Pumping Test

Principles of Pumping Test

The principle of a pumping test involves applying a stress to an aquifer by extracting groundwater from a pumping well and measuring the aquifer response to that stress by monitoring drawdown as a function of time.

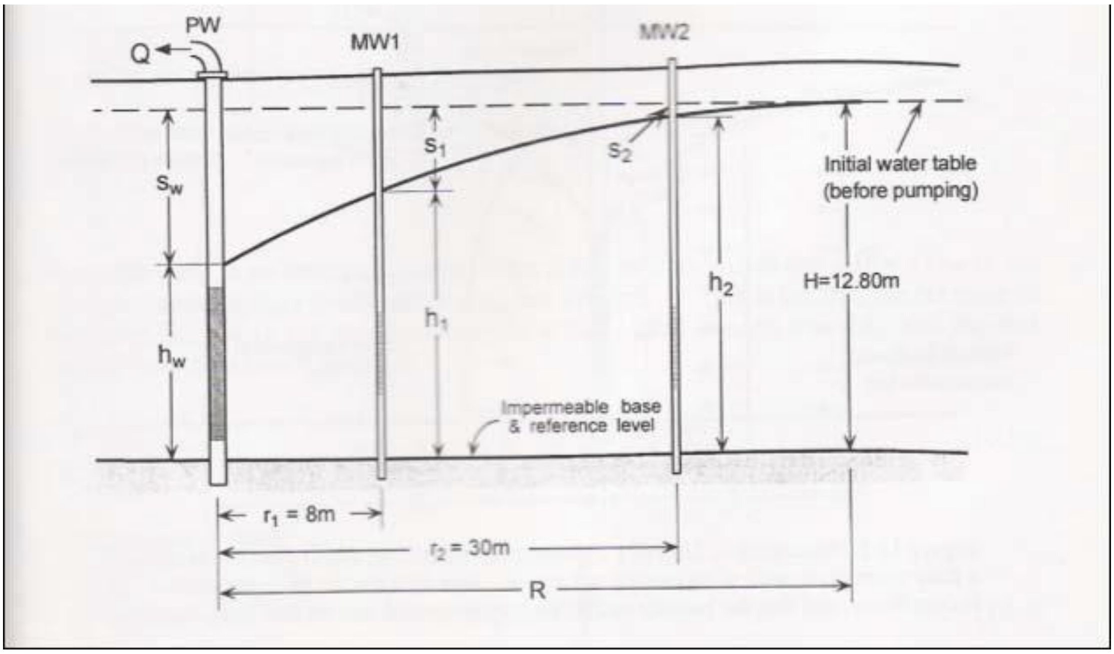


Figure shows pumping well with observation wells in unconfined aquifer

These measurements are then incorporated into an appropriate well flow equation to calculate the hydraulic parameters of the aquifer.

تساهم هذه الحسابات في ايجاد العوامل الهيدروليكية للتكوين المائي.

The Importance of Pumping Tests

Pumping tests are carried out to determine:
1 How much groundwater can be extracted from a well based on long-term yield, and well efficiency?
2 The hydraulic properties of an aquifer or aquifers.
3 Spatial effects of pumping on the aquifer.
4 Determine the suitable depth of pump.
5 Information on water quality and its variability with time.

Design Considerations

There are several things should be considered before starting a pumping test:

1 Literature review for any previous reports, tests and documents that may include data or information regarding geologic and hydrogeologic systems or any test for the proposed area.
2 Site reconnaissance -استطلاع الموقع- to identify wells status and geologic features.
3 Pumping tests should be carried out within the range of proposed or designed rate (for new wells, it should be based on the results of Step Drawdown Test).
4 Avoid influences such as the pumping of nearby wells shortly before the test.
5 Determine the nearby wells that will be used during the test if it's likely they will be affected, this well depends on Radius of Influence. The following equation can be used to determine the radius of influence (R0):

$$R_0 = \sqrt{\left(2.25 \times T \times \frac{t}{S}\right)}$$

where, R_0 is the radius of influence (m)
T is the aquifer transmissivity (m2/day)
t is time (day)
S is the storativity

This equation can be applied for a pumping well in a *confined aquifer*.

