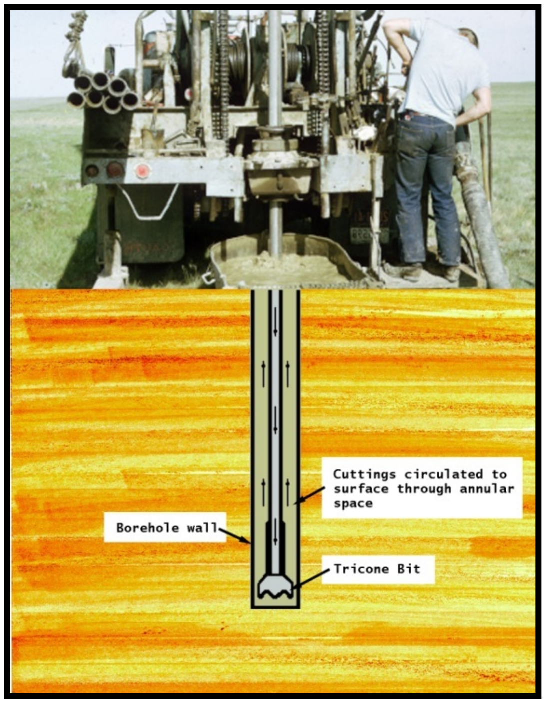
Groundwater Resources Development

Groundwater resources are used for domestic, municipal and industrial use worldwide. *Sustainable development of this vital resource is a hydrogeologist's responsibility*.



Recommended Reading: Schwartz and Zhang Ch. 9-11

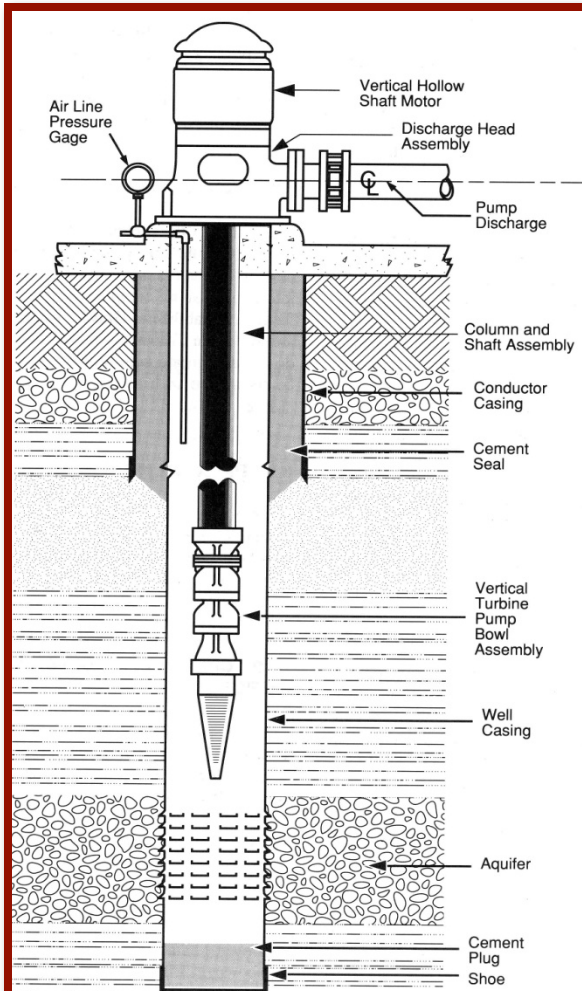


Figure 6.1. Typical well installation.

Developing Groundwater Resources

- location of accessible aquifer unit
- installation of production water well
- quantifying capacity of the aquifer unit
- assess performance and impacts of long-term groundwater extraction

Why is the turbine located in the bottom of the well?

Typical Well Installation

Roscoe Moss, 1990

Aquifer Tests

An aquifer test involves stressing the aquifer by pumping and measuring how water levels respond in one or more wells. Hence, aquifer tests are commonly called *pumping tests*.

Generally, we conduct aquifer tests to:

1. *Determine aquifer parameters T and S at larger scales*
2. *Evaluate the aquifer response to pumping*
   - *check for "non-ideal" conditions*
   - *estimate area of pumping influence*
3. *Estimate well efficiency*
4. *Estimate a suitable long-term pumping rate*

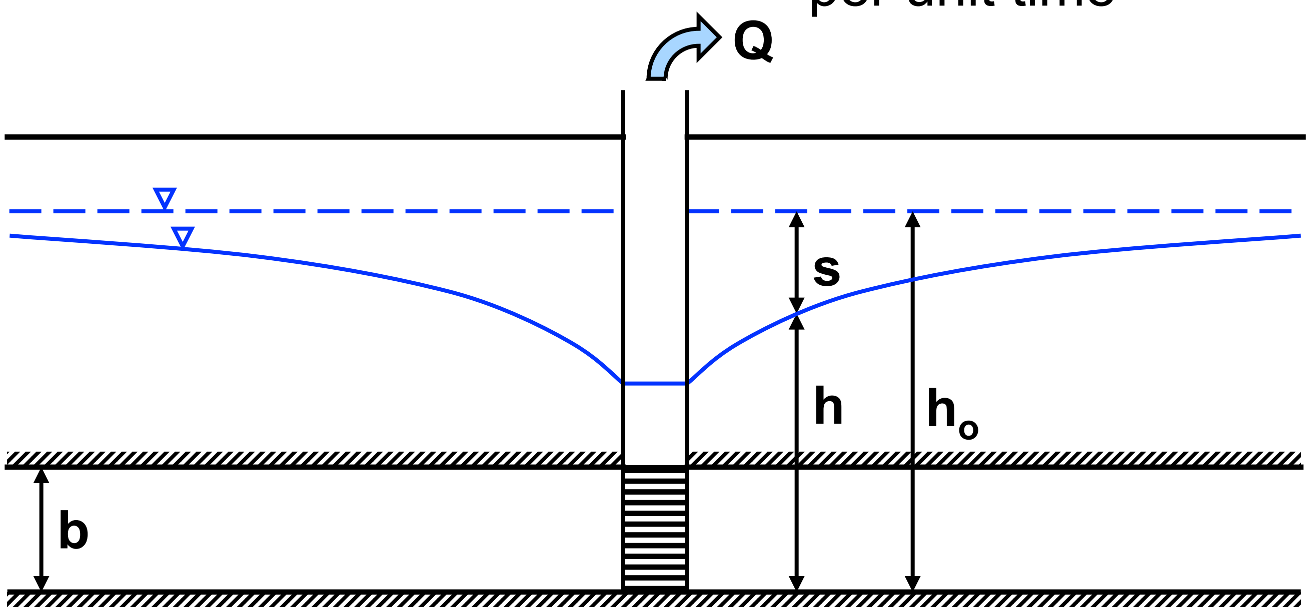
Aquifer Testing Terminology

Static Water Level [SWL] (h_o)
- equilibrium water level before pumping commences

Pumping Water Level [PWL] (h)
- water level during pumping

Drawdown ($s = h_o - h$)
- the difference between static and pumping water levels

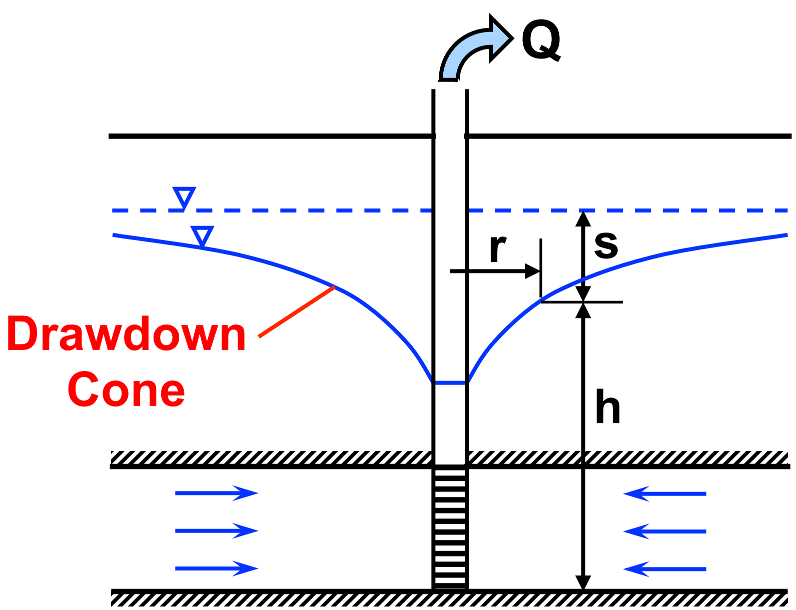
Pumping Rate (Q)
- volume of water pumped per unit time



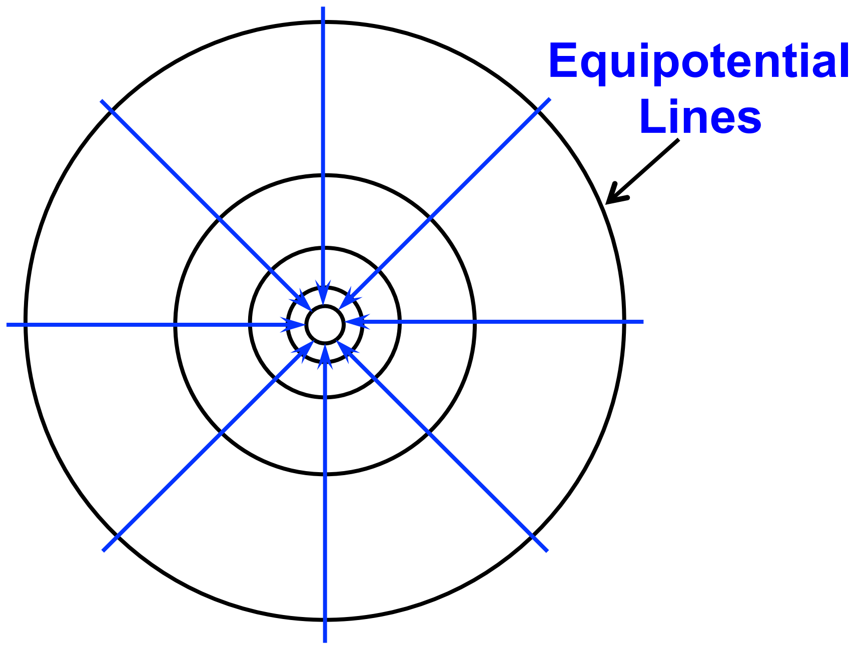
Radial Flow and the Drawdown Cone

Consider flow in a homogeneous, isotropic, confined aquifer. Pumping from a well at one location will lower the hydraulic head and water will flow toward the well from all directions. Since we have *radial symmetry*, the drawdown will be centered around the well and form a *drawdown cone (or cone of depression)*.

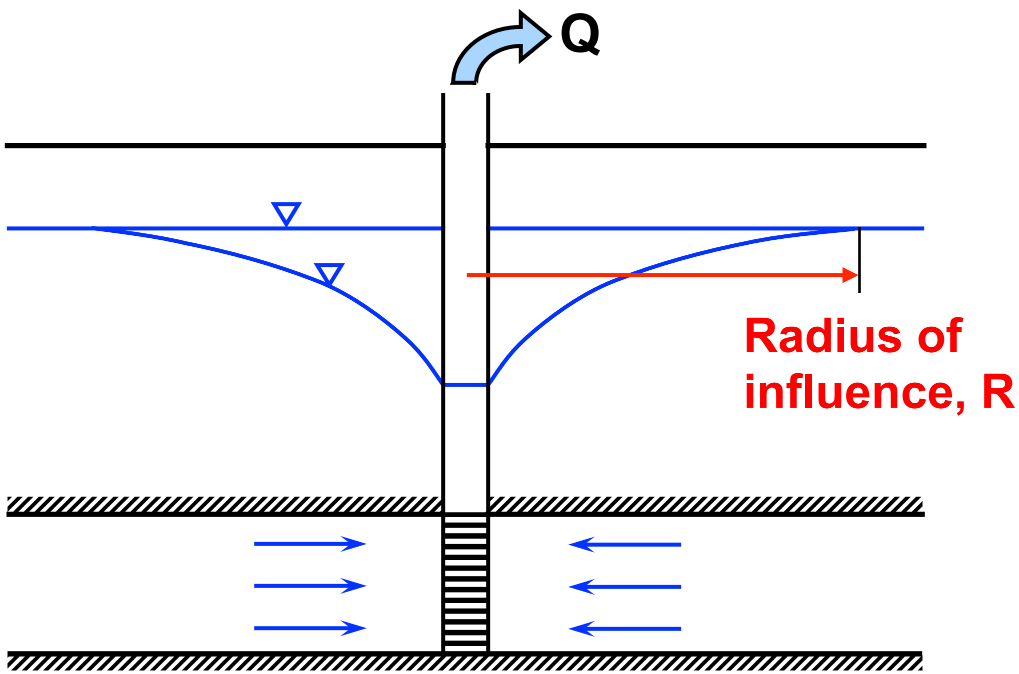
Cross-section



Plan view



Drawdown is greatest at the pumping well. Note how both the drawdown and hydraulic gradient decrease as one moves away from the pumping well. The outer limit of the drawdown cone (*i.e.*, s = 0) is referred to as the *radius of influence (R).*

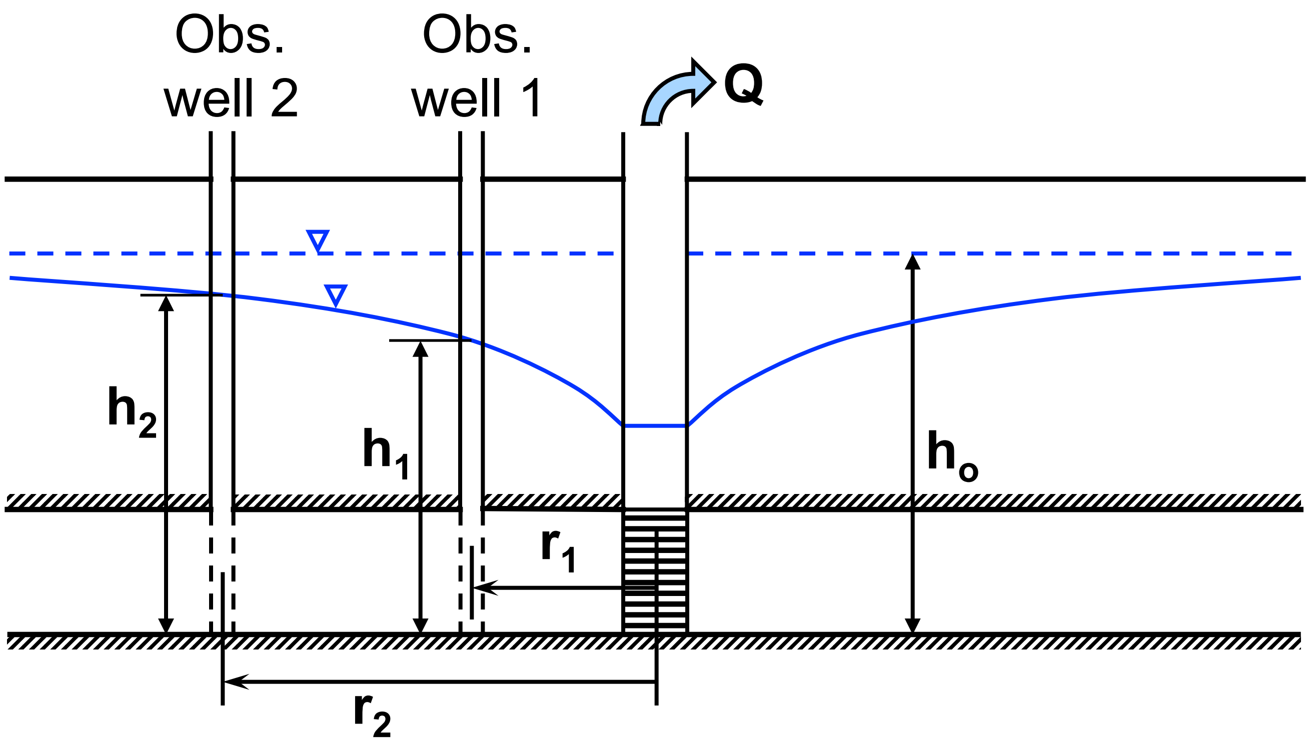


THIEM EQUATION 1906

- Steady-State
- Requires Two Observation Wells
- Calculates Transmissivity

Drawdown characteristics are controlled by Q, K, S_s, and b.

If we install and monitor *observation wells* at different radial distances from the pumping well, we can evaluate the aquifer response.

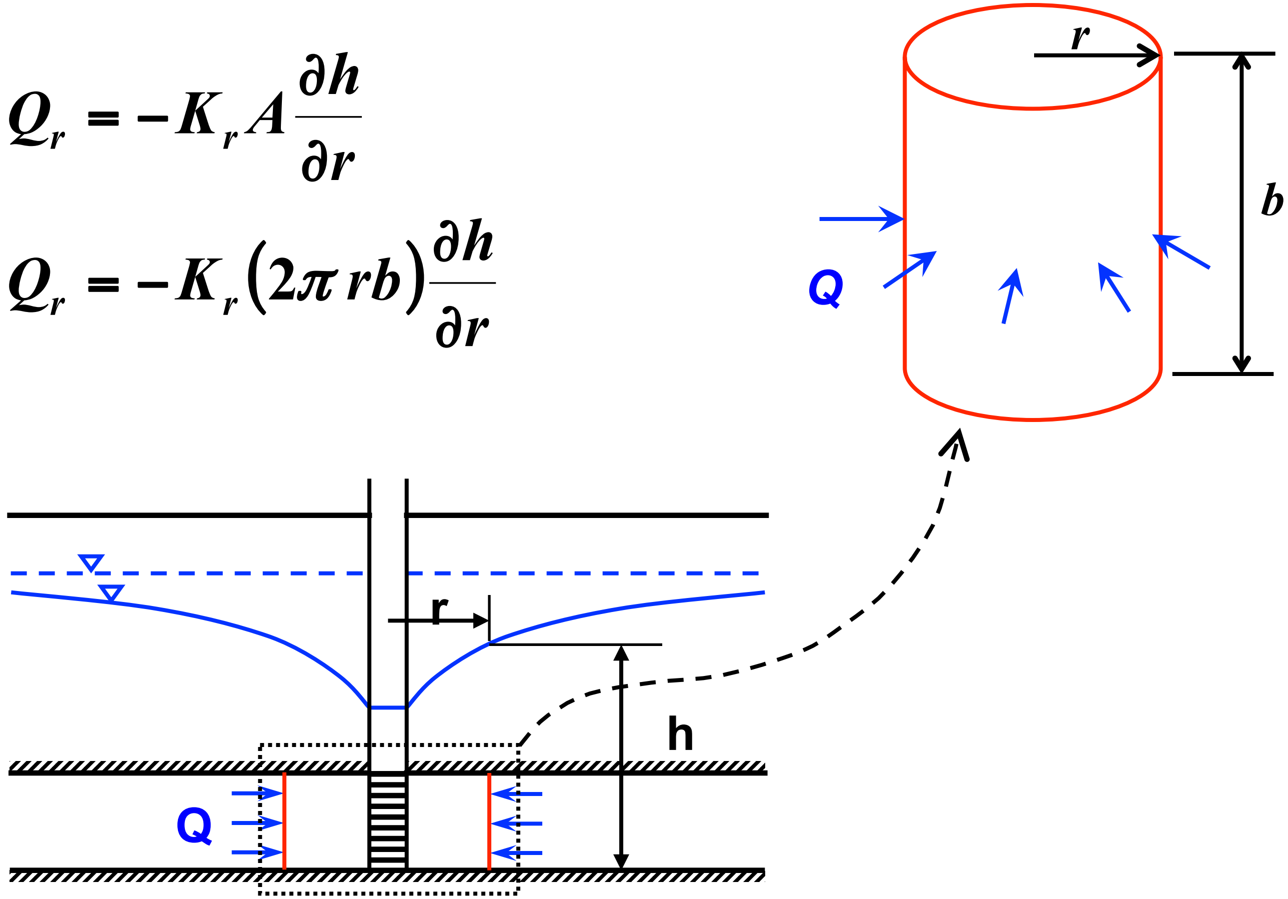


Radial Flow Equations

If flow is symmetrical, we can write Darcy's Law for radial flow toward a well in a confined aquifer as:

$$Q_r = -K_r A \frac{\partial h}{\partial r}$$

$$Q_r = -K_r (2\pi r b) \frac{\partial h}{\partial r}$$

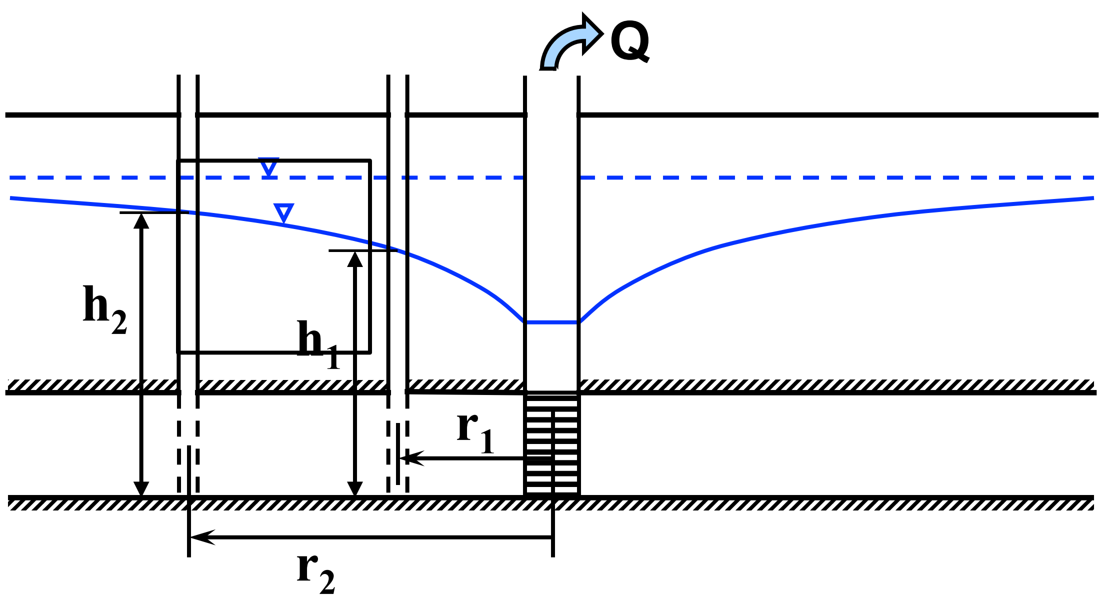


Steady State Radial Confined Flow

At steady state, we know that Q_r across any cylinder within the radius of influence R is the same.

