Single Well Response Tests

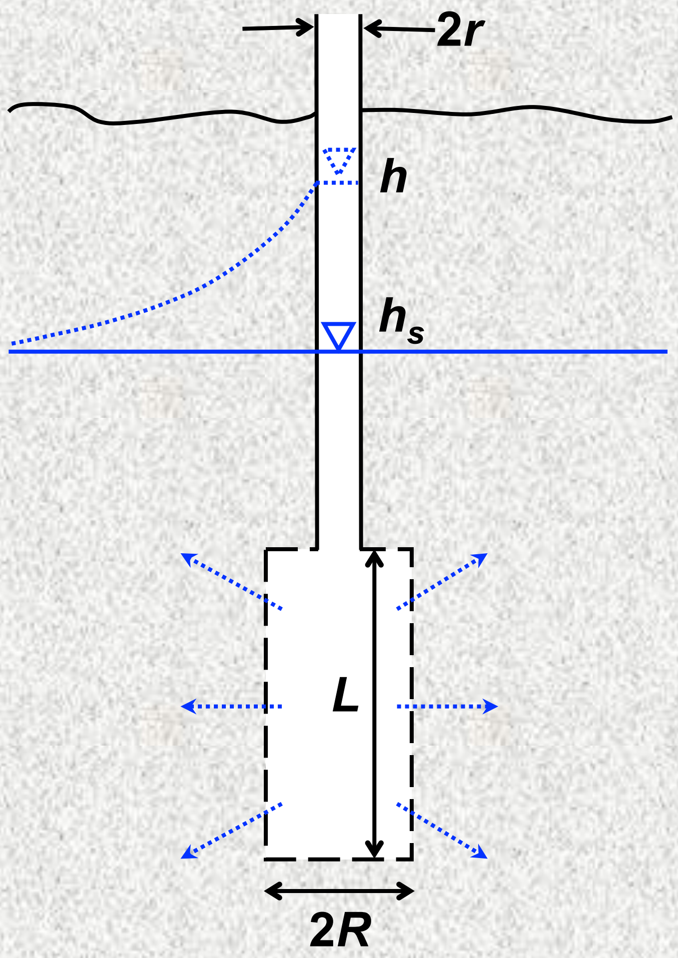
Suggested reading: Schwartz and Zhang Ch. 12

Often times pumping wells do not exist at a site or pumping tests are not practical. In this case, estimates of hydraulic conductivity, and to a lesser extent storage parameters, can be obtained from tests on individual wells.

Because of the way they are conducted, these tests are often referred to as "slug tests" or "bail tests".

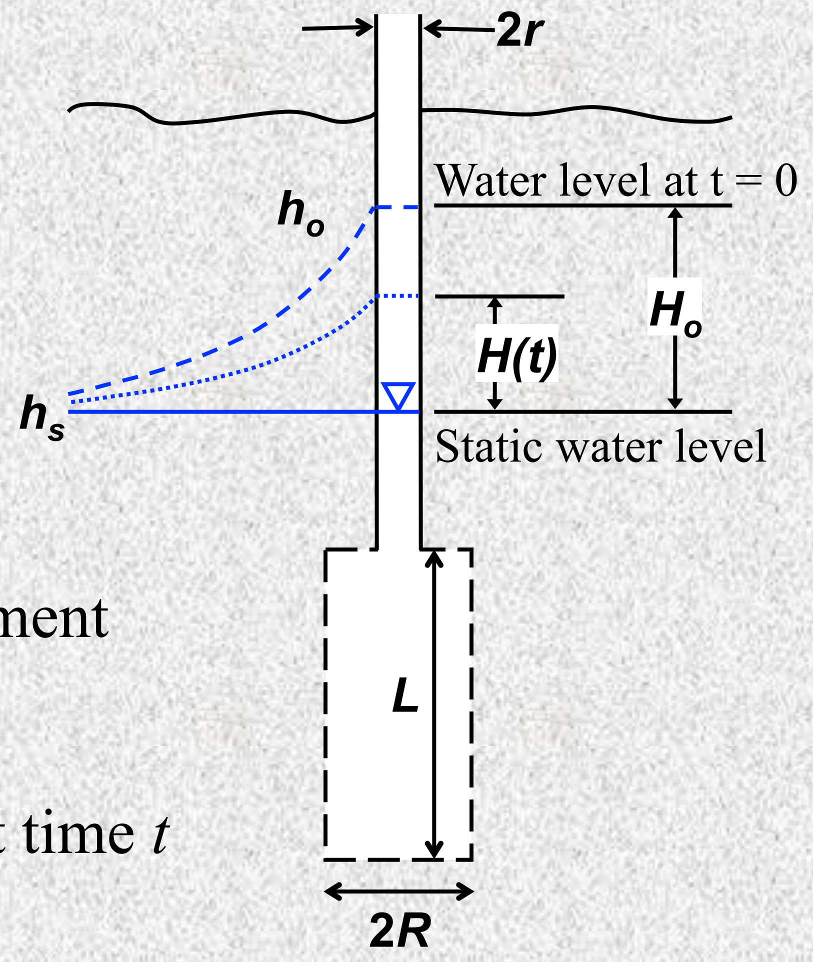
The water level in a well or piezometer is rapidly displaced away from its static or equilibrium position (h_s). A "slug test" raises the water level and a "bail test" lowers the water level.

