture, but has no relationship to clean-up efficiency. It is important to keep in mind that:

- **Removal efficiency depends primarily on the volume of vapor extracted per unit mass of residual contaminant ($Q \times t/V_{min}$)**
- **Removal is also dependent on the vapor flow field relative to the contaminant location**
- **More SVE wells generally leads to better removal (even at the same total flow)**



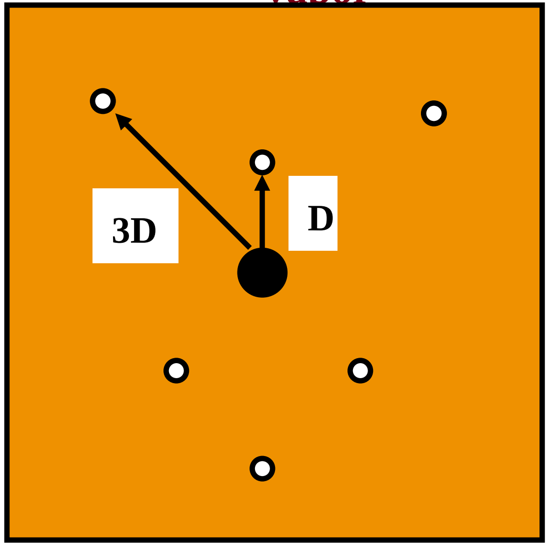
Don't forget that: $R = Q*C_{vapor}$

Pilot Testing - What Should Be Done?

If you are constrained to a short-term test, you should focus on looking for signs of infeasibility (i.e. indications that SVE won't work) and measurements that have relevance to key design components:

- **flowrate vs. applied vacuum (8-h test)**
  (blower selection, removal rate calculation, anomolies...)
- **effluent vapor concentration (8-h test)**
  (vapor treatment, removal rate calculation, anomolies...)
- **vacuum vs. distance (& time) (8-h test)**
  (extent of pressure field, permeability, anomolies...)
- **soil gas concentrations (72-h test)**
  (biodegradation rate, removal efficiency, anomolies...)

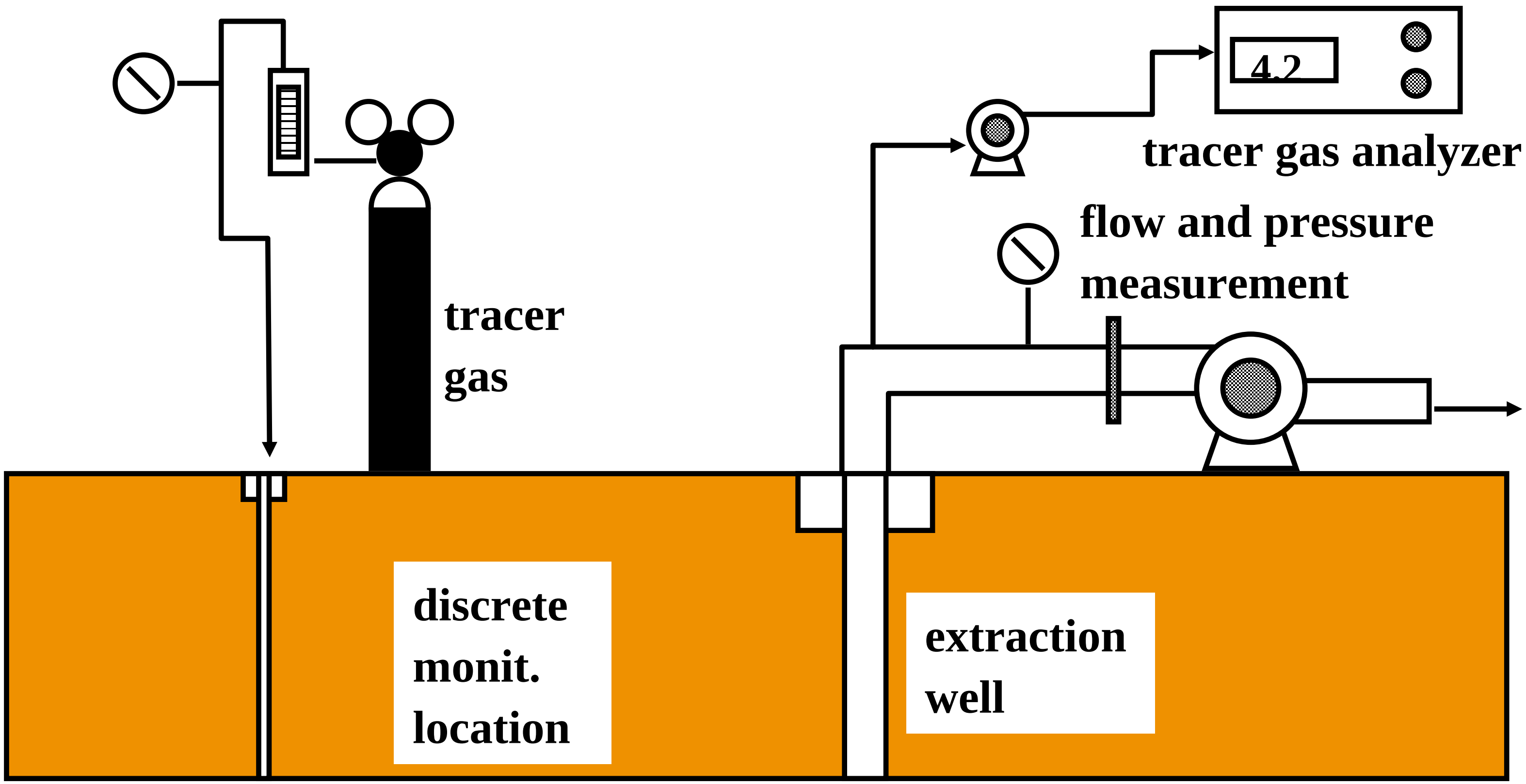
Don't forget that:
$R = Q*C_{vapor}$



D = Depth below groundwater to top of extraction well screen

Pilot Testing - What Should Be Done?