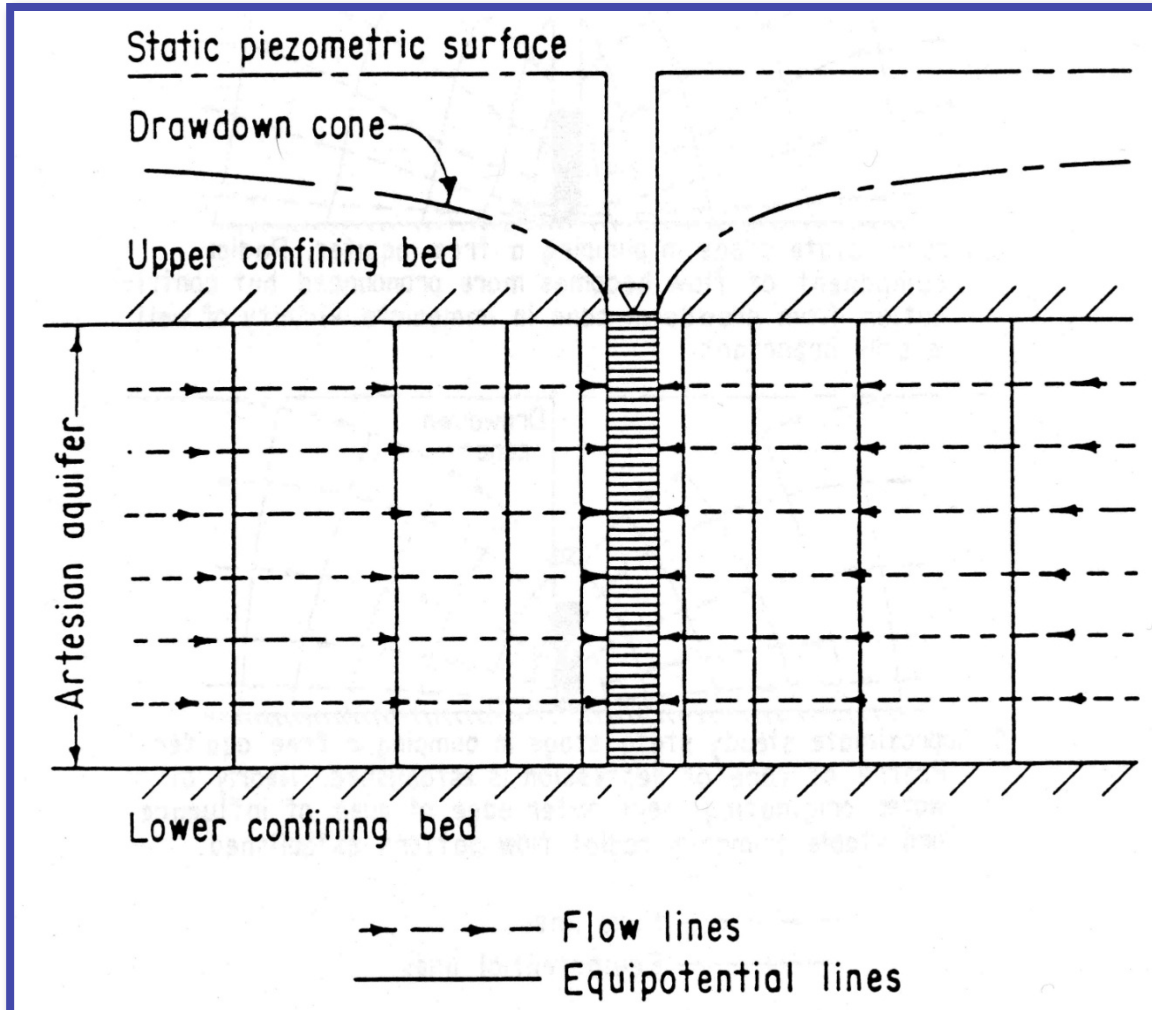
We start with Darcy's Law.

$$Q = -K_r\left(2\pi rb\right)\frac{\partial h}{\partial r} = -2\pi rT\frac{\partial h}{\partial r}$$



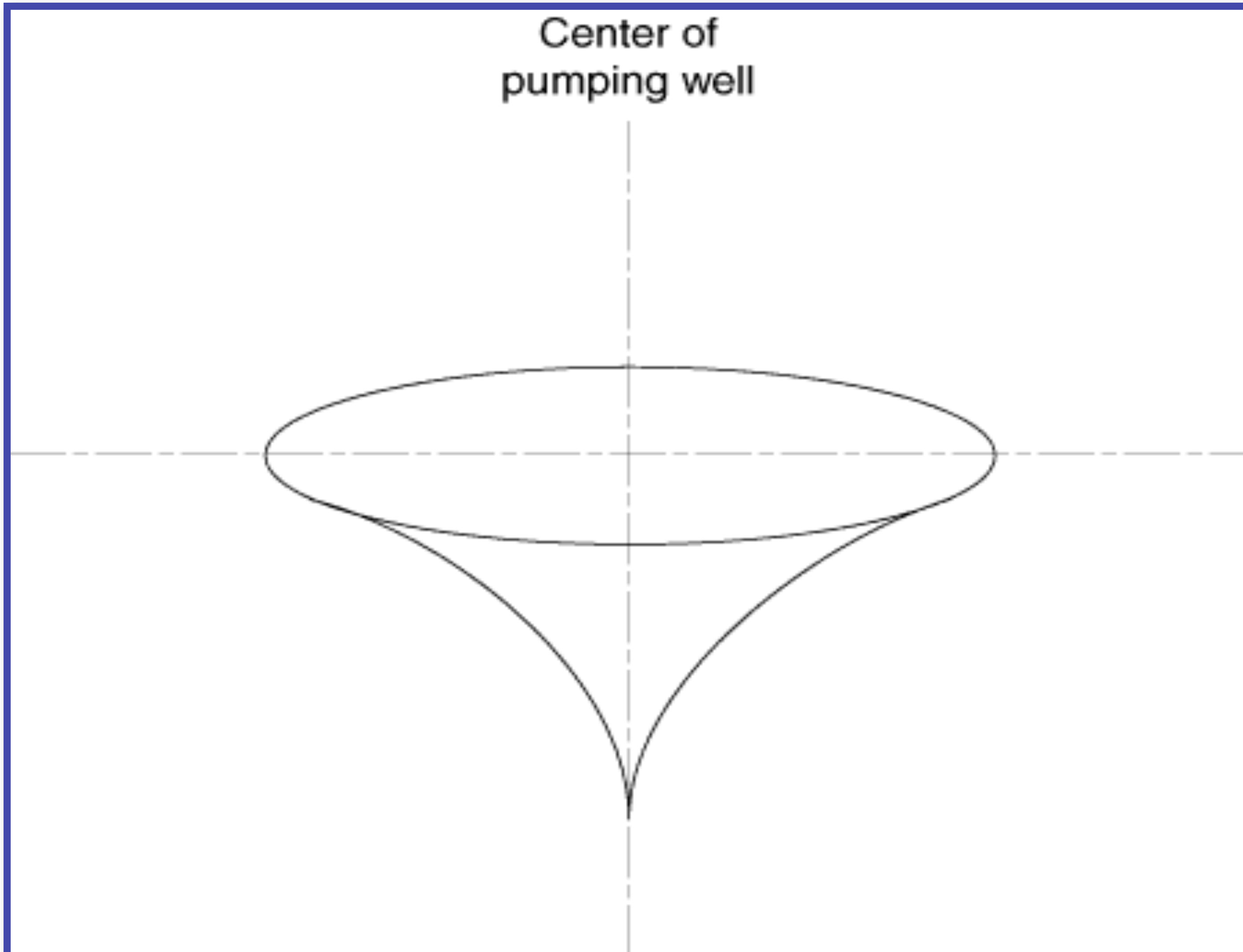
Physical Conditions

- Hydraulic heads, gradients and flow velocities are invariant in time (i.e. steady state)
- *No change in storage*

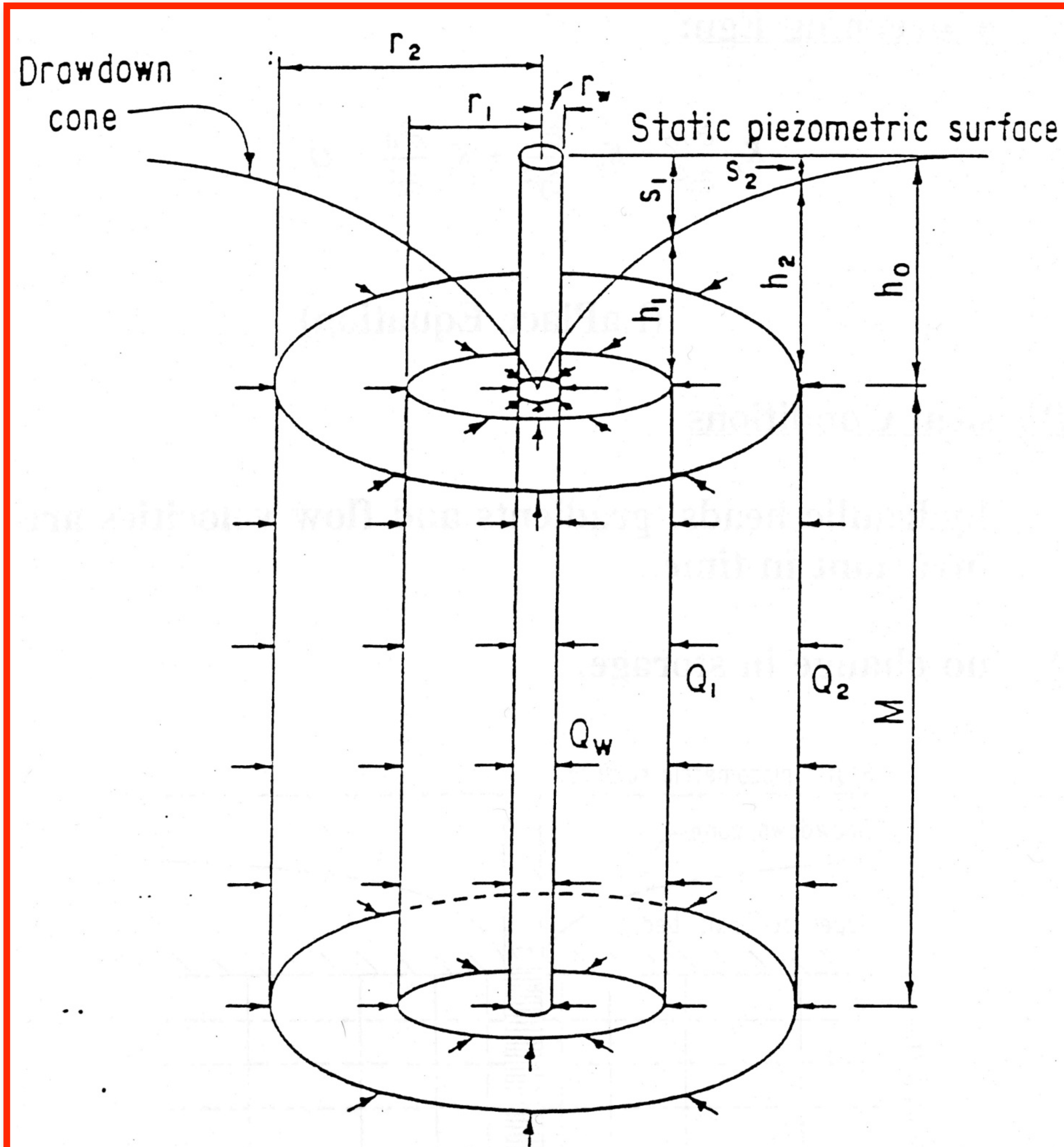


Ground Water Manual, 1977

Cone Of Depression



Source: USGS



Drawdown cone
r_2
r_1
r_w
Static piezometric surface
s_1
s_2
h_1
h_2
h_0
Q_1
Q_2
Q_w
M

Source: NWWA

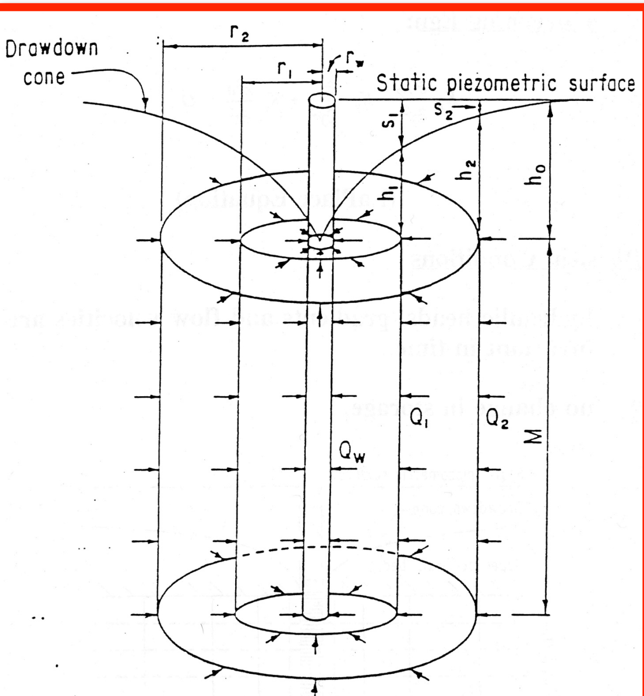
Steady State Radial Flow

$$Q_r = (K2\Pi r_1 b)\left(\frac{dh_1}{dr_1}\right) = (K2\Pi r_2 b)\left(\frac{dh_2}{dr_2}\right)$$

Where: $A = 2\Pi rb$

Because ***K2πb*** is a constant in an isotropic, homogeneous medium, and

Because $r_2 > r_1$



$$\frac{dh_1}{dr_1} > \frac{dh_2}{dr_2}$$

for Q = constant

Thiem Equation (1906)

$$Q_r = K \frac{\delta h}{\delta r} 2\Pi r b$$

$$\delta h = \frac{Q_r}{2\Pi b K} \frac{\delta r}{r}$$

$$\int_{h_1}^{h^2} \delta h = \frac{Q_r}{2\Pi b K} \int_{r_1}^{r_2} \frac{\delta r}{r}$$

$$(h_2 - h_1) = \frac{Q_r}{2\Pi b K} \ln \frac{r_2}{r_1}$$

$$\Delta h = \frac{2.3 Q_r}{2\Pi T} \log \frac{r_2}{r_1}$$

Thiem Equation

To determine T:

1. Plot distance-drawdown data from steady-state cone on log-linear graph
2. Determine drawdown over 1 log distance interval for convenience
3. Solve Thiem equation for T

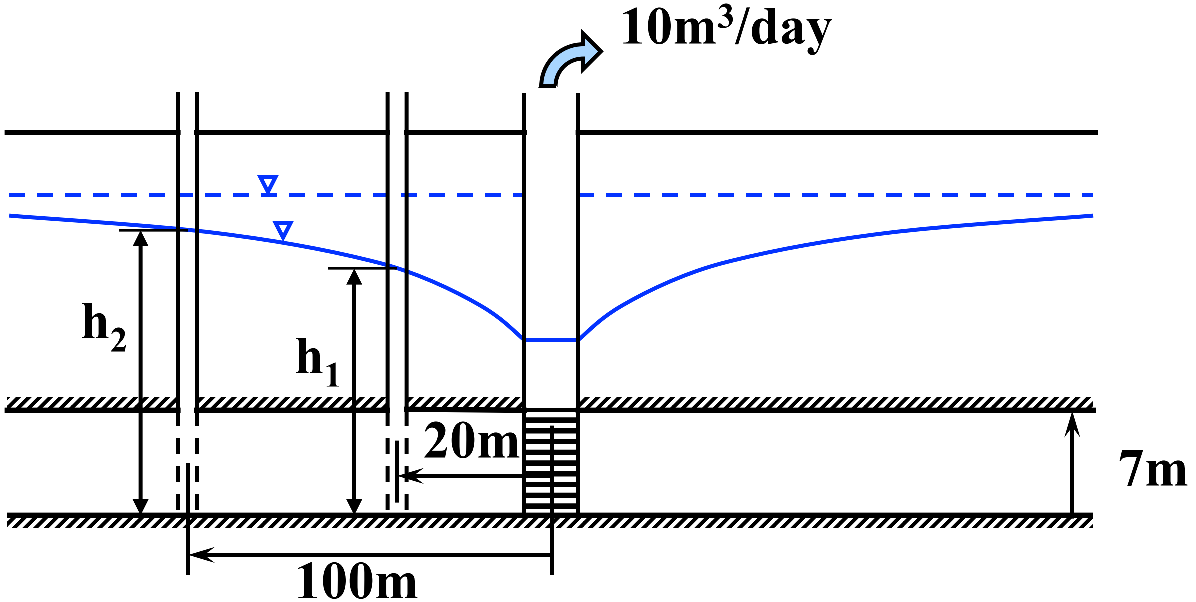
$$\boxed{\log \frac{r_2}{r_1} = 1}$$

Thiem Equation (1906)

Applications and Limitations

- Flow system must be close to steady-state
- More than one observation well is required
- Not possible to determine storage coefficient
- Can be useful where recharge boundaries are near and equidistant (*i.e.* pumping well in centre of island)

Calculate K



$h_1 = 23$ m

$h_2 = 25$ m

$$\boxed{\Delta h = \frac{2.3Q_r}{2\Pi T}\log\frac{r_2}{r_1}}$$

THEIS EQUATION 1935

- Transient
- Calculates Transmissivity and Storativity
- Only need information from one well

Consider transient flow to a well:

Governing Equation:

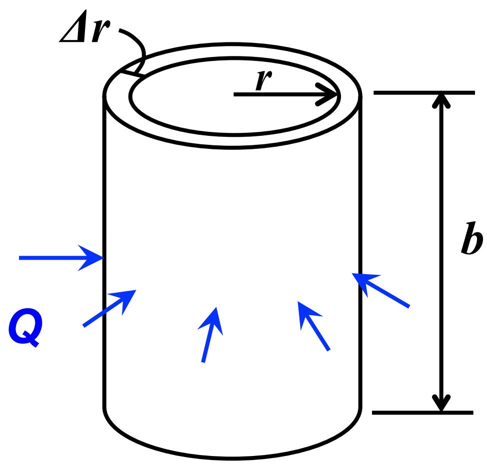
$$\boxed{\frac{\delta^2 h}{\delta x^2}+\frac{\delta^2 h}{\delta y^2}+\frac{\delta^2 h}{\delta z^2}=\frac{S}{T}\frac{\delta h}{\delta t}}$$

or $$\boxed{\frac{\delta^2 h}{\delta r^2}+\frac{1}{r}\frac{\delta h}{\delta r}=\frac{S}{T}\frac{\delta h}{\delta t}}$$ ***Radial Coordinates***

Transient Groundwater Flow

If we derive the groundwater flow equations using a mass balance on a thin cylindrical element we end up with the following equation:

$$T\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial h}{\partial r}\right) = S\frac{\partial h}{\partial t} \quad \text{or} \quad \boxed{T\left(\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r}\right) = S\frac{\partial h}{\partial t}}$$



GW Flow Equation
(Radial Flow)

Where:

Transmissivity, $T = Kb$ and
Storativity, $S = S_s b$

Transient Radial Flow in a Confined Aquifer

Theis Equation (1935)

Flow equation:

$$\boxed{T\left(\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r}\right) = S\frac{\partial h}{\partial t}}$$

Initial condition: $h = h_0$ at $t = 0$ for all r.

Boundary conditions: $h = h_0$ at $r = \infty$ for all t.

$2\pi r T \, \partial h/\partial r = Q$ as $r \rightarrow 0$ for all t.

