Chapter 36: Groundwater Hydrology

Introduction

Groundwater hydrology is the branch of hydrology that deals with the study of subsurface water — water found beneath the Earth's surface in soil pore spaces and in the fractures of rock formations. This chapter delves into the fundamental concepts governing groundwater movement, storage, and extraction. It covers permeability, storage coefficient, transmissibility, Darcy’s law, and well hydraulics, offering insights into how groundwater systems are quantified and analyzed for engineering applications.

36.1 Permeability

Permeability is a measure of the ability of a porous material (like soil or rock) to allow fluids to pass through it. It is a crucial property in groundwater movement and depends on the size and connectivity of pores in the material.

- **Coefficient of Permeability (k)**: Defines the rate of flow under a unit hydraulic gradient through a unit area. It is expressed in m/s or cm/s.
- **Factors Affecting Permeability:**
  - **Grain size and distribution** – Larger and more uniformly graded grains have higher permeability.
  - **Void ratio** – More voids increase permeability.
  - **Degree of saturation** – Fully saturated soils have higher permeability.
  - **Viscosity of fluid** – Higher viscosity reduces permeability.
  - **Structure and compaction** – More compacted soils have lower permeability.
- **Laboratory Methods for Determining Permeability**:
  - **Constant head test** (used for coarse-grained soils like sand and gravel).
  - **Falling head test** (used for fine-grained soils like silt and clay).

36.2 Storage Coefficient (S)

The **storage coefficient** is the volume of water that a unit area of an aquifer releases from or takes into storage per unit change in hydraulic head.

- **In Confined Aquifers**: Water is released due to compressibility of the aquifer and the water. Storage coefficient is typically between 10^{-3} and 10^{-5}.
- **In Unconfined Aquifers**: Water is released due to gravity drainage. Storage coefficient approximates the specific yield (typically 0.1 to 0.3).

Specific Storage (Ss)

It is the volume of water that a unit volume of aquifer releases from storage under a unit decline in head.

$$S_s = \rho g (\alpha + n\beta)$$

Where:

- ρ = Density of water
- g = Acceleration due to gravity
- α = Compressibility of the aquifer skeleton
- β = Compressibility of water
- n = Porosity

36.3 Transmissibility (T)

Transmissibility (T) is the rate at which groundwater flows through a unit width of the aquifer under a unit hydraulic gradient. It is the product of permeability and saturated thickness of the aquifer.

$$T = k \cdot b$$

Where:

- k = Coefficient of permeability
- b = Saturated thickness of aquifer

Transmissibility is typically expressed in m^2/day. High transmissibility indicates a more productive aquifer.

36.4 Darcy's Law

Darcy's Law is a fundamental equation that describes the flow of groundwater through porous media.

$$Q = -k A \frac{dh}{dl}$$

Where:

- Q = Discharge (m³/s)
- k = Coefficient of permeability (m/s)
- A = Cross-sectional area to flow (m²)
- $\frac{dh}{dl}$ = Hydraulic gradient (change in head per unit length)

Assumptions of Darcy's Law:

- The flow is laminar.
- The porous medium is homogeneous and isotropic.
- The fluid is incompressible and has constant viscosity.
- The flow is steady.

Darcy's law is valid for low Reynolds number flows (Re < 1), typical in most groundwater systems.

36.5 Well Hydraulics

Well hydraulics involves the study of water flow towards wells, which is critical for estimating groundwater availability and designing pumping schemes.

Steady Radial Flow into Wells

(i) Confined Aquifer

For steady radial flow towards a well fully penetrating a confined aquifer:

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

Where:

- Q = Discharge
- T = Transmissibility
- h_1, h_2 = Hydraulic heads at radial distances r_1 and r_2

(ii) Unconfined Aquifer

In unconfined aquifers, the saturated thickness changes with drawdown:

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

Where:

- h_1, h_2 = Water table elevations

Assumptions for Steady Flow:

- Aquifer is homogeneous and isotropic.
- Flow is horizontal and radial.
- Well is fully penetrating the aquifer.
- Flow is steady (inflow = outflow).

36.6 Recuperation Tests

Recuperation test is used for **open wells** to determine their yield capacity. It involves pumping out water and observing the rate at which the water level returns (recuperates) to the static level.

Let:

- H = Initial drawdown
- h = Residual drawdown at time t
- A = Area of well
- Q = Discharge

Then, the yield of well:

$$Q = \frac{2.3\,A\,H}{t}\log_{10}\left(\frac{H}{h}\right)$$

This test is particularly useful for wells in unconfined aquifers and is easier to perform compared to step drawdown tests.

36.7 Well Constants

Well constants are derived from pumping test data and are used to evaluate the aquifer properties.

- **Well function** (Theis Solution): Applied for unsteady flow conditions.
- **Theis Equation**:

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

Where:

- s = Drawdown
- Q = Discharge
- T = Transmissibility
- $W(u)$ = Well function
- $u = \frac{r^2 S}{4Tt}$

Well constants can be obtained by plotting time-drawdown data and matching it with type curves (e.g., Theis or Jacob's method).

These constants help in designing wells, estimating sustainable yields, and understanding aquifer behavior over time.