1 Lab Methods

Hydrogeologic Parameters: Grain Size

- Grain Size Analysis, Sandy material
- Hazen's equation: $K = C(d_{10}^2)$,
  - C constant ranging from 100 to 150 $sec \cdot cm^{-1}$
  - d_{10} is screen size (10% passing)
- assumes uniformly graded (poorly sorted) sands ($\frac{d_{60}}{d_{10}} < 5$)

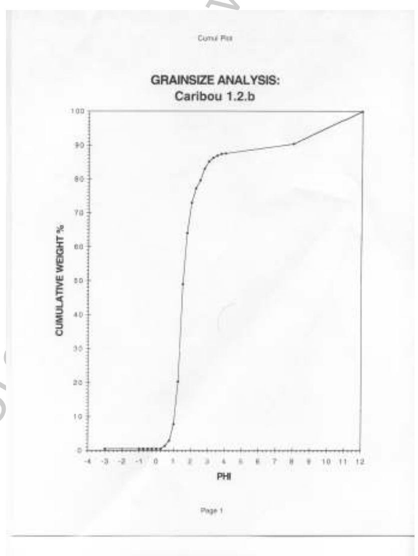
Hydrogeologic Parameters: Grain Size

- Kozeny-Carmen equation
- Several variation with different assumptions
- For spherical particles with radius=r

$$K = \frac{\rho g}{\mu} \frac{n^3}{(1-n)^2} \frac{r^2}{45}$$

$$K = \frac{\rho g}{\mu} \frac{n^3}{(1-n)^2} \frac{d_{50}^2}{180}$$

Grain Size Curve

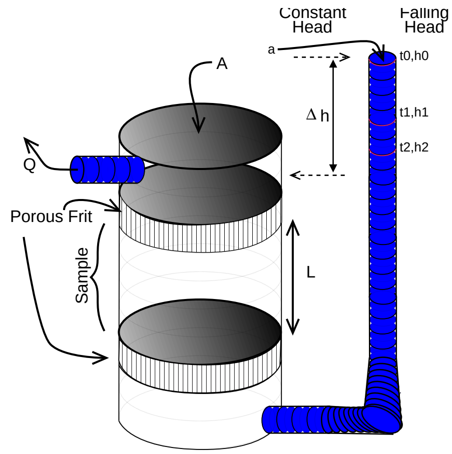


Hydrogeologic Parameters: Permeameters

- Constant head permeameter
- Measure hydraulic conductivity of permeable sediments
- based on the simple rearrangement of Darcy's Law

$$K = \frac{QL}{AH}$$

Hydrogeologic Parameters: Permeameters



Hydrogeologic Parameters: Permeameters

- Falling head permeameter
- for lower permeability sediments
- measure rate that water falls in a manometer
- head gradient discharge through sample change with time
- set flux based on Darcy's Law equal to the volume change in the manometer

$$KA\frac{h(t) - H_o}{L} = a\frac{dh}{dt}$$

$$K = \frac{aL}{A(t_2 - t_1)} \ln\left[\frac{h_2}{h_1}\right]$$

2 Slug Testing

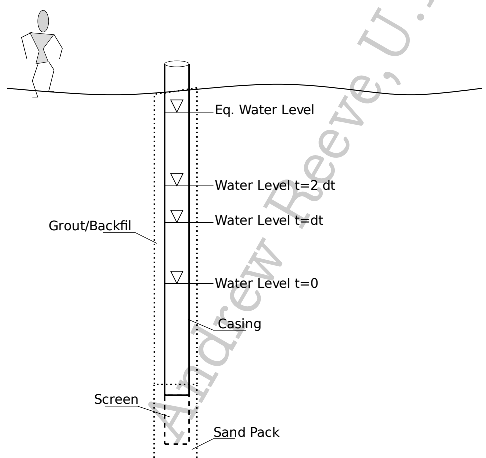
Piezometer Testing

- Measure pre-test water level in well
- Introduce (or remove) 'slug', rapidly change water level
- Measure water level recovery with time
- Rate of recovery related to hydraulic conductivity

Piezometer Testing

- Information needed:
  - Equilibrium water level
  - Water levels and times during recovery
  - Volume of 'slug'
  - Well geometry
    * screen length
    * well casing radius
    * sand pack or screen radius
    * screen length
    * distance between screen and water table
  - location of confining layers

Piezometer Testing



Hvorslev Method

- Simplest method for interpreting piezometer tests
- Based on water balance between flux across screen and volume changing in casing

