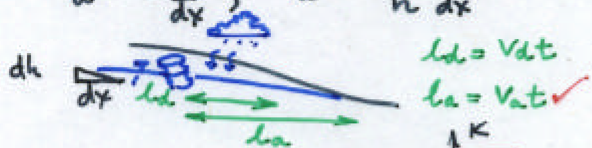
Historical perspective: { 1930s – 1970s — Resource exploitation; 1970s + Resource protection.

2. PHYSICAL HYDROLOGY

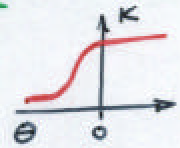
REVIEW

What do we know? → what do we need to know?

Category	Specifics	Uncertainties
UNDERLYING PRINCIPLES	1. Hydrologic cycle and budgets	
SCIENTIFIC PRINCIPLES	2. Darcy's law $q = -AK\frac{dh}{dx}$	
	$V_d = -K\frac{dh}{dx}$; $V_a = -\frac{K}{n}\frac{dh}{dx}$	DISCRETE PATH
	Unsaturated flow:	UNSATURATED
QUANTIFICATION	3. Continuity: $\frac{dq_i}{dx_i} = S_s\frac{dh}{dt} \Rightarrow \frac{\partial}{\partial x}K\frac{\partial h}{\partial x} = S_s\frac{\partial h}{\partial t}$	
	Evaluate: q, V_d, V_a	
CHARACTERIZATION	4. Drilling & Geophysics	LOCATE PATHWAYS
	Theim; Theis; Unconfined; Leaky	EVALUATE PARAMS
	$T = Kb$; T and $S = S_s b$	
PROJECT BEHAVIOR	5. Mathematical models	DATA POOR
	Flow / Transport / Non-aqueous flow	
	Geochemical transformation	
REMEDIATION	6. —	WHAT METHODS



Unsaturated flow:



DISCRETE PATHS

A. Discrete pathway flows – Rootholes
– Fractures – Alberta till

– Lovisianna clays – 160'
free product DNAPL
– Radwaste – fracture zone

UNSATURATED

B. Unsaturated/partial saturation zones (All fluids transit zone)
1. Trap immiscible fluids (abstraction)
2. Reservoir for immiscible fluids (dissolution)

LOCATE PATHWAYS

A. Locate pathways / pathway depth to determine free product / migration location
B. Fast pathways for advection & dissolution
Large surface area for retardation

EVALUATE PARAMETERS

A. Evaluate – dispersion
– retardation

DATA POOR

- Models well understood but data poor
- Sensitivity approach

WHAT METHODS

- What methods are <u>economic</u>

Throughout → Economics

FLOW – REFRESHER

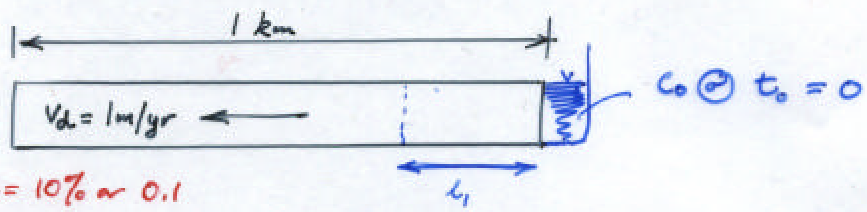
Permeability (L^2) — Hydraulic conductivity (LT^{-1})

$$\frac{k}{\mu} = \frac{K}{\rho g}$$

$$Q = -AK\frac{dh}{dx} \quad ; \quad v_d = -K\frac{dh}{dx}$$

$$v_a = \frac{v_d}{n}$$

RTD (Residence Time Distribution) or "Breakthrough" Curves

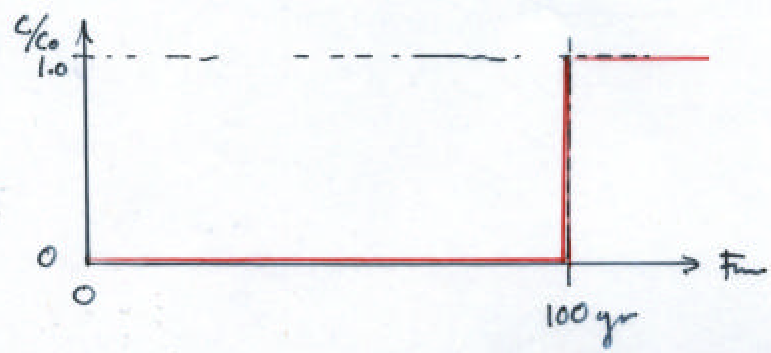


Porosity, n = 10% or 0.1

Darcy Velocity: $v_d = 1 \text{ m/yr} = \frac{1}{1000} \text{ km/yr}$

Advective velocity: $v_a = \frac{v_d}{n} = \frac{10^{-3}}{0.1} = 10^{-2} \text{ km/yr}$

Breakthrough time: $v_a = \frac{l}{t} \quad \therefore \quad t = l/v_a = \frac{1 \text{ km}}{10^{-2} \text{ km/yr}} = 100 \text{ yr}$



LNAPL Idealized behavior

eg. Gasoline, kerosene.