If it is critical to define or verify the vapor capture zone, the use of a conservative gas tracer (e.g., helium) is recommended

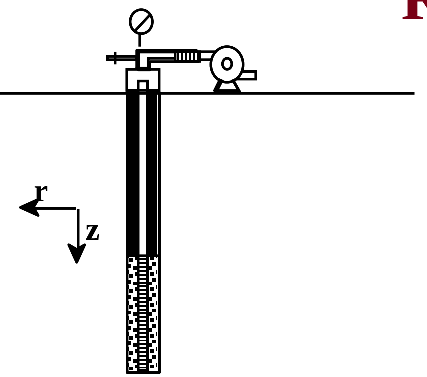


System Design - What Should I Know?

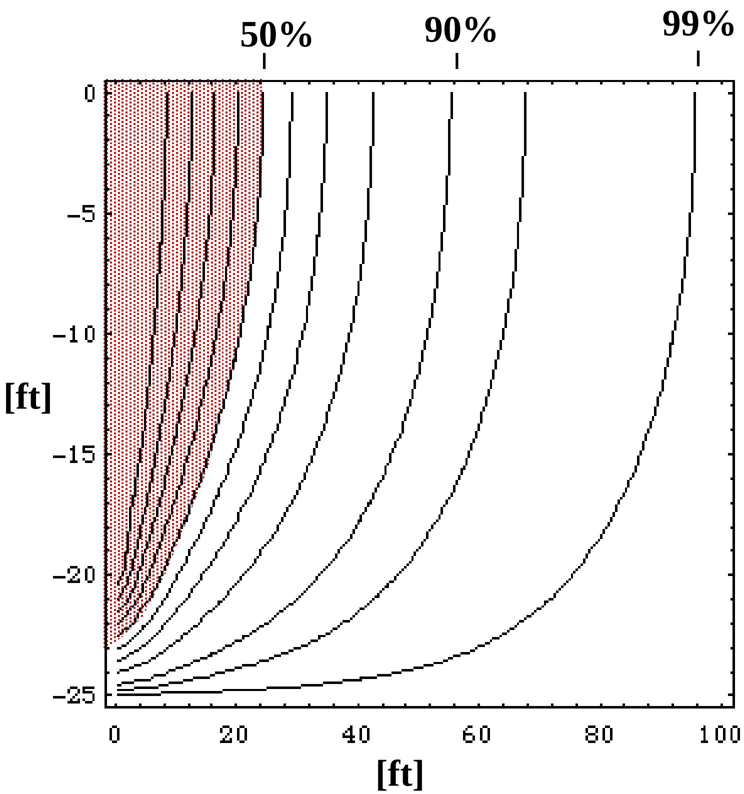
2-D radially-symmetric steady flow
(homogenous, anisotropic media)

Baehr, A.L. and M.F. Hult. 1991. Evaluation of unsaturated zone air permeability through pneumatic tests. Water Resources Research. 27(10).

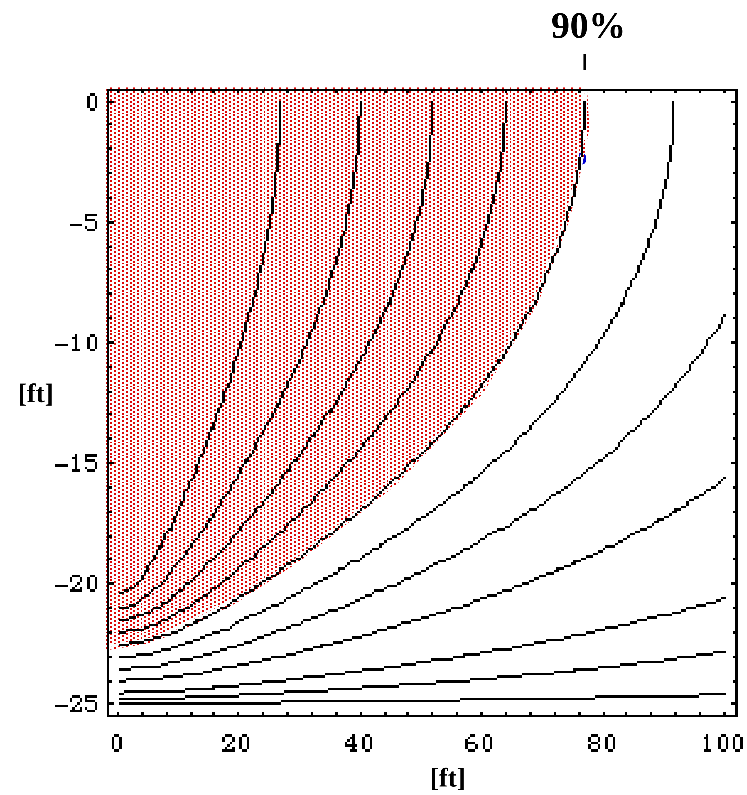
$$R_F \approx D_w \times (k_h/k_v)^{1/2}$$



$k_h/k_v = 1$

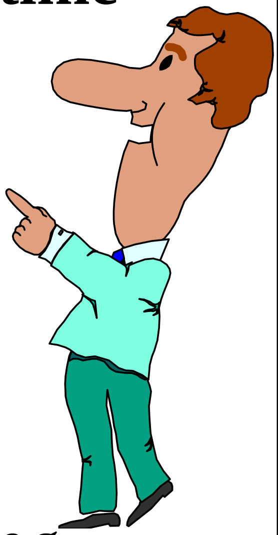


$k_h/k_v = 10$



System Design - What Should I Do?

