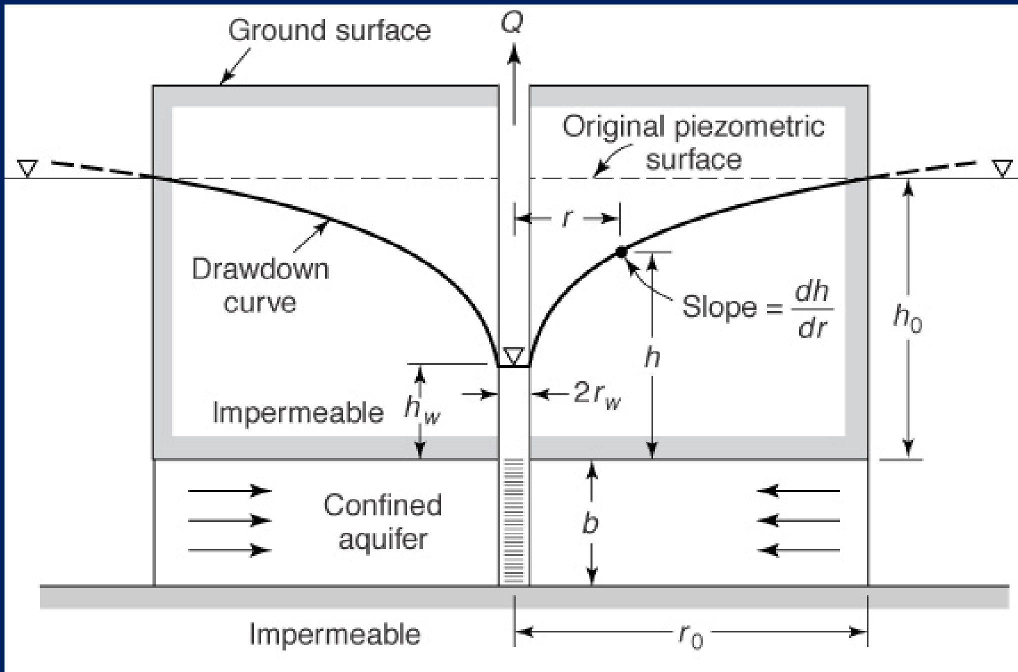
Well Hydraulics in steady state condition

Primary goal of groundwater resources evaluation should be the prediction of hydraulic-head drawdowns in the aquifer under a proposed pumping scheme. The theoretical response of idealized aquifers to pumping can be examined by different methods. Hydraulic characteristics of aquifers (T, K, S) may be determined by means of pumping tests. They involve removal or the addition of water to a well and observation of reaction of the aquifer to change.

Steady-state or equilibrium methods: Yields values of transmissivity and related hydraulic conductivity
Non-steady state or nonequilibrium methods: Yields values of transmissivity, hydraulic conductivity, and storage coefficient.

