Field Tracer Tests to Characterize the Vadose Zone Geochemical and Hydrologic Properties

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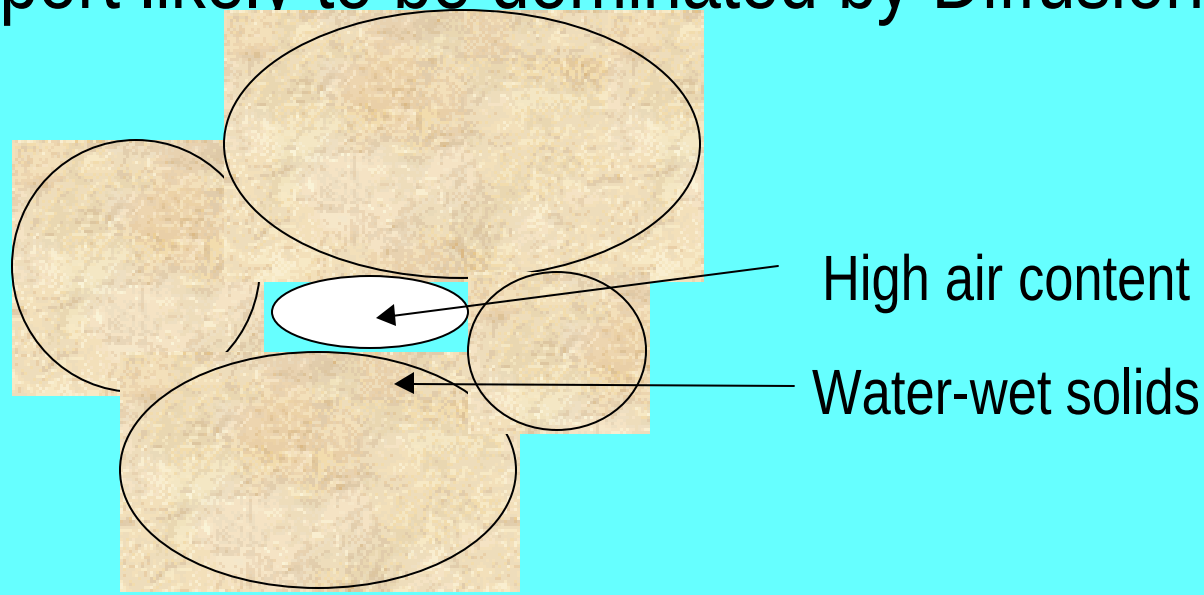
Hanford Site Vadose Zone Features

- Low Moisture Content
- Silty Sand to Fine Gravel
- Transport likely to be dominated by Diffusion



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Critical Vadose Zone Characteristics

- **Water saturation (S_w)**
  Air saturation (S_a)
  Hydraulic conductivity (K)
  Relative permeability ($k_{r,i}$)
  Air-water interfacial area (a_{aw})
  Air morphology index ($I_a = S_a/a_{aw}$)
  Water morphology index ($I_w = S_w/a_{aw}$)

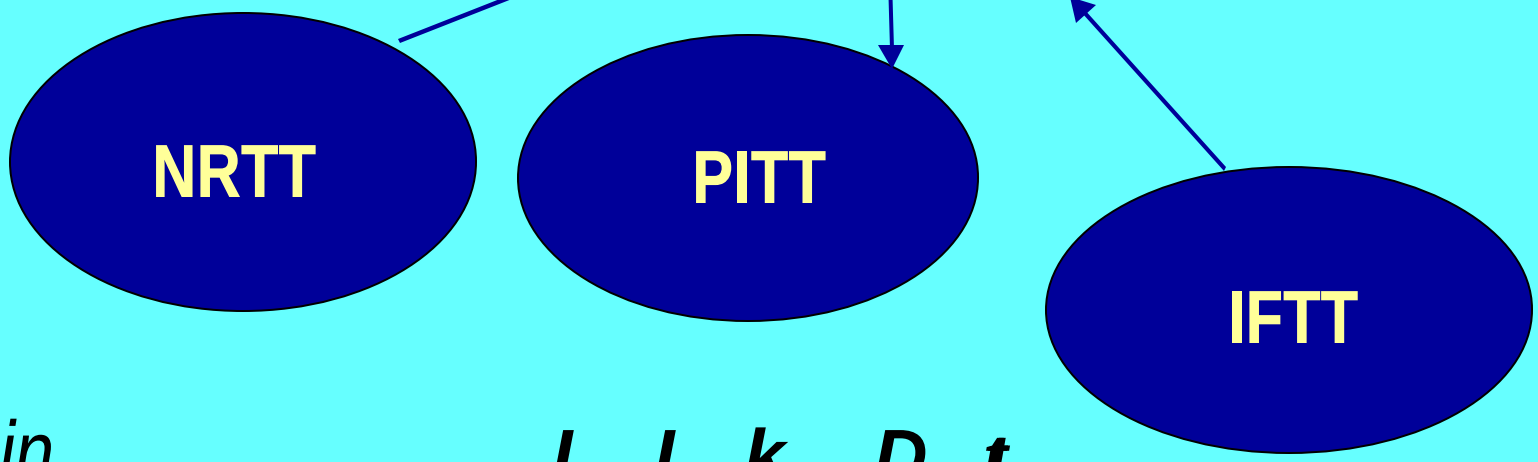
  Effective diffusion coefficient (D_e)
  Tortuosity factor (t)
  Constrictivity factor (d)
  Dispersion parameter (D)

