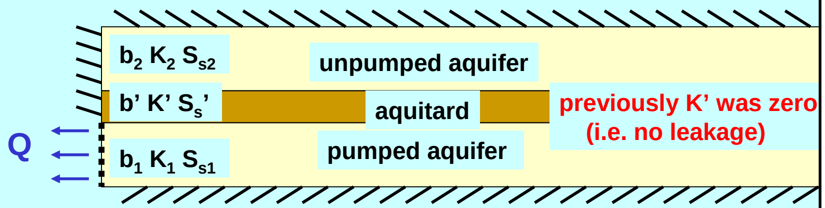
Leaky Aquifers

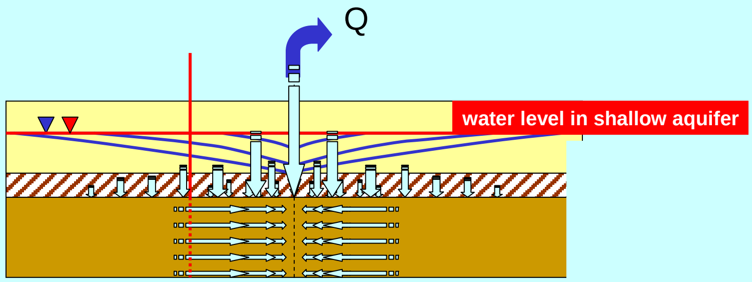


subscript **1** = **pumped** zone
subscript **2** = **unpumped** aquifer
prime = **aquitard**

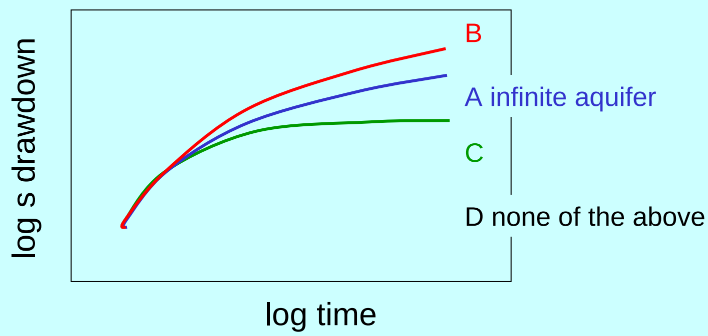
Q = pumping rate
b = thickness
K = hydraulic conductivity
S_s = specific storage

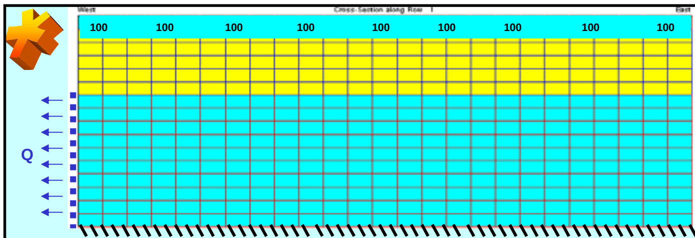
assume:
- no head change in shallow aquifer
- horizontal flow in aquifers
- vertical flow in aquitards
- aquifer extends far enough to intercept enough leakage to satisfy Q
- Theis assumptions (other than impermeable aquitard) apply

Solution is similar to Theis Solution but well function is more complex

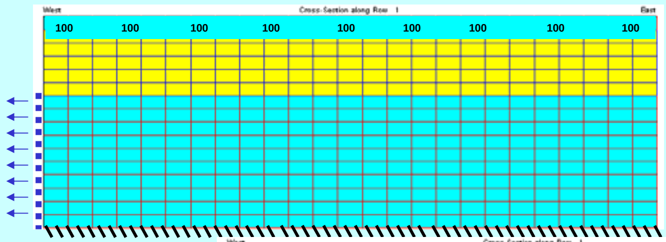


will the red observation well look more like? …..