Theis made analogy to *transient heat flow*:

$$s = h_o - h = \frac{Q}{4\pi T}\int_u^{\infty}\frac{e^{-u}}{u}du \qquad \text{where} \qquad u = \frac{r^2 S}{4Tt}$$

The integral is known as the exponential integral and can be replaced with an infinite series:

$$s = \frac{Q}{4\pi T}\left(-0.5772 - \ln u + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} - \frac{u^4}{4\cdot 4!} + \cdots\right)$$

If we define a function *W(u)*, known as the *well function*:

$$\boxed{s = h_o - h = \frac{Q}{4\pi T}W(u)}$$

Theis Equation

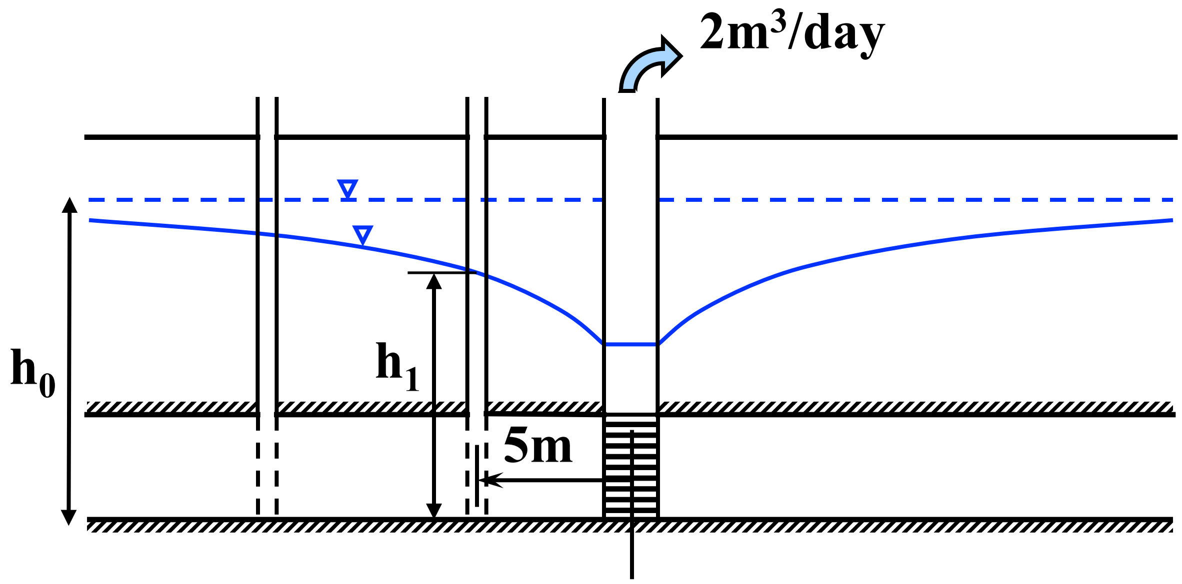
W(u) Table for Theis Solution

TABLE 9.2 **Values of well function $W(u)$**

u	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
$\times 1$	0.219	0.049	0.013	0.0038	0.0011	0.00036	0.00012	0.000038	0.000012
$\times 10^{-1}$	1.82	1.22	0.91	0.70	0.56	0.45	0.37	0.31	0.26
$\times 10^{-2}$	4.04	3.35	2.96	2.68	2.47	2.30	2.15	2.03	1.92
$\times 10^{-3}$	6.33	5.64	5.23	4.95	4.73	4.54	4.39	4.26	4.14
$\times 10^{-4}$	8.63	7.94	7.53	7.25	7.02	6.84	6.69	6.55	6.44
$\times 10^{-5}$	10.94	10.24	9.84	9.55	9.33	9.14	8.99	8.86	8.74
$\times 10^{-6}$	13.24	12.55	12.14	11.85	11.63	11.45	11.29	11.16	11.04
$\times 10^{-7}$	15.54	14.85	14.44	14.15	13.93	13.75	13.60	13.46	13.34
$\times 10^{-8}$	17.84	17.15	16.74	16.46	16.23	16.05	15.90	15.76	15.65
$\times 10^{-9}$	20.15	19.45	19.05	18.76	18.54	18.35	18.20	18.07	17.95
$\times 10^{-10}$	22.45	21.76	21.35	21.06	20.84	20.66	20.50	20.37	20.25
$\times 10^{-11}$	24.75	24.06	23.65	23.36	23.14	22.96	22.81	22.67	22.55
$\times 10^{-12}$	27.05	26.36	25.96	25.67	25.44	25.26	25.11	24.97	24.86
$\times 10^{-13}$	29.36	28.66	28.26	27.97	27.75	27.56	27.41	27.28	27.16
$\times 10^{-14}$	31.66	30.97	30.56	30.27	30.05	29.87	29.71	29.58	29.46
$\times 10^{-15}$	33.96	33.27	32.86	32.58	32.35	32.17	32.02	31.88	31.76

Source: From Wenzel (1942).

Calculate h_1



$h_1 = ?$

$h_0 = 36$ m

$T = 0.07$ m^2/day

$S = 0.002$

$t = 30$ days

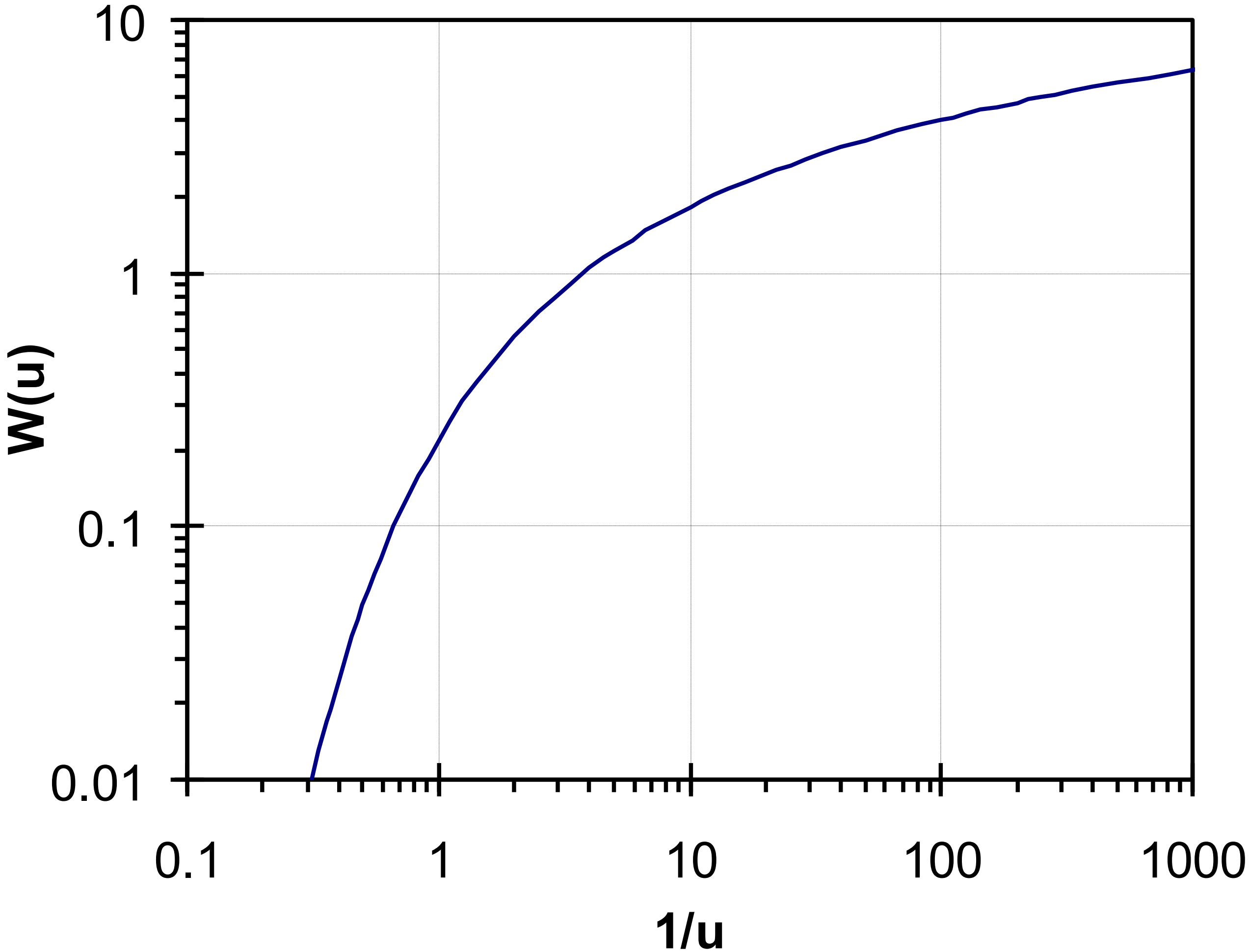
$$s = h_o - h = \frac{Q}{4\pi T} W(u)$$

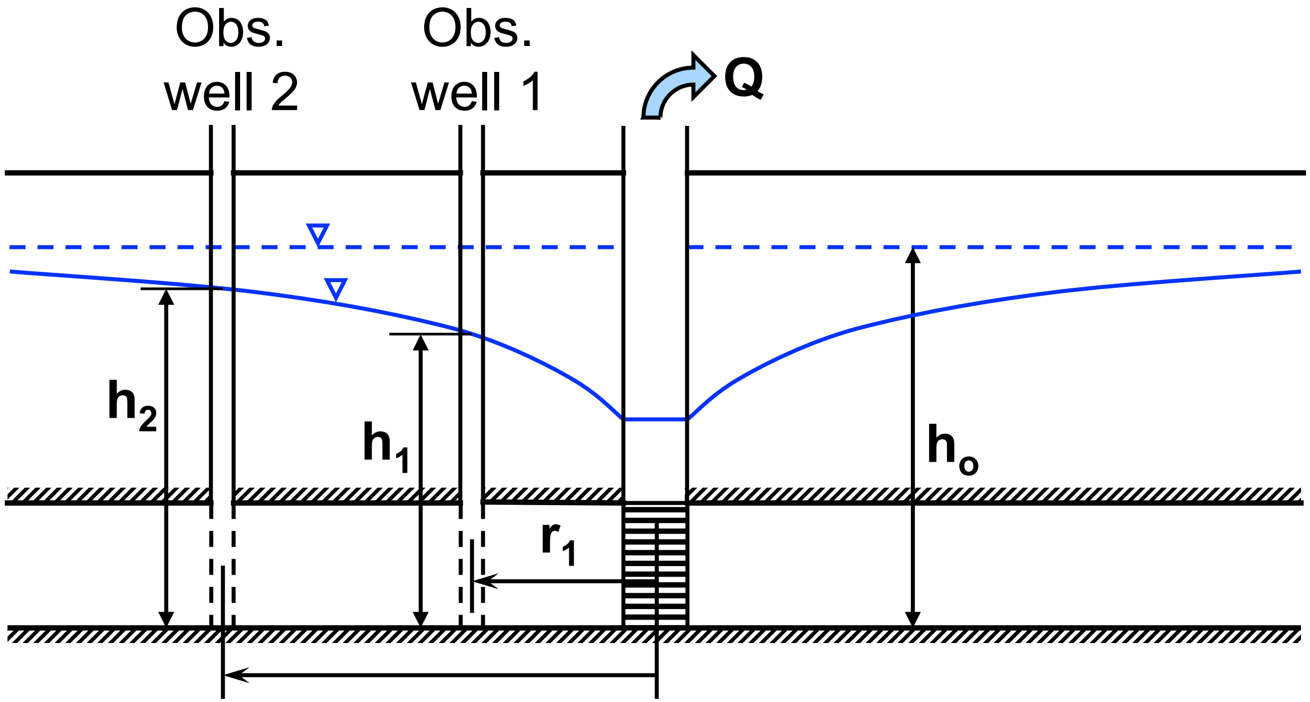
$$u = \frac{r^2 S}{4Tt}$$

THEIS EQUATION
Graphical Method for Temporal Field Data

- Transient
- Calculates Transmissivity and Storativity
- Only need information from one well

- Values for **u** and **W(u)** have been tabulated in detail
- The <u>Theis type curve</u> is plotted on a log-log scale. The relationship between *W* and *1/u* is *unique*.





- Isotropic
- Homogeneous
- Flat lying
- Infinite
- Water is released instantly from storage
- Fully confined
- Flow is radial to the well

Aquifer:

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

Pumping Well:

- Discharges at a constant rate
- Fully penetrating
- No borehole storage

- If values for **T and S** can be estimated and the **Theis assumptions** are valid for a particular case,
  - *The **drawdown** at any distance from the pumping well, at any time, can be **estimated** from the equation*
  - *A simple relationship can be developed between the **Theis equation** and the exponent **u** that produces two independent equations that differ by a constant*

Graphical Method

$$s = \frac{Q}{4\pi T} W(u) \longrightarrow \boxed{\log s = \log \frac{Q}{4\Pi T} + \log W(u)}$$

and

$$\boldsymbol{u = \frac{r^2 S}{4Tt}} \longrightarrow \boxed{\log \frac{1}{u} = \log \frac{4T}{r^2 s} + \log t}$$

- If log **s** vs **t** is plotted and **log W(u)** vs **log 1/u** is plotted, the two graphs represent functions that only **differ** through **constants**

Graphical Method con't:

i.e.:

s – W(u) axes related through $\boxed{\dfrac{Q}{4\Pi T}}$

t – 1/u axes related through $\boxed{\dfrac{r^2 s}{4T}}$

- When the two graphs are superimposed on each other, unique values of u, W(u), t and s can be determined so that both equations can be solved and T and S determined.

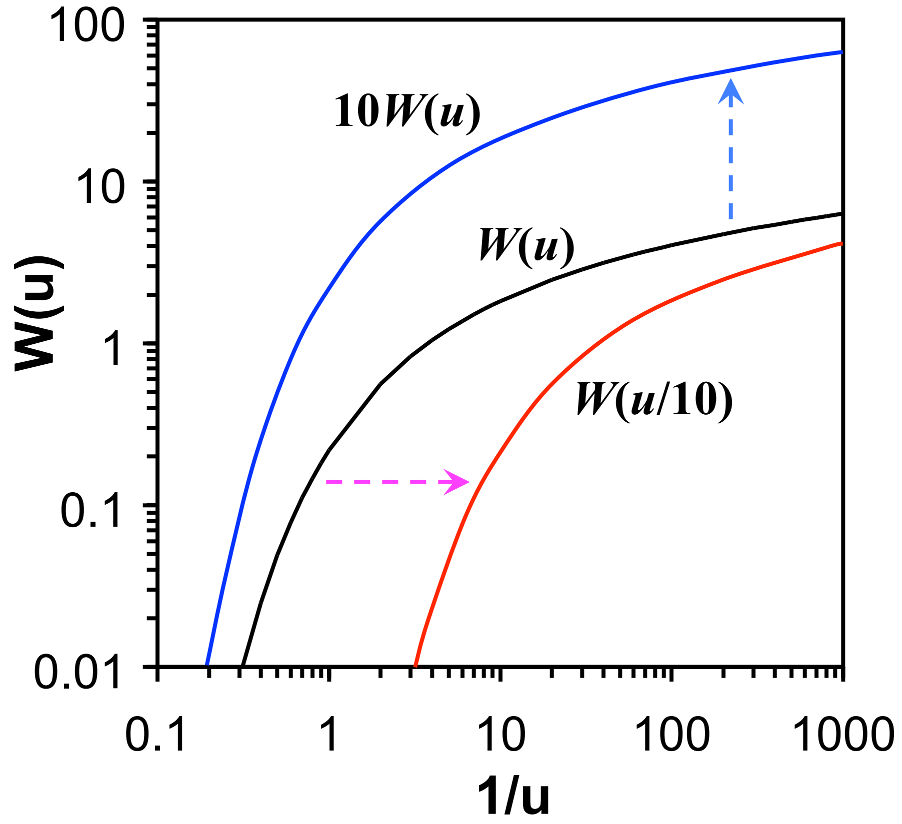
Properties of log-log graphs

The shape of a curve does not change when variables are multiplied by constants.

From the definition of *W*(*u*) and *u*;

$$s = \frac{Q}{4\pi T} W(u)$$

$$t = \frac{r^2 S}{4T} \frac{1}{u}$$



Graphical Procedure

1. Collect all physical data required
   - *Aquifer thickness*
   - *Depth to static level*
   - *Distance to observation well*
2. Select pumping rate 1.5 x higher than desired rate
3. Monitor time-drawdown data in both pumping well and observation well (s) *(early-time data critical)*

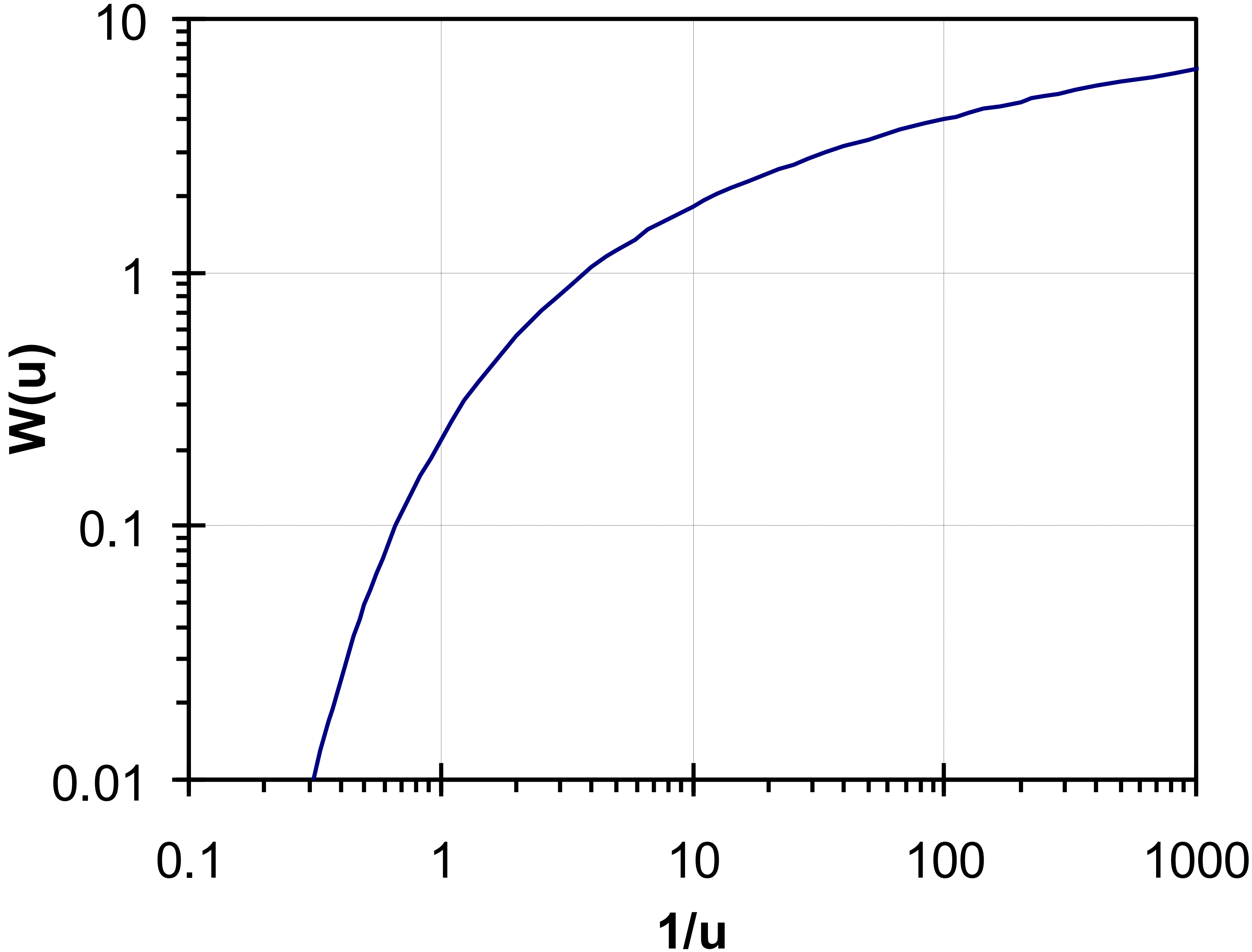
Graphical Procedure

4. Plot drawdown vs time data on log-plot as test proceeds (same scale as available type curve)
5. When rising limb begins to flatten out, stop test
6. Monitor recovery in both wells