Objective and Methods

Objective *Field Tracer Methods to Characterize the Vadose Zone*

Field Methods

Measure D, K, S_w, S_a, a_{aw}

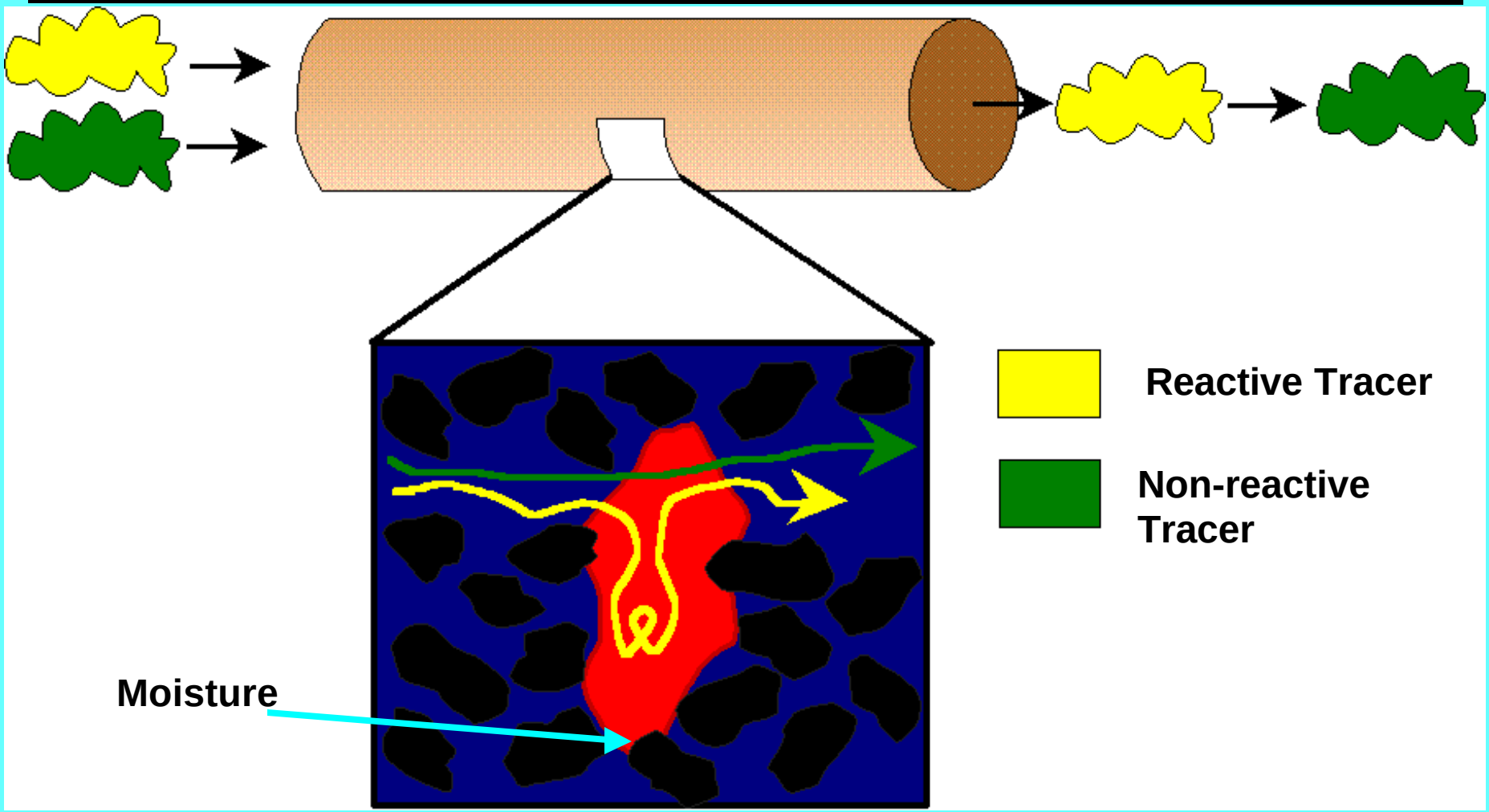


to obtain $I_w, I_a, k_{r,i}, D_e, t$

Tracers to Characterize Unsaturated Zone

		Water based	Vapor based
Non-reactive Tracers	K, D	KBr, PFBA	Methane
Partitioning Tracers	S_w	Alcohols	Difluoromethane
Interfacial Tracers	a_{aw}, I	SDBS, SDSS	Heptane

Retardation of Reactive Tracers



Interfacial Tracer Data Analysis: Method of Moments

Retardation Factor relative to Non-reactive Tracer

$$R_{ift} = \frac{m_{ift}}{m_{nr}} = 1 + \frac{a_{aw}}{q_w}(dG/dC)\big|_{C_o,T} + \frac{r}{q_w}(dS/dC)\big|_{C_o,T}$$

field

lab

lab

First Normalized Moment Corrected for Tracer Pulse Width

$$m = \frac{\int_0^\infty t\,C\,dt}{\int_0^\infty C\,dt} - \frac{t_s}{2}$$

Partitioning Tracer Data Analysis: Method of Moments

Retardation Factor relative to Non-reactive Tracer

$$R_{ift} = \frac{m_{ptt}}{m_{nr}} = 1 + \frac{S_w}{1 - S_w}(K)\big|_{C_o,T} + \frac{r}{q_w}(dS/dC)\big|_{C_o,T}$$

field

lab

lab

First Normalized Moment Corrected for Tracer Pulse Width

