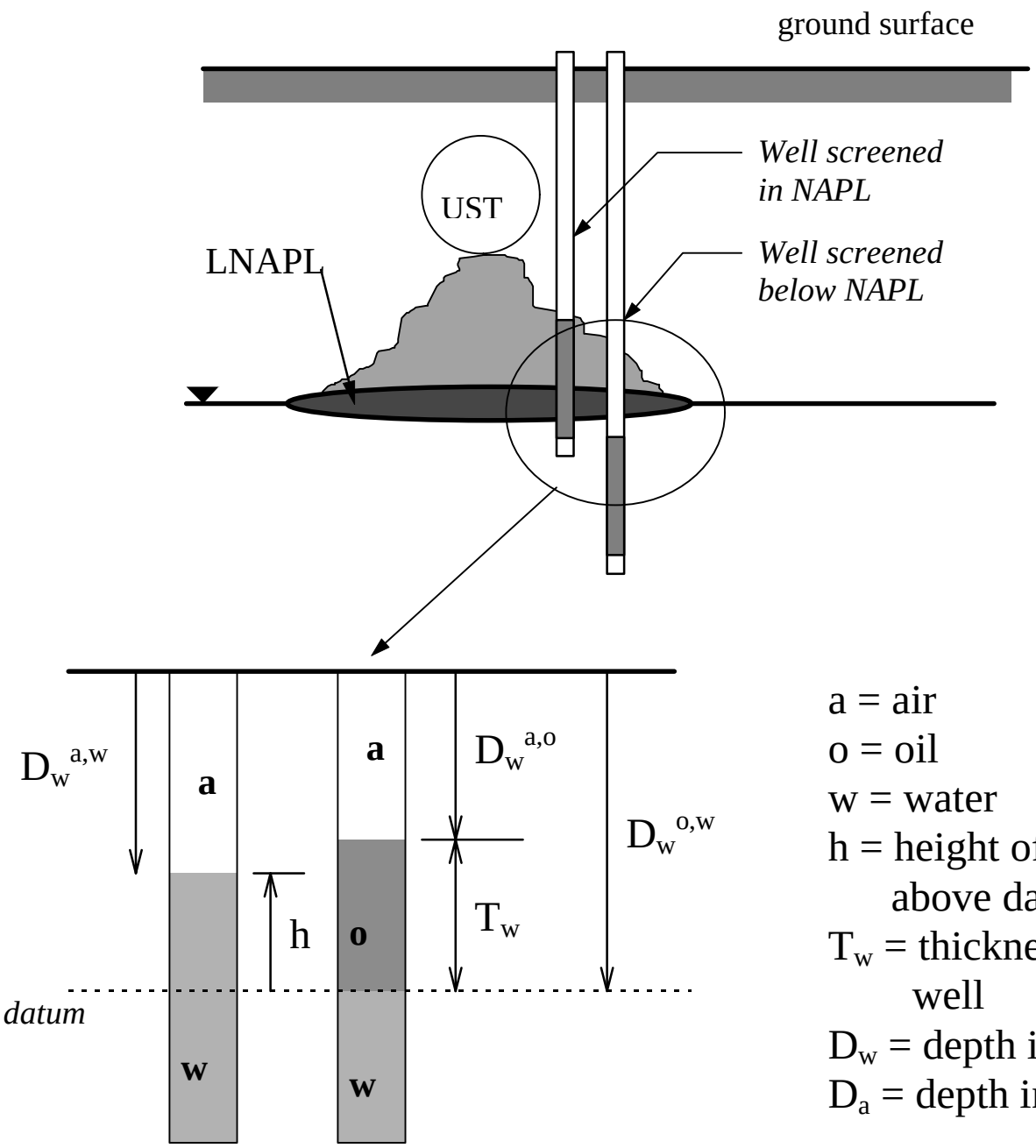
Estimating Volumes of LNAPL in Porous Media



a = air
o = oil
w = water
h = height of water above datum
T_w = thickness of oil in well
D_w = depth in well
D_a = depth in aquifer

- We have thickness, T_w, of oil in well
- How does this relate to oil thickness in formation?