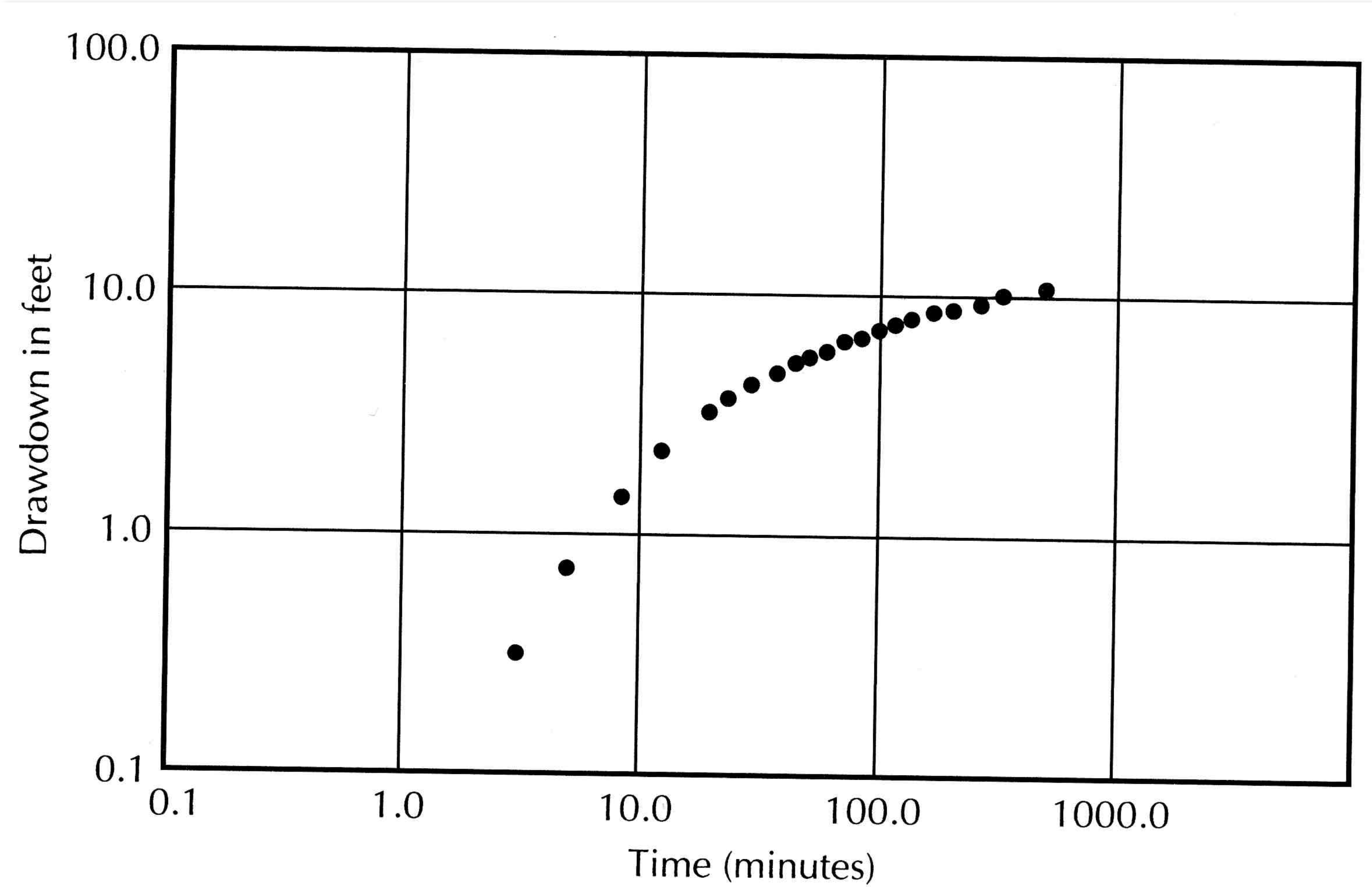
Graphical Procedure

7. Superimpose s vs t data on W(u) vs 1/u plot and match curves as best as possible focusing on the early time data particularly.
8. Select any convenient point on superimposed graphs and record ***u, W(u), s, t.***

W(u) vs. 1/u

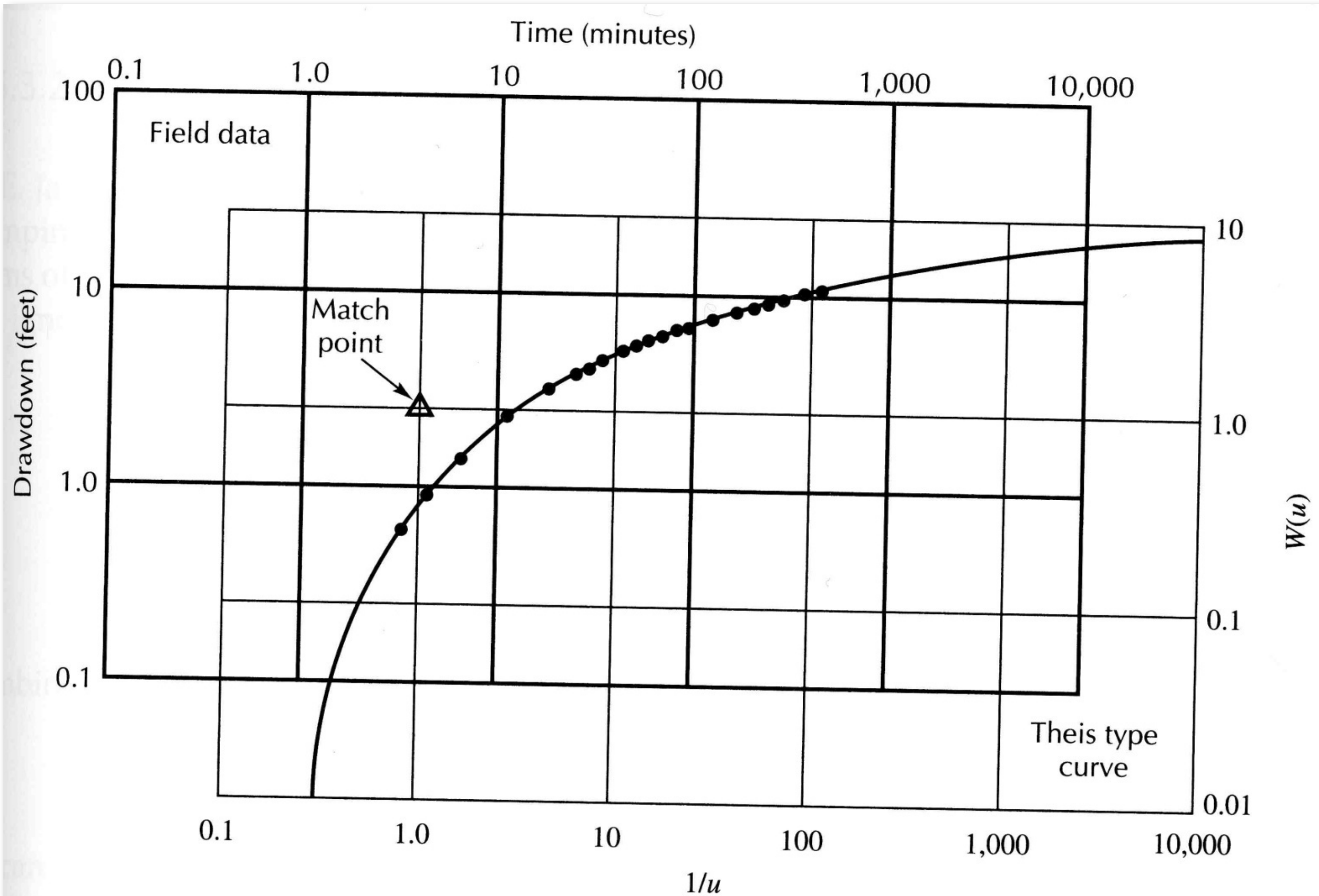


Field Data Plot



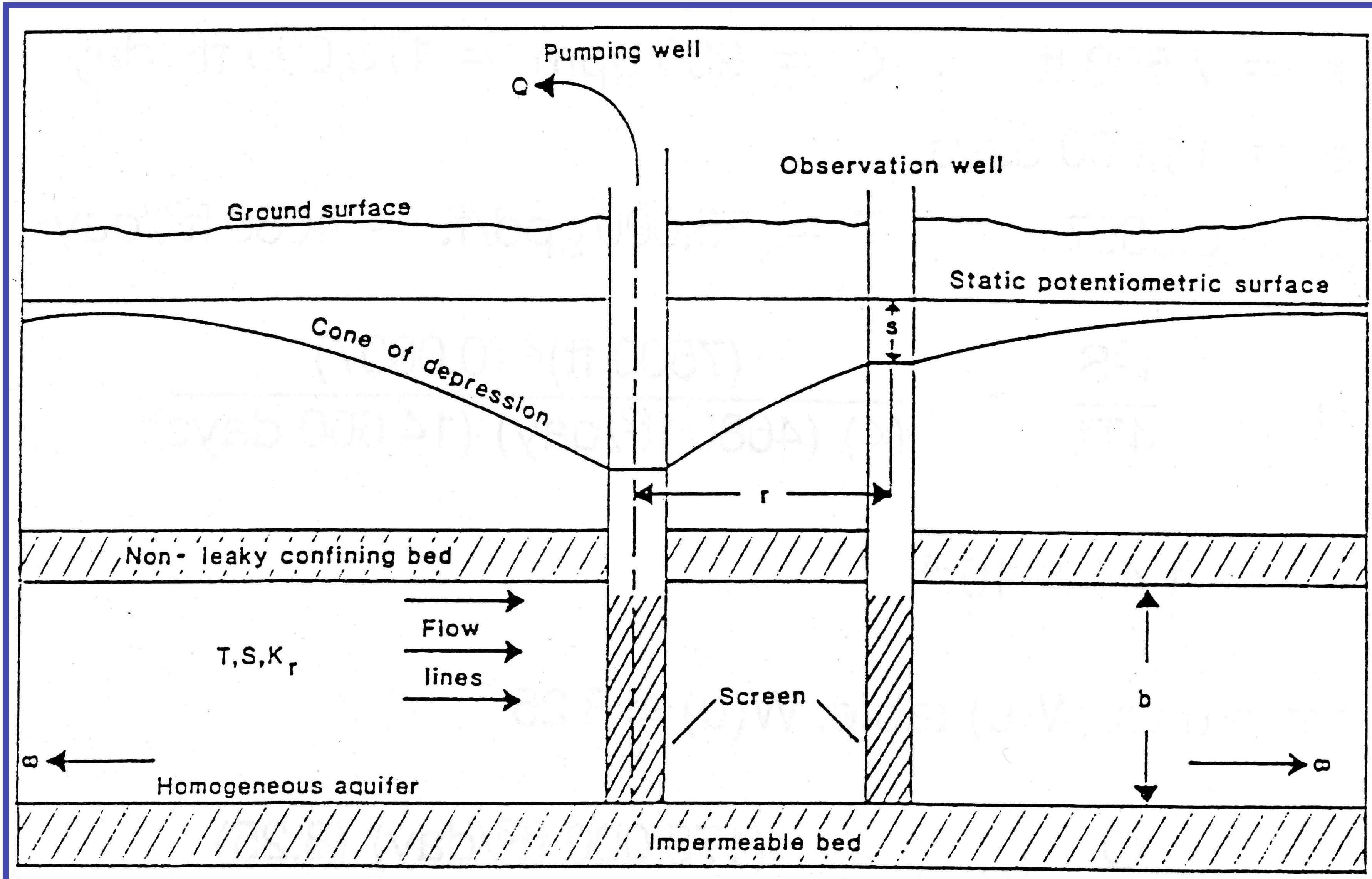
Fetter, 2001

Curve Matching



Fetter, 2001

Step 1: $s = \dfrac{Q}{4\pi T} W(u)$ **Step 2:** $u = \dfrac{r^2 S}{4Tt}$



Modified from Reed, 1980

Theis Example Problem

Given:

$r = 7{,}500$ ft

$Q = 900$ gpm $= 173{,}000$ ft^3/day

$t = 14{,}600$ days

$S = 0.0007$

$T = 35{,}000$ gpd/ft $= 4680$ ft^2/day

$$u = \frac{r^2 S}{4Tt} = \frac{(7500\ \text{ft})^2\,(0.0007)}{(4)\,(4680\ \text{ft}^2/\text{day})\,(14{,}600\ \text{days})}$$

$$= 1.44 \times 10^{-4}$$

Theis Problem

from u vs. W(u) table, $W(u) \cong 8.25$

$$s = \frac{Q}{4\pi T} W(u)$$

$$= \frac{(173{,}000\ \text{ft}^3/\text{day})\ (8.25)}{(4)\ (3.1416)\ (4680\ \text{ft}^2/\text{day})}$$

$$= 24.3\ \text{ft}$$

COOPER-JACOB
STRAIGHT LINE METHOD (1946)

- Transient
- Calculates Transmissivity and Storativity
- Only need information from one well

Cooper-Jacob Straight Line Method (1946)

Recall: $$s = \frac{Q}{4\pi T}\left(-0.5772 - \ln u + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} - \frac{u^4}{4\cdot 4!} + \cdots\right)$$

It was noted by Cooper & Jacob (1946) that when u becomes small (<0.01) , all but the first two terms become negligible.

$$s = \frac{Q}{4\pi T}\left(-0.5772 - \ln u\right)$$

Simplifying and converting to base 10 logarithm gives:

$$\boxed{s = \frac{2.3Q}{4\pi T}\left(\log\frac{2.25Tt}{r^2 S}\right)}$$

When does this apply?

- This is common if the distance to the observation well is small and the time is large

Plotting s vs. t on a semi-log graph gives us a straight line with a slope of $2.3Q/4\pi T$ over each log cycle. We can show that:

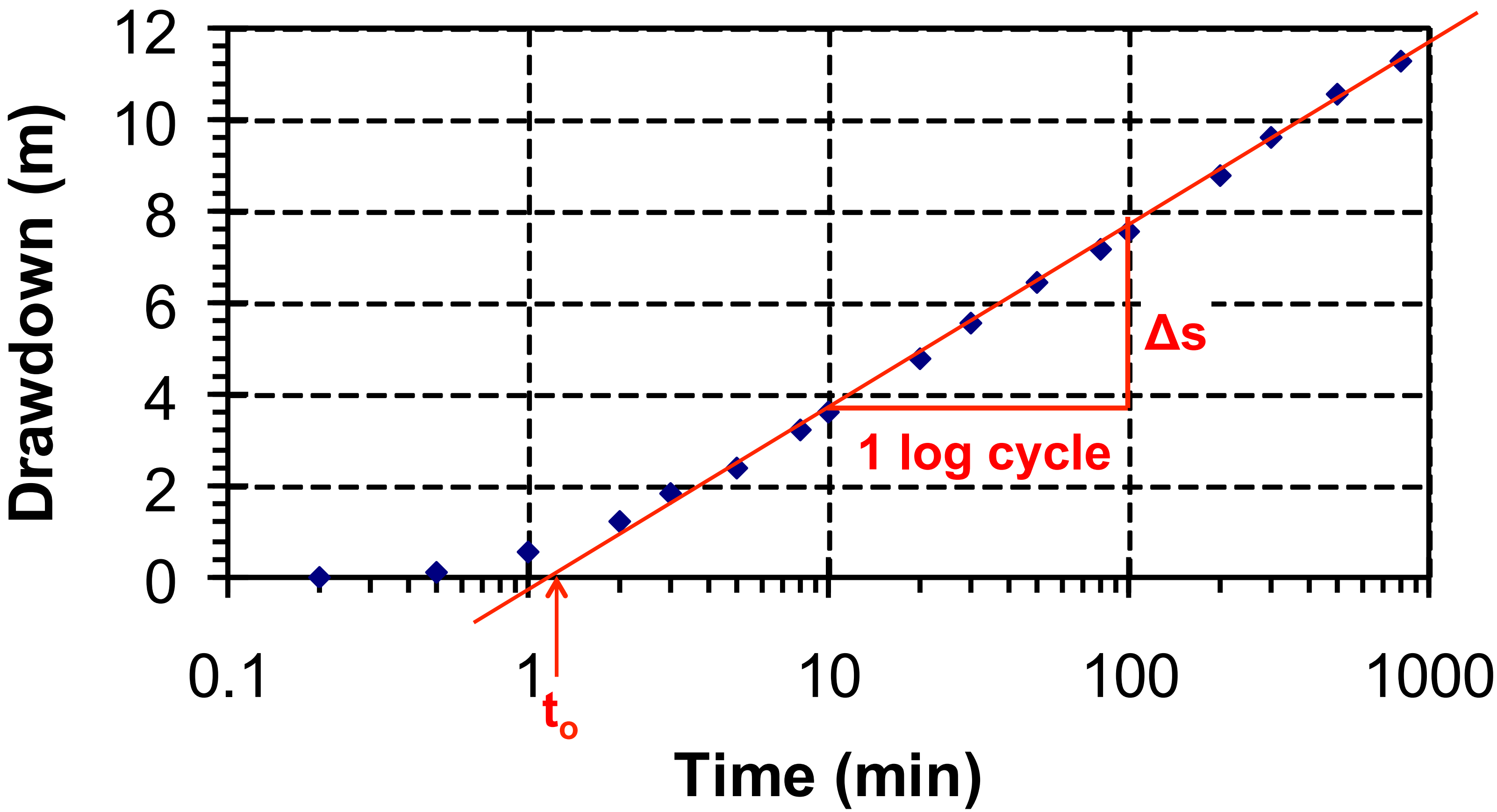
$$\Delta s = \frac{2.3Q}{4\pi T}$$

We also know the x-intercept, designated t_o, occurs where s = 0. This occurs when the log term in the original equation equals 1 [i.e., $\log_{10}(1)=0$].

$$1 = \frac{2.25Tt_o}{r^2 S}$$

If we take the slope and intercept as indicated, we get,

$$\boxed{T = \frac{2.3Q}{4\pi\Delta s}} \qquad \boxed{S = \frac{2.25T\,t_o}{r^2}}$$



To estimate T and S using the Cooper-Jacob time-drawdown method:

(1) Plot s against log t on a semi-log graph.

(2) Fit a straight line for the large-t portion of the data.

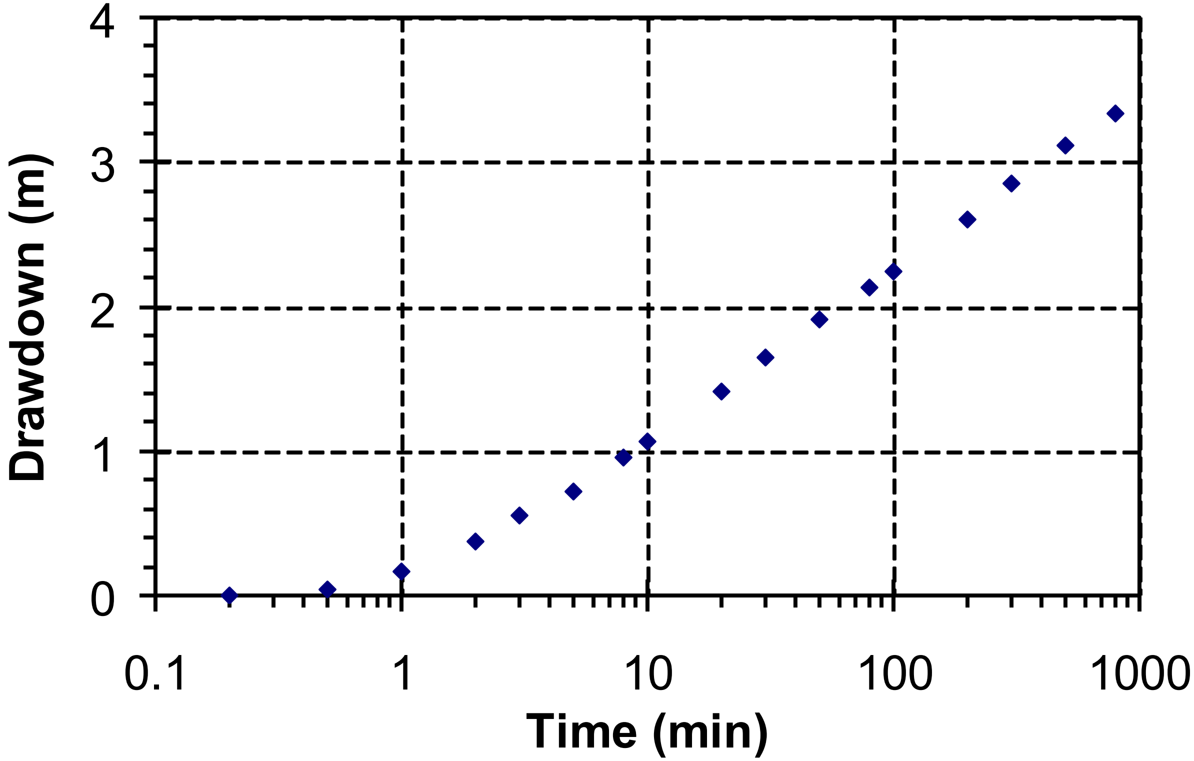
(3) Read the drawdown over one log cycle, Δs
(e.g. $t_1 = 100$ and $t_2 = 1000$).

(4) Extend the line and find t_o, at which $s = 0$.

(5) Calculate T and S from:

$$T = \frac{2.3\,Q}{4\pi\Delta s} \qquad S = \frac{2.25\,T\,t_o}{r^2}$$

Example: Calculate T & S from the following drawdown data measured a distance of 5 m from the pumping well. The pumping rate, Q = 400 m^3/d.