$$m = \frac{\int_0^\infty t\,C\,dt}{\int_0^\infty C\,dt} - \frac{t_s}{2}$$

Tortuosity and Rel. Permeability from Tracer Tests

(Saripalli, K.P., Serne, R. J., Meyer, P. D. and McGrail, B. P., 2000)

$$t_a = \frac{a_{aw}}{a_{aw,o}} \quad \text{where} \quad a_{aw,o} = \left(\frac{2f}{r} \sqrt{1 - S_w} \right)$$

$$D_i = t_a D_f$$

Diffusion Coefficient

Rel. Permeability

$$k_{r,i} = t_a k_{sat}$$

$$k_{ri} = S_i^3 \frac{(A_{i-rock} + A_{j-rock})^2}{e^{aj}(A_{ij} + A_{j-rock})^2}$$

Lake and Embid, 1997

Partitioning & Interfacial Tracer Field Tests

- *Hill AFB, Utah, Operable Unit 1 (OU1) - 14 tests*
- *Sandia National Laboratories, New Mexico*
- *Hill AFB, Utah, Operable Unit 2 (OU2) - 5 tests*
- *DOE Portsmouth Ohio, X701B area - 2 tests*
- *PPG Lake Charles, LA*
- *Kirtland AFB, Albuquerque, New Mexico - 2 tests*
- *MCB Camp Lejeune*
- *Hill AFB, Utah, Operable Unit 1 (OU1) IFTs*
- *Dover AFB*
- *University of Tuebingen, Germany*

Partitioning Tracers for Water Content Measurement

- ***Field tracer test for moisture measurements***
- ***difluoromethane sulfurhexafluoride***

