

Chapter 2

Hydrogeology

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Hydrogeology is the study of water in geologic formations beneath the earth's surface (Hölting 2013). Groundwater moves in soil and rock (aquifers) and supplies springs, wells, and when near the surface, lakes and streams. The upper limit of the saturated zone is called the water table. Aquifer formations have different geological characterizations:

- **Lithology** is the physical makeup, including the mineral composition, grain size and grain packing of the sediments or rocks that make up the geological systems.
- **Stratigraphy** describes the geometrical and age relations between the various layers, beds and formations in geologic systems of sedimentary origin.
- **Structural features** such as cleavages, fractures, folds and faults are the geometrical properties of the geologic systems produced by deformation after deposition or crystallization.

2.1 Aquifer Types

An **aquifer** is a saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients (Hölting 2013; Kresic 2007). The below definitions of aquifer types are from Freeze and Cherry (1979):

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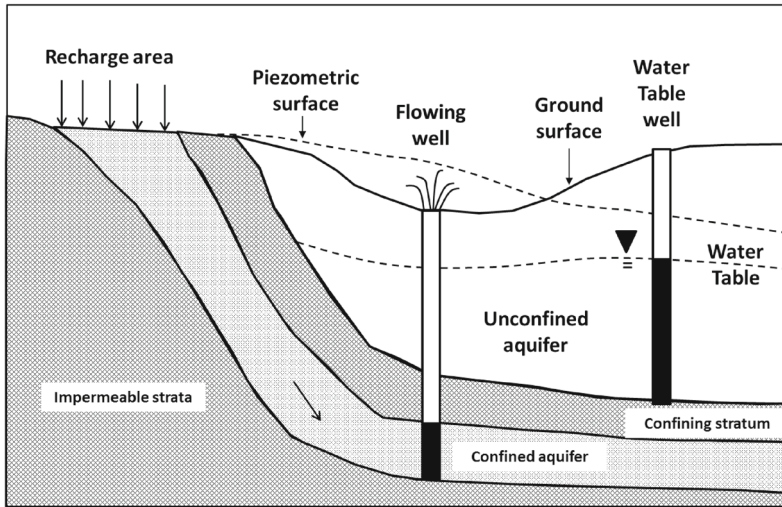


Fig. 2.1 Schematic cross section illustrating unconfined and confined aquifers

- An **aquitard** is a saturated bed in a stratigraphic sequence with such low permeability that it cannot deliver water at a productive rate.
- An **aquiclude** is defined as a saturated geologic unit incapable of transmitting significant quantities of water under ordinary hydraulic gradients and that restricts vertical flow.

Figure 2.1 illustrates unconfined and confined aquifers.

- **Unconfined aquifers** are exposed at surface. These aquifers are bounded by the water table (water level in borehole). The water table can have tendency to mimic the topographic contours of the land surface above.
- A **confined aquifer** is an aquifer, where a low permeability layer (e.g. clay) borders the upper surface of the aquifer, thereby confining the groundwater under pressure. Artesian conditions exist when this impermeable layer is breached, and water rises up above the top of aquifer. A confined aquifer is fully saturated (Kresic 2007).

Groundwater recharge (GWR) is the inflow of water to a groundwater reservoir from the surface infiltration of precipitation and its movement to the water table.

2.2 Aquifer Characteristics

Aquifers are formed from different rocks, e.g., unconsolidated sediments, sedimentary rocks, igneous and metamorphic rocks, and have corresponding characteristics. Originated rock types are responsible for source (yield), storage, filtering and routing of groundwater. Based on Gupta (2001), aquifers are characterised by the following parameters:

- **Porosity** n of a soil or rock is that fraction of a given volume of material that is occupied by void space, or interstices. Porosity, indicated by the symbol n , is usually expressed as the ratio of the volume of voids. Most rocks naturally contain a certain percentage of voids that can be occupied by water.
- **Percolation** is the rate at which water moves downward through porous medium.
- **Permeability** k is an expression of movement of water in any direction.
- **Specific yield** is the ratio of the volume of water, that, after saturation, can be drained by gravity (Eq. 2.1).
- **Storage coefficient** S is the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in head normal to that surface (Eq. 2.2).
- **Hydraulic conductivity** K is a constant that serves as a measure of the permeability of the porous medium.
- **Transmissivity** T rate at which water is transmitted through a unit width of aquifer under unit hydraulic gradient; $T = Kb$, where b is the saturated thickness of aquifer.