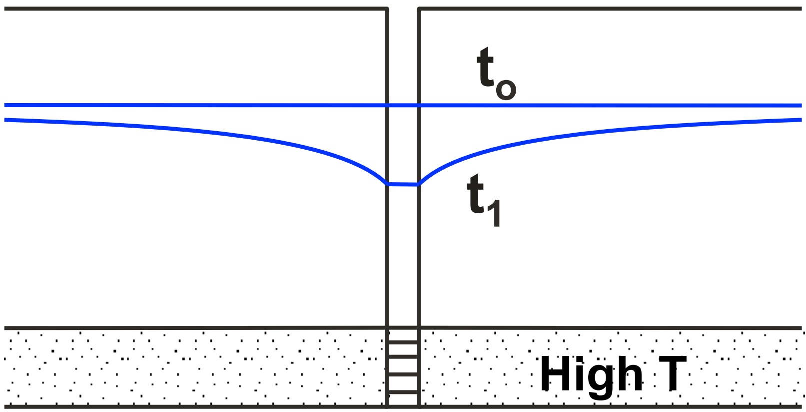


$$T = \frac{2.3\,Q}{4\pi\Delta s}$$

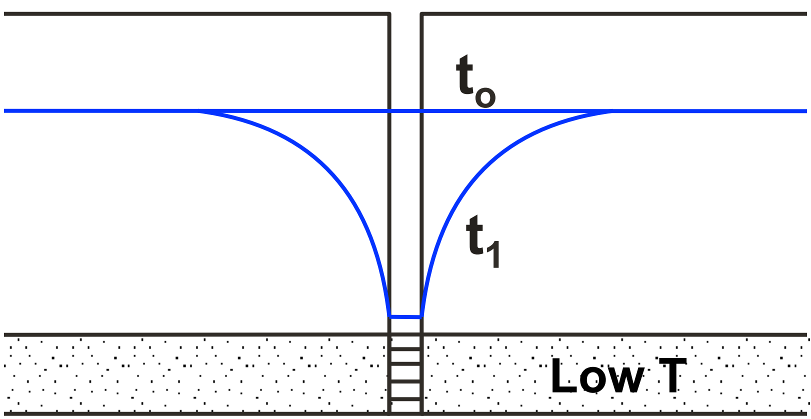
$$S = \frac{2.25\,T\,t_o}{r^2}$$

Influence of Transmissivity (Uniform S)

High Transmissivity



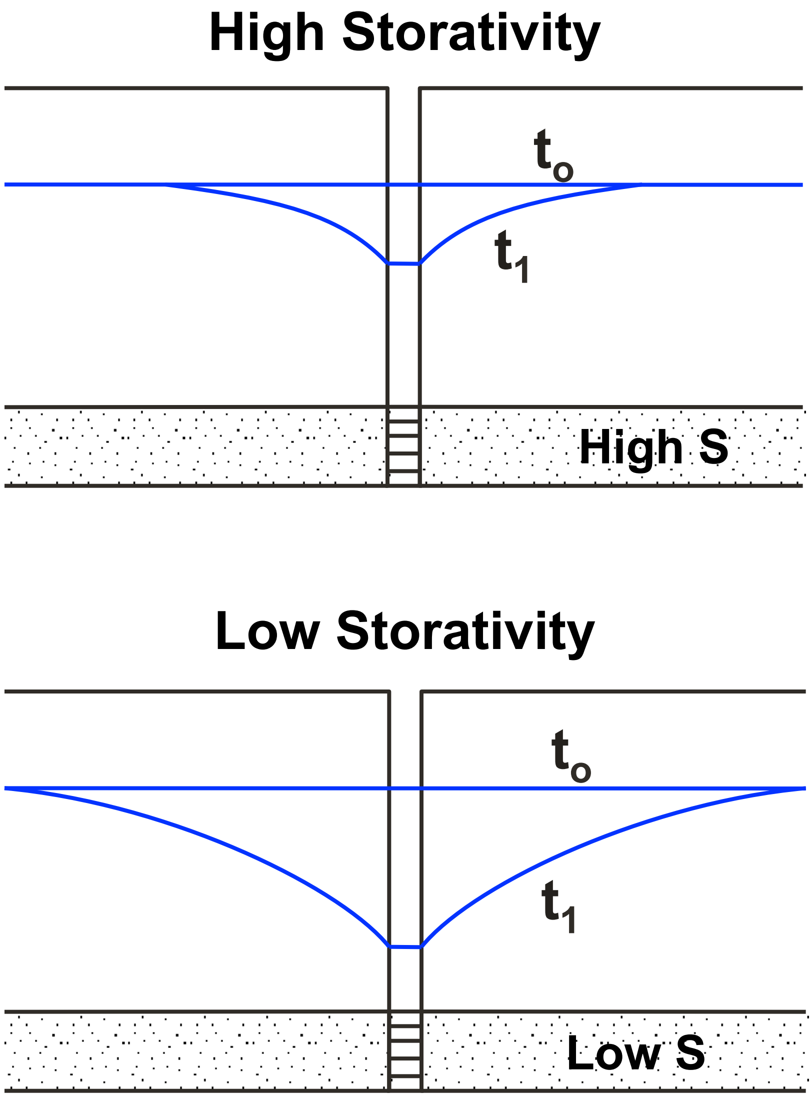
Low Transmissivity



Higher gradient is needed to get the same flow volume in the low T case.

Note that the volume of the drawdown cone is the same in both cases.

Influence of Storativity (Uniform T)

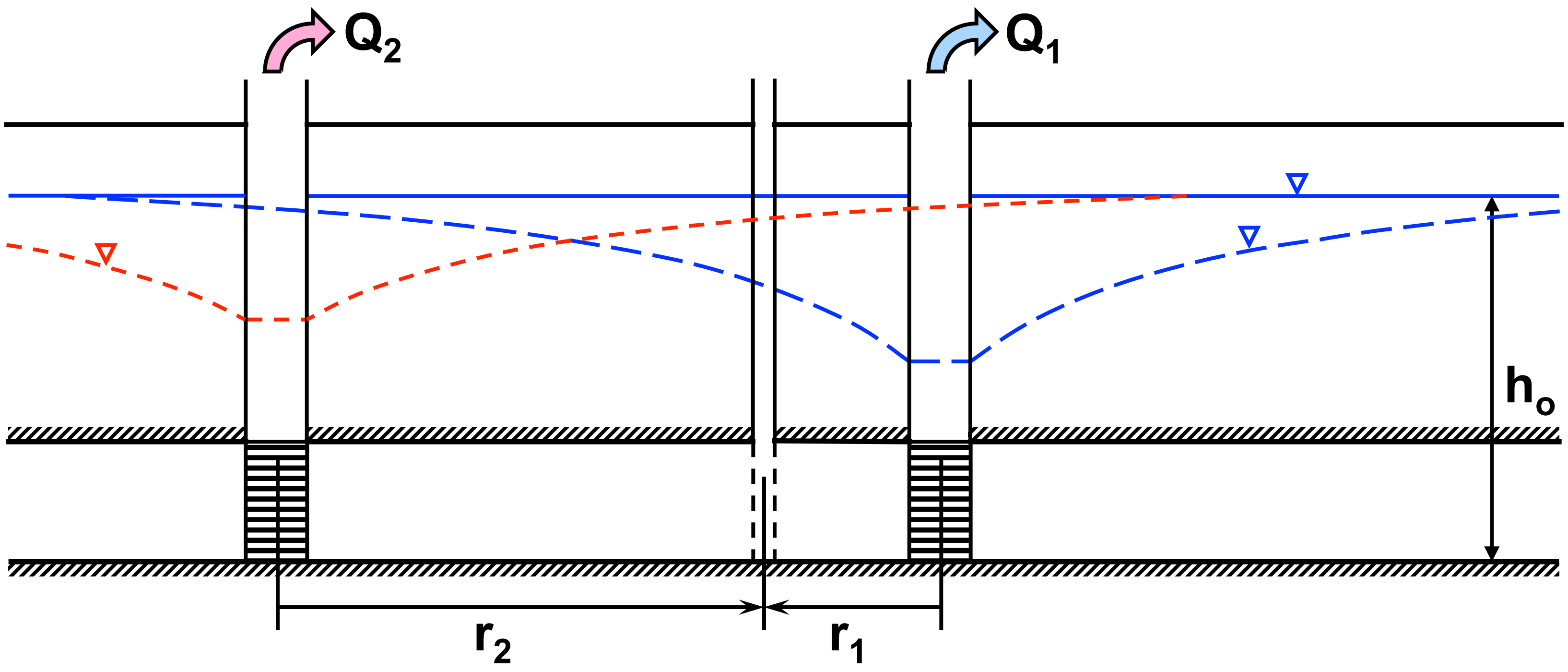


Less drawdown is needed for the high S case because the aquifer releases more water from storage per unit unit decline in head.

Note that the gradient at the well is the same in both cases.

Multiple Pumping Wells

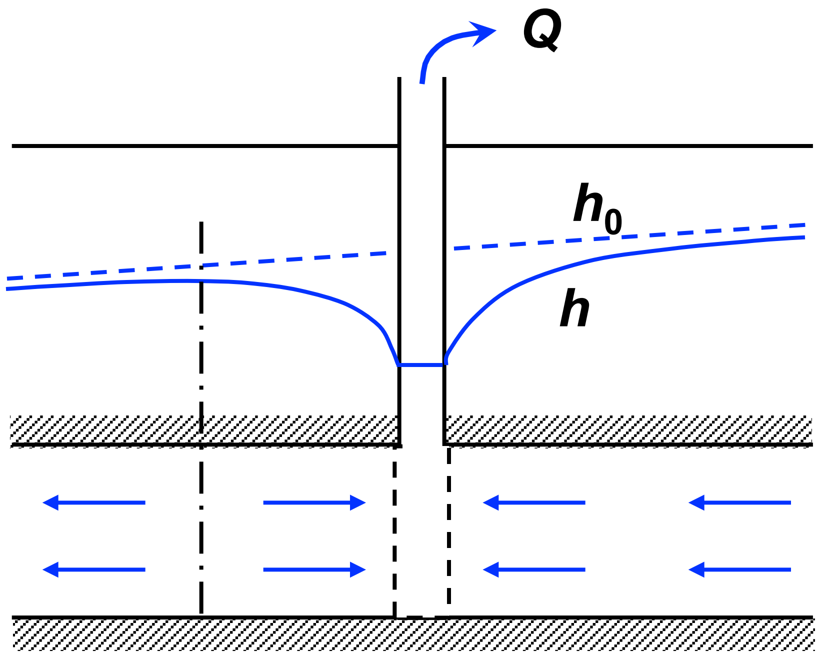
What is the drawdown in the observation well?



The composite drawdown cone is obtained by adding the drawdown contributions from each well.

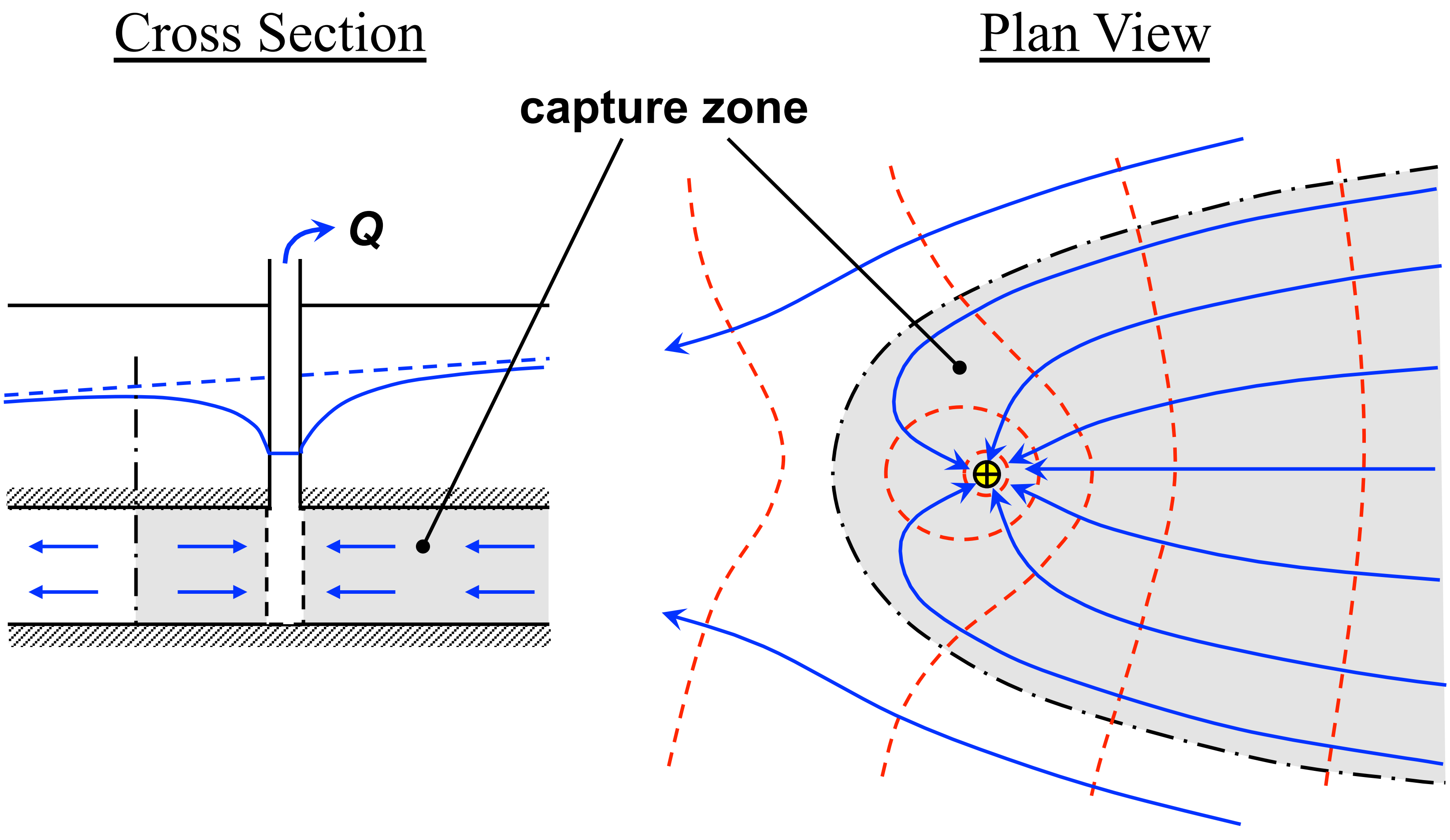
Regional Gradient and Capture Zones

Suppose the regional potentiometric surface dips at a constant slope. The actual drawdown surface is obtained by superimposing an ideal drawdown cone on top of the regional hydraulic gradient.



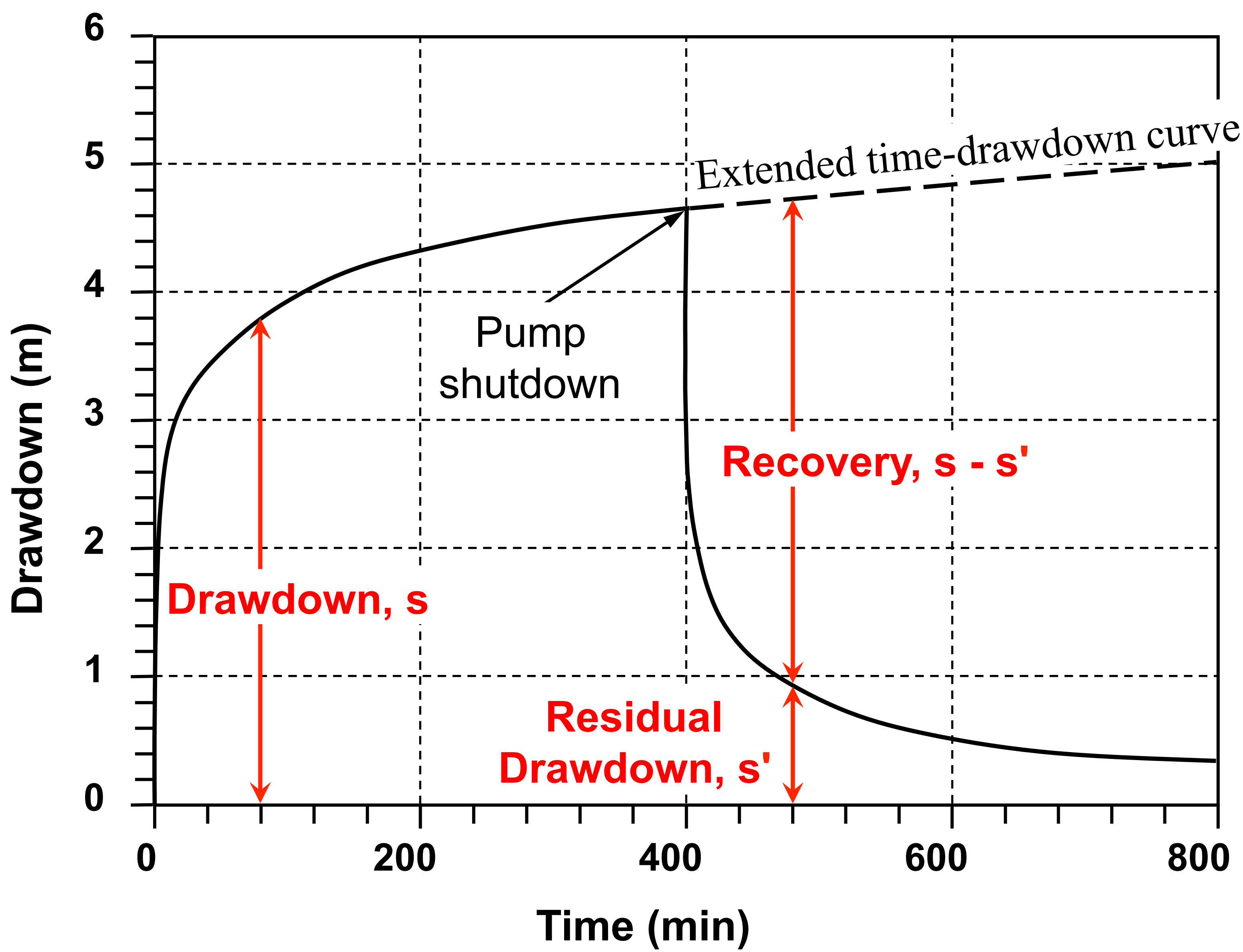
Note that a divide forms on the down-gradient side of the well. This results in a stagnation point.

A <u>capture zone</u> is the region of water around a pumping well that will (eventually) be captured by the well.



Water Level Recovery Data

Once pumping is stopped, water levels will rise and gradually return to their static levels. This is termed recovery and the amount of drawdown during this period is termed residual drawdown (s').



Extended time-drawdown curve
Pump shutdown
Recovery, s - s'
Drawdown, s
Residual Drawdown, s'
Drawdown (m)
Time (min)
0
1
2
3
4
5
6
0
200
400
600
800

Non-Ideal Aquifers

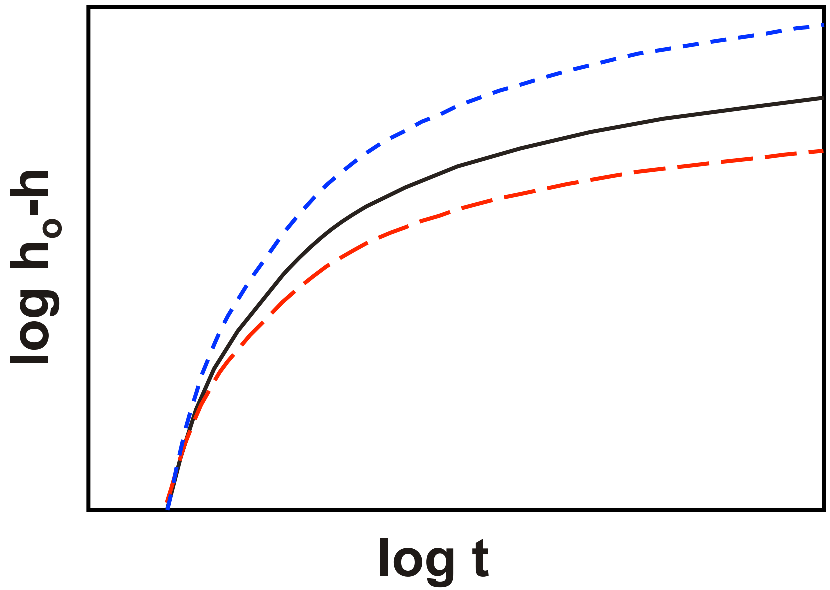
Suggested reading: Schwartz and Zhang Ch. 13

To this point, we have made a lot of assumptions in trying to determine T & S for an aquifer. In particular, this includes all of the assumptions incorporated into our “ideal” Theis aquifer.

However, no real aquifers have these ideal characteristics. Can we still estimate T & S in these cases? What other information can we gather from the measured water level responses?

Many natural aquifers have drawdown-time graphs that follow the Theis curve at **early time** and then deviate from the Theis curve at later times.

- early time portion - estimate T and S
- late time portion - useful information on aquifer conditions due to non-ideal aquifer effects

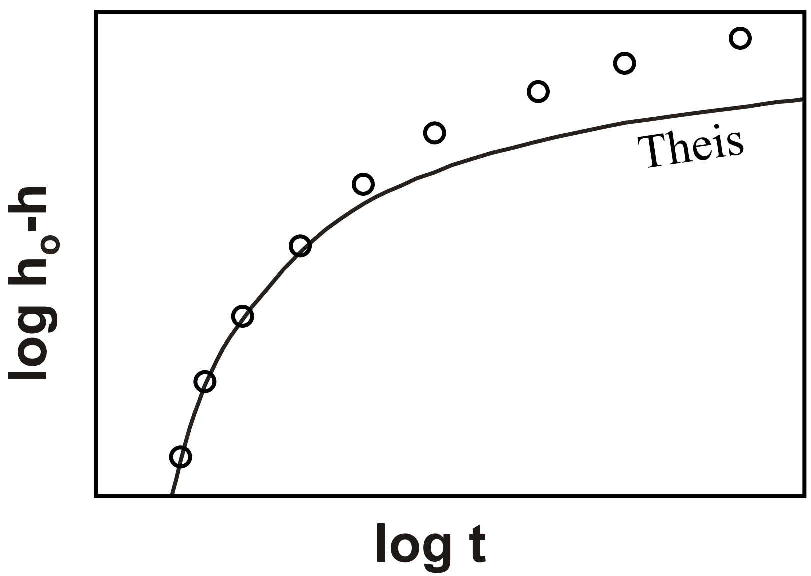


What causes these deviations?