- Deeds et al. (1999) *Environ. Sci. Technol.*, *33*, 2745-2751

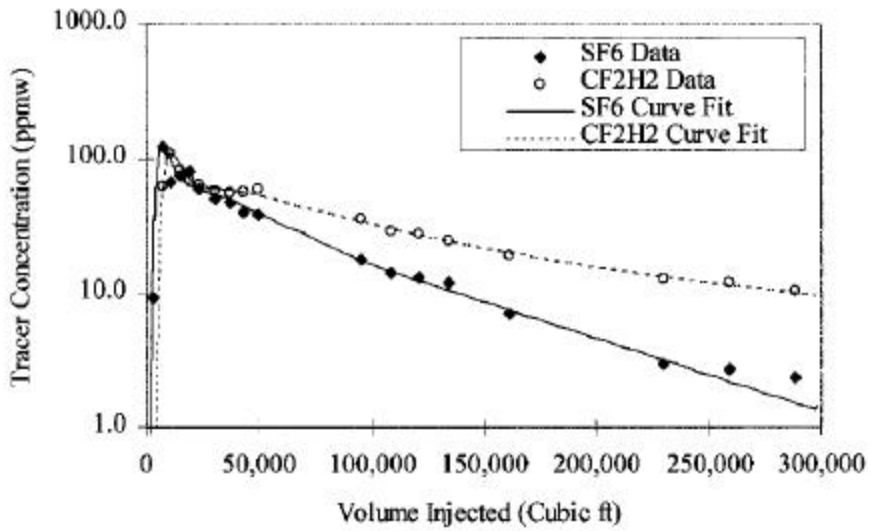


FIGURE 4. Breakthrough curves of shallow zone SF_6 and CF_2H_2 indicate 23 ± 2.0% water saturation.

Interfacial Tracer Test: Field Test Results

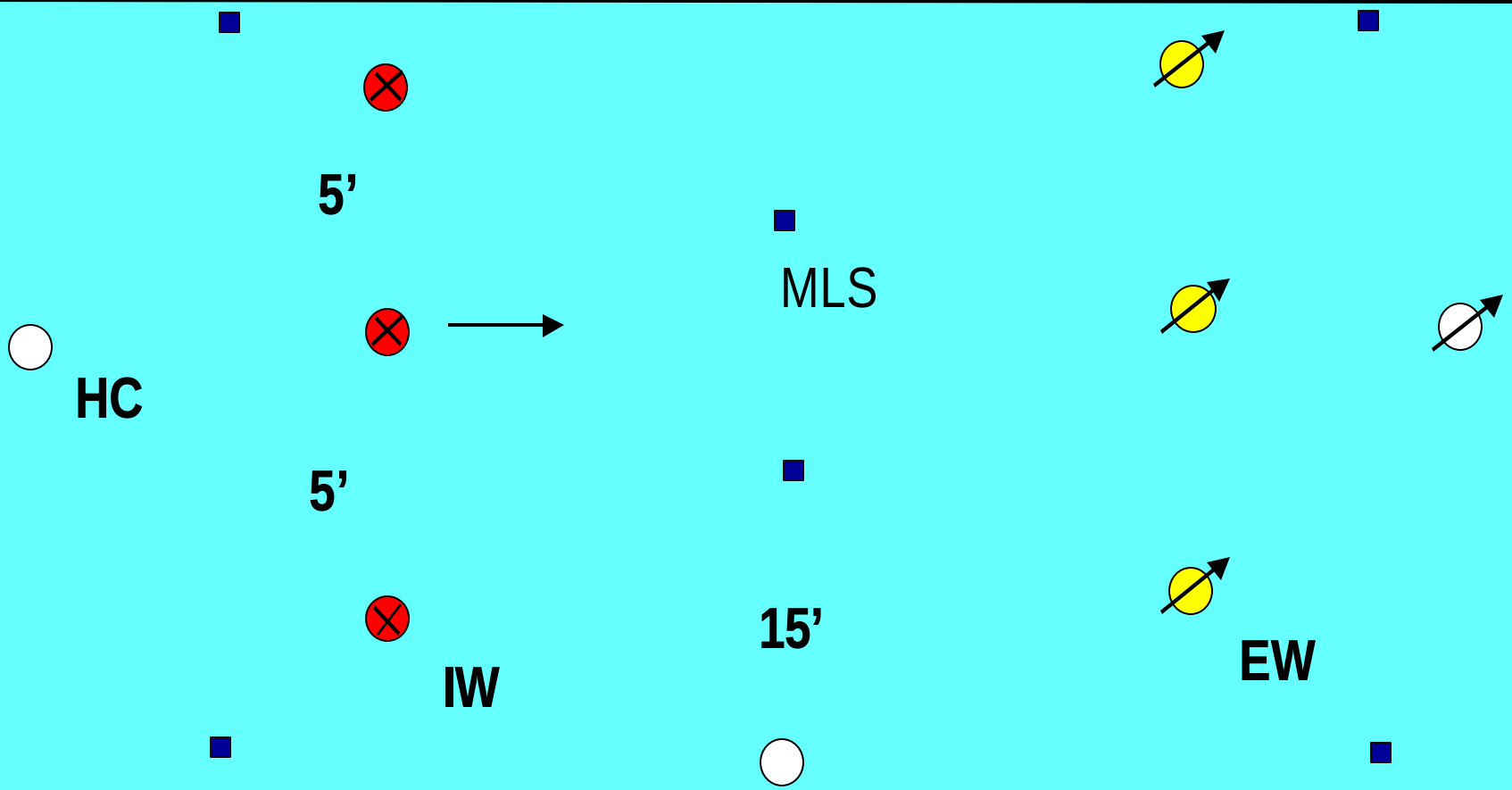
1. Hill Air Force Base, Utah	a_{nw}	S_n	I
MLS32 Blue, 20 ft bgs	49	*0.124*	*397*
MLS32 Red, 22 ft bgs	270	*0.064*	*4230*