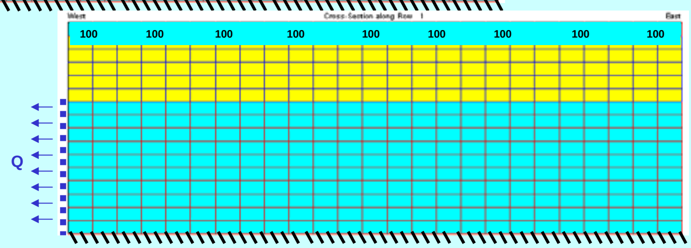


The system is hydrostatic at a head of 100 ft when pumping begins. The shallow aquifer head remains 100ft. The pumped aquifer is laterally "infinite".



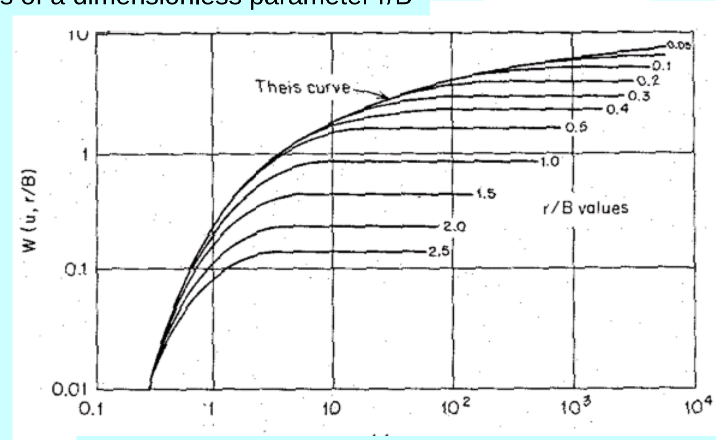
Work with a partner to draw the head distribution at early, middle and late time.

$K = 1\times10^{-1}$ ft/day
$K' = 1\times10^{-6}$ ft/day
S & $S' = 1\times10^{-5}$
$b = 10$ ft $b' = 5$ ft
$Q = 0.2$ GPM
head in shallow aquifer=100ft



Hantush & Jacob 1955
assumed no storage in the aquitard
and expressed this solution
in terms of a dimensionless parameter r/B

$$\frac{r}{B} = r\sqrt{\frac{K'}{K_1 b_1 b'}}$$



What does no storage in the aquitard mean relative to the last transient animation we watched? How does it change?

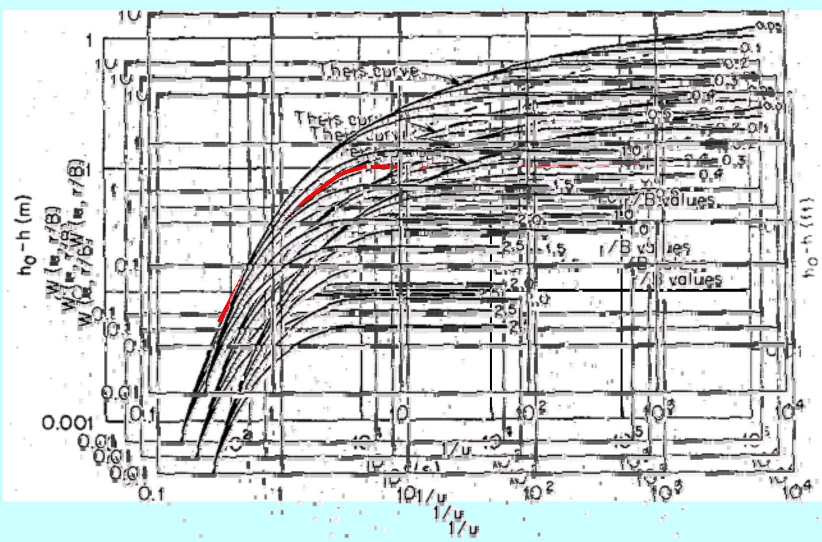
Curve match
W(u, r/B) r/B 1/u   matched with $s = h_o - h = \frac{Q}{4\pi T} W(u, r/B)$

