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Groundwater Hydrology

3rd class

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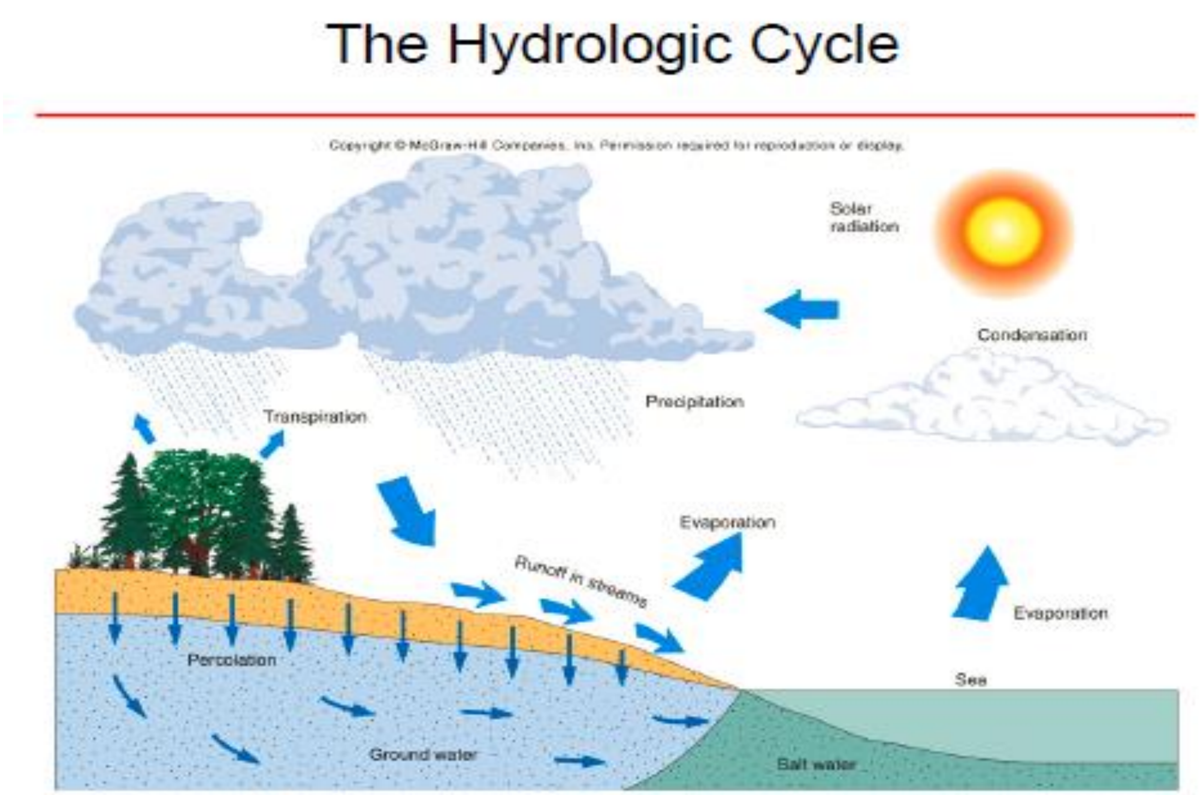
<u>Contents</u>

References:

- Groundwater Hydrology by **Herman**
- Groundwater Hydrology by **Todd**

Chapter 1

Introduction



Importance of Groundwater:

- Groundwater is the primary source of water in many areas in the world
- Groundwater is important to those who have limited precipitation each year
- Groundwater is the safest and most reliable source of freshwater
- Groundwater is protected from evaporation
- Groundwater aquifers do not occupy valuable land on the ground surface

- More than 97% is sea water, 2.2% occurs in solid form as ice, 0.2% is fresh water in rivers and lakes, and the remaining 0.6% is groundwater

Groundwater Hydrology Definitions:

- Groundwater Hydrology. The science that considers the occurrence, distribution, and movement of water below the surface of the earth. It is concerned with both the quantity and quality aspects of groundwater
- Hydrogeology. The science that deals with the distribution and movement of water (groundwater) in the aquifers with respect to the **geology** of the area

What Groundwater Scientists Do?