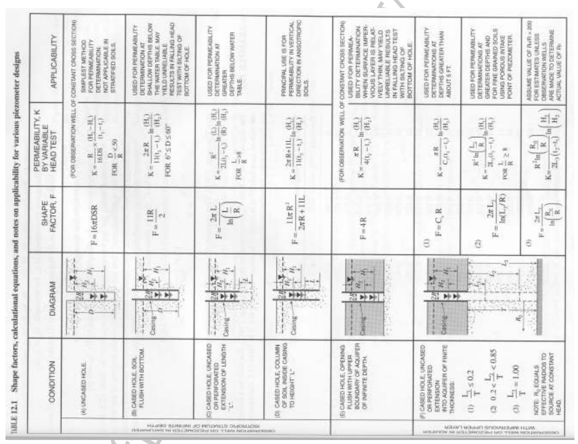
$$q = \pi \cdot r_c^2 \frac{dh}{dt}$$
$$q = -F \cdot K(h_{eq} - h_i)$$
$$F = \frac{A}{\Delta r}$$
$$T_0 = \frac{\pi \cdot r_c^2}{F \cdot K}$$

$$\pi \cdot r_c^2 \frac{dh}{dt} = -F \cdot K(h_{eq} - h_i)$$
$$-\int_{t_0}^{t_i} \frac{1}{T_0} dt = \int_{t_0}^{t_i} \frac{1}{h_{eq} - h_i} dh$$
$$-\frac{\Delta t}{T_0} = \ln\left(\frac{h_{eq} - h_i}{h_{eq} - h_0}\right)$$

Hvorselv method

- This result can be used in two ways:
  - when $T_0 = \Delta t$, normalized head (H_n) is 0.37
  - plot $\log(H_n)$ vs. time
  - find T_0 (time when H_n is 0.37)
  - solve $T_0 = \frac{\pi \cdot r_c^2}{F \cdot K}$
- slope of $\log(H_n)$ vs. time equals $\frac{1}{T_0}$
  - pick two points on linear portion of $\log(H_n)$ vs. time plot
  - solve $-T_0 = \frac{t_2 - t_1}{\ln(H_n^{t_2}) - \ln(H_n^{t_1})}$
- The formation factors (F) in Fitts(2002) cannot be used interchangeable with equations developed by Horvslev(1951) and widely cited in textbooks (and next slide).
  - additional manipulation of flow equations
  - included cross-sectional area of the well into formation factor

Hvorslev Method



Hvorslev (1951) as presented by Schwarz and Zhang (2003)

Hvorslev Method

- For common well:
  - $r_e >> r_s$
  - screen much longer than radius
  - assuming isotropic conditions
  - screen not near confining units
-

$$K = \frac{r_c^2 \cdot \ln\left(\frac{r_e}{r_s}\right)}{2 \cdot l \cdot T_0}$$

$$K = \frac{r_c^2 \cdot \ln\left(\frac{r_e}{r_s}\right)}{2 \cdot l \cdot \Delta t} \ln\left(\frac{\Delta h_1}{\Delta h_2}\right)$$

- r_e typically set equal to screen length or $200 \cdot r_s$ (Butler,1998)

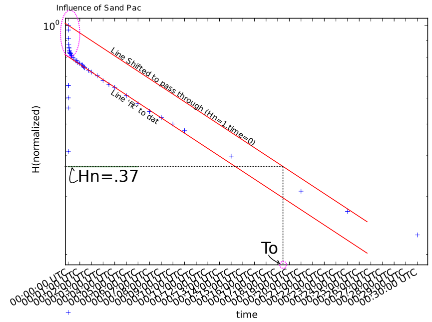


Figure 1: Example of graphical analysis by the Hvorslev method. The linear fit to the data can be used to determine the lag time (T_0) or used to find two points along the best fit line. The inverse of the lag time should equal $\ln(\frac{H_1}{H_2})\frac{1}{\Delta t}$. Note semilog graph.

Hvorslev Example

Cooper at al. Method (WRR,1967)

- Cooper et al. (1967) solved radial flow equation for instantaneous source.
  - infinite extent
  - significant storage in well and aquifer
  - fully penetrating well
- $$\frac{H}{H_0} = \frac{8\alpha}{\pi^2}\int_0^{\inf} \frac{\exp(\frac{-\beta u^2}{\alpha})}{u \cdot \Delta u}$$

$$\Delta u = (u \cdot J0(u) - 2 \cdot \alpha \cdot J1(u))^2 + (u \cdot Y0(u) - 2 \cdot \alpha \cdot Y1(u))^2$$

$$\alpha = \frac{r_s^2 S_s b}{r_c^2}$$

$$\beta = \frac{Kbt}{r_c^2}$$

Cooper et al. Method

- Cooper et al (1967) presented type curves for different values of alpha and beta
- plot normalized head (arithmetic scale, y-axis) vs. time (log scale, x-axis)
- overlay data plot on type curves, slide along x-axis until data matches a type curve
- pick time and note corresponding beta value, note alpha value of matched type curve
- calculate T and S
- Note that S lacks accuracy