The water level (h) in the well is monitored with time as it gradually recovers to its original static position. The rate of response is used to estimate the K of the material around the well.



Hvorslev Method

In the classic Hvorslev (1951) method, water level deviations from the static level are expressed as H.



$H_o = h_o - h_s$

= initial water level displacement

$H(t) = h - h_s$

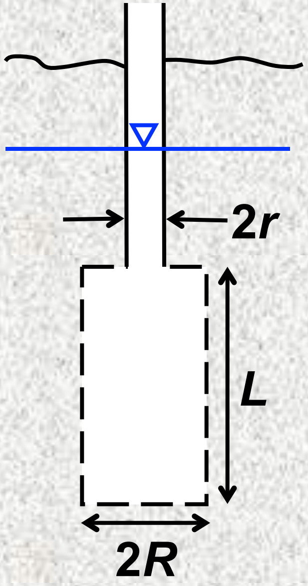
= water level displacement at time t

If we ignore storage within the formation, we can write a mass balance equation that results in:

$$K = \frac{A}{F(t_2 - t_1)} \ln\left(\frac{H_1}{H_2}\right)$$

where A is the cross-sectional area of the well casing, F is a shape factor, and H_1 and H_2 are the displacements at times t_1 and t_2, respectively.

Shape factors are given for a variety of well geometries (see Table 12.1 in Schwartz and Zhang, 2003). The most common well geometry is shown here.



R = screen/borehole radius

r = standpipe radius

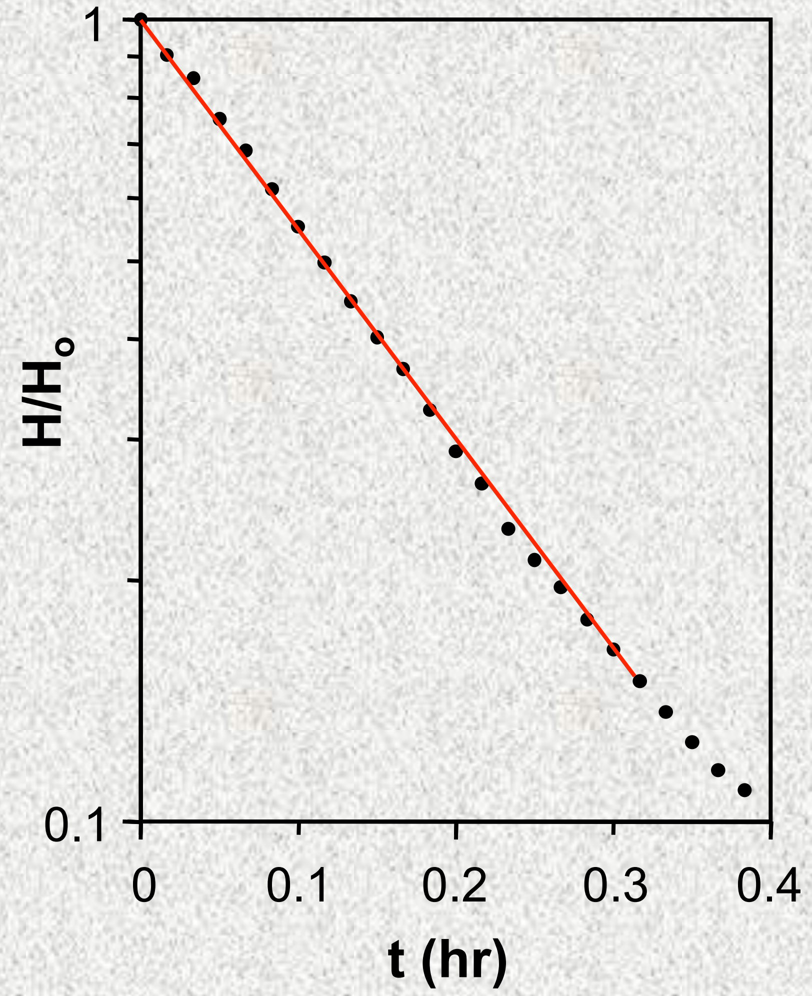
L = screen length

$$F = \frac{2\pi L}{ln\left(L/R\right)} \quad \text{for L/R>8}$$

The previous equation then becomes:

$$\boxed{K = \frac{r^2 \ln(L/R)}{2L(t_2 - t_1)} \ln\left(\frac{H_1}{H_2}\right)}$$

The data plot as a straight line (in theory) on a semilog plot of H vs time. Typically, the data are plotted as a drawdown ratio H/H_o which ranges from zero to one.



Picking any two values from the straight line segment and placing them in the previous equation will give K.