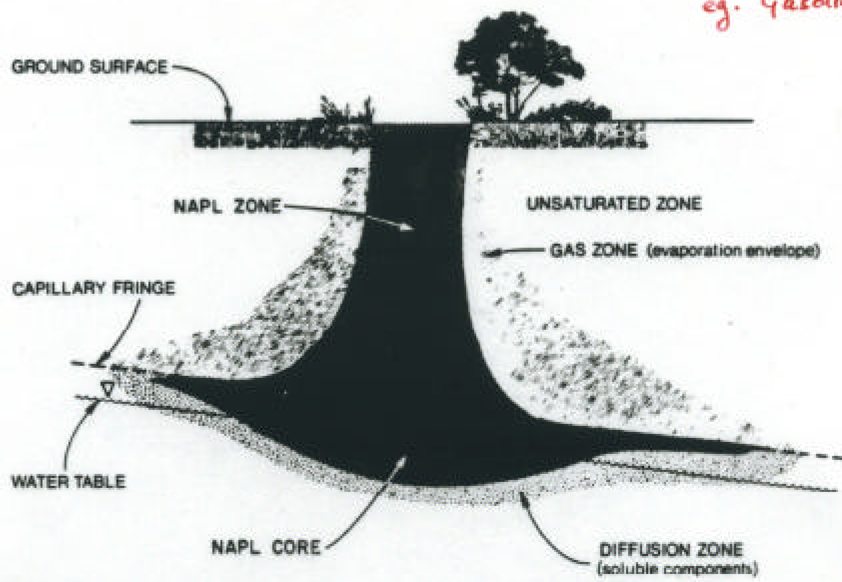


Fig. 1. Schematic representation of lighter than water NAPL movement through the unsaturated and into the saturated zone [after *Abriola and Pinder*, 1985a].

DNAPL eg. Dry cleaning solvents, TCE, PERC.

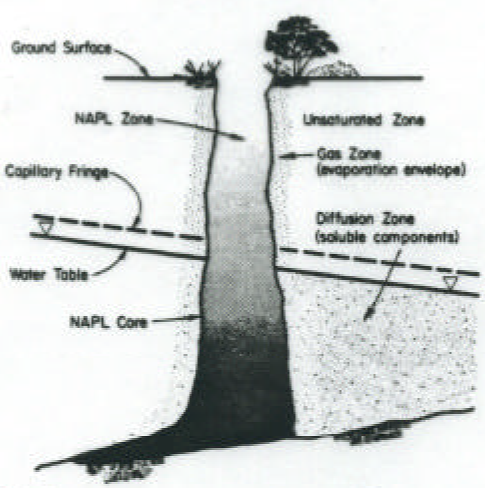


Fig. 2. Schematic representation of heavier than water NAPL movement through the saturated and unsaturated zones.

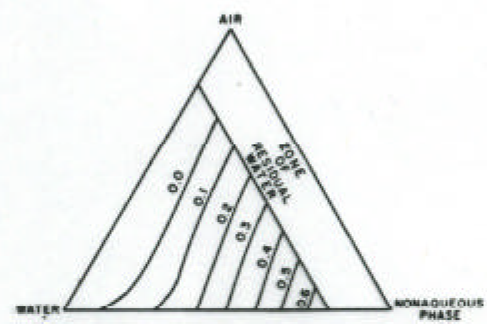
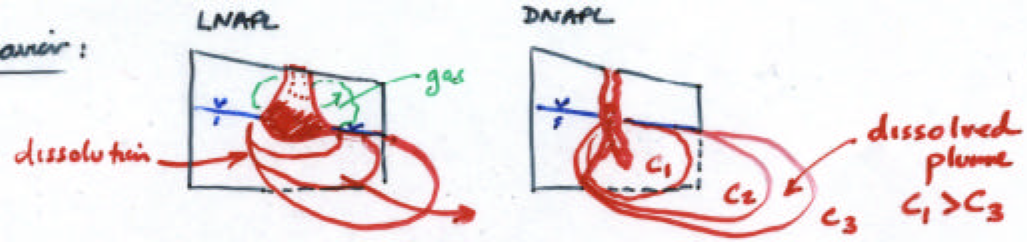


Fig. 3. Ternary diagram showing the relative permeability of the nonaqueous phase as a function of phase saturations [after *Faust*, 1985].

Immiscible Transport

Idealized behavior:



If contaminants are immiscible then these processes are important

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True behavior:

1. Fingering results
2. Erratic and unpredictable distribution
3. DNAPLs "very" penetrative { low viscosity, high density, low interfacial tension

Questions:

- How far will they migrate
- What are the controls on penetration
  - clay -vs- sand aquitards
  - fractured -vs- unfractured
- How do they dissolve / bind / retard
- How may they be:
  - Remobilized
  - Chemically immobilized
  - Physically isolated.