- Water supply

  Water supply wells for drinking water, irrigation, and industrial purposes are drilled after assembling data on the hydrogeology of the region

- Water resources management

  Since groundwater reservoirs (aquifers) cross property lines and political boundaries, difficult decisions must be made about who is allowed to pump water, how much can be pumped, where wells can be located, and where locations of potential contaminant sources can be considered

- Environmental investigations and clean-up

  Active remediation of contaminated aquifers is important and might involve pumping and treating water or other schemes

- Analysis of groundwater resources

  This entails mainly the prediction of the status of groundwater resources under different natural and man-made scenarios

Chapter 7

WELL HYDRAULICS

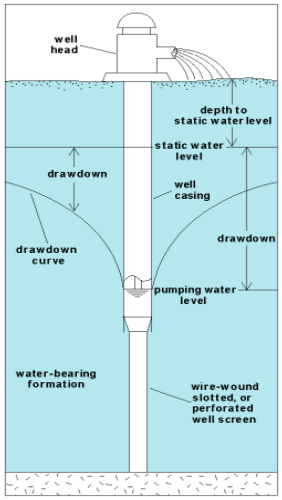
Steady State Analysis

(Confined Aquifers)

Introduction:

What is well hydraulics?

Concentrates on the analysis of drawdown due to pumping with time and distance



Importance of well hydraulics

Groundwater withdrawal from aquifers are important to meet the water demand. Therefore, we need to understand well hydraulics to design a pumping strategy that is sufficient to furnish the adequate amounts of water

Basic Assumptions

The following are the key assumptions for deriving the basic equations:

- The potentiometric surface of the aquifer is horizontal prior to start of pumping
- The aquifer is homogeneous and isotropic
- All flow is radial toward the well
- Groundwater flow is horizontal
- The pumping well fully penetrates the aquifer

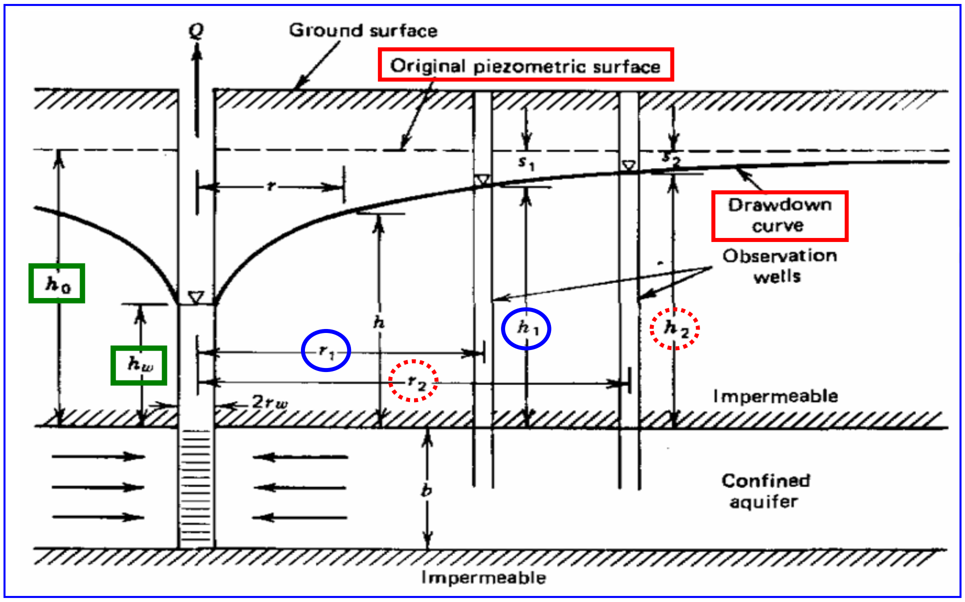
Steady versus Transient

Steady state implies that the drawdown is a function of location only s = f(r) in case of steady state