Steady-state Radial Flow to a Well in a Confined Aquifer



$Q = A*v$

$= -2\pi rbK\frac{dh}{dl}$

Curved surface area of the cylinder

Rearrange, integrate for the boundary conditions at the well $h=h_w$, $r=r_w$

$h=h_0$, $r=r_0$

$$Q = 2\pi Kb\frac{h-h_w}{\ln(\frac{r}{r_w})}$$

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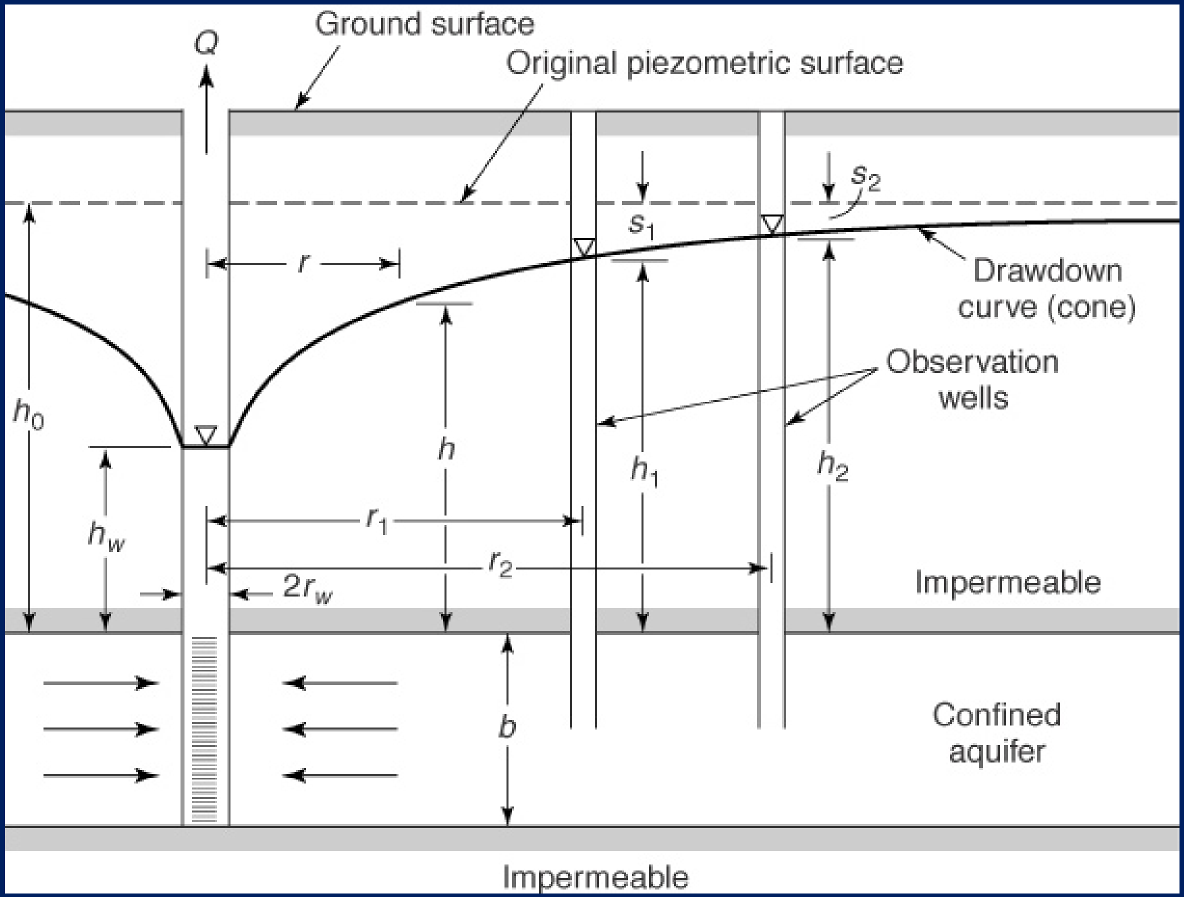


$$Q = 2\pi K b \frac{h - h_w}{\ln(\frac{r}{r_w})}$$

T= Kb

$$T = \frac{Q}{2\pi(h_2 - h_1)} \ln\frac{r_2}{r_1}$$

Drawdown change must be negligible.

The observation wells should be located close enough to the pumping well

We assume that;

1. The well is pumped at a constant rate and fully penetrates the aquifer.
2. The aquifer is homogeneous and isotropic, is of uniform thickness, and is of infinite areal extent; that the well penetrates the entire aquifer; and that initially the piezometric surface is nearly horizontal.
3. Water is initially removed from the storage upon a decline of head
4. The flow in the aquifer obeys Darcy’s law

If there are 4 observation wells, you may choose pairs of wells and apply the Thiem equation for each pair. Including pumping well, PW, you will have 10 pairs of calculations of Transmissivity. An Average value of T can then be calculated.

