Hydrology
Storativity and Transmissivity

Aquifer parameters
So far, we have discussed most of the physical parameters that are needed to describe and estimate the flow of groundwater in a saturated aquifer.

Water
Density ($\rho$), viscosity ($\mu$), and compressibility ($\beta$)

Sediments / Rock
Porosity ($n$), permeability ($k$), and compressibility ($\alpha$)

Medium compressibility ($\alpha$)
This is also a factor in the porous media through which groundwater flows.

Compression of the granular skeleton of the porous medium results from the overlying weight of the medium as well as the water saturating the medium.

The more overlying weight there is on a geologic formation, the more compressed it will be. Different materials compress to a different degree, depending on their structure. Generally, compression is accomplished by rearranging the grains of the medium into a more compact configuration.

In a confined aquifer, the groundwater is under pressure. This pressure produces a force pushing the individual grains of the medium apart. So, compression from the weight of the overburden is alleviated by the pore pressure of the aquifer fluid.

What does this mean? **It means that in a confined aquifer total storage is increased as pressure increases because the granular skeleton expands to create more voidspace.**

Contrariwise, if water is removed from a confined aquifer and pressure decreases, so will storage space as the granular skeleton compresses under its own weight.

Water compressibility ($\beta$)
We have already discussed the fact that water is slightly compressible. In a large aquifer, as water is put under increasing pressure, it takes-up a slightly smaller volume.

Contrariwise, as water is removed from the aquifer and pressure decreases, the water will expand in volume.

**Let’s consider what all this means in terms of groundwater storage:**

If water is added to a groundwater reservoir, what happens?

Hydraulic head increases - water level in wells rises.
Fluid pressure increases in the aquifer.
Porosity increases as the granular skeleton expands.
The volume of water decreases as the water compresses.

Likewise, if water is removed from a groundwater reservoir....

Hydraulic head decreases - water level in wells falls.
Fluid pressure decreases in the aquifer.
Porosity decreases as the granular skeleton contracts.
The volume of water increases as the water compresses.

Because we monitor change in storage in aquifers by measuring changes in hydraulic head (water level in wells), what would be useful to have an expression that relates a change in hydraulic head to the amount of water that is absorbed or expelled from the aquifer.

**Storativity (S):** the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head.

Storativity is a dimensionless property: \[ S = \frac{L^3}{L^2 \times L} \]

**The equations for estimating storativity are different for confined and unconfined aquifers.**

Think about it this way...

In an unconfined aquifer, the height of the hydraulic head is shown by the water table.

Thus, a change in hydraulic head results in either increasing or decreasing saturation of the aquifer. A large change in hydraulic head results in a large change in the volume of water in the aquifer.

In a confined aquifer, the height of the hydraulic head is given by the potentiometric surface, which is usually above the upper surface of the aquifer. Water can be added or removed from the aquifer without affecting the saturation of the aquifer.

The potentiometric surface can rise and fall, but as long as it stays above the upper surface of the aquifer, there is no change in saturation in the aquifer.

In this case, the change in hydraulic head is being accomplished by a change in pressure. The amount of water that is absorbed or expelled from the aquifer is determined by the changes in water volume and porosity that result from the change in pressure.
Because the changes in water volume and porosity are relatively small, in a confined aquifer a large change in hydraulic head does not result in a large change in storage.

Now, let’s look at the formulas used to quantify what I just described:
The amount of water per unit volume of a saturated aquifer that is absorbed or expelled due to changes in the compression of the fluid and medium caused by a change in hydraulic head is called - **specific storage** \((S_s)\).

\[
S_s = \rho g (\alpha + n\beta)
\]

- \(S_s\) has units of \(1/L\)
- \(n\) = % porosity
- \(\alpha\) = medium compressibility
- \(\beta\) = water compressibility
- \(\rho x g\) = specific weight of the water in the aquifer

In a confined aquifer, the equation for storativity becomes:

\[
S = bS_s
\]

where \(b\) is the thickness of the aquifer.

In an unconfined aquifer, a change in hydraulic head results in both a change in pressure in the saturated portion of the aquifer, as well as a change in the thickness of the saturated zone. In this case, storativity equals:

\[
S = S_y + hS_s
\]

\(S_y\) is the **specific yield** of the aquifer - the amount of water per unit volume that will drain from an aquifer under the influence of gravity.

Specific yield is usually several orders of magnitude larger than \(hS_s\) so that in all but very fine grained units the \(hS_s\) component is ignored and storativity is considered equivalent to specific yield.

If you want to know the volume of water that will be drained from or added to an aquifer as the head is raised or lowered, the equation is:

\[
V = SA\Delta h
\]

where \(A\) is the area overlying the aquifer.
Transmissivity

This is a measure of how much water can be transmitted horizontally through a unit width of a fully saturated aquifer under a hydraulic gradient of 1.0.

Transmissivity is the product of the hydraulic conductivity and the saturated thickness of the aquifer:

\[ T = bK \]

\( T \) has units of \( L^2/T \)

Seepage velocity

Now, before moving on, let us return to consider the speed at which groundwater moves.

Imagine a pipe carrying water. The volume of water moving per unit time is the flow and is given by the equation \( Q = vA \), which can be rearranged to solve for velocity: \( v = Q/A \)

Remember Darcy’s law?

\[ Q = -KA \frac{dh}{dl} \]

Likewise, we can divide \( Q \) by \( A \) and get a velocity. We have seen this before, and we called it specific discharge (\( v \)).

This is an apparent velocity - it is the speed at which water would move through an open pipe given the rate of flow measured.

However, an aquifer is not an open pipe. The cross sectional area of flow is not open space in an aquifer. The open space that is actually available for flow is much smaller = to the effective porosity x area.

So, the actual velocity that water is moving through the unit area has to be greater than the apparent velocity, because the water is really moving through a much smaller area.

To convert apparent velocity measured from flow through an aquifer into the actual velocity that the water is moving - seepage velocity or average linear velocity - one must divide specific discharge by the effective porosity.
\[ V_{\text{seepage}} = \frac{v_{\text{effective}}}{n_e} = \frac{Q}{n_e A} \]

Disclaimer:
The seepage velocity cannot be used to accurately predict the movement of a solute front, for example contamination coming off of a waste site, because there are other factors that must be taken into account that effect the movement of a solute, such as dispersion and diffusion.