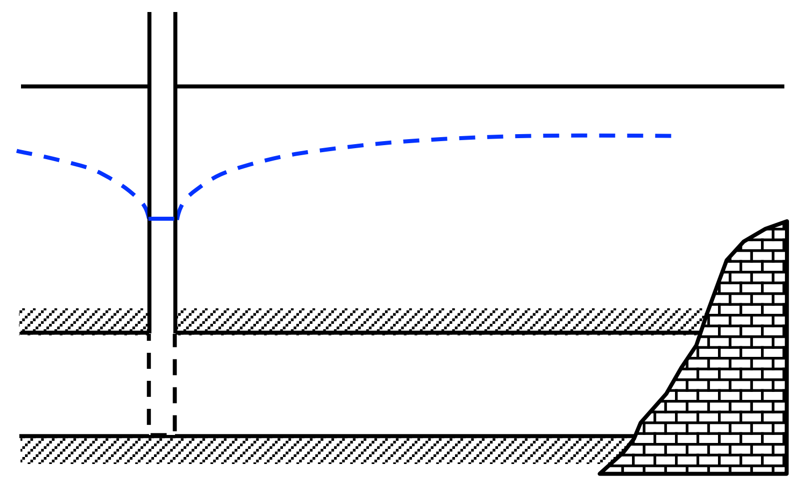
Bounded Aquifer

The aquifer is discontinuous due to the presence of an impermeable boundary or "pinching out" of the aquifer.

- Greater drawdown must occur to maintain the pumping rate, Q.



Impermeable boundary

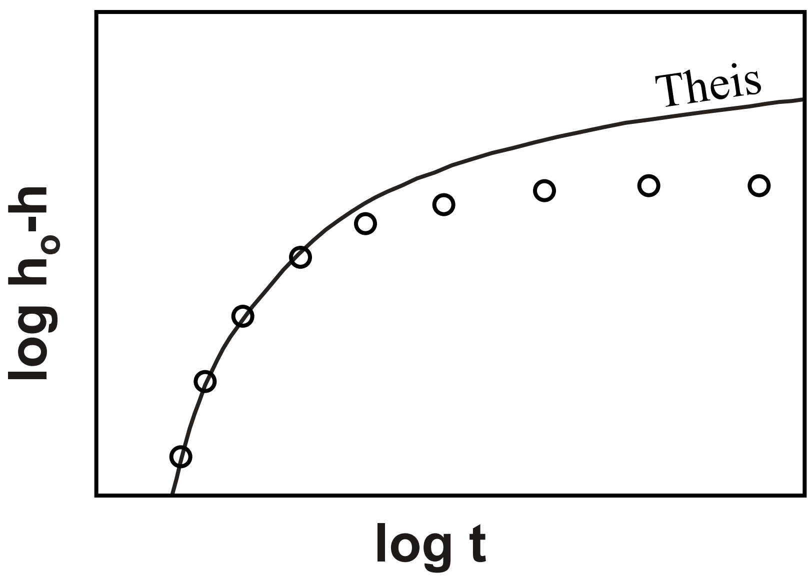


Recharge Boundary

The aquifer is connected to a surface water body (or other recharge source).

- Less drawdown occurs because water is being pumped from a source other than just elastic storage

Recharge boundary



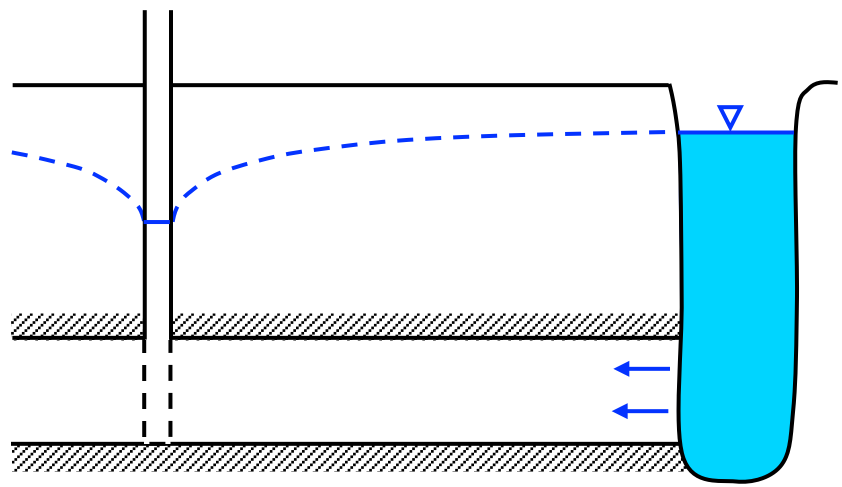


Image Wells

- Used to resolve hydrological boundary conditions
- Based on the concept of superposition:

$$F(x_1 + x_2 + \ldots) = F(x_1) + F(x_2)$$

- No flow boundaries
  - Sheet Pile, Foundations, and Bedrock...
- Recharge boundaries
  - Rivers, Lakes, and Oceans...

No Flow Boundaries

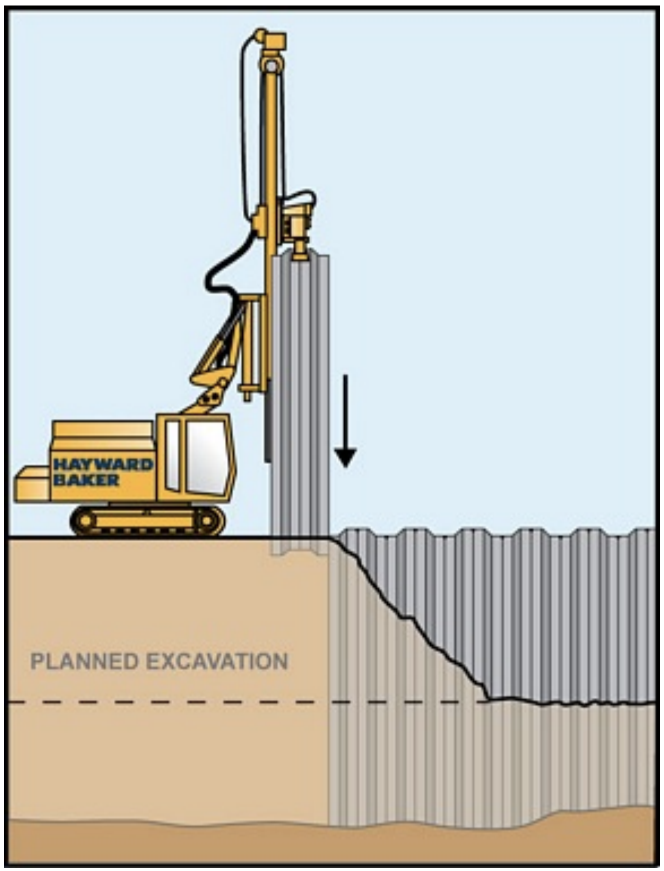


Figure: Sheet Pile

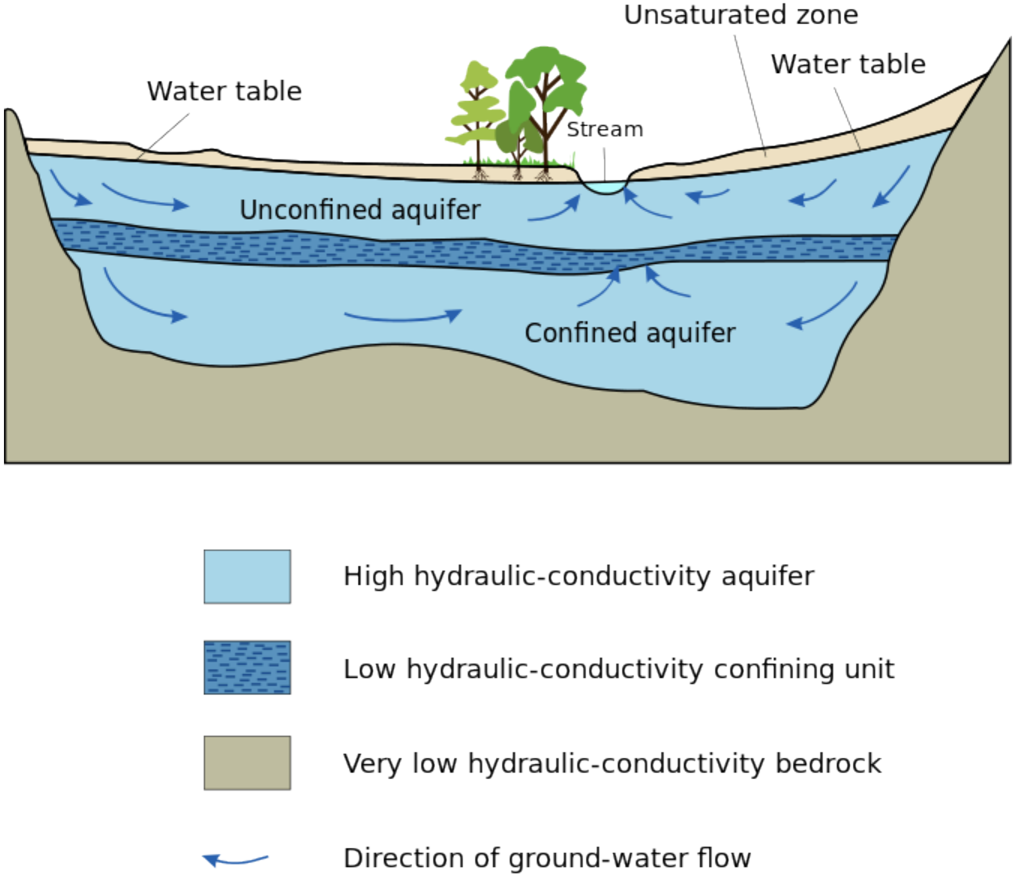
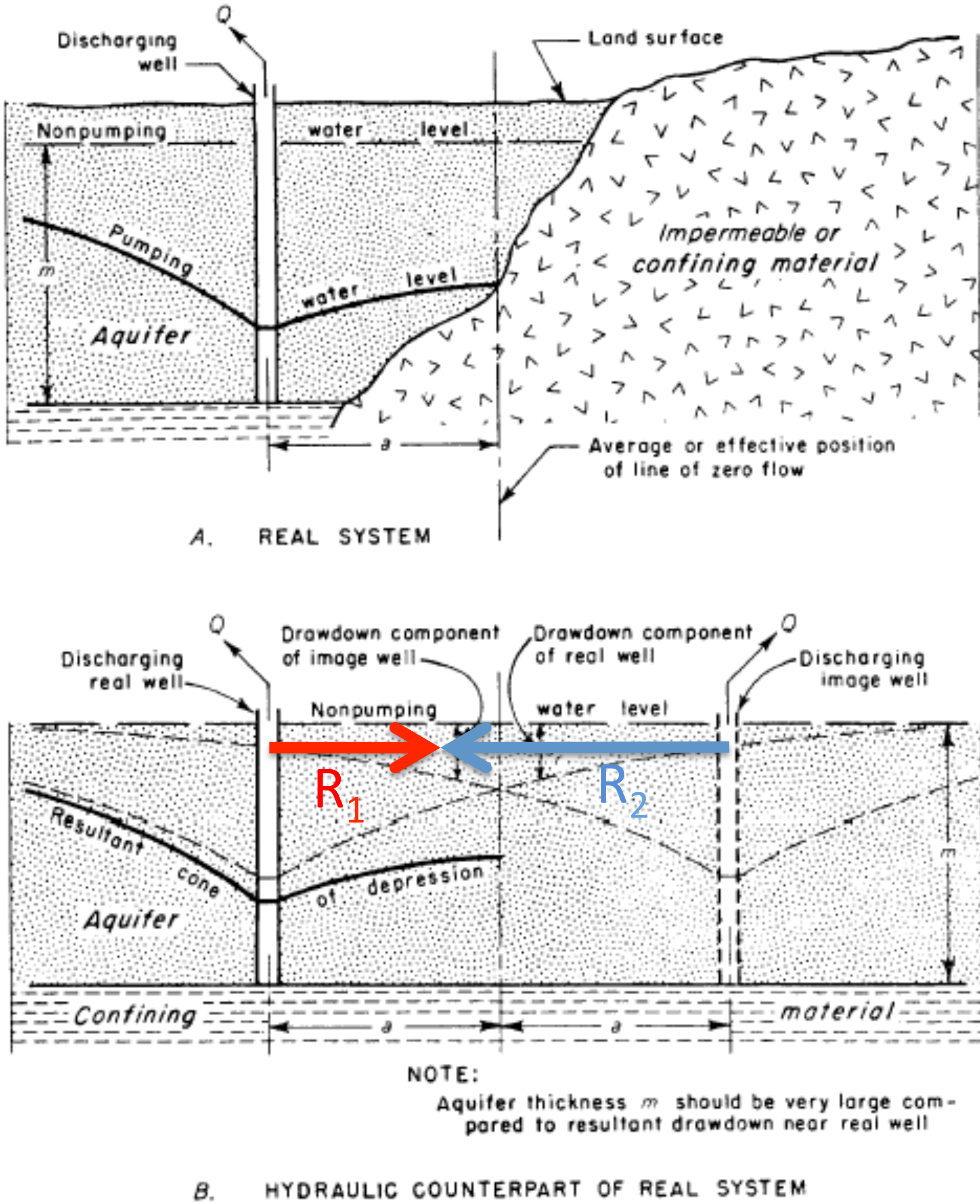


Figure: Bedrock divide.

No Flow Boundaries



Pumping Well

$$s = \frac{Q}{4\pi T} W(u_1)$$

$$u_1 = \frac{r_1^2 S}{4Tt}$$

Image Well

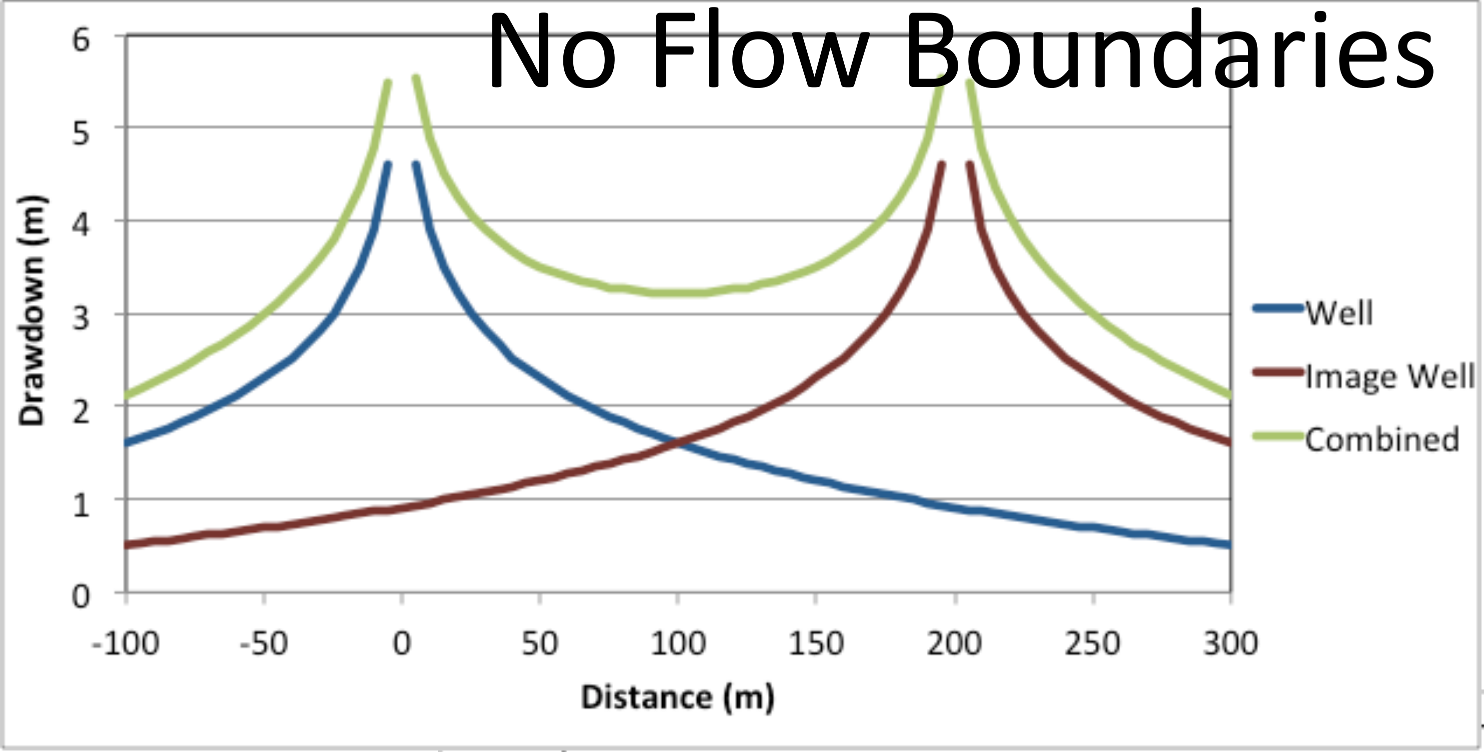
$$s = \frac{Q}{4\pi T} W(u_2)$$

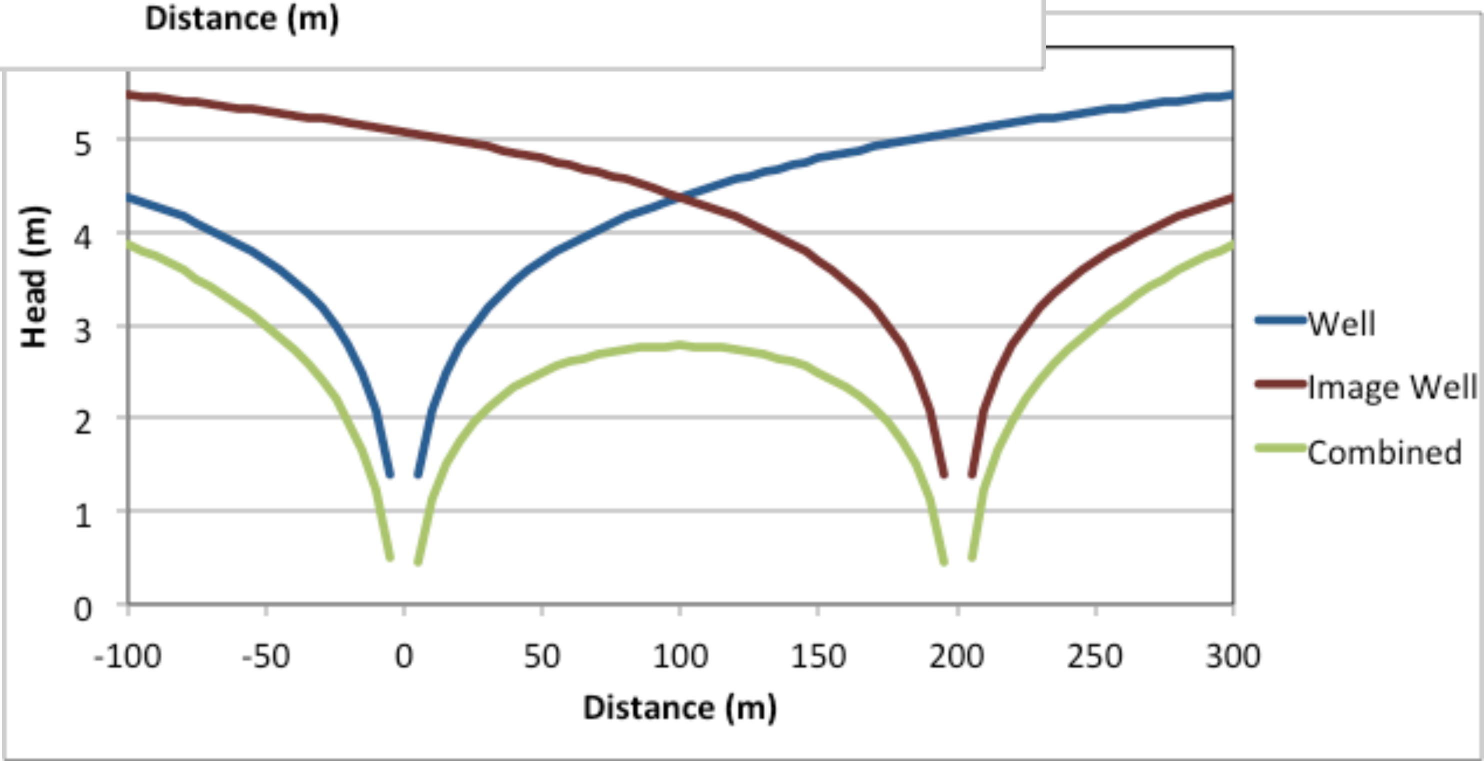
$$u_2 = \frac{r_2^2 S}{4Tt}$$

Combing the two wells:

$$s = \frac{Q}{4\pi T} W(u_1) + \frac{Q}{4\pi T} W(u_2)$$

No Flow Boundaries



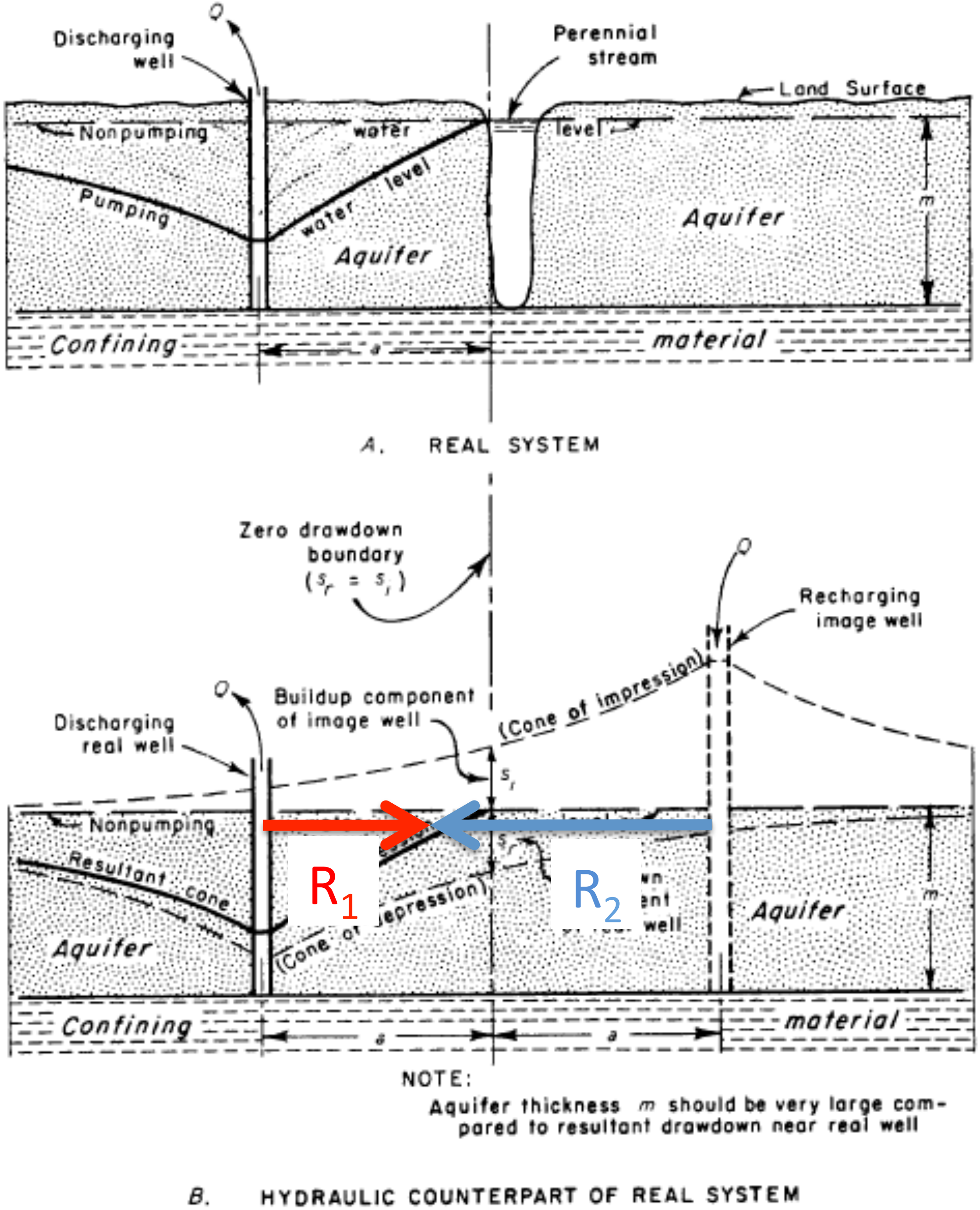


Recharge Boundary

Figure: River Boundary

Figure: Lake Boundary

Recharge Boundary



Pumping Well

$$s = \frac{Q}{4\pi T} W(u_1)$$

$$u_1 = \frac{r_1^2 S}{4Tt}$$

Recharge Image Well

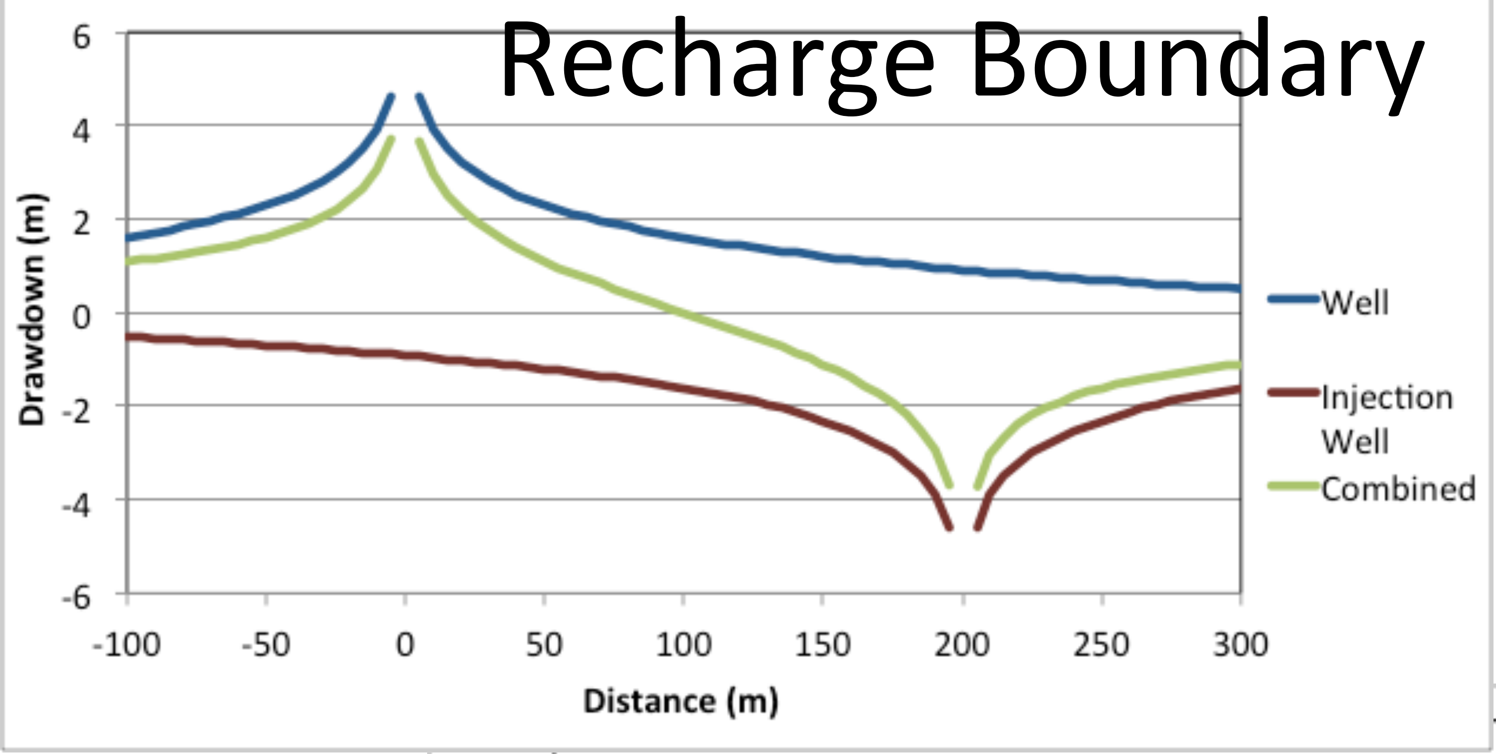
$$s = -\frac{Q}{4\pi T} W(u_2)$$

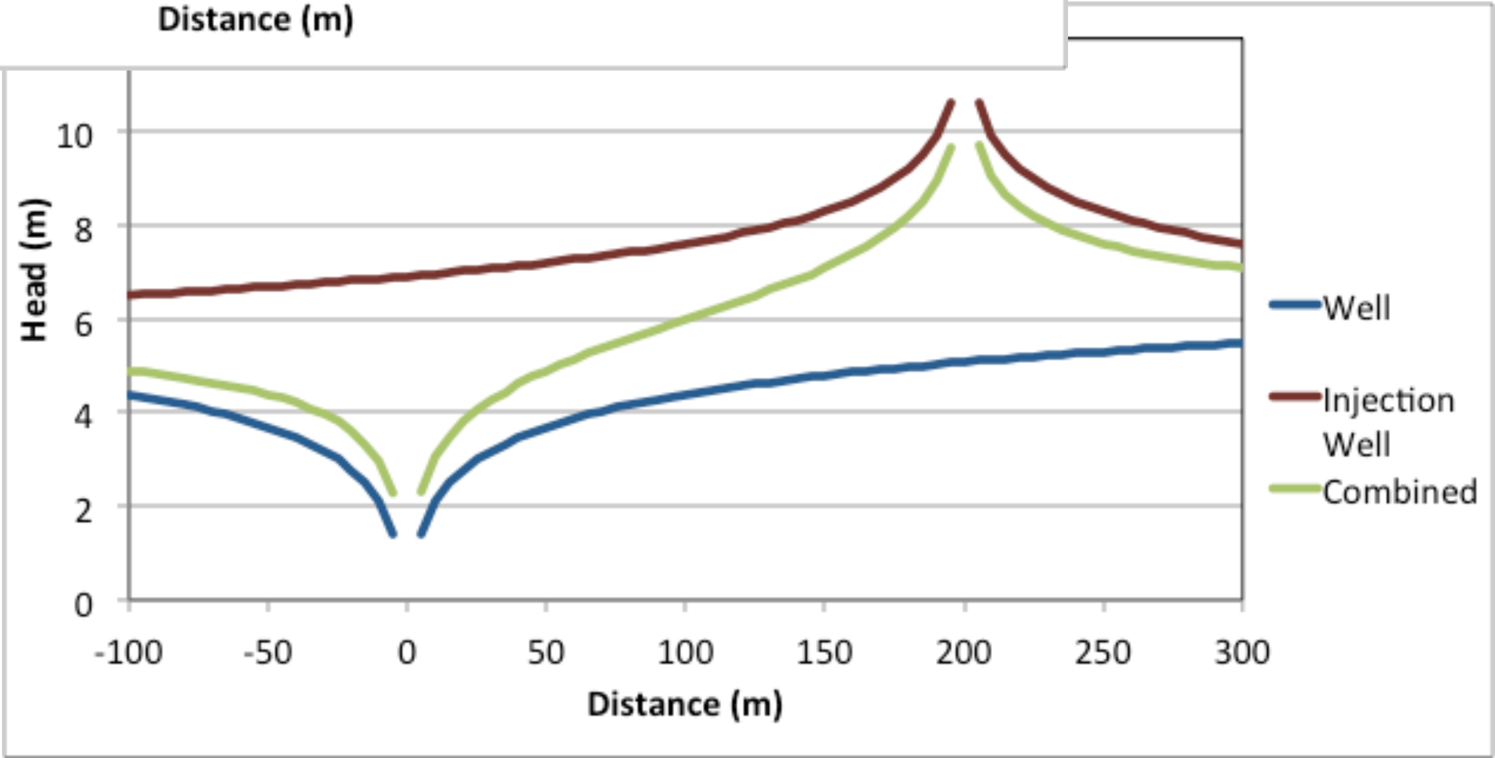
$$u_2 = \frac{r_2^2 S}{4Tt}$$

Combing the two wells:

$$s = \frac{Q}{4\pi T} W(u_1) - \frac{Q}{4\pi T} W(u_2)$$

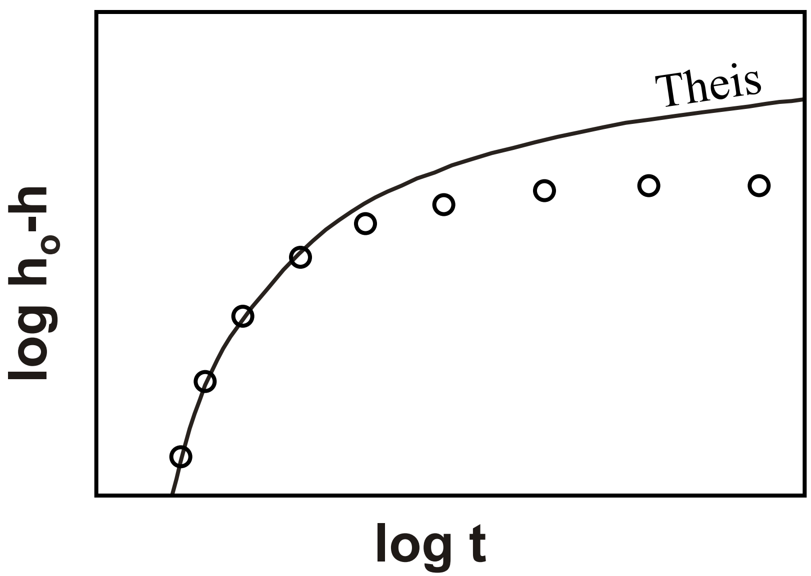
Recharge Boundary



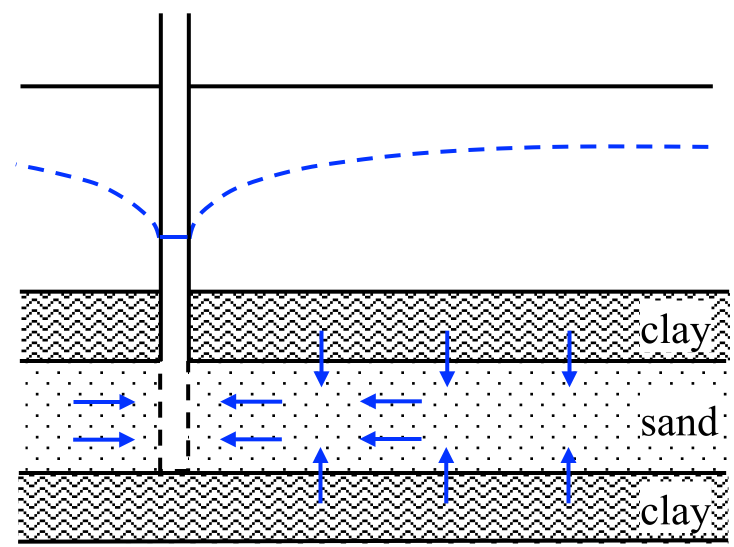


Leaky Aquitards

If the aquitards are not perfectly confining, water will leak across them and recharge the aquifer. Since water is being added to the aquifer, drawdown is less than for a "Theis" aquifer. The response is similar to that of a recharge boundary.



Leakage across confining layers



Analysis of Leaky Aquitards

There are a variety of methods for analysis of vertical leakage through aquitards. The simplest method for dealing with the transient drawdown response for leakage into a confined aquifer is given by Hantush and Jacob (1955).

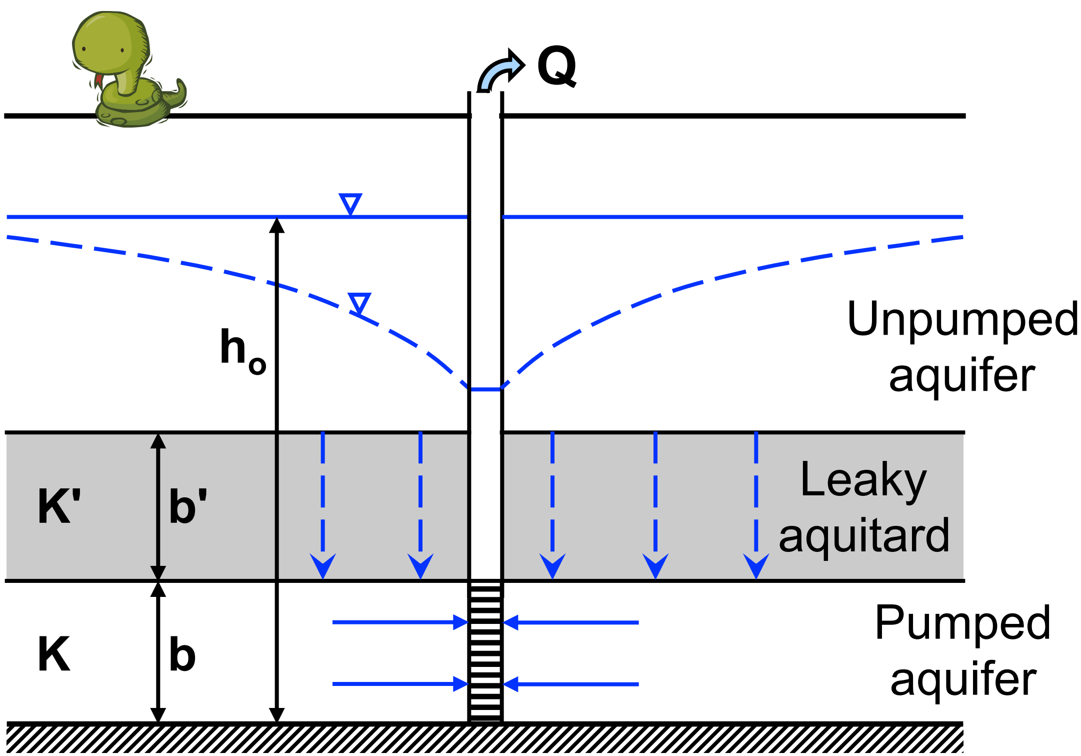
All of the Theis assumptions apply except that there is vertical leakage across the aquitard(s) into the pumped aquifer.

There are two important additional assumptions:

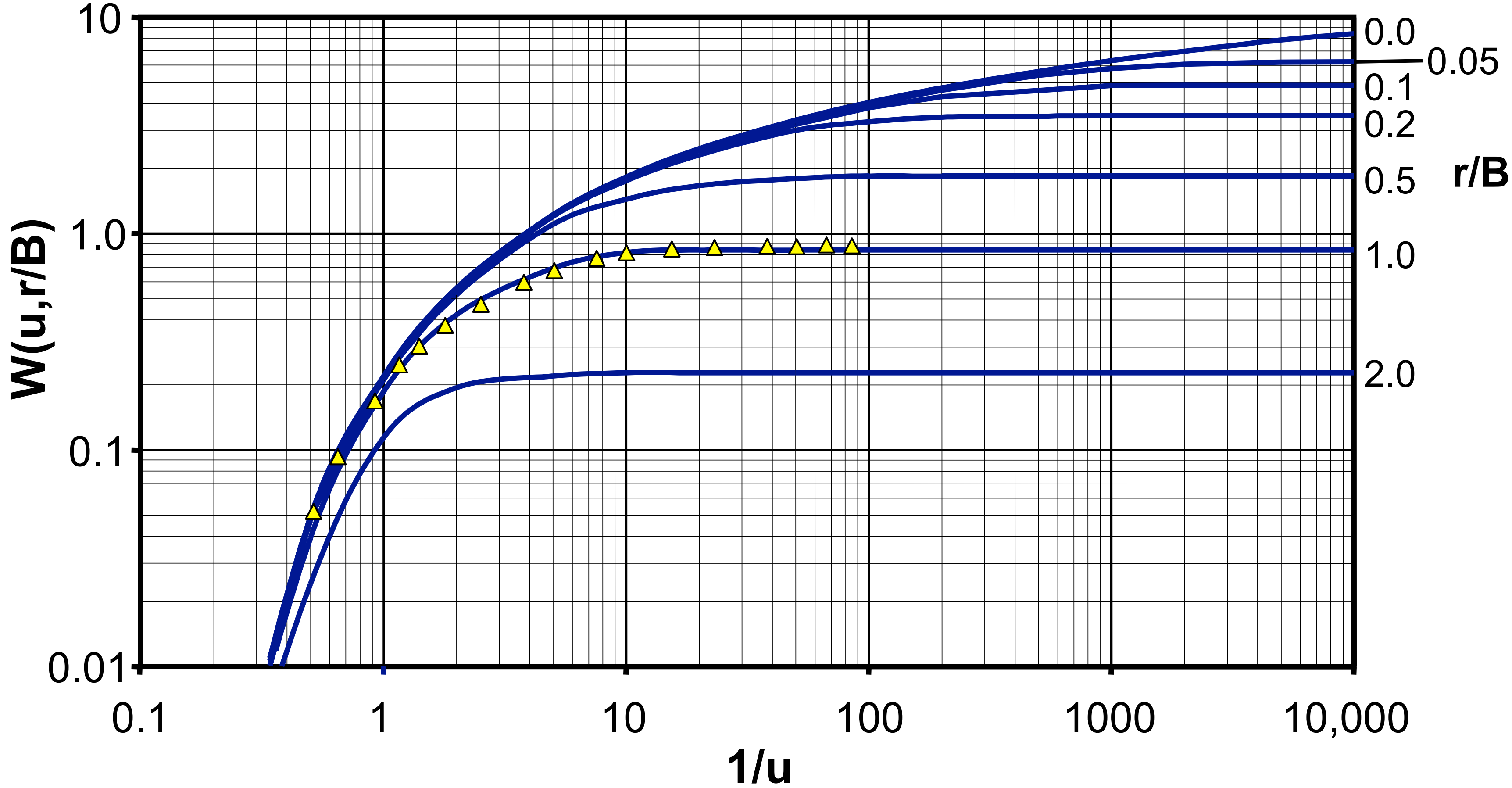
- the adjacent unpumped aquifer has a constant hydraulic head (i.e., not affected by pumping)
- the aquitard is incompressible (i.e., it transmits water but does not release water from storage within the aquitard)