Solve for T_1 by rearranging and using s and W from curve match

Solve for K_1 from $K_1 = T/b_1$

Solve for K' from $\frac{r}{B} = r\sqrt{\frac{K'}{K_1 b_1 b'}}$

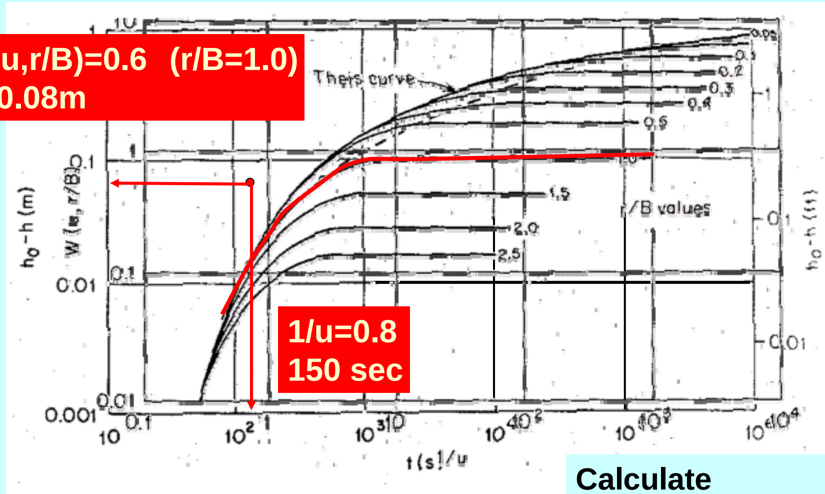
Solve for S_1 from $u = \frac{r^2 S}{4Tt}$



Q=0.004 m^3/sec
r=55m

b_1=30.5m
b'=3.05m

W(u,r/B)=0.6   (r/B=1.0)
s=0.08m



1/u=0.8
150 sec

Calculate
K_1 S_{s1} K'
Work with a neighbor

Q=0.004 m^3/sec
r=55m

b_1=30.5m
b'=3.05m

Q=0.004 m^3/sec
r=55m

b_1=30.5m
b'=3.05m

W(u,r/b)=0.6   (r/B=1.0)   1/u=0.8   u=1.25
s=0.08m   150 sec

$$s = h_o - h = \frac{Q}{4\pi T} W(u, r/B)$$

$$u = \frac{r^2 S}{4Tt} \qquad \frac{r}{B} = r\sqrt{\frac{K'}{K_1 b_1 b'}}$$

The Hantush & Jacob 1955 solution was based on
2 restrictive assumptions

1. hydraulic head in unpumped aquifer remains constant
2. rate of leakage into pumped aquifer is proportional to gradient across aquitard

Hantush 1960 added concept of S in the aquitard to equations

Neuman & Witherspoon 1969 presented complete solution including release from aquitard storage and head decrease in unpumped aquifer

Allows us to evaluate properties of both aquifers and the aquitard
in aquifers s(r,t)
in aquitard s(r,t,z)

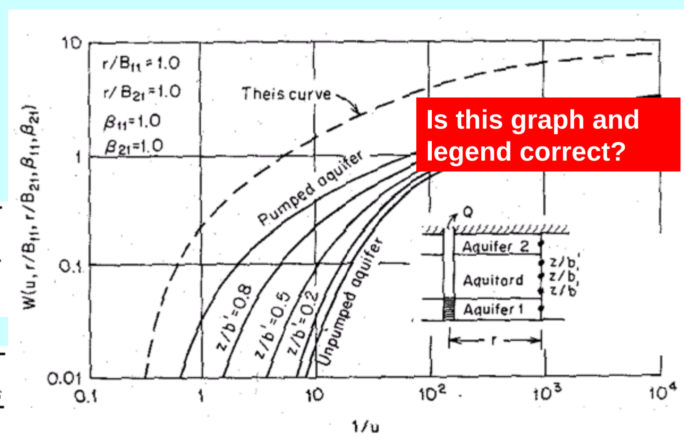
$$s = h_o - h(r,z,t) = \frac{Q}{4\pi T} W\left(u, \frac{r}{B_{11}}, \frac{r}{B_{21}}, \beta_{11}\beta_{21}\right)$$