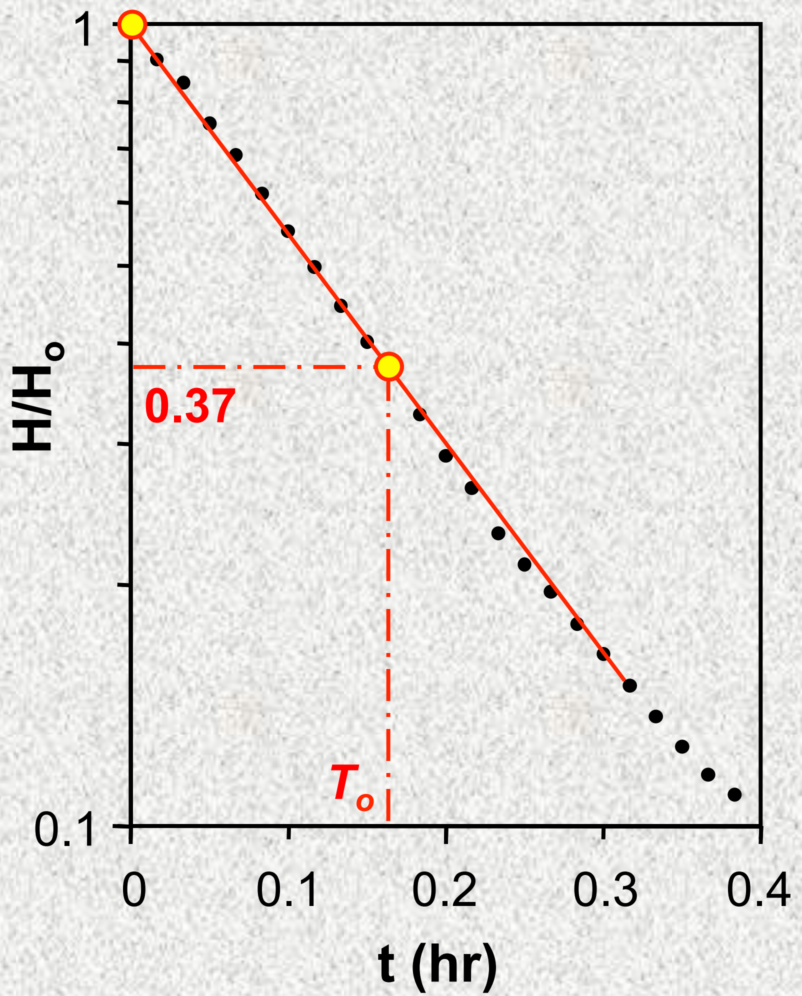
It is convenient to take the following two points:

$H/H_o = 1$ at $t = 0$, and

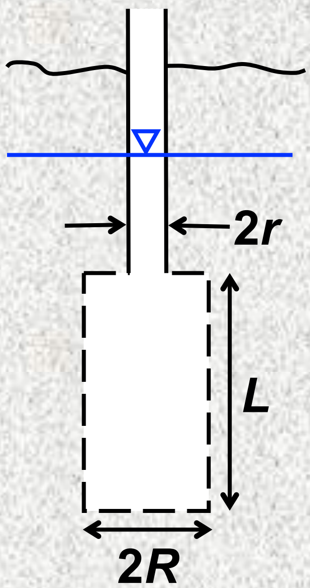
$H/H_o = 0.37$ at $t = T_o$

T_o is called the basic time lag. The equation for K then simplifies to:

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$

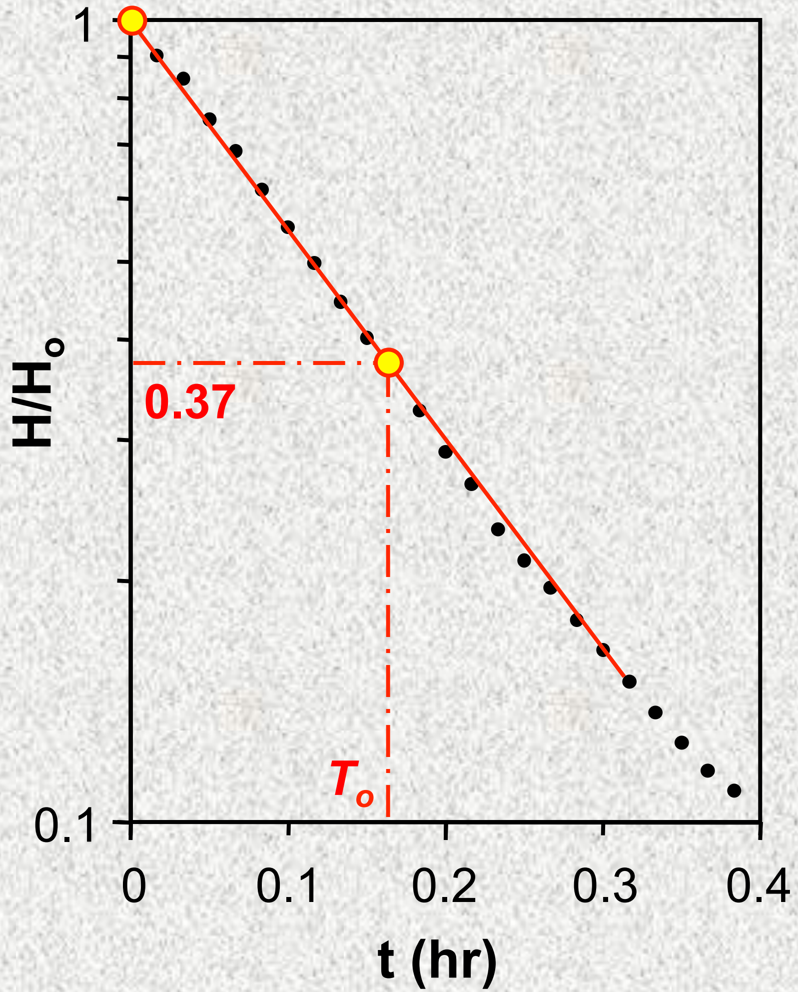


Find K



r = 2 cm
L = 1 m
R = 10 cm

$$K = \frac{r^2 \ln(L/R)}{2LT_0}$$



Procedure for a Single Well Test

(1) Obtain the construction details of the well.

(2) As quickly as possible, raise or lower the water level by a known amount.

- insert or remove a metal "slug" of known volume
- insert or bail a known volume of water
- pressurize the well by air injection

(3) Monitor the water level response. It may take anywhere from a few seconds to a year.

- pressure transducers are very helpful

(4) Repeat steps 2 and 3 at least two more times (ideally)

(5) Choose an appropriate analysis method and plot your data accordingly. Typically H/Ho against t in some fashion.

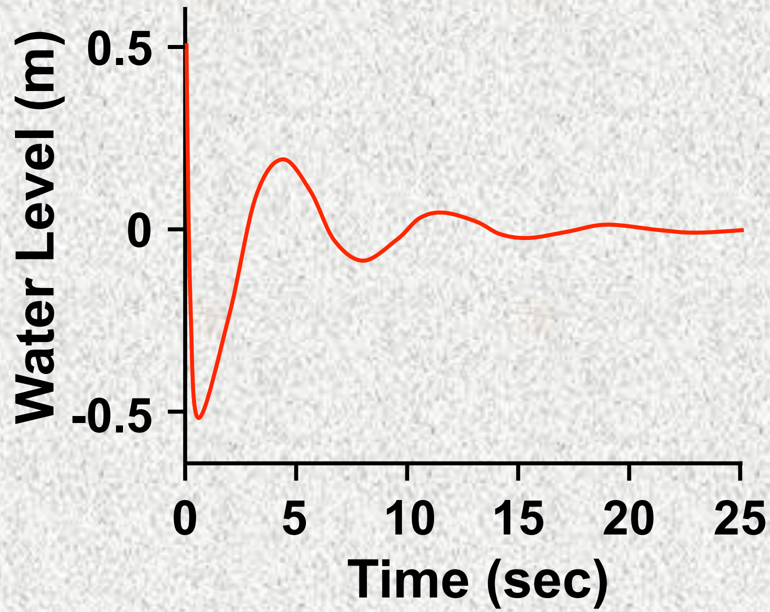
(6) Use the method to estimate K (or T) and S (if applicable).

Complicating Factors

There are several factors that can affect the interpretation of single well response tests.

Underdamped Response

For highly permeable materials, the water level in the well may oscillate due to inertial effects. Reliable estimates of aquifer properties can still be obtained. See van der Kamp (1976) or Kipp (1985).



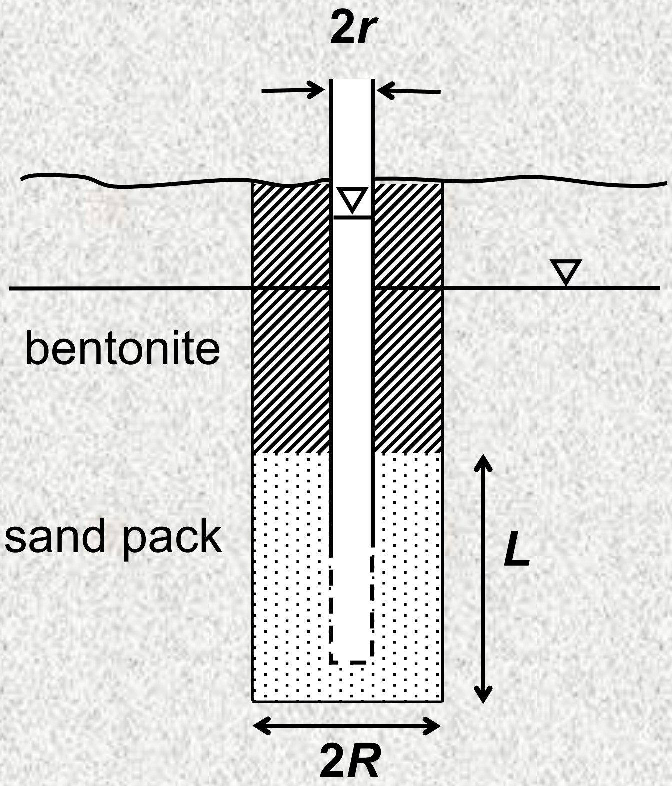
Skin Effects

The zone of alteration around the well is called the wellbore skin. It can influence how the well responds during the test and will undoubtedly affect our interpretation of the test results.