Storage characteristics are different in unconfined and confined aquifers (Fig. 2.2).

$$S = \frac{V}{A\Delta h} \quad \text{Specific yield} \quad (2.1)$$

$$S = S_S b \quad \text{Storativity} = \text{Capacity} \quad (2.2)$$

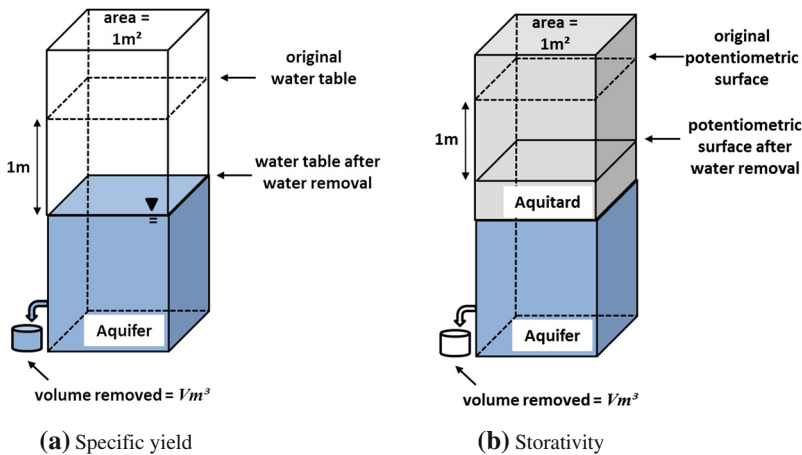


Fig. 2.2 Specific yield in an unconfined aquifer and storativity of an confined aquifer; modified based on Hornberger et al. (1998)

2.3 Groundwater Flow Equation

In this chapter we briefly describe the derivation of the groundwater flow equation. The groundwater flow equation is derived from the conservation principles of mass and momentum balance. The basic idea is the Eulerian concept of motion in the frame of continuum mechanics.

We start with the equation of fluid mass balance in a static (i.e. non-deformable) porous medium (Eq. 2.3). In case of a porous medium, the available room for fluid flow is reduced to the pore space. The ratio of pore space to the total volume of a porous medium is given by the porosity n . The porosity can change in case of deformation processes, which is neglected here. All variables and parameters of the equations are given at the end of this section.

$$\frac{\partial n\rho}{\partial t} + \nabla \cdot (n\rho\mathbf{v}) = Q_\rho \quad (2.3)$$

For an incompressible fluid (such as water) we have

$$\rho \frac{\partial n}{\partial t} + \rho \nabla \cdot (n\mathbf{v}) = Q_\rho \quad (2.4)$$

Incompressibility means that the density of the fluid is nearly constant in the given range of groundwater pressure values, i.e. $\rho = \rho_0$. Now dividing by the reference density ρ_0 we yield

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = \frac{Q_\rho}{\rho_0} \quad (2.5)$$

The temporal change of porosity is expressed by the storativity concept in groundwater hydraulics. There is a linear relationship between porosity and groundwater pressure changes. The proportion factor is given by the storativity coefficient S (see Sect. 2.2).

$$\frac{\partial n}{\partial t} = S \frac{\partial h}{\partial t} \quad (2.6)$$

Now we make use of Darcy's law (see Sect. 1.5).

$$n\mathbf{v} = \mathbf{q} = -\mathbf{K}\nabla h \quad (2.7)$$

Combining the above balance (Eq. 2.5) and constitutive equations (Eqs. 2.6 and 2.7) we yield the groundwater flow equation.

$$\begin{aligned}
 S \frac{\partial h}{\partial t} + \nabla \cdot (n\mathbf{v}) &= Q \\
 S \frac{\partial h}{\partial t} - \nabla \cdot (\mathbf{K}\nabla h) &= Q \\
 S \frac{\partial h}{\partial t} - \frac{\partial}{\partial x} \left(K_x \frac{\partial h}{\partial x} \right) - \frac{\partial}{\partial y} \left(K_y \frac{\partial h}{\partial y} \right) - \frac{\partial}{\partial z} \left(K_z \frac{\partial h}{\partial z} \right) &= Q \quad (2.8)
 \end{aligned}$$

With following parameters (units):

- h hydraulic head or piezometric head (m),
- \mathbf{K} hydraulic conductivity tensor (m/s),
- K_x, K_y, K_z hydraulic conductivity values in coordinate directions (m/s),
- n porosity (m^3/m^3),
- \mathbf{q} Darcy or percolation velocity (m/s),
- Q_ρ source-sink term of groundwater ($\text{kg}/\text{m}^3\text{s}$),
- S storage coefficient (1/m),
- t time (s),
- \mathbf{v} pore velocity vector (m/s),
- ρ fluid density (kg/m^3).

The theoretical derivation of the groundwater flow equation is the prerequisite for the practical application of the numerical modelling of hydrological processes in *OpenGeoSys*.

OpenGeoSys-Tutorial

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