- **Define remedial goals (time, clean-up goals, etc.)**
- **Determine the minimum flow volume requirement to achieve the remedial goals**
- **Calculate the minimum number of wells required to achieve the minimum flow requirement in the desired time**
- **Determine the zone of air flow for a given well construction (pilot data & theory)**
- **Choose the number of wells to ensure adequate flow volume and flow field coverage**
- **Select above-ground equipment (blowers, piping, etc.)**
- **Be sure to allow for maximum flexibility in operation (e.g., valves to all wells, etc.)**
- **Be sure to allow for diagnostic performance monitoring (e.g., vapor flow from each well, concentration from each well, etc.)**



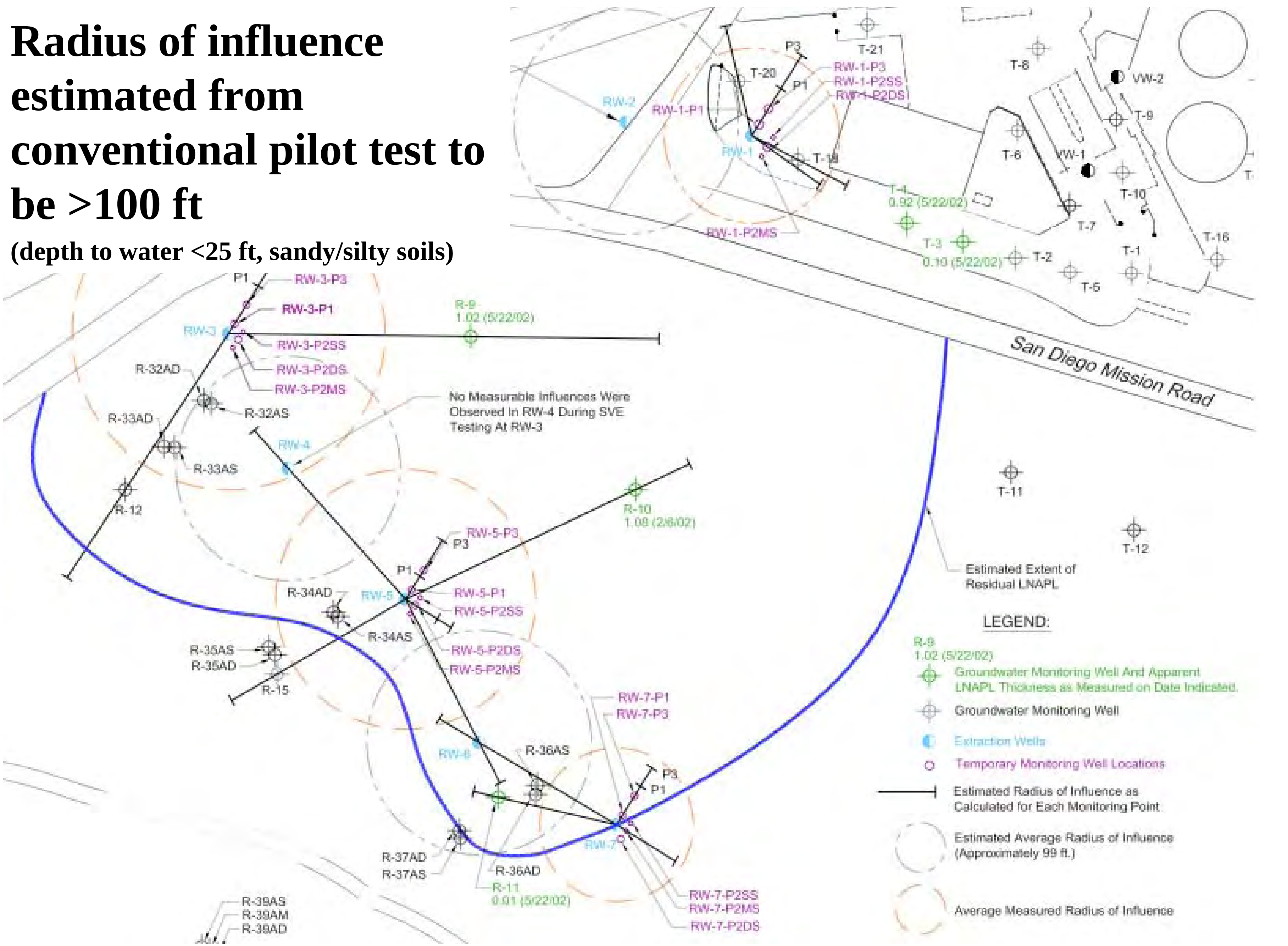
SVE Case Study

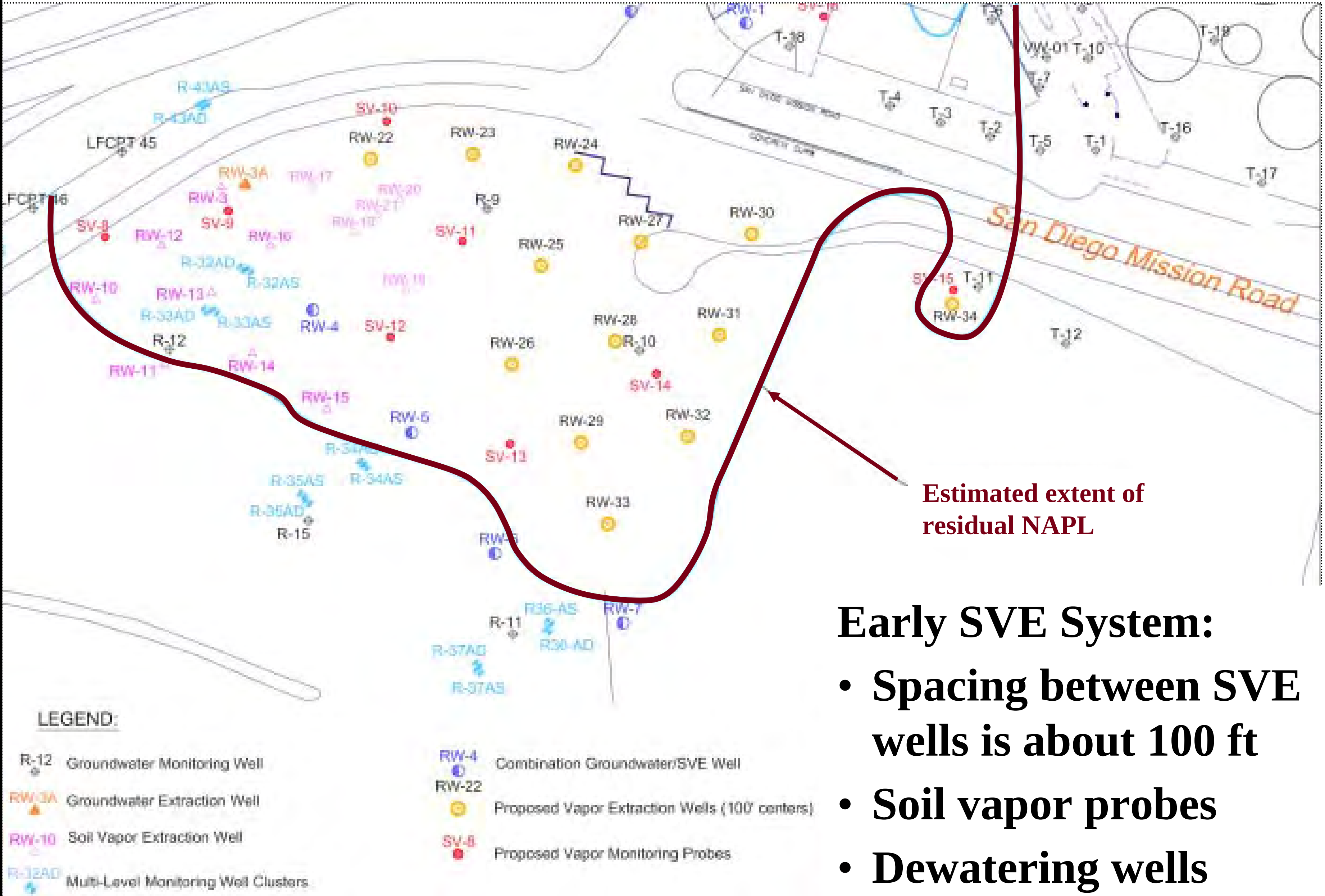
Cleanup required by end of 2010 or severe penalties will be incurred (it really needs to be cleaned up…).

Remediation system selected combines aquifer dewatering + SVE

Radius of influence estimated from conventional pilot test to be >100 ft

(depth to water <25 ft, sandy/silty soils)