- Positive skin effect - reduction in K around the wellbore
  - e.g., clay smearing, clogging of filter pack with drilling mud, biofouling
- Negative skin effect - increase in K around the wellbore
  - e.g., fracturing during drilling

Filter Pack vs. Screen Size

In fine-grained materials, wells are often constructed with a sand filter pack around the well screen. The high K sand pack will respond much quicker than the lower K formation material.

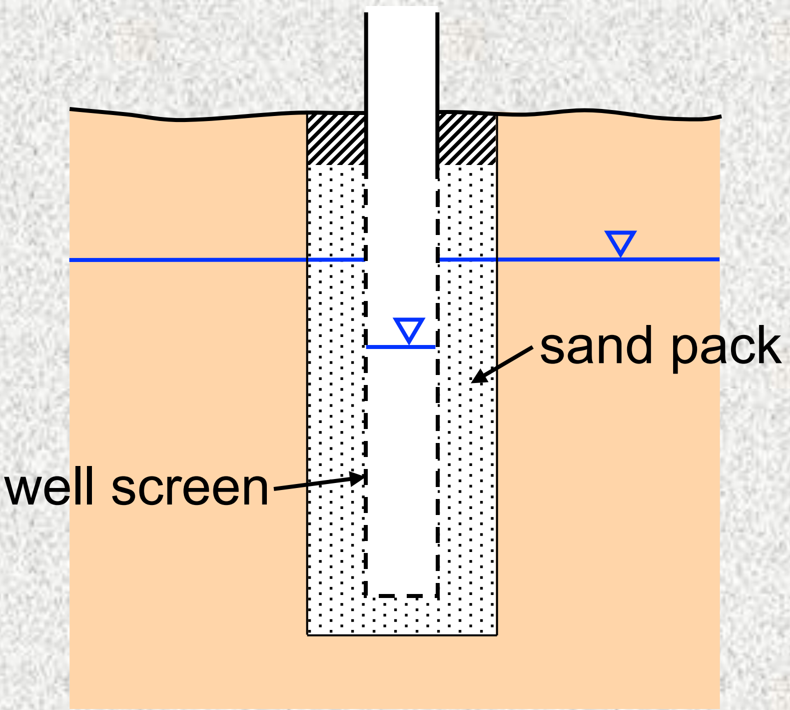


The response test partially measures *K* of the material in the sand pack, which may not represent the true properties of the formation. In this case, the dimensions L and R should be taken from the sand pack, not the screen.

Partially Submerged Screens

In unconfined aquifers, the static water level can be located within the screened interval or be lowered into the screened interval during testing. Partial submergence complicates analysis and should be avoided if possible.

The sand pack will fill or drain at a different rate than the formation material and result in a multistage water level response. Binkhorst and Robbins (1998, Ground Water, 36[2]:225-229) provide a method of analysis for this condition.



