Assessment of Sustainable Yields of Aquifers

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What do we mean by “Sustainability”?

- To maintain an activity , especially over a specified period of time.

- To maintain an activity indefinitely.

"Sustainable Development"

- A development which meets the needs of the present without compromising the ability of the future generations to meet their own needs.

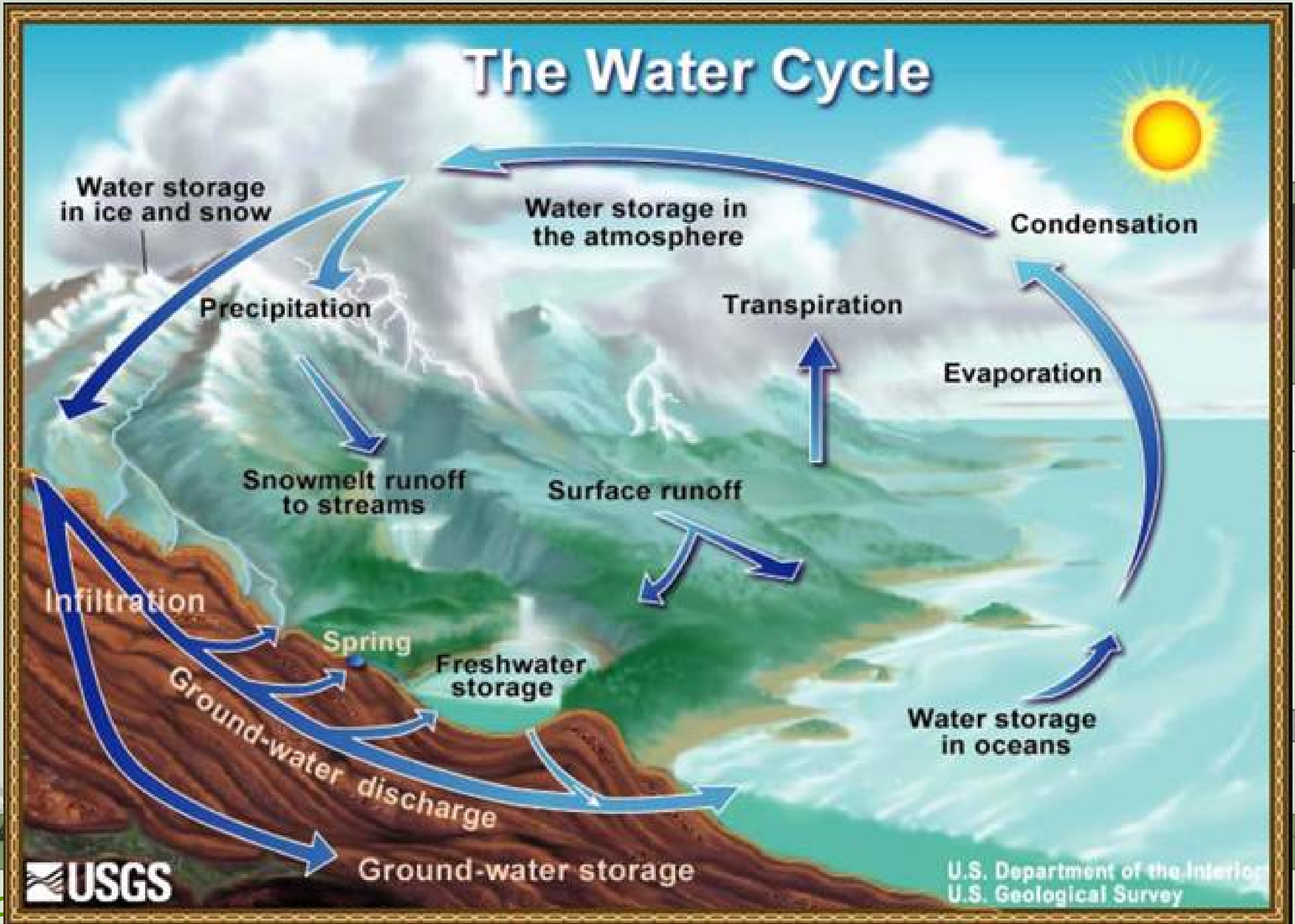
Sustainable Water Resources Development

- Ensure that the benefits of use of a hydrological system will meet present objectives of society without compromising the ability of the system to meet future objectives.