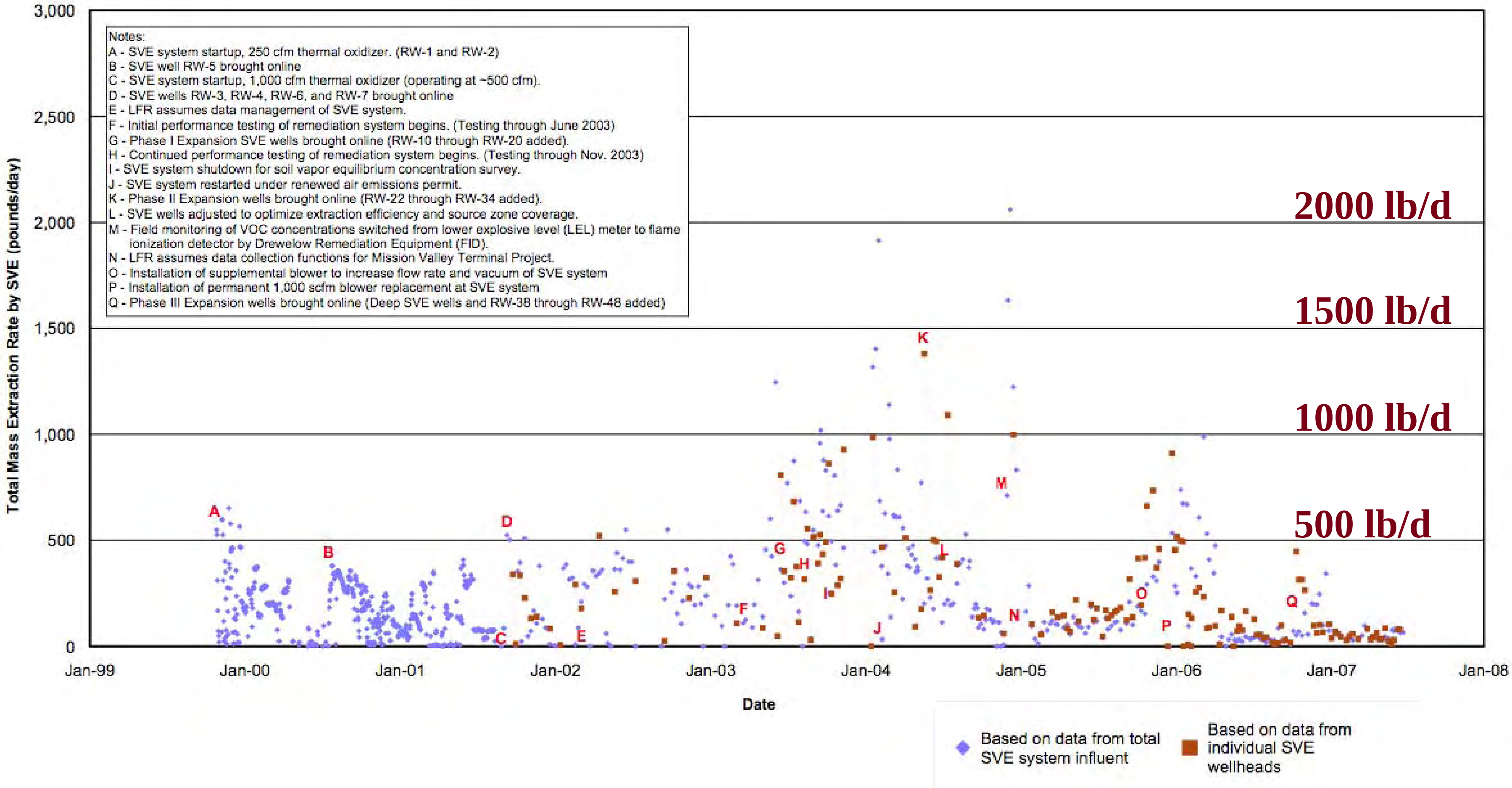




Early SVE System:

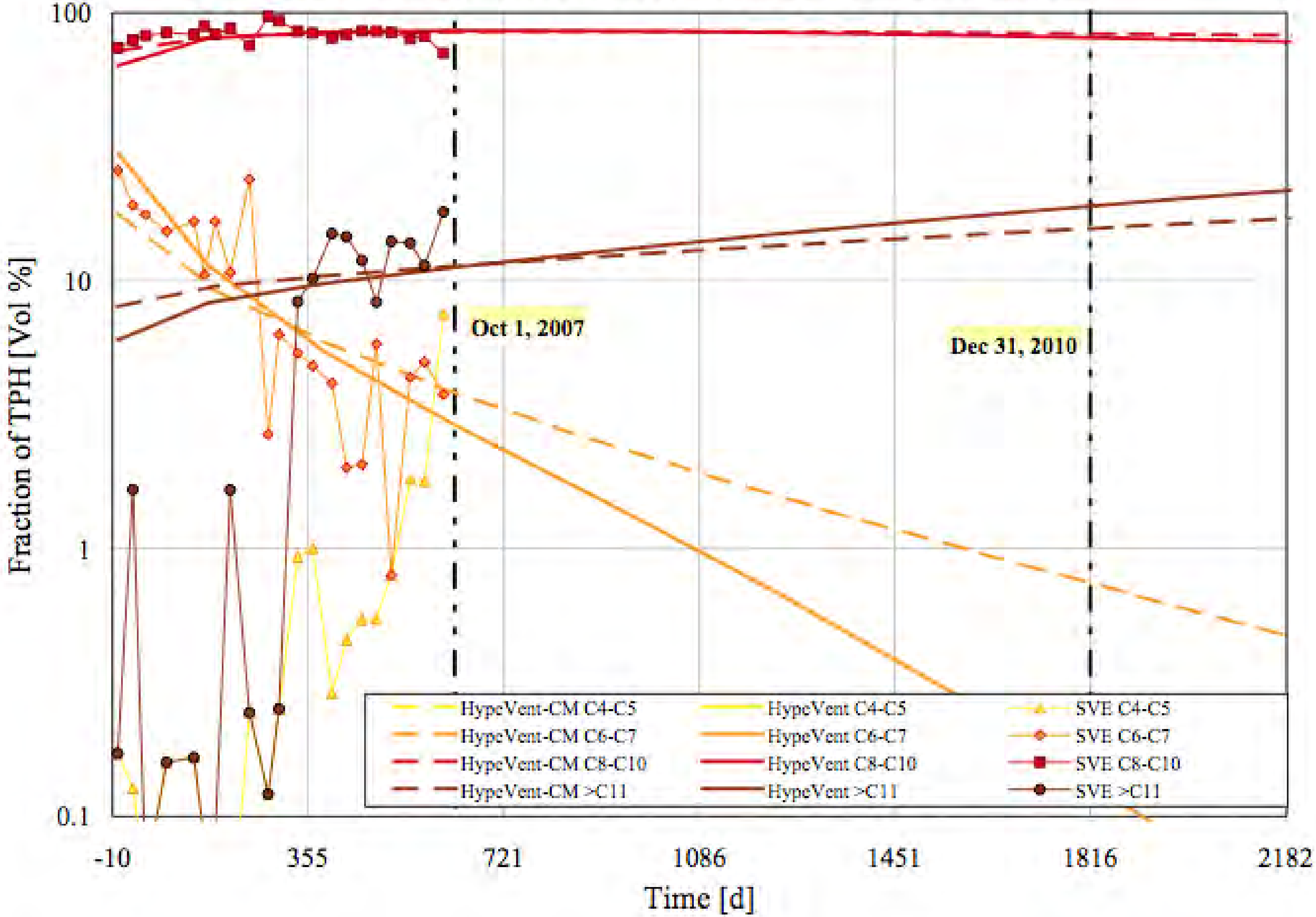
- Spacing between SVE wells is about 100 ft
- Soil vapor probes
- Dewatering wells