Rao *et al*, 1998

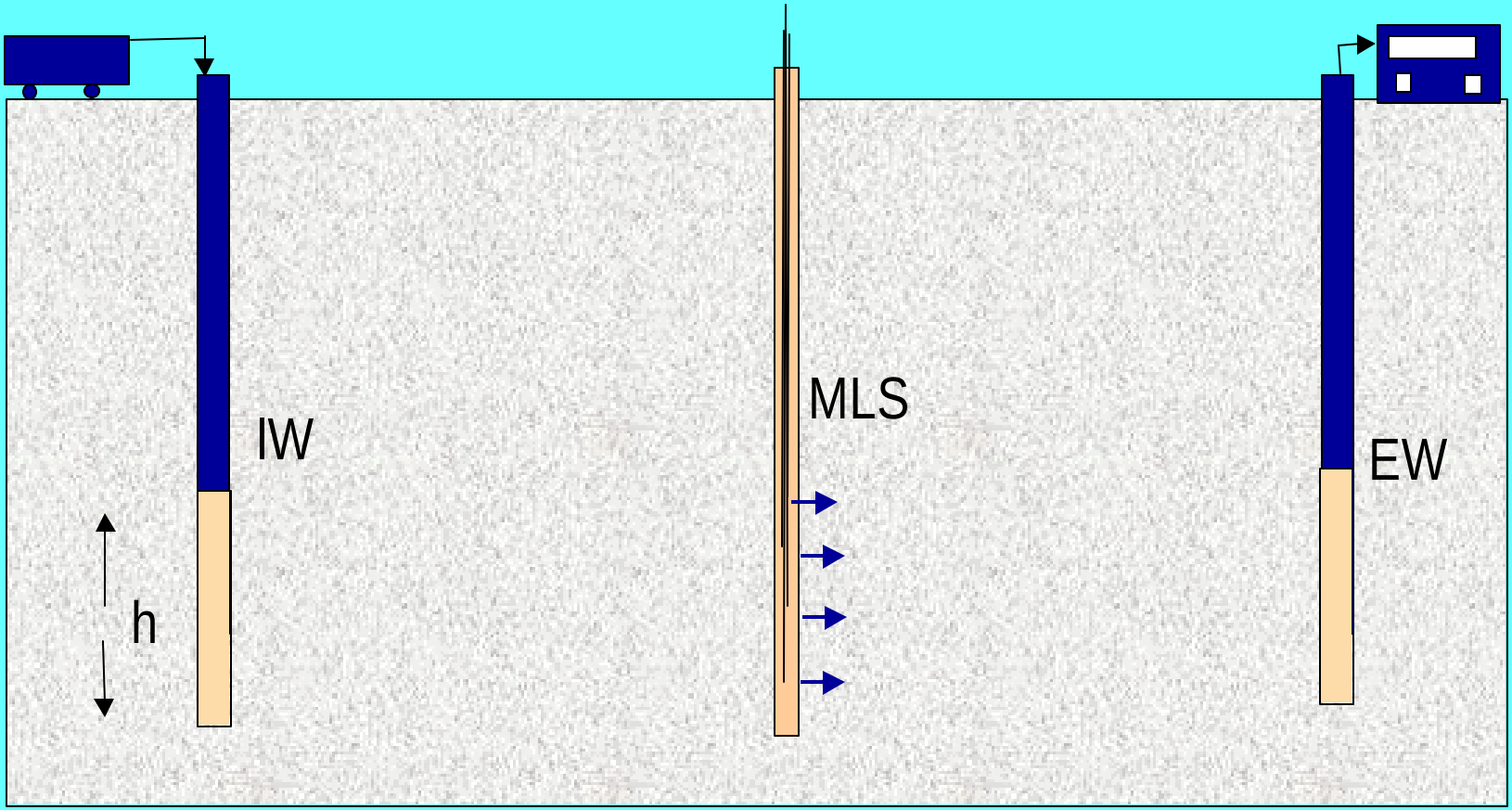
2. University of Tuebingen	a_{nw}	S_n	I
Presurfactant flood, EW	2320	*0.32*	*36914*
Postsurfactant flood, EW	0	*0.095*	*0*