Transient state implies that the drawdown is a function of location and time

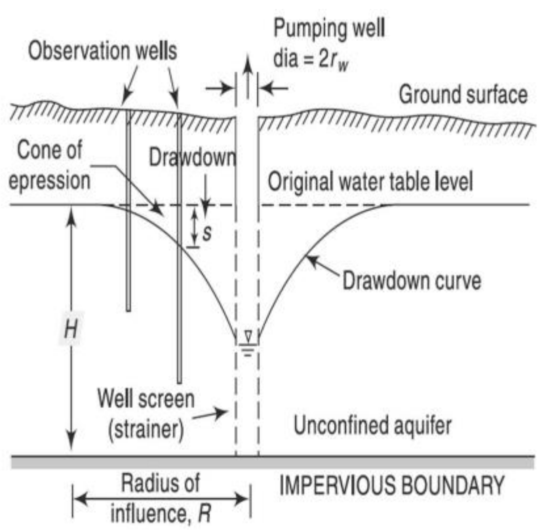
s = f(r,t) in case of transient state

Steady Radial Flow to a Well in Confined Aquifers



- When water is pumped from a confined aquifer, the pumpage creates a drawdown in the piezometric surface that induces hydraulic gradient toward the well

- Drawdown at a given point is the distance by which the water level is lowered. A drawdown curve shows the variation of drawdown with distance from the well



❖ Apply Darcy's law to derive the flow equation that relates drawdown with pumping:

$$Q = A\ q = (2\pi rb)(-K\frac{dh}{dr}) = -2\pi rbK\frac{dh}{dr}$$

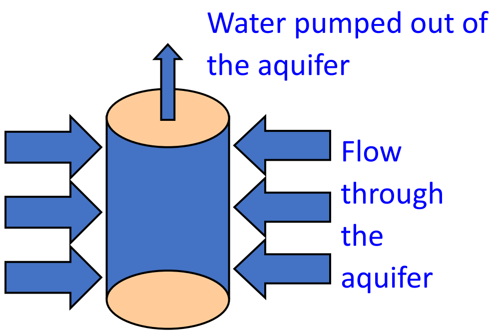
❖ Rearranging and integrating for the boundary conditions at

the well $h = hw$ and $r = rw$

and

at the edge of the aquifer $h = h0$ and $r = r0$

yields (with the negative sign neglected):



$$h_0 - h_w = \frac{Q}{2\pi Kb}\ln\frac{r_0}{r_w}$$

$$Q = 2\pi Kb\frac{h_0 - h_w}{\ln\frac{r_0}{r_w}} \qquad Q = 2\pi Kb\frac{h - h_w}{\ln\frac{r}{r_w}}$$

or in a general form $$h_r = h_w + \frac{Q}{2\pi Kb}\ln\frac{r}{r_w}$$

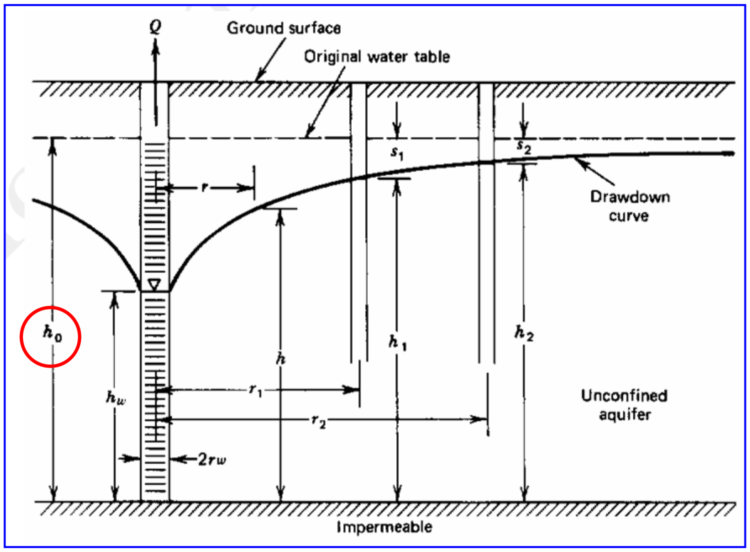
Steady State Analysis

(Unconfined Aquifers)