6 Measure groundwater levels in both the pumping test well and nearby wells before 24 hours of start pumping.
7 Make sure that the water discharged during the test does not interfere with shallow aquifer tests.
8 Determine the reference point of water level measurement in the well.
9 Determine number, location and depth of observation wells (if any).

First- Steady Radial Flow to Wells

1- **Confined Aquifers**

If a fully penetrating small-diameter well penetrating a confined aquifer is pumped for a very long period of time until the water level reached a steady state, i.e. the water level and the cone of depression became stable, and then by applying Darcy equation it is possible to calculate the well discharge:

$$Q = Av = 2\pi\, r\, D\, K \frac{dh}{dr}$$

Where:

A= Cross-sectional area of flow (L^2)

V= Darcy velocity (L/T)

r= radial distance from main well to any point in the aquifer (L),

D= thickness of the aquifer (L).

K= hydraulic conductivity (L/T).

h= head (L)

since:

T = Dk

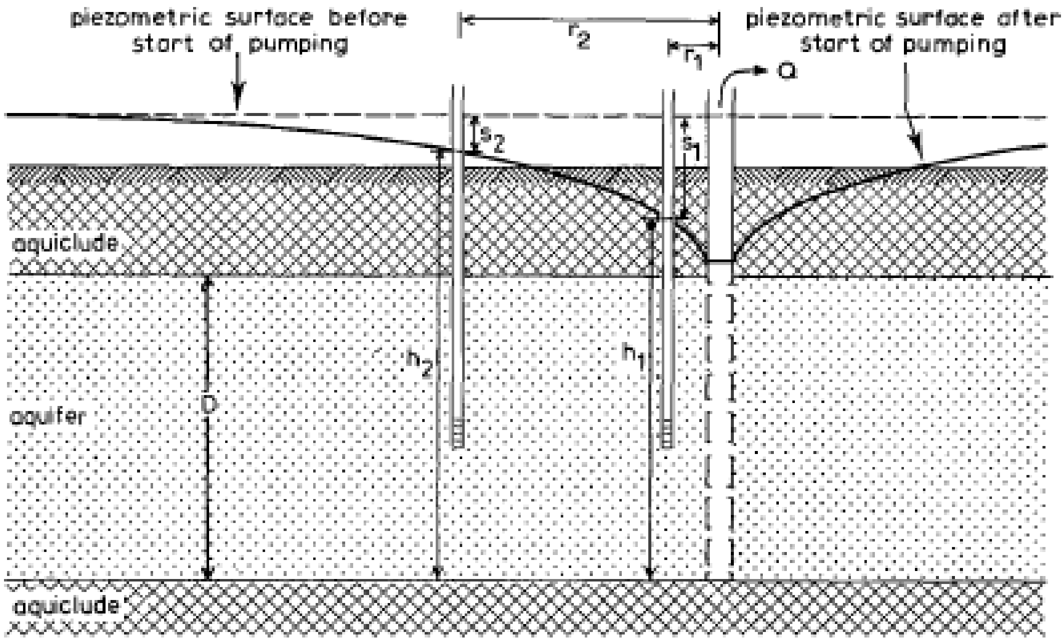
Then

$$Q = 2Л\, r\, T \frac{dh}{dr}$$

By arranging and integrating: $\partial r/r = (2\,ЛT/Q)\,\partial h$

$$\int \partial r/r = 2\,Л\,T/Q \int_{h_2}^{h_1} \partial h$$
$$\ln r_2/r_1 = 2\,Л\,T/Q\,(h_2 - h_1)$$

$$\boxed{Q = 2\,Л\,T \frac{[h_2 - h_1]}{\ln(r_2/r_1)}}$$ This is called Thiem's equation.