We introduce a new leaky well function.

$$s = \frac{Q}{4\pi T} W\left(u, \frac{r}{B}\right) \quad \text{where} \quad r/B = r\sqrt{\frac{K'}{Kb\,b'}} = r\sqrt{\frac{K'}{T\,b'}}$$



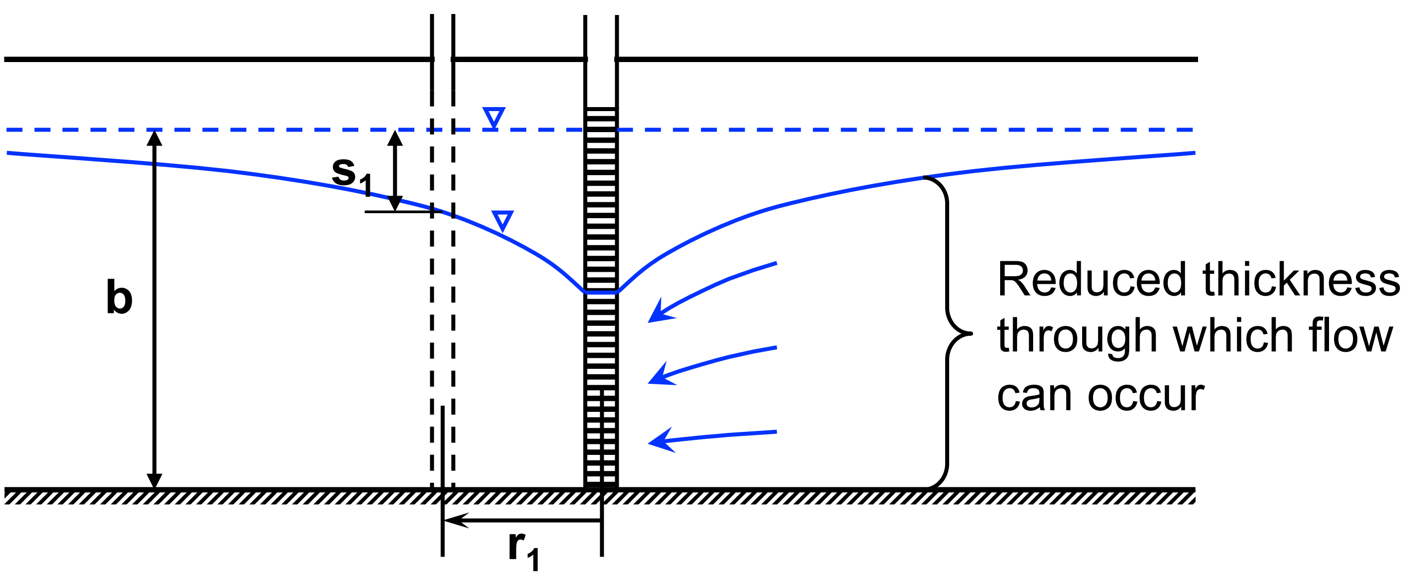
Hantush-Jacob Leaky Aquifer Type Curve



There is a family of r/B curves and we match the drawdown-time data in a similar fashion as for Theis curve matching.

Transient Unconfined Aquifer Response

The response of an unconfined aquifer to pumping is complicated and still not fully understood. The biggest differences from the confined case are the release of water from storage and the influence of vertical flow (or gradients).

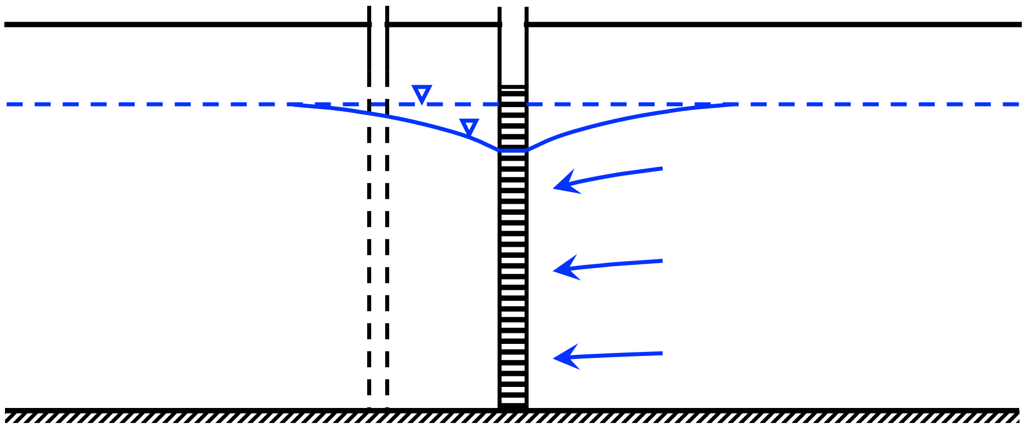


The basic assumptions are similar to a confined Theis aquifer except:

- the water table forms the upper surface of the aquifer
- water is released from both elastic storage and gravity drainage
- drawdown is small in comparison to the saturated thickness of the aquifer

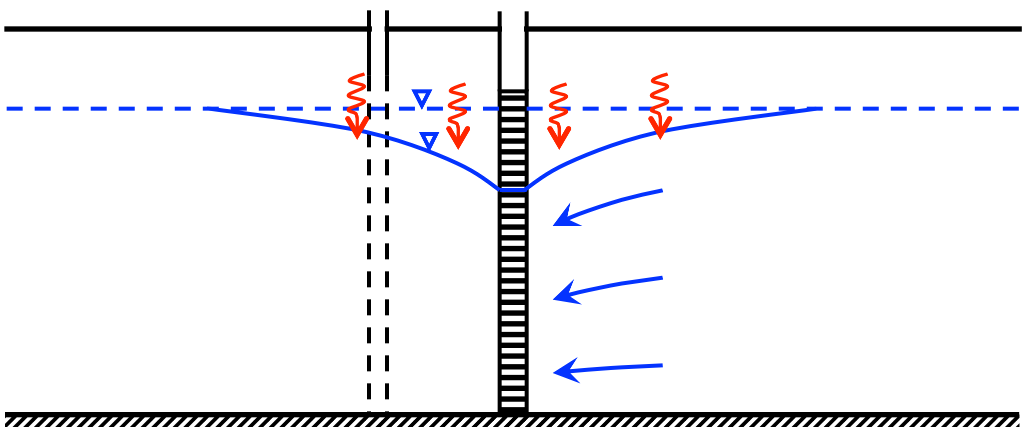
Phase 1

- Drawdown is relatively rapid
- Water is released from elastic storage (compression of matrix and expansion of water)
- Response follows a Theis curve
  - obtain estimates of T and S ($=S_S \cdot b$)



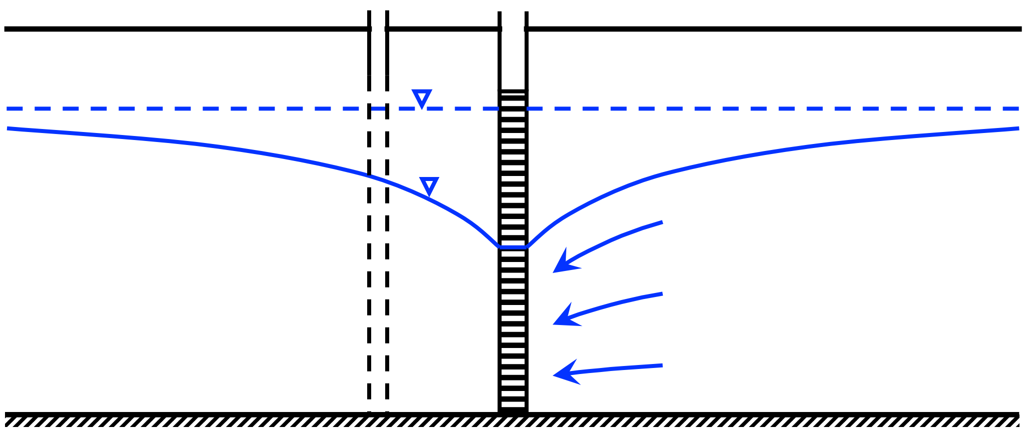
Phase 2

- Rate of drawdown decreases due to delayed drainage
- Water is released from the newly formed vadose zone as a result of lowering of the water table
- Vertical hydraulic gradients increase
- Produces an apparent "recharge effect" and response resembles a leaky aquifer (deviates below the Theis curve)

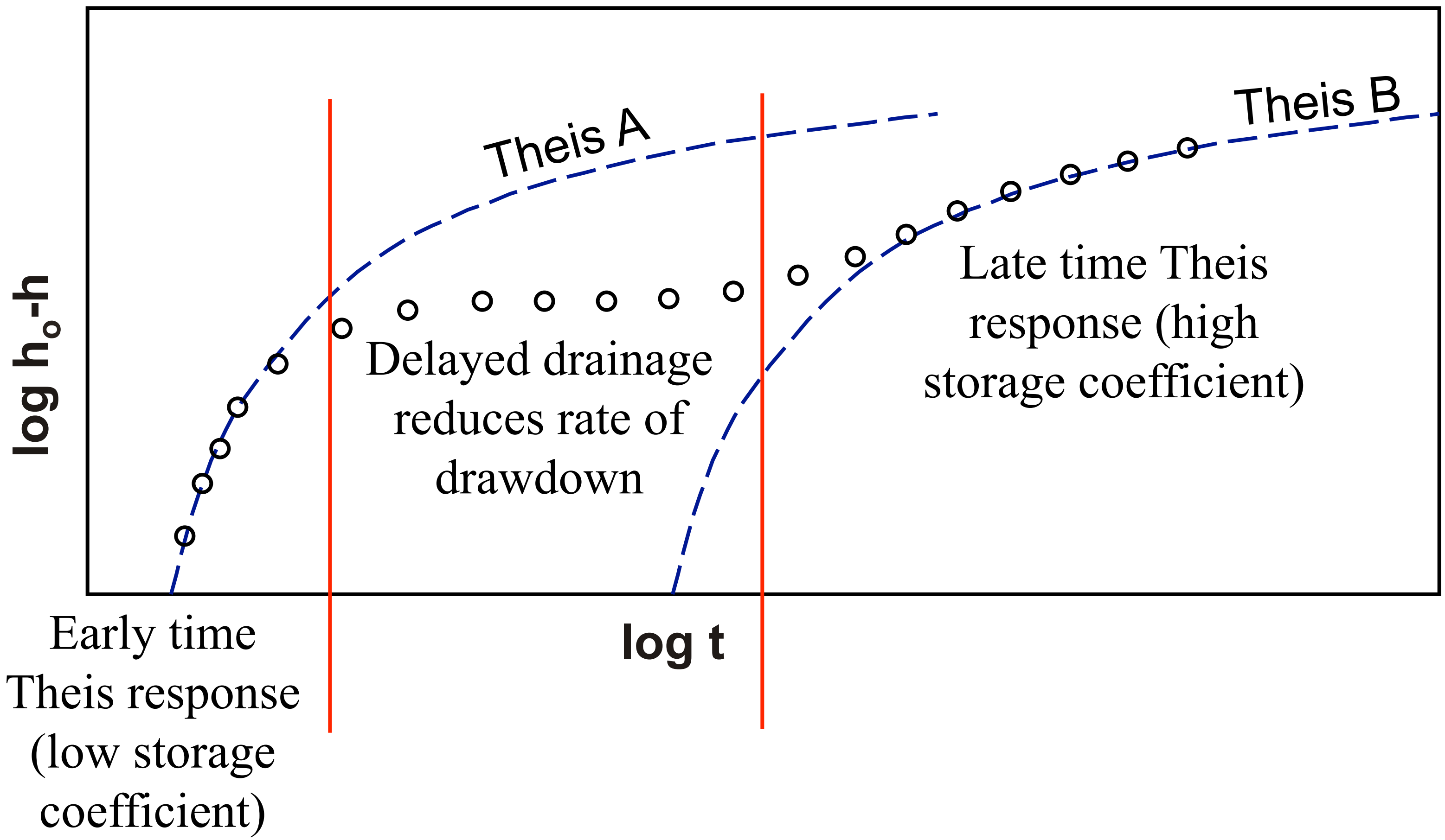


Phase 3

- Drainage reaches an "equilibrium"
  - can take a very long time to reach this stage
- Water released by drainage of pores balances drawdown
- Response again follows a Theis curve with storage associated with specific yield
  - obtain estimates of T and S ($=S_Y$)



The response of an unconfined aquifer on a log-log plot. The length of time of Phase 2 depends on material (vadose zone) properties and the magnitude of drawdown.



Neuman (1975) defines a well function $W(u_A,u_B,\beta)$

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

where each parameter corresponds to a different time phase:

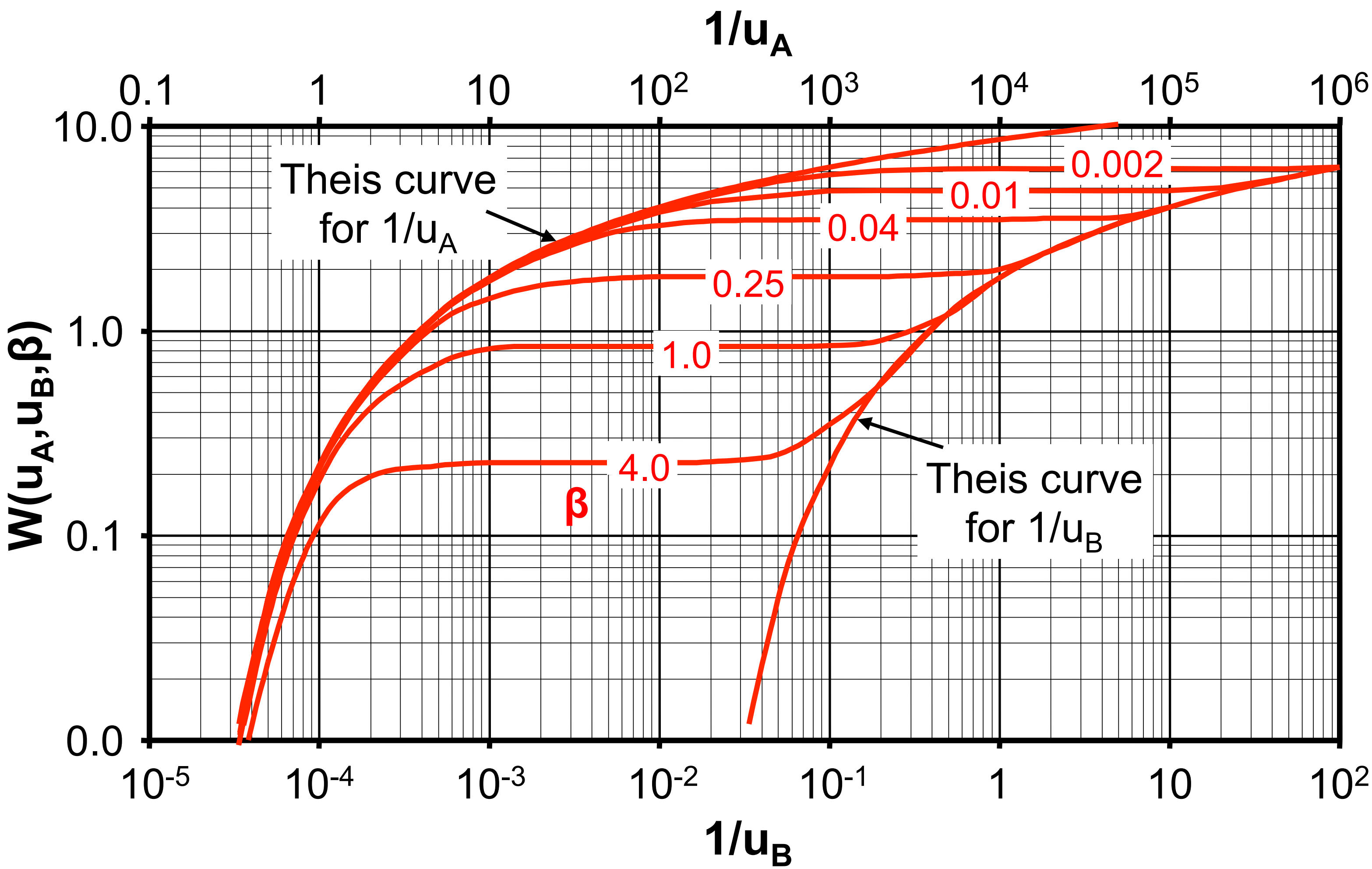
- early-time response is controlled by $u_A = \dfrac{r^2 S}{4Tt}$

- intermediate-times are controlled by $\beta = \dfrac{r^2 K_V}{b^2 K_H}$

- late-time response is controlled by $u_B = \dfrac{r^2 S_Y}{4Tt}$

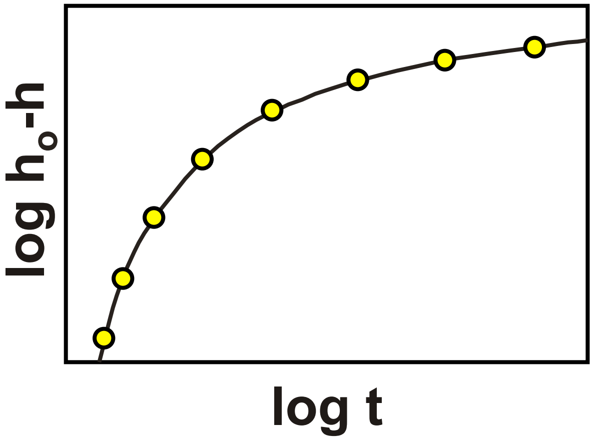
The intermediate time response is related to vertical drainage and hence includes the vertical hydraulic conductivity, K_V.

Neuman Unconfined Aquifer Type Curves

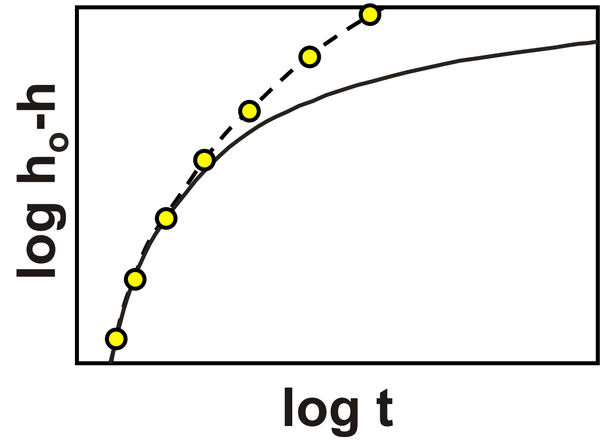


Summary of Pumping Test Responses

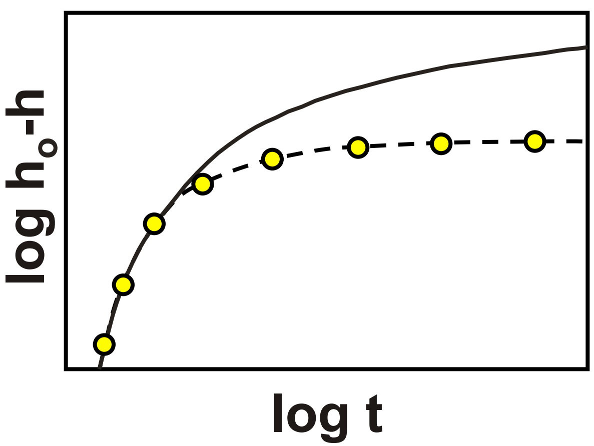
Ideal (Theis)



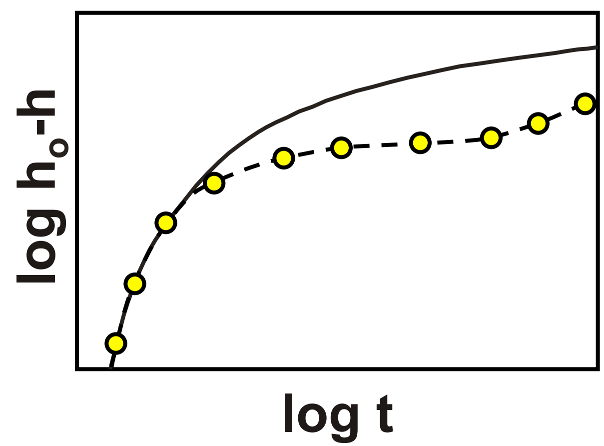
Impermeably Bndy



Leaky Aquitard or Recharge Bndy



Unconfined



Because of the similarity of aquifer responses and different type curves, it is often difficult to arrive at a unique interpretation.

- e.g., leaky, recharge boundary, and unconfined responses are very similar

Key point: Use of other hydrogeologic evidence (borehole logs, maps, geophysics, other wells in area) will help to arrive at a reliable interpretation.

Even through the drawdown data may match a particular curve, this does not mean all assumptions have been met.

- e.g., all aquifers are heterogeneous, so T and S estimates are effective values averaged in some fashion over the volume of aquifer tested