Cooper et al. Example

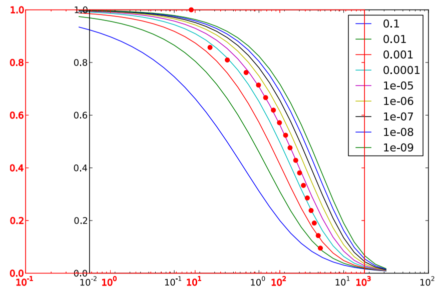
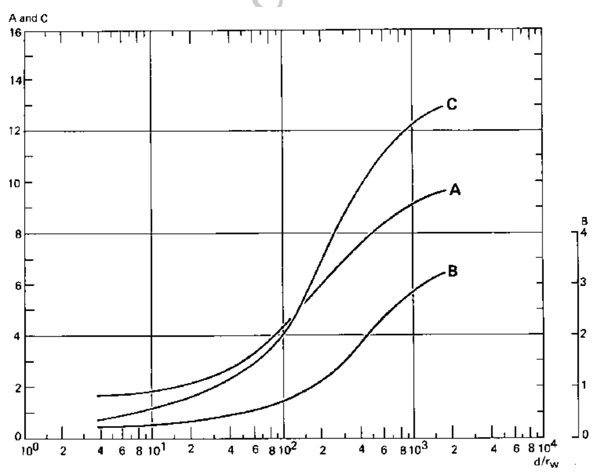


Figure 2: Type curves (black axes, β vs H_n) overlain with data (red axes, time (sec) vs H_n). Data is obviously of poor quality, and illustrates the difficulty in picking a correct type curve. Here, $\alpha = 10^{-5}$ and one possible match point on the x-axis is (time=1, $\beta =\approx 0.018$).

Bouwer-Rice Method (WRR,1976)

- Slug testing method developed for unconfined aquifers
- Similar to Hvorselv method (plotting)
  - plot log(normalized head) vs. time
  - pick value from straight portion of curve and get t, h_t
  - use ratio of l/r_s and type curves to calculate A,B,and C.
  - use appropriate eqn to calculate K

Bouwer-Rice Method



Bouwer-Rice Method

$$r_s^* = r_s\sqrt{\frac{K_v}{K_h}}$$

$$A = 1.472 + 3.537\cdot10^{-2}\frac{b}{r_s^*} - 8.148\cdot10^{-5}\left(\frac{b}{r_s^*}\right)^2 + 1.028\cdot10^{-7}\left(\frac{b}{r_s^*}\right)^3 - 6.484\cdot10^{-11}\left(\frac{b}{r_s^*}\right)^4 + 1.573\cdot10^{-14} * \left(\frac{b}{r_s^*}\right)^5$$

$$B = 0.2372 + 5.151\cdot10^{-3}\frac{b}{r_s^*} - 2.682\cdot10^{-6}\left(\frac{b}{r_s^*}\right)^2 - 3.491\cdot10^{-10}\left(\frac{b}{r_s^*}\right)^3 + 4.738\cdot10^{-13}\left(\frac{b}{r_s^*}\right)^4$$

$$C = 0.7920 + 3.993 \cdot 10^{-2} \frac{b}{r_s^*} - 5.7443 \cdot 10^{-5} \frac{b}{r_s^*}^2 + 3.858 \cdot 10^{-8} \frac{b}{r_s^*}^3 - 9.659 \cdot 10^{-12} \frac{b}{r_s^*}^4$$

Bouwer-Rice Method

- Calculate effective radius
  - for partially penetrating wells (H_{br} = distance from bottom of screen to water table.):

$$\ln \frac{R_e}{r_s} = \left[\frac{1.1}{\ln(\frac{H_{br}}{r_s})} + \frac{A + B \ln\left[\frac{b - H_{br}}{r_s}\right]}{\frac{l}{r_s}} \right]^{-1}$$

  - if $\ln(\frac{b-H_{br}}{r_s})$ is greater than 6.0, then 6.0 should be used
  - for fully penetrating wells:

$$\ln \frac{R_e}{r_s} = \left[\frac{1.1}{\ln(\frac{H_{br}}{r_s})} + \frac{C}{\frac{l}{r_s}} \right]^{-1}$$

- calculate K

$$K = \frac{r_c^2 \ln \frac{R_e}{r_s}}{2l} \frac{1}{t} \ln \frac{h_0}{h_t}$$

$$K = \frac{r_c^2 \ln \frac{R_e}{r_s}}{2lT_0}$$