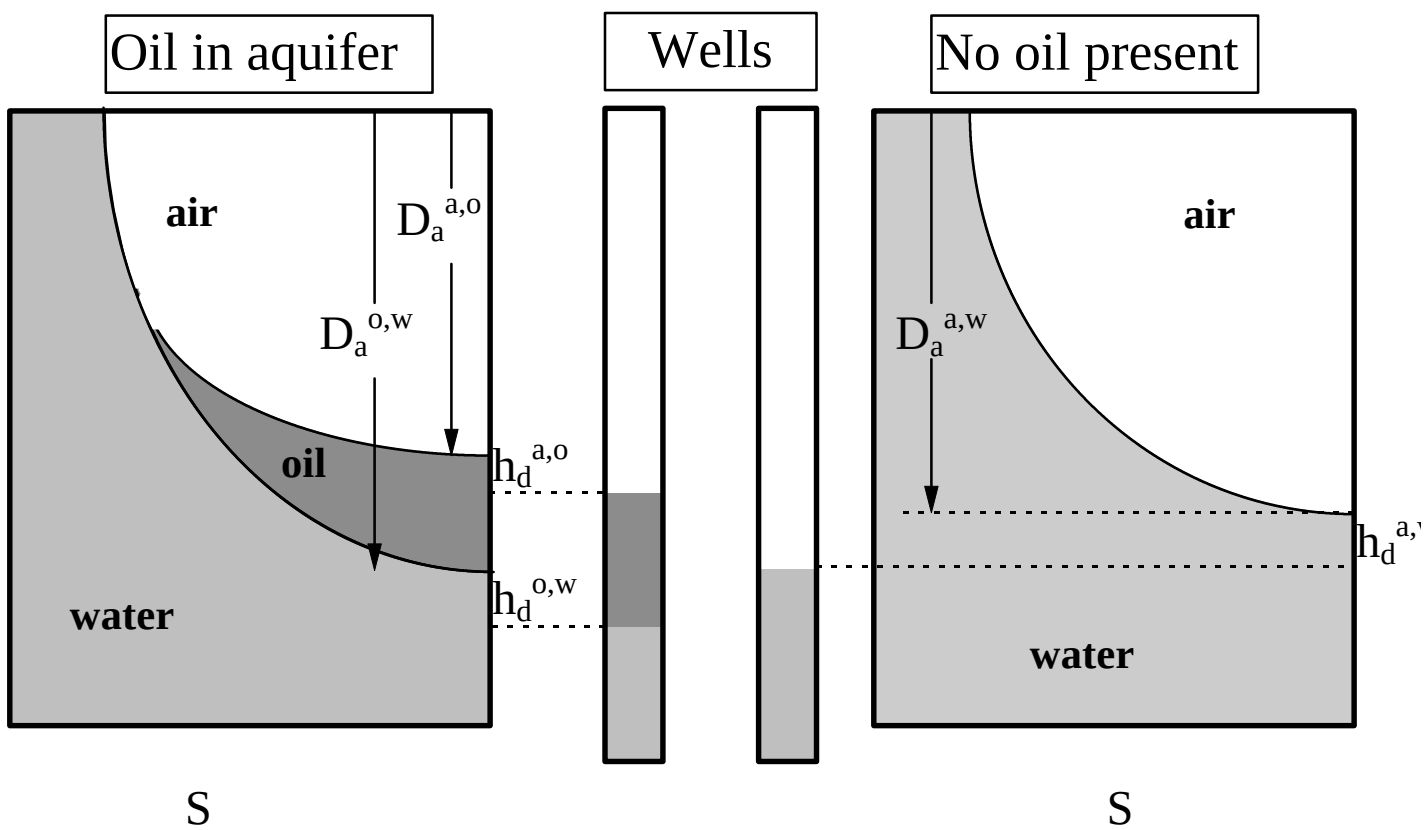
1. Relationship between T_w and h:

Pressure at datum in both wells are equal:

$$\rho_o g T_w = \rho_w g h$$

$$T_w = \frac{\rho_w}{\rho_o} h$$

2. Draw Capillary Pressure - Saturation (p_c vs. S) curves for aquifer for two cases:



Capillary rise:

Water in air-water system: $$h_d^{a,w} = \frac{p_d^{a,w}}{\rho_w g}$$

Water in oil-water system: $$h_d^{o,w} = \frac{p_d^{o,w}}{(\rho_w - \rho_o) g}$$

Oil in air-oil system: $$h_d^{a,o} = \frac{p_d^{a,o}}{\rho_o g}$$

Oil Thickness Calculations:

- Thickness of oil in well: $$T_w = D_w^{o,w} - D_w^{a,o}$$
- "Thickness" of oil in aquifer, T_a:

$$\begin{aligned} T_a &= D_a^{o,w} - D_a^{a,o} \\ &= \left(D_w^{o,w} - h_d^{o,w}\right) - \left(D_w^{a,o} - h_d^{a,o}\right) \\ &= T_w + h_d^{a,o} - h_d^{o,w} \end{aligned}$$

Questions:

- What is the minimum T_a for oil to appear in a well?
- What is the minimum T_w if oil appears in a well?

3. How to calculate volume of LNAPL in aquifer?

- Option 1: Thickness of oil in well

$$V_o = nT_w$$

Overestimates V_o

porosity

Volume of oil per unit area

- Option 2: "Thickness" of oil in aquifer

$$V_o = nT_a$$

Probably overestimates V_o

- Option 3: Integrate over P_c-S curve:

$$V_o = \frac{n(1-S_r)H}{1-\lambda}\left\{\lambda + (1-\lambda)\left(\frac{T_w}{H}\right) - \left(\frac{T_w}{H}\right)^{1-\lambda}\right\} : \lambda \neq 1$$

$$V_o = n(1-S_r)\left\{1 - H(1+\ln T_w)\right\} ; \lambda = 1$$

$$H = h_d^{o,w} - h_d^{a,o}$$

Need: T_w, λ, $p_d^{o,w}$, $p_d^{a,o}$, S_r, ρ_o, ρ_w

Assumes:
1. No trapped oil below the water table.
2. No residual oil high in vadose zone.

Reference: Mishra *et al* (1989) J. Hydrol., 108:1-18