Typical Mass Removal vs. Time Data

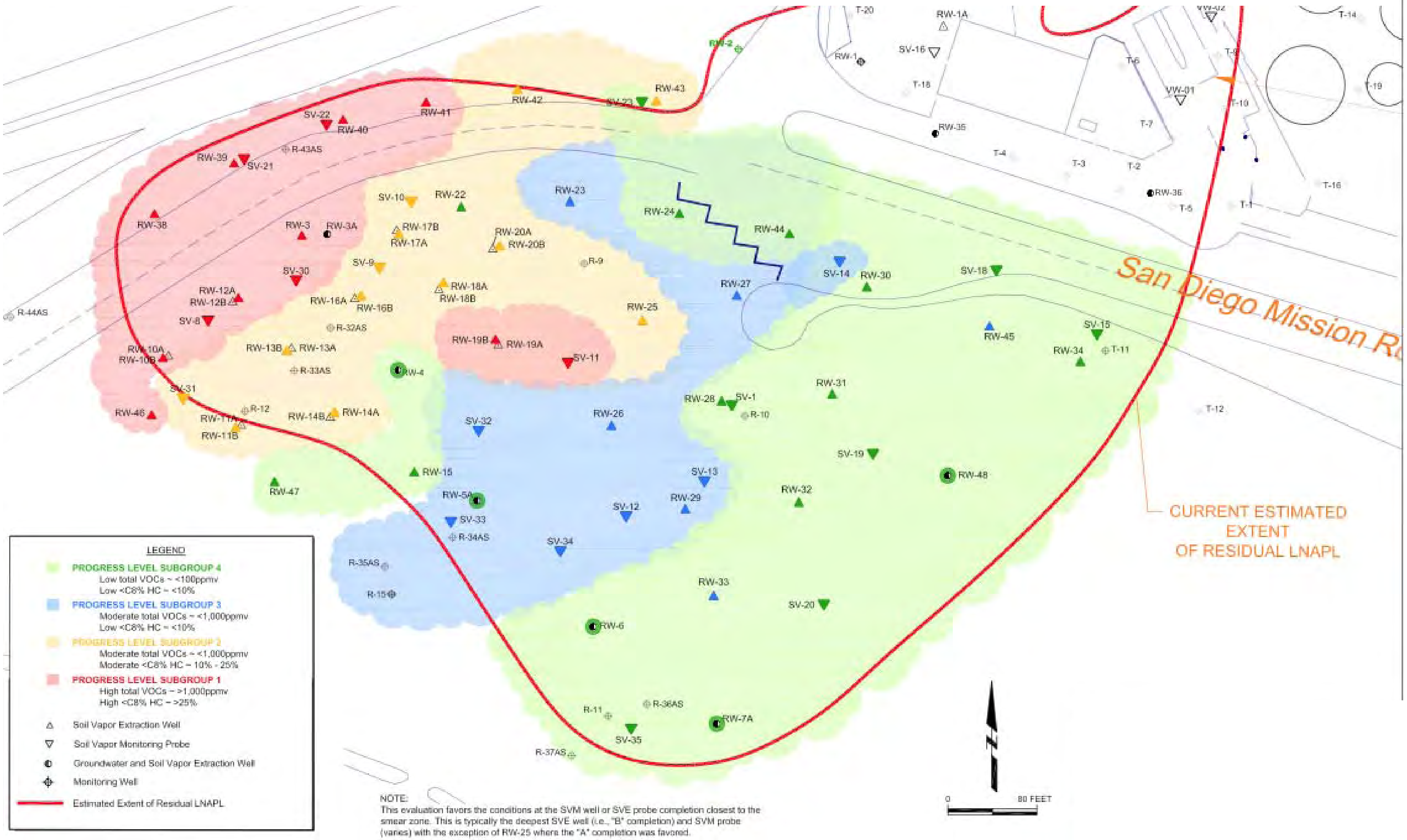


But…Will the system meet the desired cleanup goal by 2010?

