

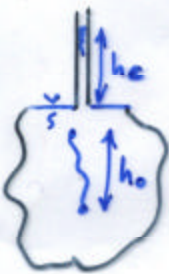
3.8 Behavior of DNAPLS

3.8.1 Vadose zone migration

- Similar characteristics to LNAPL but \uparrow density \rightarrow more penetrative (water table)
- Preferentially chooses large pores and continuous pore throat channels
- Displaces air and reaches capillary zone.
- Displaces water @ capillary zone.

3.8.2 Vertical movement in saturated zone

Static fluid: Hobson's Formula - defines required critical height for penetration, h_0



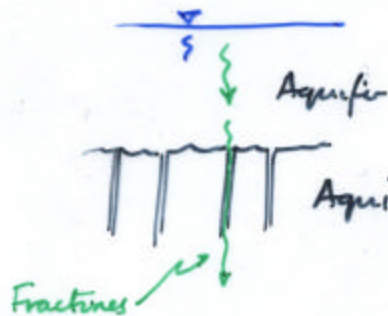
$$h_0 = \frac{+2\sigma \cos \theta (1/r_t - 1/r_p)}{g(\rho_w - \rho_o)}$$

r_p = pore radius
 r_t = throat radius

$$h_c = \frac{P_b}{\gamma_o}$$

Rhombohedral packing, $r_p = .212d$
 $r_t = .077d$ } d = grain diameter

Same as $h = \frac{h_c}{(1 - \rho_w/\rho_{nw})}$ if $h_c = \frac{2\sigma \cos \theta}{r^* \gamma_{nw}}$
as h_c includes $(\theta, \sigma, r^*, \gamma_{nw})$



Capillary tube: $h_c = \frac{4\sigma \cos \theta}{d \gamma_w}$
Fracture: $h_c = \frac{2\sigma \cos \theta}{b \gamma_w}$

Monitoring wells:

- Place at aquifer base to collect flow from mobile DNAPL -
Will separate in well into individual components.
 - water at saturation (potentially).
- DNAPL level is intermediate within zone of mobile water and DNAPL
- Deep wells record pulse DNAPL depth.

Vertical distribution of DNAPL

Accumulation depends on grain size (actually pore size) distribution \rightarrow since controls capillary pressure distribution.

Small pores/fractures: Low $K \rightarrow$ thin pure DNAPL layer
thick DNAPL + water

Large pores/fractures: High $K \rightarrow$ thick pure DNAPL layer
thin DNAPL + water.

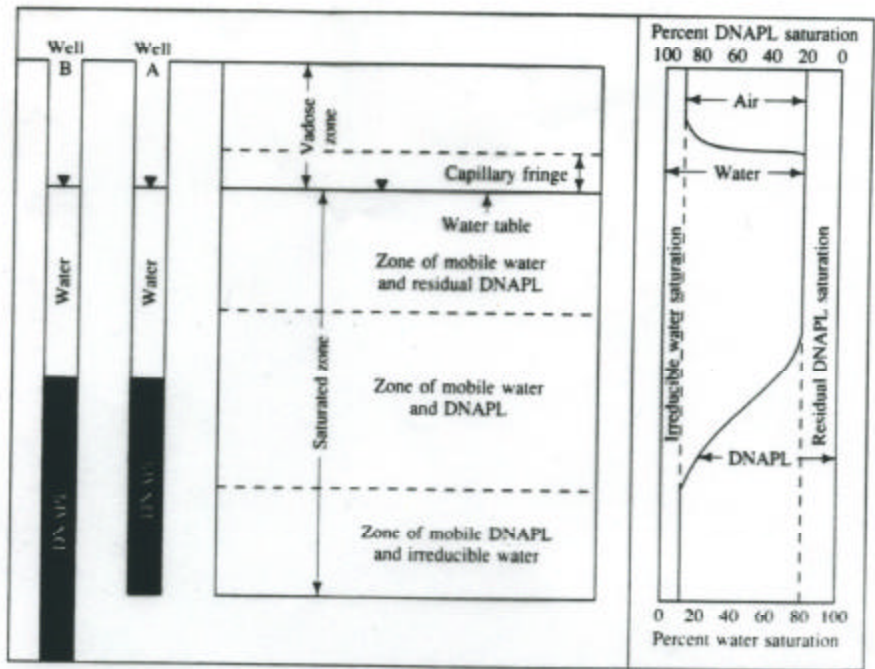


FIGURE 5.23 Zones of a DNAPL and the relationship of mobile DNAPL and nonmobile DNAPL to the DNAPL saturation; relationship of mobile DNAPL thickness to thickness of DNAPL is measured in a monitoring well.

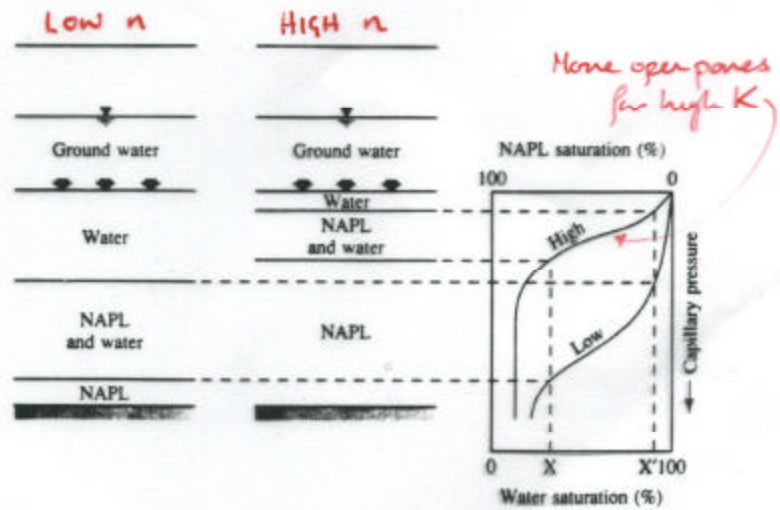


FIGURE 5.24 Effect of high and low permeability (and porosity) on the distribution of mobile DNAPL at the bottom of an aquifer; the arrows indicate level of original injection of the DNAPL. Source: J. F. Villiaume, *Ground Water Monitoring Review* 5, no. 2 (1985):60-74. Copyright © 1985 Water Well Journal Publishing Co.

3.8.3. Horizontal Movement in Saturated Zone

• Difficult to estimate potential for movement

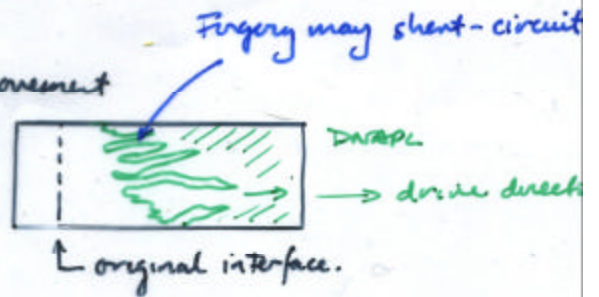
- Water drive will produce fingering

Classical fingering

1) Due to instability

2) Accentuated by heterogeneity

- heterogeneity has overriding effect in most shallow aquifers.



Gradient required to move DNAPL (horizontally)

$$\nabla p = \frac{2\sigma}{L_0 \left(\frac{1}{r_t} - \frac{1}{r_p} \right) r^*}$$

L_0 = length of continuous DNAPL phase
 r_t = throat ; r_p = pore radii

eg. to determine radius of influence of capture well:

$$\frac{dp}{dr} = \frac{1}{\gamma_w} \frac{dh}{dr}$$



Difficulty in estimating L_0 .