Setarge *et al*, 1999

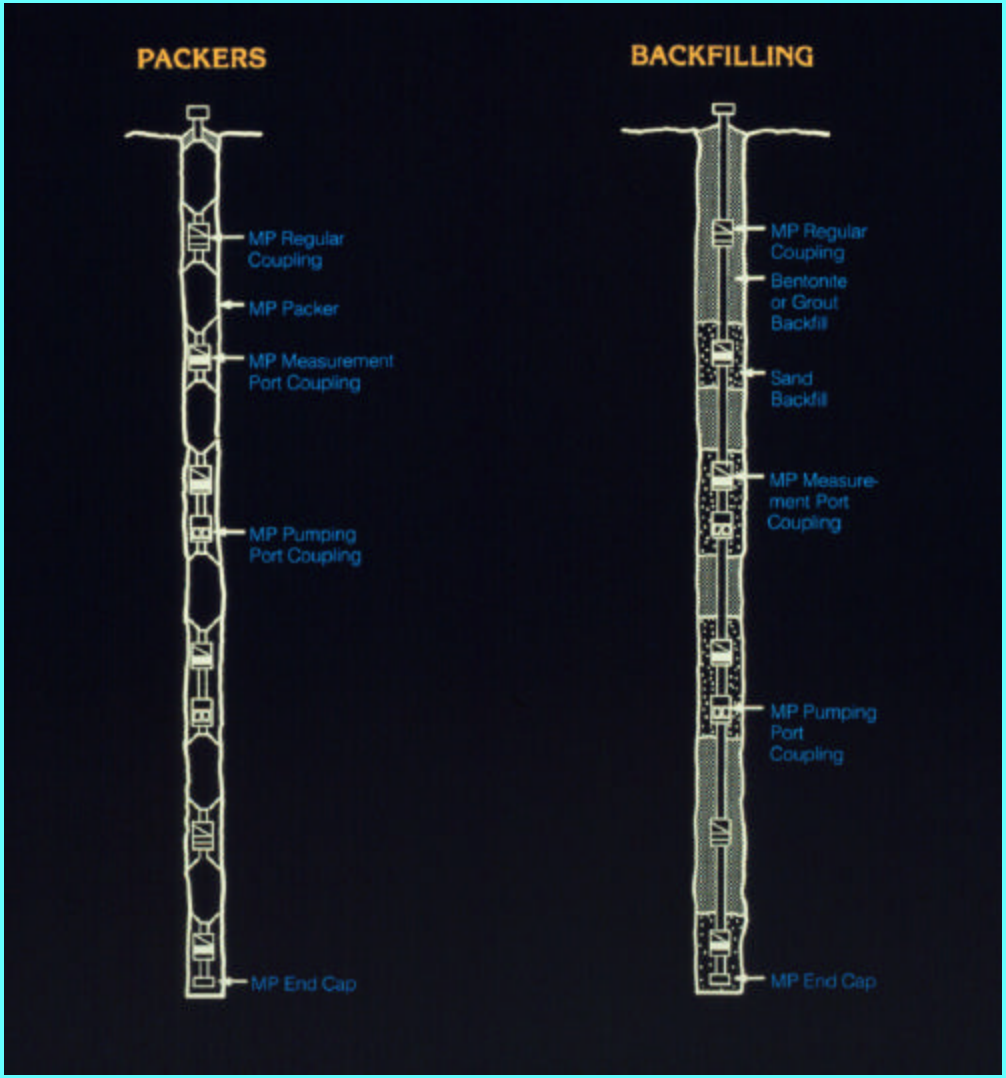
Inter-well Tracer Test Method



Longitudinal Section through Injection-Extraction Pair



Multi-level Sampler Design Detail



Critical Issues in Hanford Vadose Zone Tracer Field Tests

- *Low water saturations* • *High immobile water content*

Diffusion dominated transport • *Use of existing wells*

Site-specific issues

Design concerns

•*Multilevel sampling* • *Mechanical vs. pneumatic isolation* •

Artificial raise of water content • *Forward and inverse modeling support* • *Coordination of different objectives (methods) in a single cell* • *Sampling*