Composition vs. Time Data Combined with Simple HypeVent Model Projections

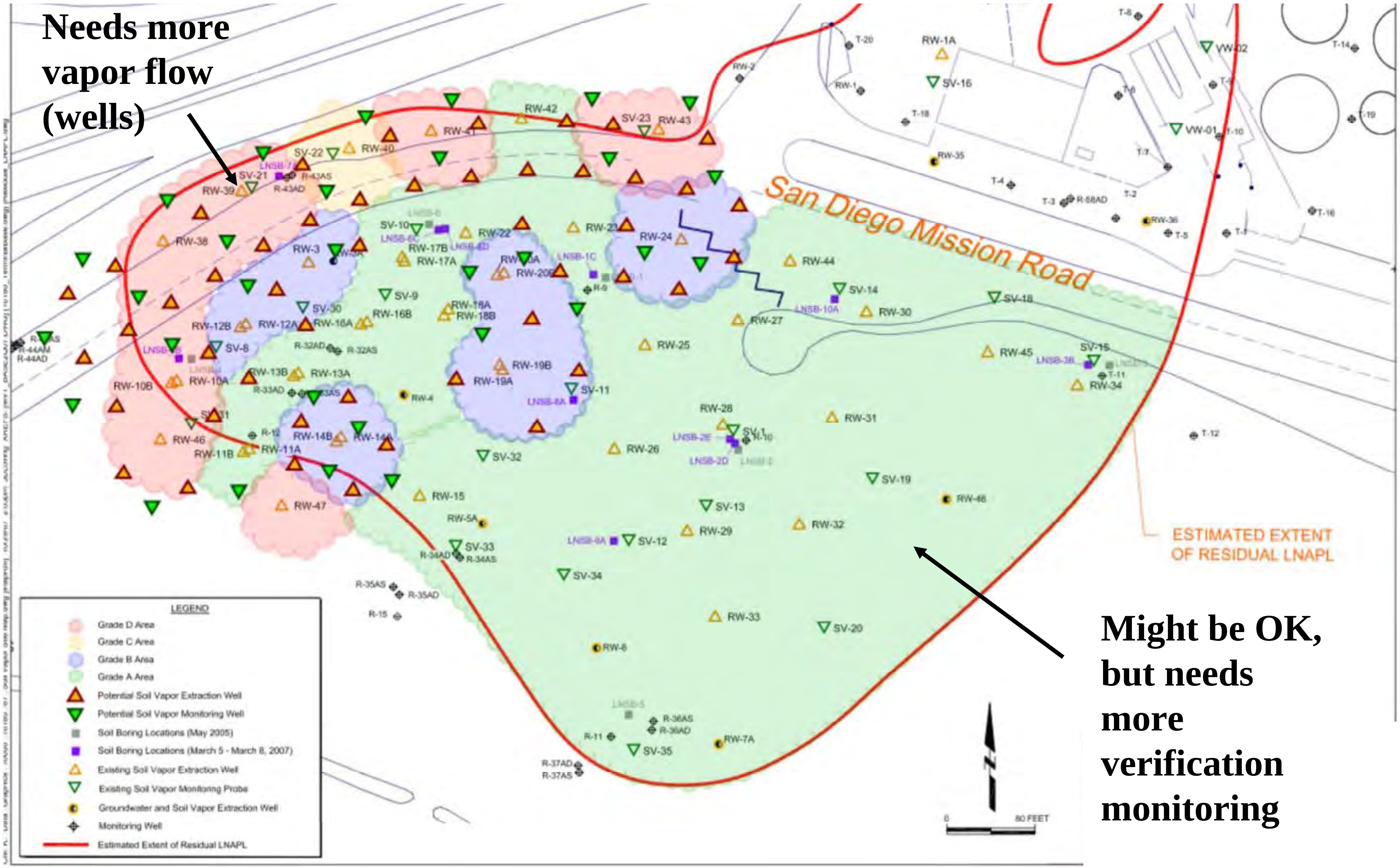


Characterization of the Remedial Progress and Identification of Areas Needing Attention



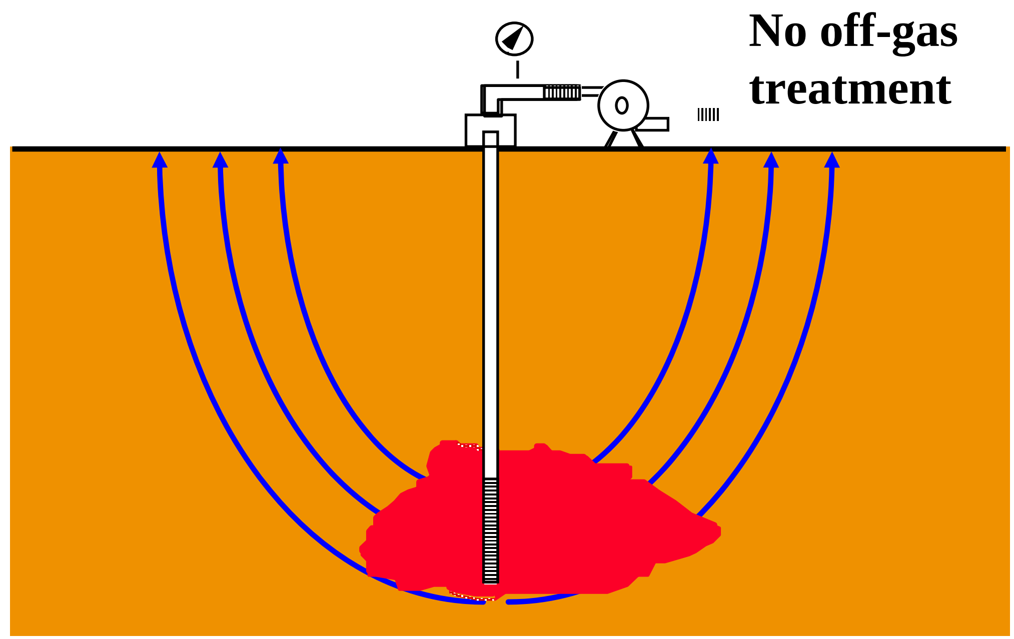
Characterization of the Remedial Progress and Identification of Areas Needing Attention

Needs more vapor flow (wells)



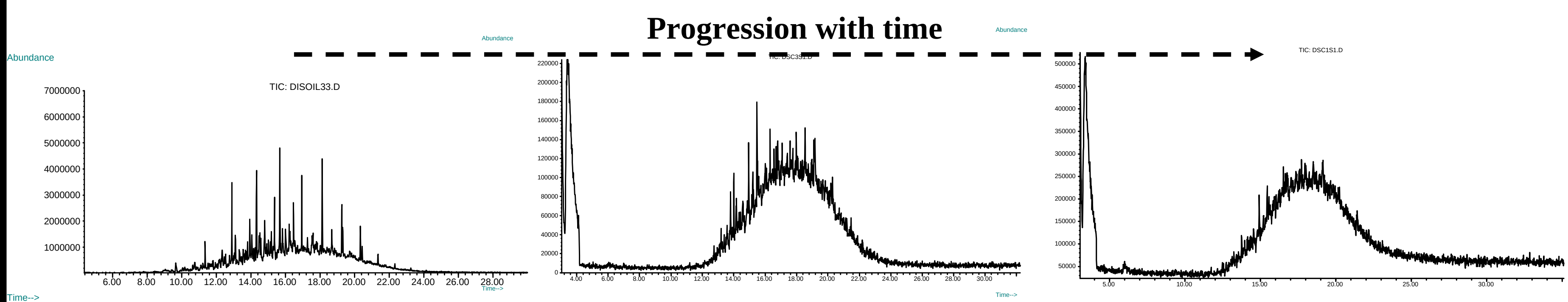
Might be OK, but needs more verification monitoring

Bioventing



Inject air at minimum flowrate necessary to achieve >5% v/v O_2 in soil gas (generally determined empirically)