In order to apply this equation a small diameter fully penetrating well is pumped and the drawdowns are measured in two observation wells (s1,s2) at two different distances (r1,r2) .The equation can be written as:

$$\boxed{Q = \frac{2\pi T(s1 - s2)}{\ln(r2/r1)}} \qquad (1)$$

This is the simple form of Thiem's Law for confined aquifers

لتطبيق هذا القانون تحفر بئر رئيسية وبئري رصد 1-2 على مسافتين مختلفتين بعـد ذلـك يضخ البئر الرئيسي ويقاس هبوط مستوى الماء في بئري الرصد الى أن يصل فيهما مستوى الماء إلى حالة استقرار. نقيس اكبر هبوط للمستوى البيزومتري في بئري الرصد وهما S_1-S_2

Thiem Equation can be used to estimate the transmissivity

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

عند استعمال بئر رصد واحدة فقط يصبح القانون :

$$Q = \frac{2\pi T(s\,w - s1)}{\ln(r1/rw)}$$

حيث sw الهبوط في البئر الرئيسي.

sw = drawdown in the pumped (main) well.
To calculate the radius of influence (R) s1 is assumed = 0, since it is located at the end of the cone of depression, hence the equation becomes:

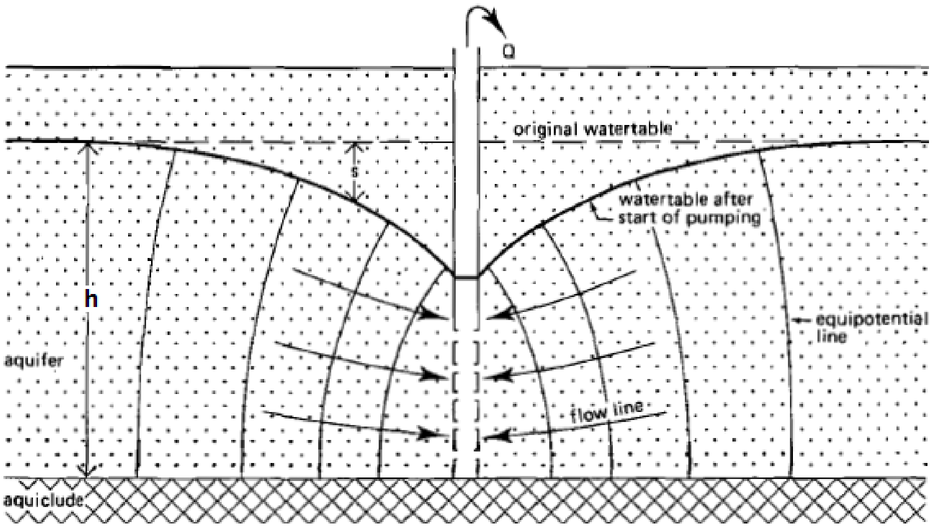
$$Q = \frac{2\,\pi\,T\,(s_w)}{\ln\,(R/r_w)}$$

the equation can be written as:

$$s_w = \frac{Q}{2\pi T} \ln\left(\frac{R}{r_w}\right)$$

2-Unconfined Aquifers

In unconfined aquifers the saturated thickness (D) is variable; therefore it is not possible to apply it in the flow equation. As an alternative we use the head (h), *which represents the elevation of the water level above the base of the aquifer.*



Hence Q becomes:

$$Q = 2\,\pi\, r\, h\, k\, (\partial h/\partial r)$$

by rearranging: $\partial r/\partial r = (2\,\pi\, k / Q).h\partial h$

and integrating: $\int \partial r/r = 2\,\pi\, k / Q \int_{h_2}^{h_1} .h\partial h$

$$Q = \pi\, k\, (h^2{}_2 - h^2{}_1) / \ln(r_2 - r_1)$$

Replacing h by s, the equation becomes:

$$\boxed{\mathbf{Q = \frac{\pi\, k\, (s^2{}_1 - s^2{}_2)}{\ln(r_2/r_1)} \qquad (2)}}$$