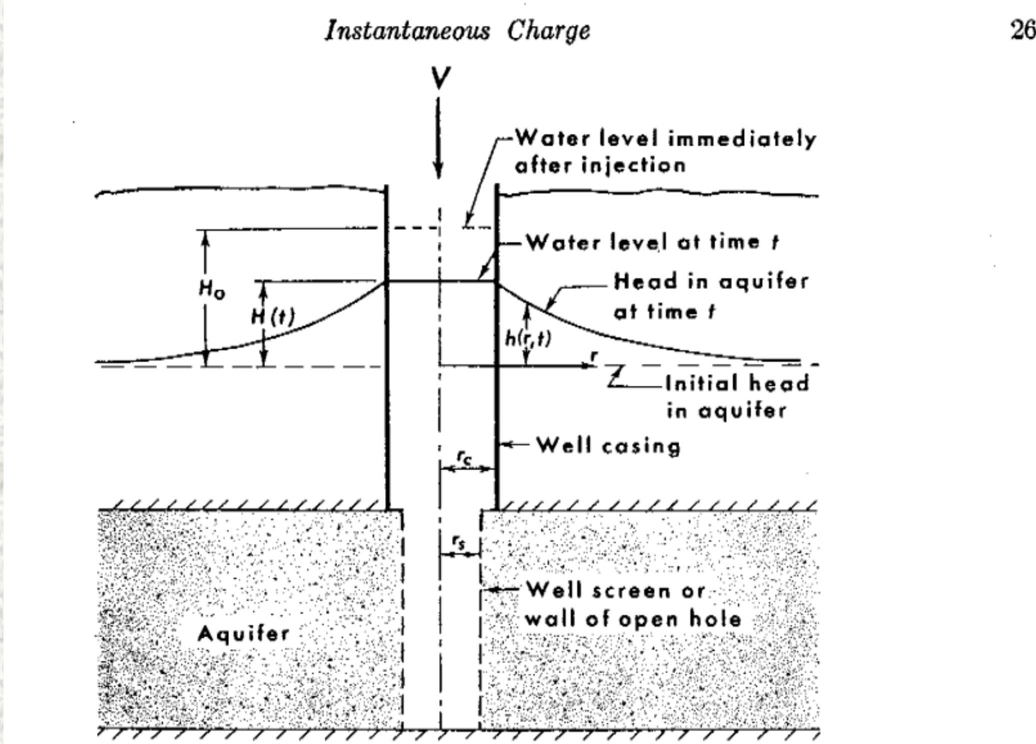
Cooper-Bredehoeft-Papadopulos Test

Response of a Finite-Diameter Well to an Instantaneous Charge of Water (Cooper et al., 1967)

More sophisticated single well test used for finding transmissivity and storativity in a nonleaky confined aquifer.

Assumptions:

- Nonleaky confined Aquifer
- Infinite areal extent
- Homogeneous, isotropic, and uniform thickness
- Potentiometric surface is initially horizontal or flat
- Water is instantaneously discharged or injected
- Flow to well is horizontal
- Water is instantaneously released from storage
- Solved the same as Theis



Idealized representation of a well into which a volume V of water is suddenly injected.

Cooper-Bredehoeft-Papadopulos Test

Response of a Finite-Diameter Well to an Instantaneous Charge of Water (Cooper et al., 1967)

Analytical solution for drawdown in a confined aquifer for a fully penetrating well:

$$\frac{s}{s_0} = \frac{8\alpha}{\pi^2}\int_0^\infty \frac{e^{-\frac{\beta u^2}{\alpha}}}{u([uJ_0(u)-2\alpha J_1(u)]^2+[uY_0(u)-2\alpha Y_1(u)]^2)}\,du$$

Simplified as:

$$\frac{s}{s_0} = F(\beta, \alpha)$$

where,

$$\beta = \frac{Tt}{r_c^2} \text{ and } \alpha = \frac{r_s^2 S}{r_c^2}$$

s_0	Initial Head Change after Injection or Withdrawal time = 0
s	Head change at time = t
T	Transmissivity
S	Storativity
r_s	Effective Radius of the Well
r_c	Radius of the Casing
t	time
F	Tabulated values

Cooper-Bredehoeft-Papadopulos Test

Response of a Finite-Diameter Well to an Instantaneous Charge of Water (Cooper et al., 1967)

TABLE 1. Values of H/H_0 for a Well of Finite Diameter (computed from equation 9)

	s/s_0				
Tt/r_c^2	$\alpha = 10^{-1}$	$\alpha = 10^{-2}$	$\alpha = 10^{-3}$	$\alpha = 10^{-4}$	$\alpha = 10^{-5}$
1.00×10^{-3}	0.9771	0.9920	0.9969	0.9985	0.9992
2.15×10^{-3}	0.9658	0.9876	0.9949	0.9974	0.9985
4.64×10^{-3}	0.9490	0.9807	0.9914	0.9954	0.9970
1.00×10^{-2}	0.9238	0.9693	0.9853	0.9915	0.9942
2.15×10^{-2}	0.8860	0.9505	0.9744	0.9841	0.9888
4.64×10^{-2}	0.8293	0.9187	0.9545	0.9701	0.9781
1.00×10^{-1}	0.7460	0.8655	0.9183	0.9434	0.9572
2.15×10^{-1}	0.6289	0.7782	0.8538	0.8935	0.9167
4.64×10^{-1}	0.4782	0.6436	0.7436	0.8031	0.8410
1.00×10^{0}	0.3117	0.4598	0.5729	0.6520	0.7080
2.15×10^{0}	0.1665	0.2597	0.3543	0.4364	0.5038
4.64×10^{0}	0.07415	0.1086	0.1554	0.2082	0.2620
7.00×10^{0}	0.04625	0.06204	0.08519	0.1161	0.1521
1.00×10^{1}	0.03065	0.03780	0.04821	0.06355	0.08378
1.40×10^{1}	0.02092	0.02414	0.02844	0.03492	0.04426
2.15×10^{1}	0.01297	0.01414	0.01545	0.01723	0.01999
3.00×10^{1}	0.009070	0.009615	0.01016	0.01083	0.01169
4.64×10^{1}	0.005711	0.005919	0.006111	0.006319	0.006554
7.00×10^{1}	0.003722	0.003809	0.003884	0.003962	0.004046
1.00×10^{2}	0.002577	0.002618	0.002653	0.002688	0.002725
2.15×10^{2}	0.001179	0.001187	0.001194	0.001201	0.001208