Steady Radial Flow to a Well in (Unconfined Aquifers):

- The flow equation is similar for that of confined aquifers except we use h instead of b

$$Q = -2\pi rKh\frac{dh}{dr}$$



- Rearranging and integrating for the boundary conditions:

  at the well, $h = h_w$ and $r = r_w$

  at the edge of the aquifer, $h = h_0$ and $r = r_0$

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

- Converting to heads (h_1 and h_2) and radii at two observation wells at locations r_1 and r_2:

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

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

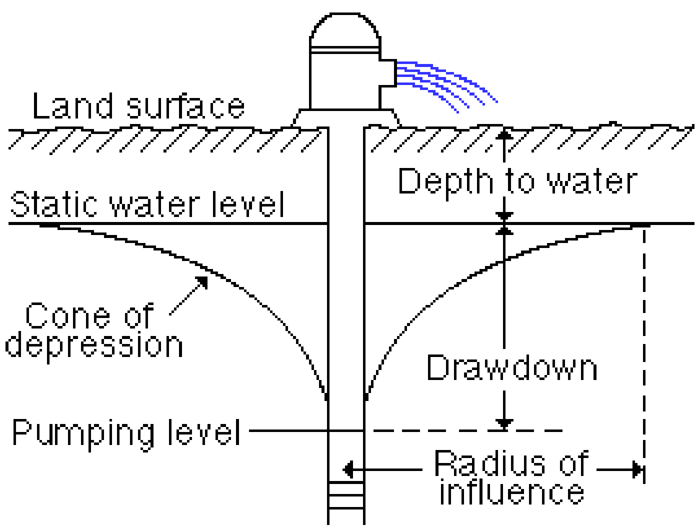
$$Q = \pi K \frac{h_2^2 - h_1^2}{\ln \frac{r_2}{r_1}}$$

- Rearranging to solve for the hydraulic conductivity:

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

❖ The following form is a useful one for computing h as a function of r:

$$h_r^2 = h_0^2 - \frac{Q}{\pi K} \ln \frac{r_0}{r}$$



- where r_0 is the radius of influence at which the drawdown is negligible

Example [1]:

The steady-state drawdown at a specific location (r_1) is 30 feet with a constant pumping rate of 20 gpm. The aquifer is unconfined and the saturated thickness is 100 feet. What is the steady-state drawdown measured at the same location (r_1) when the constant pumping is 10 gpm?

Solution:

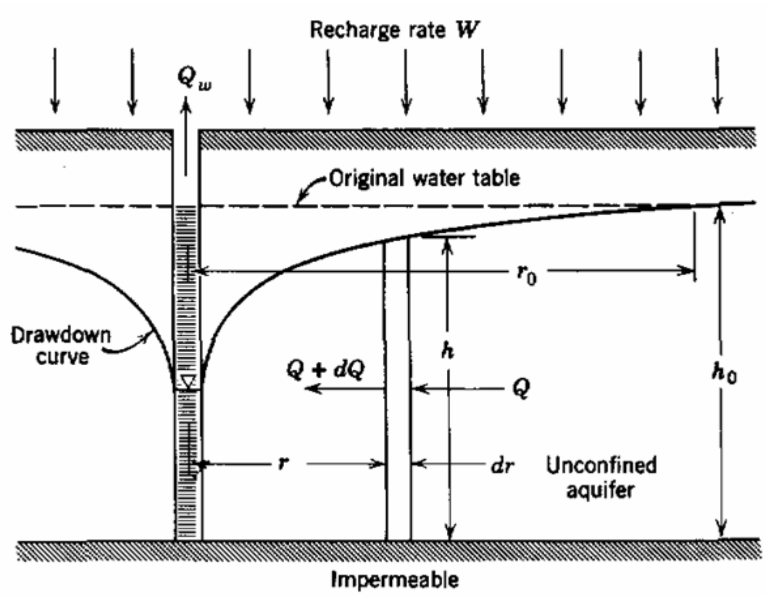
Using the unconfined solution:

$$Q_1 = \frac{\pi K(h_0^2 - h_1^2)}{\ln \frac{r_0}{r_1}} \qquad Q_2 = \frac{\pi K(h_0^2 - h_2^2)}{\ln \frac{r_0}{r_1}} \Rightarrow \frac{Q_1}{Q_2} = \frac{h_0^2 - h_1^2}{h_0^2 - h_2^2}$$

$h_0 = 100$ feet, $h_1 = 100 - 30 = 70$ feet, $Q_1 = 20$ gpm, and $Q_2 = 10$ gpm $h_2 = 86.3$ feet and $s_2 = 100 - 86.3 = 13.7$ feet

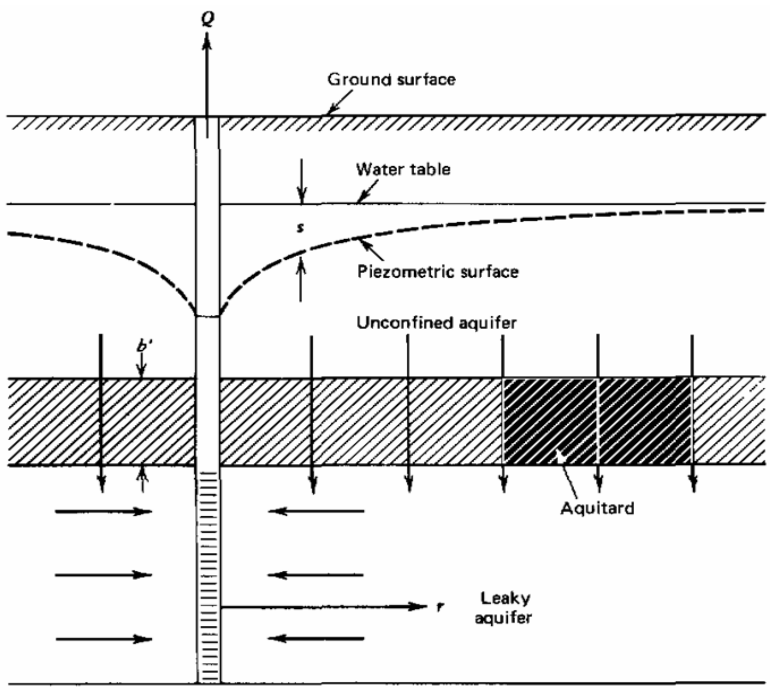
❖ Steady Flow to a Well in Unconfined Aquifers with Uniform Recharge

$$h = \sqrt{h_0^2 - \frac{W}{2K}(r^2 - r_0^2) - \frac{Q_w}{\pi K}\ln\frac{r_0}{r}}$$



❖Steady Radial Flow in Leaky Aquifers:

$$s(r) = \frac{Q}{2\pi T}\left[K_0\left(\frac{r}{B}\right)\right]$$



s(r): drawdown

T: transmissivity

b': thickness of the confining bed

K_0( ): modified Bessel function

B: leakage factor → $B = \sqrt{\frac{Tb'}{K'}}$

K´: hydraulic conductivity of the confining bed

For r/B < 1 then → $K_0\left(\frac{r}{B}\right) \approx \ln\left(\frac{1.123}{r/B}\right)$

For r/B > 1 then → $K_0\left(\frac{r}{B}\right) \approx \sqrt{\frac{\pi}{2r/B}}\, e^{-r/B}$

R = 1.123×B is known as the apparent radius of influence