This is the simple form of Thiem's Law for unconfined aquifers

If the well suffers from large drawdown compared to the saturated thickness of the aquifer (h_o), then transmissivity (T) becomes nearly equal to: $T = k\,h_o$

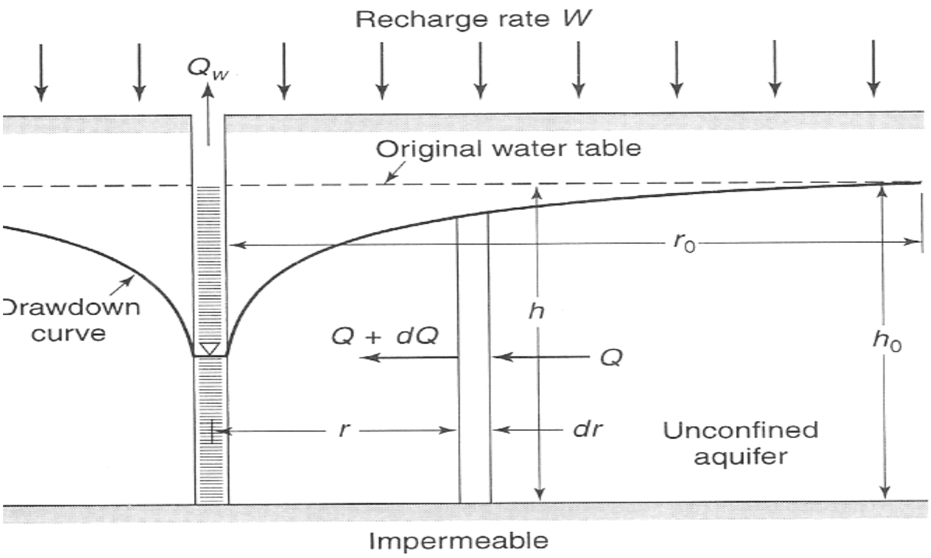
Therefore equation 2 becomes;

$$T = \frac{Q\,(\ln r_2/r_1)}{2\,\pi\,[s_1-(s^2{}_1/2\,h_o)]-[s_2-(s^2{}_2\,/2\,h_o)]}$$

An approximate steady state flow condition in an unconfined aquifer will only be reached after long pumping time.

Well in a Unconfined Aquifer with Uniform Vertical Recharge

Figure below shows a well penetrating an unconfined aquifer that is recharged uniformly at rate W. The flow rate Q toward the well increases as the well increase as the well is approached, reaching a maximum of Q_w at the well.



The discharge of the well is supplied by the vertical recharge and the aquifer storage. Thus

$$Q = \pi r^2 W + 2\pi r h k (dh/dr) \qquad (1)$$

Integrating, and noting that $h=h_0$ at $r=r_0$, yield the equation for the drawdown curve:

$$h_0 - h_2 = \frac{W}{2K}(r^2 - r_0^2) + \frac{Q_w}{\pi K} \ln \frac{r_0}{r} \qquad (2)$$

By comparing this Thiem equation the effect of vertical recharge becomes apparent.

It follows that when $r = r_0$ $Q=0$, so that equation 1 becomes:

$$Q = \pi r_0^2 W$$

Thus the total flow of the well equals the recharge within the circle defined by the radius of influence, which means that the radius of influence is controlled by the well pumping and the recharge rate only. This results in a steady- state drawdown.

Relationship between Discharge and Drawdown in Steady-State Flow

Water level drawdown in wells depends on the rate of discharge. It is possible to make a relationship between the drawdown values of groundwater levels and the discharge of wells penetrating either confined or unconfined aquifers.
Specific Capacity (discharge / drawdown Q_s): is defined as the amount of well discharge per one meter drop in the groundwater level.