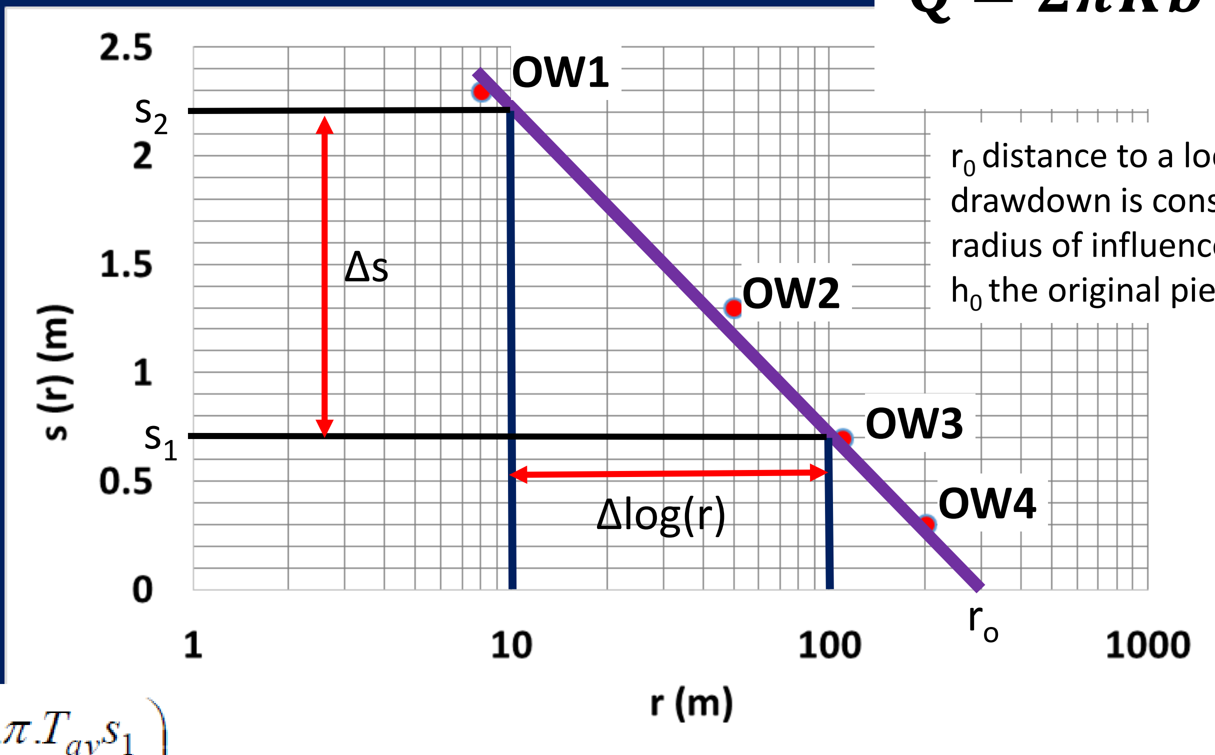
$$T = \frac{Q}{2\pi(s_1 - s_2)} \ln\left({}^{r_2}/_{r_1}\right)$$

	OW1	OW2	OW3	OW4
PW	x	x	x	x
OW1		x	x	x
OW2			x	x
OW3				x

When there is more than one well, a plot of s(r) versus r on a semi-log paper should yield a straight line from the slope of which we obtain T.