$$\frac{r}{B_{11}} = r\sqrt{\frac{K^{\prime}}{K_1 b_1 b^{\prime}}}$$

$$\frac{r}{B_{21}} = r\sqrt{\frac{K^{\prime}}{K_2 b_2 b^{\prime}}}$$

$$\beta_{11} = \frac{r}{4b_1}\sqrt{\frac{K^{\prime} S^{\prime}_s}{K_1 S_{s_1}}}$$

$$\beta_{21} = \frac{r}{4b_2}\sqrt{\frac{K^{\prime} S^{\prime}_s}{K_2 S_{s_2}}}$$



Is this graph and legend correct?

Click here to see visualization of different conceptual models for pumping in IE
http://www.mines.edu/~epoeter/_GW/14wh3LeakyUnconf/PumpingDifferentAquiferypes.html

Unconfined - aquifer is dewatered, not only depressurized

aquifer thickness decreases and vertical components of flow exist

Two mechanisms for water delivery

1. first **elastic storage**
2. second actual **dewatering**

Click here to visualize pumping in an uncofined aquifer
http://www.mines.edu/~epoeter/4_GW/14wh3LeakyUnconf/PumpingUnconfinedAquifer.html

Three distinct phases of time-drawdown curves

1. shortly after start of pumping, water from **elastic storage, horizontal flow**
2. water table begins to decline, water primarily from **gravity drainage, horizontal & vertical flow**
3. at later times, **rate of drawdown decreases, essentially horizontal flow**

Type Curves based on:

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \Gamma)$$

$$u_A = \frac{r^2 S}{4Tt} \quad \textit{early time}$$

$$u_B = \frac{r^2 S_y}{4Tt} \quad \textit{late time}$$

$$\Gamma = \frac{r^2 K_v}{b^2 K_h}$$

Valid for: $S_y >> S$ $s << b$

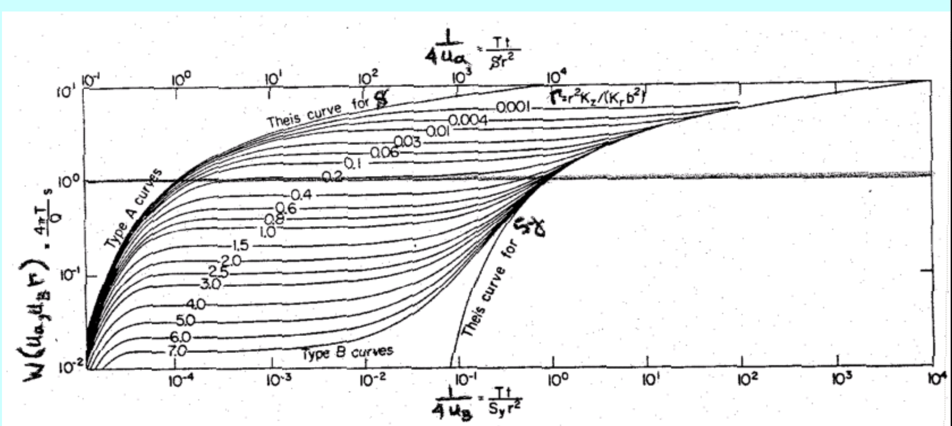
Fully penetrating pumping and observation wells

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \Gamma)$$

$$u_A = \frac{r^2 S}{4Tt} \quad \textit{early time}$$

$$u_B = \frac{r^2 S_y}{4Tt} \quad \textit{late time}$$

$$\Gamma = \frac{r^2 K_v}{b^2 K_h}$$



Adjusted field data for delayed yield analysis on Fairborn, Ohio, well (from Lohman) [49]