يعتمد الهبوط في مستوى المياه في الآبار على معدل التصريف ويمكن عمل علاقة مابين قيم الهبوط في مستوى المياه الجوفية وتصريف الآبار المحفورة في التكاوين المائية المحصورة وغير المحصورة.
التصريف النوعي Specific Capacity (التصريف /الهبوط): مقدار تصريف البئر لكل هبوط يساوي واحد متر في مستوى الماء الجوفي

$$Q_s = Q/s_w$$

1- In confined aquifers- according to Thiem equation:

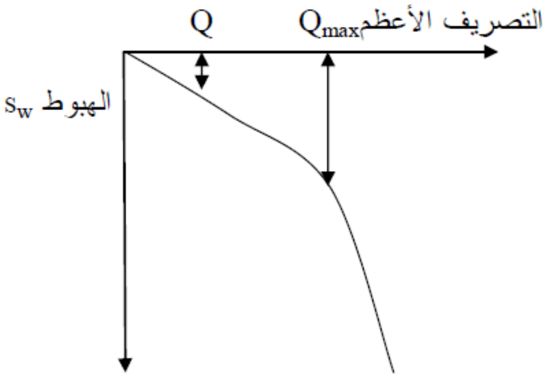
$$Q/s_w = 2\Pi T/\ln(R/r_w)$$

2- In unconfined aquifers

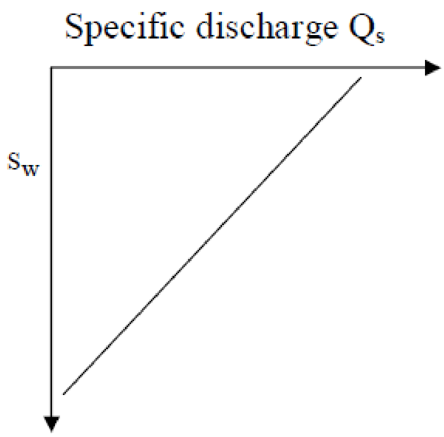
$$Q/s_w = \Pi K s_w / \ln(R/r_w)$$

When plotting discharge vs. drawdown we obtain a curve of two parts:
1- Initial part is a straight line
2- A parabola starts when the drawdown reaches critical point where minor increase in the discharge rate causes large drop in the groundwater level.

1- الجزء الأول خط مستقيم
2- قطع ناقص يبدا عند وصول الهبوط الى نقطة حرجة حيث الزيادة الصغيرة في التصريف يقابلها هبوط كبير في مستوى الماء. التصريف الذي يقابل النقطة الحرجة هو التصريف الاعظم Q_{max}



The relation between specific discharge and drawdown is linear:



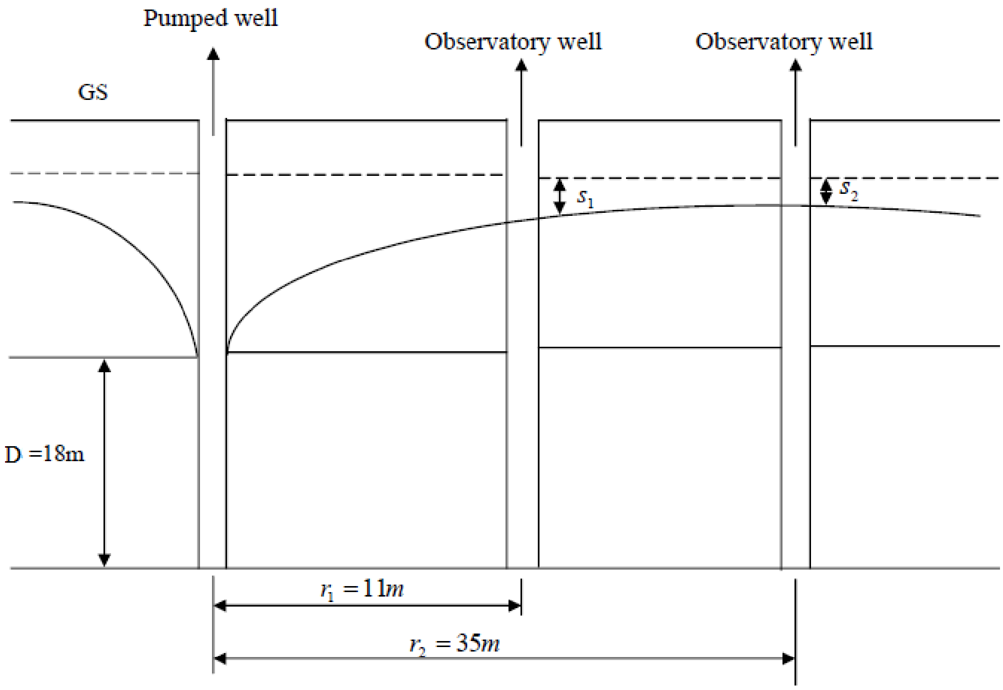
If we consider that the radius of influence of a well penetrating a confined aquifer is 3000meter and the main well radius is 0.2 m; then the equation of specific discharge for confined aquifers become:

$$Q / s_w = T/1.6$$

On the other hand, if we consider that the radius of influence of a well penetrating an unconfined aquifer is 300meter and the main well radius is 0.15 m; then the equation of specific discharge for unconfined aquifers become:

$$Q / s_w = T/1.2$$

<u>Example 1/</u> A 30cm diameter well penetrates vertically through an aquifer to an impermeable stratum located 18.0 m below the static water table. After a long period of pumping at a rate of 1.2 m3/min, the drawdown in test holes 11m and 35 m from the pumped well is found to be 3.05 and 1.62m respective. What is the hydraulic conductivity of the aquifer? Express in meters per day. What is its transmissivity? Express in cubic meters per day per meter. What is the drawdown in the pumped well?



Given

D = 18.0m;
Q = 1.2 m^3/min = 0.02m^3/s;
$r_1 = 11$ m;
$r_2 = 35$ m;
$s_1 = 3.05$ m;
$s_2 = 1.62$; $d = 0.3$ m

Confined Aquifer

Solution:

$$Q = \frac{2\pi T(s1 - s2)}{\ln(r2/r1)}$$

$$0.02 = \frac{2\pi k \times 18(3.05 - 1.62)}{\ln\left(\frac{35}{11}\right)}$$

(i) $k = \frac{0.02 \times 2.303 \times 0.503}{161.73} = 1.4 \times 10^{-4}$ m/s = 12.1m/day

(ii) $T = kD = 12.1 \times 18 = 217.8$ m^3/day/m

(iii) Drawdown in the pumped well

$$Q = \frac{2\pi T(s - s_1)}{\ln\left(\frac{r_1}{r}\right)}$$

$$0.0158(s - 3.05) = 0.02 \times 2.303 \times 1.865$$

$s = 8.49$ m (drawdown)

Example 2/ The following observations were recorded during a pumping out test on a tube well penetrating fully in a free aquifer:
Well diameter = 25cm
Discharge from the well = 300 m3/hr
E.L of original water surface before pumping started = 122.0 m
E.L of water in well at constant pumping = 117.1 m
E.L of water in the observation well = 121.3 m

E.L of impervious layer = 92.0 m
Radial distance of observation well from the tube well = 50 m
Determine (a) the field permeability coefficient and
(b) radius of zero draw down.