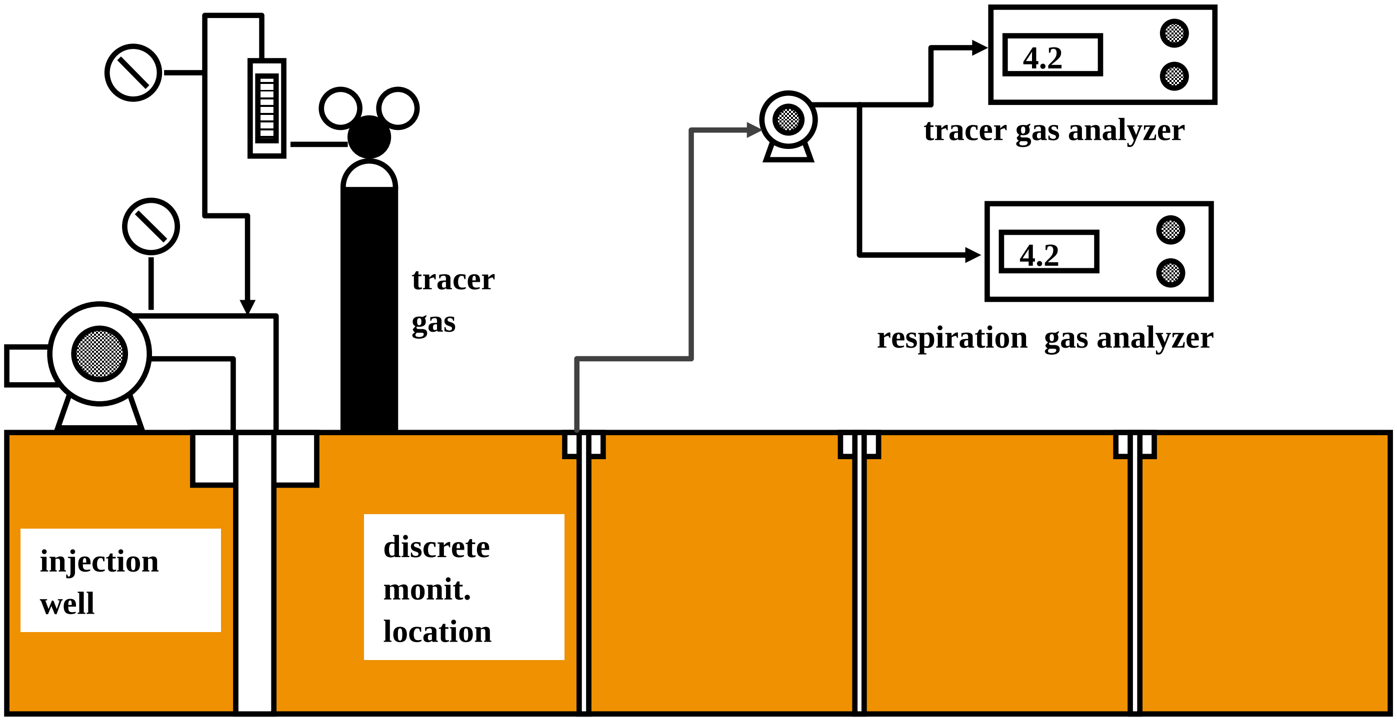
$$C_6H_{14} + 19/2\ O_2 \rightarrow 6\ CO_2 + 7\ H_2O$$



http://www.afcee.brooks.af.mil/products/techtrans/bioventing/

Pilot Testing - Bioventing

Respiration and Tracer Gas Monitoring



1. Inject air and helium (≈24-h): measure flowrate and applied pressure
2. Stop air & tracer gas injection: collect soil gas samples
3. Soil gas monitoring (≈72-h): monitor He, O_2, CO_2 in soil gas with time
4. End test when $O_2 \leq 5\%$ in soil gas
5. Determine biodegradation rate from O_2 uptake rate

Bioventing - Pilot Test Data Reduction

$$k_B = -\frac{\left[\frac{k_{O_2}}{100\%}\right]\left[\theta_a\ \rho_{O_2}\right][C]}{\rho_{soil}}$$

k_{O2}	= oxygen utilization rate [%/d]
θ_a	= vapor filled porosity [L-air/L-soil] ≈ 0.25
ρ_{O2}	= density of oxygen gas [mg-O_2/L] ≈ 1330 mg/L
C	= mass ratio of hydrocarbons to oxygen required ≈ 0.3
ρ_{soil}	= soil bulk density [kg-soil/L-soil] ≈ 1400 kg-soil/L

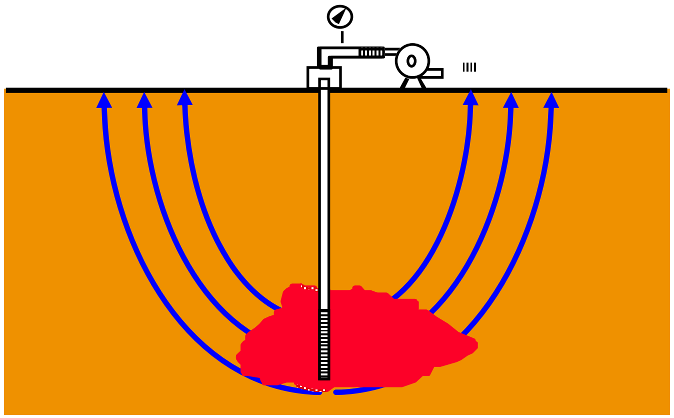
$$k_B \approx -0.68\ k_{O_2}$$

Typical initial rates are 2 - 20 mg-TPH/kg-soil/d

(gas, jet fuel, etc.)

Bioventing - Flow(rate) Requirement

$$Q_{min} \approx -\frac{k_{O_2}\, V_{soil}\, \theta_a}{20.9\% \times 60\, \frac{\text{min}}{\text{h}}}$$



Q_{min} = minimum flowrate required [ft^3/min]

k_{O2} = oxygen utilization rate [%/d]

θ_a = vapor filled porosity [ft^3-air/ft^3-soil] ≈ 0.25

V_{soil} = volume of soil to be treated [ft^3]

This is the minimum flow necessary - useful for sizing blowers - more flow will be required to achieve sufficient O_2 distribution, and verification by soil gas monitoring is important