$$T = \frac{Q}{2\pi(s_1 - s_2)} \ln\left({}^{r_2}/{r_1}\right) = 2.3\frac{Q}{2\pi(s_1 - s_2)} log_{10}\left({}^{r_2}/{r_1}\right)$$

$$Q = 2\pi K b \frac{2\pi(h_0 - h_w)}{\ln\left({}^{r_0}/{r_w}\right)}$$

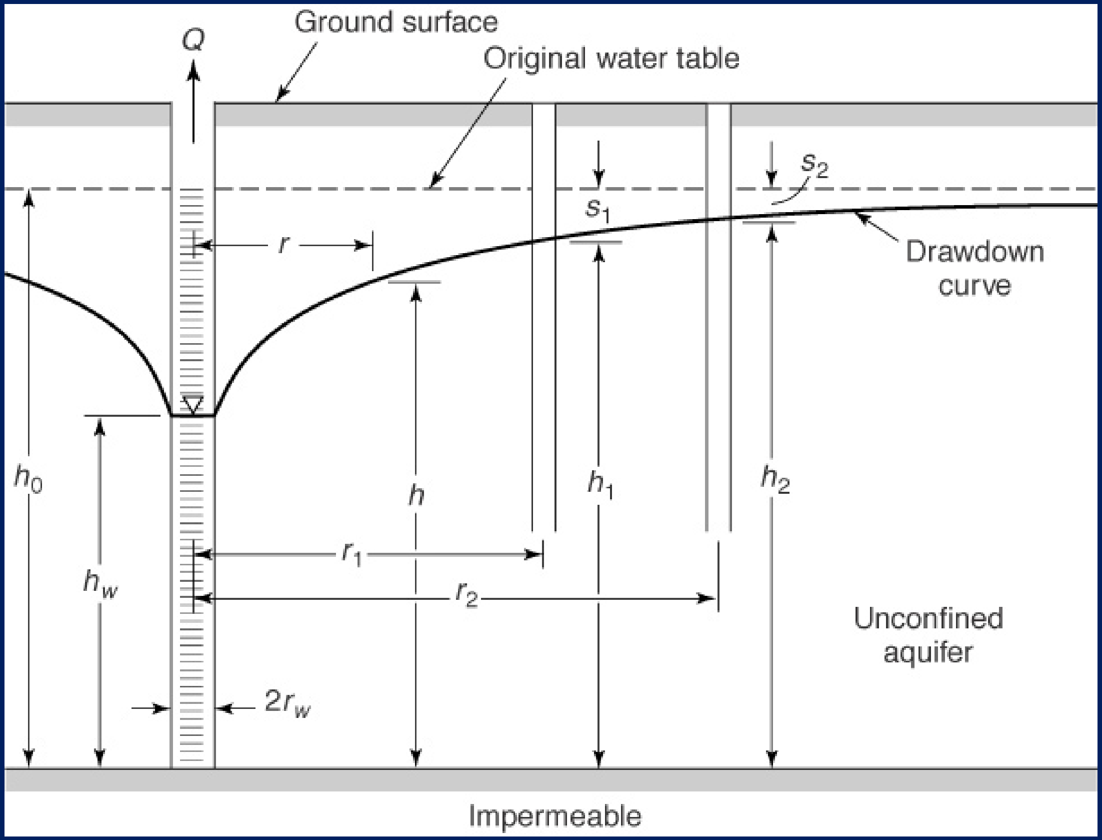


r_0 distance to a location at which drawdown is considered negligible = radius of influence of the pumping well