Solution

For test well $d = 25\,cm = 0.25\,m$

$$r = \frac{0.25}{2} = 0.125\,m$$

$$Q = 300\,{m^3}/{h} \quad = 300\frac{m^3}{h} \times \frac{1h}{60 \times 60s} = 0.083\,{m^3}/{s}$$

$$H_{elevation} = 122.0\,m$$

$$h_{elevation} = 117.1\,m$$

$$\text{Im}\,pervious\ elevation = 92.0\,m$$

$$\Rightarrow \quad H = 122.0 - 92.0 = 30\,m \ ; \qquad h = 117.1 - 92.0 = 25.1\,m$$

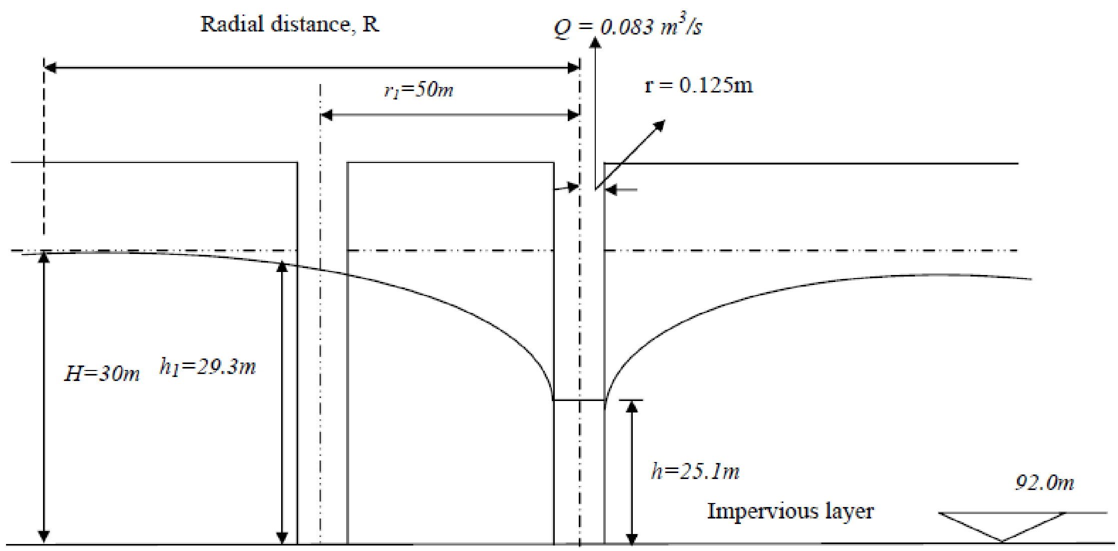
For observation well

Level of water = 121.3 m

$$h_1 = 121.3 - 92.0 = 29.3m$$

$$r_1 = 50\,m$$

S = H – h = 30.0 – 29.3 = 0.7m



Free aquifer = unconfined aquifer

(a) Field permeability coefficient (k) is given as:

$$k = \frac{Q\ ln\left(\frac{r_1}{r}\right)}{\pi\left(h_1^2 - h^2\right)} = \frac{0.083\,1\text{n}\left(\frac{50}{0.125}\right)}{\pi\left(29.3^2 - 25.1^2\right)} = 6.95 \times 10^{-4}\ {}^{m}\!/\!_{s}$$

$$k = 6.95 \times 10^{-4}\ \frac{m}{s} \times \frac{60 \times 60 \times 24s}{1day} = 60.05\ {}^{m}\!/\!_{day}$$

(b) Radius of zero drawdown = Radius of influence (R)

$$Q = \frac{\pi k\left(H^2 - h^2\right)}{ln\left(\frac{R}{r}\right)}$$

$$0.083 = \frac{\pi\ 6.95 \times 10^{-4}\left(30^2 - 25.1^2\right)}{ln\left(\frac{R}{0.125}\right)}$$

$$ln\left(\frac{R}{0.125}\right) = 7.1$$

ln R - ln 0.125 = 7.1

Ln R= 7.1+ ln 0.125 = 5.02

By convert ln to log : (*ln x= 2.303 log x*)

2.303log R= 5.02

Log R= 2.179 R= 10 $^{2.179}$

R=1.51 m

Hence the radius of zero drawdown, R = 151 m

Second :Unsteady- State Radial Flow

ثانيا: السريان الشعاعي الغيرمستقر

Theis's Method