Time since pumping began t, min	Corrected drawdowns s, ft	Time since pumping t, min	Corrected drawdowns s, ft	Time since pumping t, min	Corrected drawdowns s, ft
0. 165	0. 12	2. 65	0. 92	80	1. 28
. 25	. 195	2. 80	. 93	90	1. 29
. 34	. 255	3. 00	. 94	100	1. 31
. 42	. 33	3. 50	. 95	120	1. 36
. 50	. 39	4. 00	. 97	150	1. 45
. 58	. 43	4. 50	. 975	200	1. 52
. 66	. 49	5. 00	. 98	250	1. 59
. 75	. 53	6. 00	. 99	300	1. 65
. 83	. 57	7. 00	1. 00	350	1. 70
. 92	. 61	8. 00	1. 01	400	1. 75
1. 00	. 64	9. 00	1. 015	500	1. 85
1. 08	. 67	10. 00	1. 02	600	1. 95
1. 16	. 70	12. 00	1. 03	700	2. 01
1. 24	. 72	15. 00	1. 04	800	2. 09
1. 33	. 74	18. 00	1. 05	900	3. 15
1. 42	. 76	20. 00	1. 06	1, 000	2. 20
1. 50	. 78	25. 00	1. 08	1, 200	2. 27
1. 68	. 82	30. 00	1. 13	1, 500	2. 35
1. 85	. 84	35. 00	1. 15	2, 000	2. 49
2. 00	. 86	40. 00	1. 17	2, 500	2. 59
2. 15	. 87	50. 00	1. 19	3, 000	2. 66
2. 35	. 90	60. 00	1. 22		
2. 50	. 91	70. 00	1. 25		

$Q = 144.9\ ft^3/min$
$r = 73'$

Example Problem:

Data on previous sheet corrected drawdowns to adjust unconfined conditions for confined equations:

s < 10% b OK

s 10% - 25% b:

$$s' = s - \frac{s^2}{2b}$$

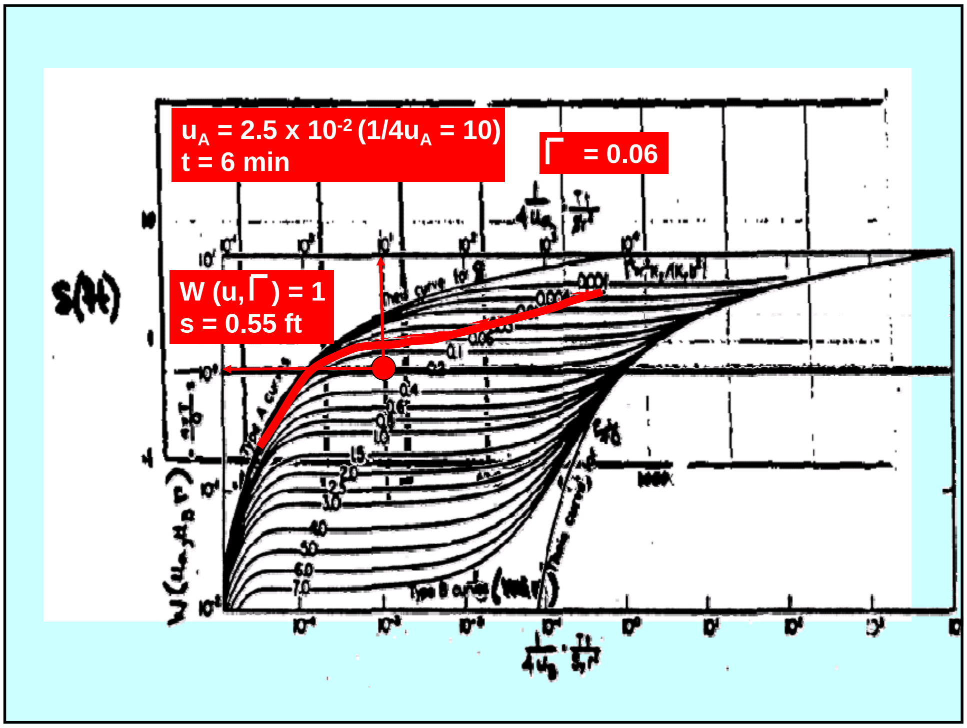
s > 25% don't trust

Plot data, curve match and read values of: $W(u_{A_{or}B}, \Gamma),\ \ u_{A_{or}B},\ \ t,\ \ s$