Cooper-Bredehoeft-Papadopulos Test

Response of a Finite-Diameter Well to an Instantaneous Charge of Water (Cooper et al., 1967)

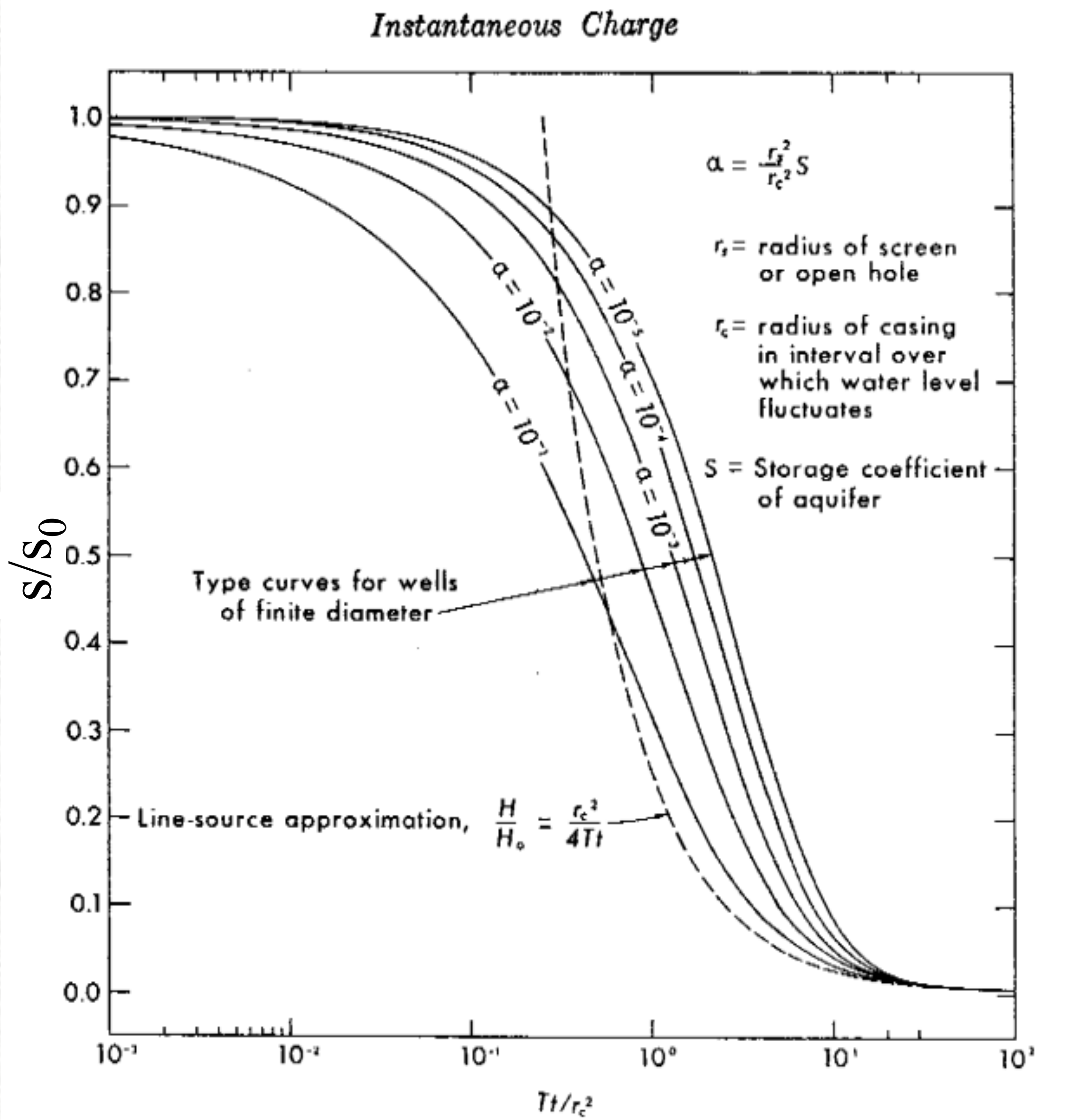


Fig. 3. Type curves for instantaneous charge in well of finite diameter.