h_0 the original piezometric height

$$r_0 = r_1 . \exp\left(\frac{2.\pi.T_{av}.s_1}{Q}\right)$$

Steady-state Radial Flow to a Well in an unconfined Aquifer



$$Q = -2\pi r K h \frac{dh}{dr}$$

Integrate between the limits $h=h_w$ at $r=r_w$
$h=h_o$ at $r=r_o$

$$Q = \pi K \frac{{h_0}^2 - {h_w}^2}{\ln(\frac{r_0}{r_w})}$$

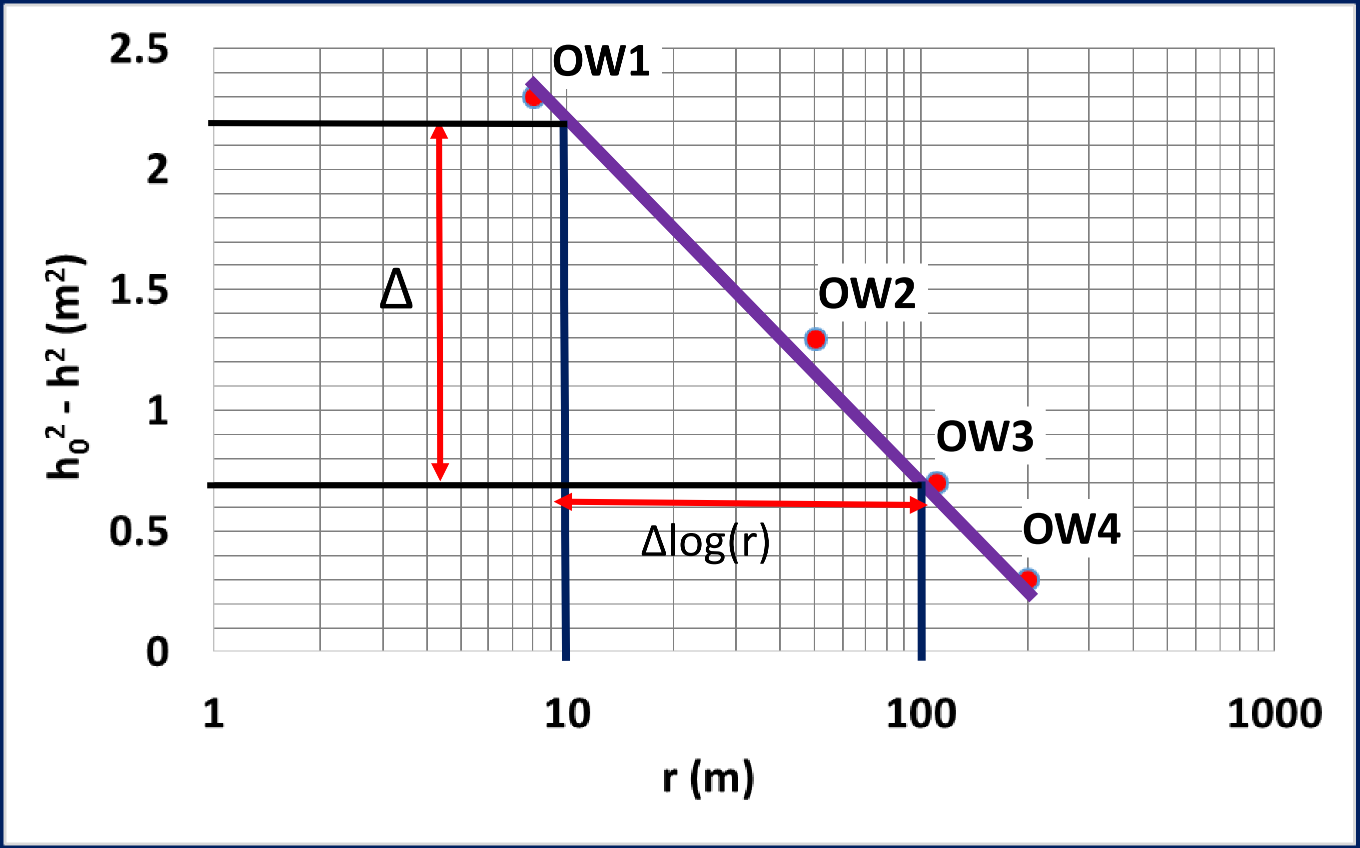
$$Q = \pi K \frac{{h_2}^2 - {h_1}^2}{\ln(\frac{r_2}{r_1})}$$

Hydraulic conductivity can be estimated from Thiem Equation as:

$$K = \frac{Q}{\pi({h_2}^2 - {h_1}^2)} \ln(\frac{r_2}{r_1})$$

$$K = \frac{2.3Q}{\pi \Delta s}$$

$$r_0 = r.\exp\left(\frac{\pi K a v}{Q}\left(h_0^2 - h_{(r)}^2\right)\right)$$



Unsteady State (Transient) Radial flow to a Well in a Nonleaky Confined Aquifer

Assumptions:

1) Darcy's law is applicable
2) Water is discharged instantenously from storage upon a decline of head
3) Aquifer is homogeneous, isotropic and has a constant thickness
4) Horizontal aquifer of infinite areal extent
5) Wells fully penetrate the aquifer and flow is horizontal

Theis (1935) method

$$s = h_0 - h = \frac{Q}{4\pi T}\int_u^{\infty}\frac{e^{-u}du}{u} = \frac{Q}{4\pi T}W(u)$$

$$W(u) = -0.5772 - lnu + u - \frac{u^2}{2x2!} + \frac{u^3}{3x3!} - \frac{u^4}{4x4!} + \cdots \ldots$$

W(u) well function

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

Q= constant pumping rate

h= hydraulic head at time t since pumping began

h_0= hydraulic head before the start of pumping

s= drawdown at point r at time t

r= radial distance from the pumping well to the observation well

T= Transmissivity

S= storativity or storage coefficient

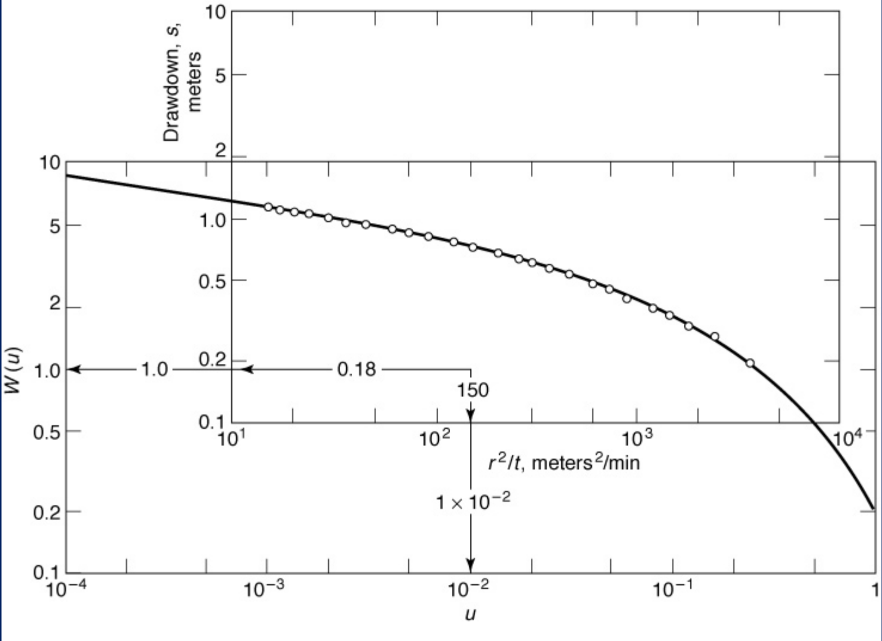
Theis suggested an approximate solution for S and T based on a graphic method of superposition.

A plot on logarithmic paper of W(u) versus u, known as a type curve is prepared.

Values of drawdowns are plotted against values of r^2/t on logarithmic paper of the same size and scale as for the type curve.

The observed time-drawdown data are superimposed on the type curve, keeping the coordinate axes of the two curves parallel, and adjusted until a position is found by trial whereby most of the plotted points of the observed data fall on a segment of the type curve.

Any convenient point is then selected, and the coordinates of this match point are recorded.



$$s = \frac{Q}{4\pi T} W(u) \qquad u = \frac{r^2 S}{4Tt}$$

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Table 4.4.1 Values of $W(u)$ for Values of 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

Advantages of unsteady state equation:

Only one observation well is required.

A shorter period of pumping is generally necessary.

No assumption of steady-state flow conditions is required.

A value for S can be determined.