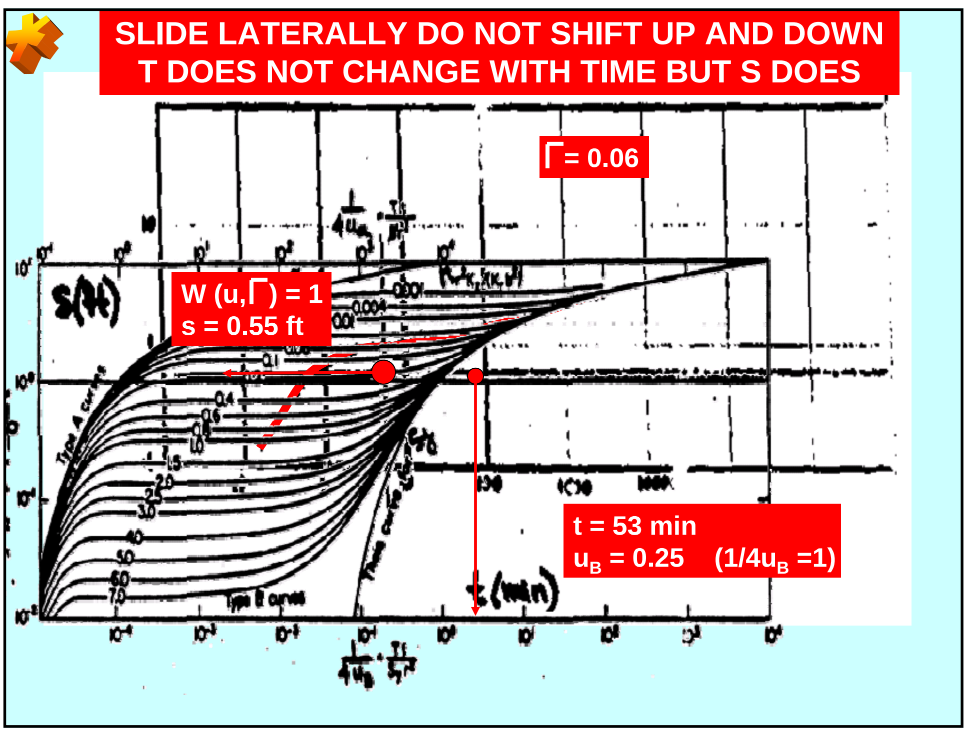
Γ comes from selected type curve and is the same for all t @ given r
it may be easier to match early time & shift horizontally to later time curves
solve for

$$T = \frac{Q}{4\pi s} W(u_A, u_B, \Gamma) \qquad K_H = \frac{T}{b} \qquad K_v = \frac{\Gamma b^2 K_H}{r^2}$$

$$S_y = \frac{4Ttu_B}{r^2} \qquad S = \frac{4Ttu_A}{r^2}$$



uA = 2.5 x 10-2 (1/4uA = 10)
t = 6 min
Γ = 0.06
W (u,Γ) = 1
s = 0.55 ft



SLIDE LATERALLY DO NOT SHIFT UP AND DOWN
T DOES NOT CHANGE WITH TIME BUT S DOES
Γ = 0.06
W (u,Γ) = 1
s = 0.55 ft
t = 53 min
uB = 0.25 (1/4uB =1)

Match

early time Γ = 0.06

W (u, Γ) = 1

$u_A = 2.5 \times 10^{-2}$ ($1/4u_A$ = 10)

t = 6 min

s = 0.55 ft

Q = 144.4 ft^3/min

r = 73 ft

b = 100 ft

late time same Γ

slide horizontally

same s = 0.55

t = 53 min

u_B = 0.25 ($1/4u_B$ =1)

Use distributed data and type curve to estimate aquifer properties

Notice the curve can be used for a confined or unconfined aquifer

Think about what parameters you can get from the data you have
the exam may only ask you to report aquifer parameters

Distance of fully penetrating observation well from pumping well = 190 ft

Initial saturated thickness = 88 ft

Pumping rate = 35 GPM