Difficulties Associated with Cooper et al. Method

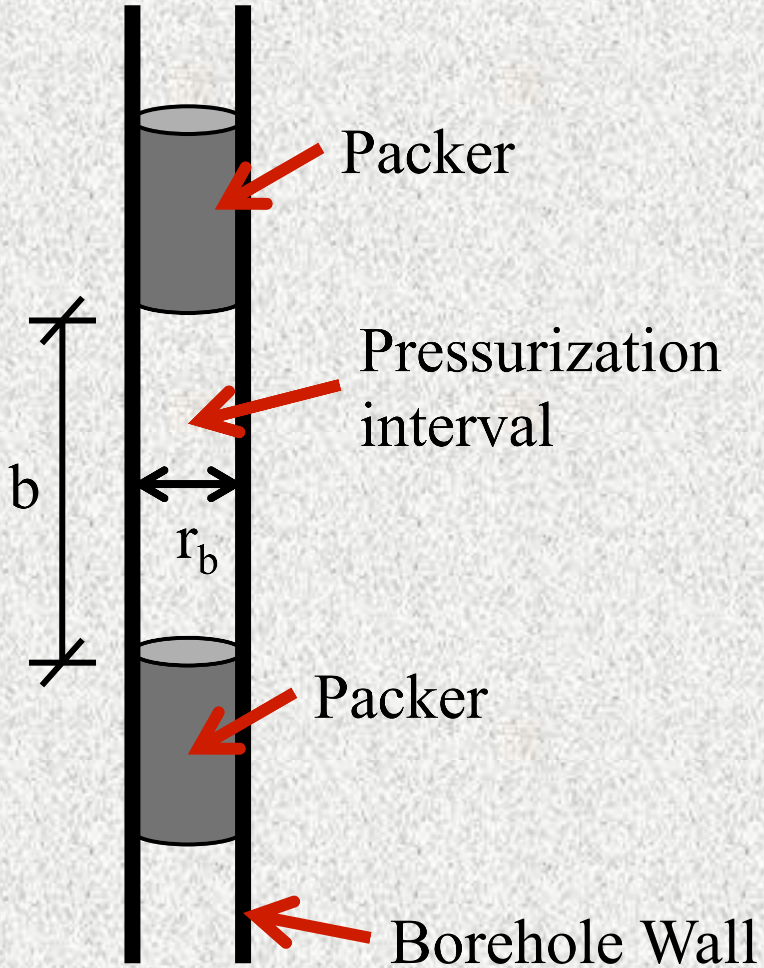
- Curves for different α have very similar slope
  - Insensitive of estimation of Storativity
  - Recommend to choose Storativity beforehand
- Flow regime assumed to be purely 1-D radial
  - Assume 1-D radial flow if screen length > 20 * screen radius

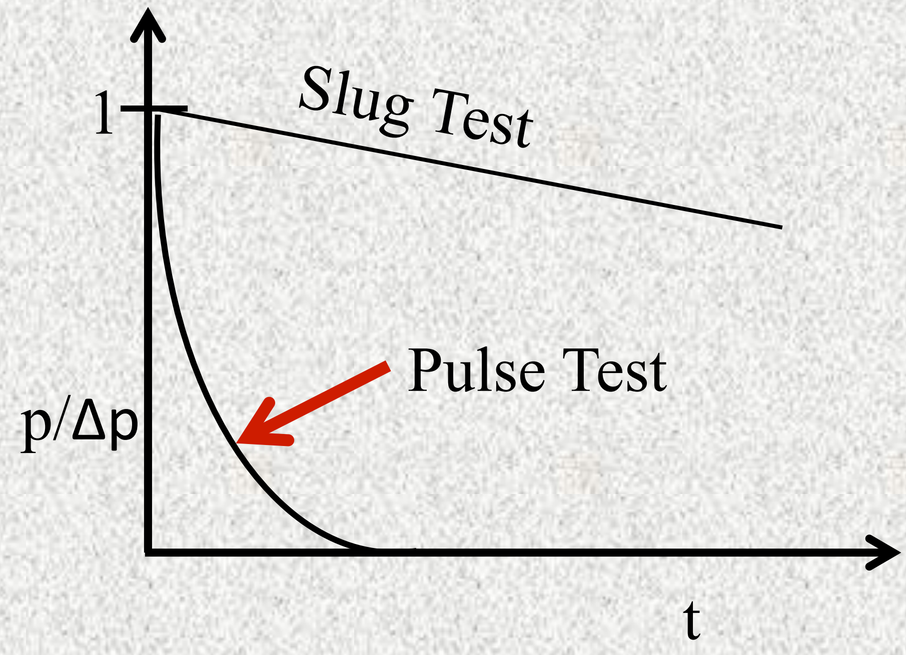
Determing Hydraulic Properties of Tight Formations

(Bredehoeft and Papadopoulos, 1980; Hayashi et al., 1987)

- Slug tests respond exceedingly slow for tight materials (clay and nonfractured rock)
- Takes a long time for water (Vol. = $\pi r_c^2 H_0$ added to standpipe to flow into formation
- Solutions:
  - Reduse standpipe diameter, but the diameter would be too small for practical purposes.
  - Shut-in pulse test is viable

Determining Hydraulic Properties of Tight Formations





Example:

$K = 10^{-10}\ m^2/s$

$s = 4*10^{-4}$

$b = 10\ m$

Pulse test takes ≈ 12 days for equilibrium

Slug test takes ≈ 32 years for equilibrium

Methods of Analysis for Pulse (Shut-in) Tests

Can use Cooper et al. (1967) type curves developed for slug tests

r_c^2 should be replaced by $V_w C_w \rho_w g/\pi$

- V_w = volume of packed-off interval
- C_w = compressibility of water
- ρ_w = density of water
- g = gravitational constant