Elements of Sustainable Water Resources

- Alternatives to Surface storage (e.g. water harvesting)
- Wastewater reclamation and reused
- Water Conservation
- Demand management
- Protection of water resources

Hydrologic Cycle



Groundwater Recharge

- Rainfall infiltration (Main component)
- Return flow (e.g. irrigation)
- Leakage from fresh water distributing systems
- River and wadi flows (Runoff)
- Artificial recharge (e.g. Injection wells)

- Leakage from wastewater collection systems (e.g. discharge points)

Recharge estimation Methods

- Recharge models
- Groundwater flow models
- Hydro-chemical methods
- Isotopes
- Spring yields and Rainfall analysis

Recharge analytical Equations

- ***Rainfall-Recharge equations:***

$R=0.6\,(P - 285)$ *P > 700 mm*

$R=0.46\,(P - 159)$ *700 mm > P >456 mm*

$R=0.3\,(P)$ *456 mm > P*

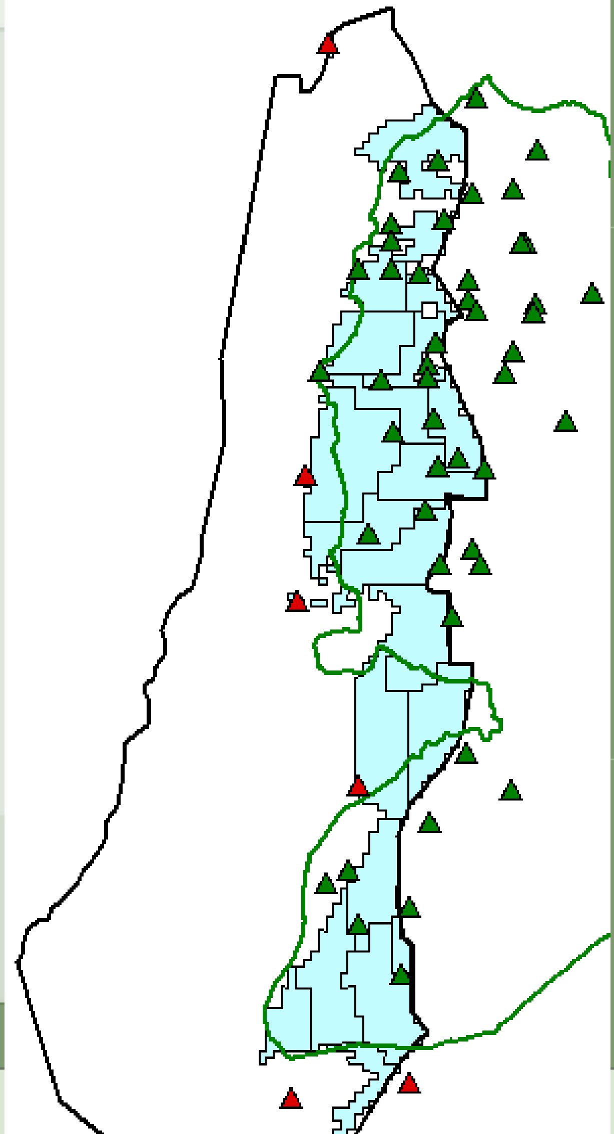
where:

R = Recharge from rainfall in mm/yr

P = Annual rainfall in mm/yr.

Estimation of Recharge

- Determine the boundary of the aquifer to estimate its recharge.
- Define the outcropping recharge areas
- Collect the readings of rainfall stations were located in and a round the recharge areas



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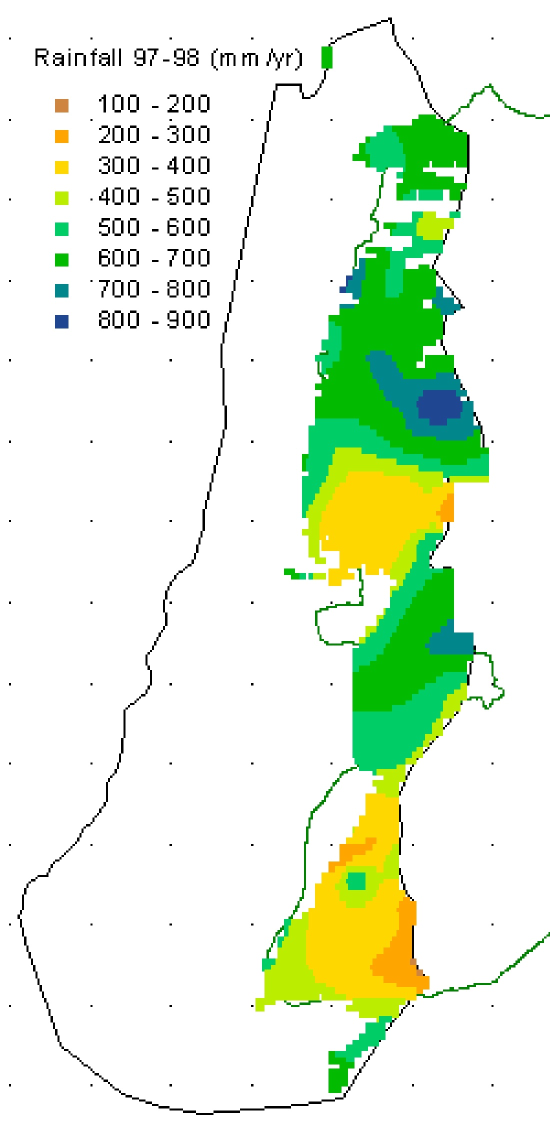
Estimation of Recharge- *Continued*

- Prepare rainfall map (rainfall distribution (mm/yr)) for the recharge areas.



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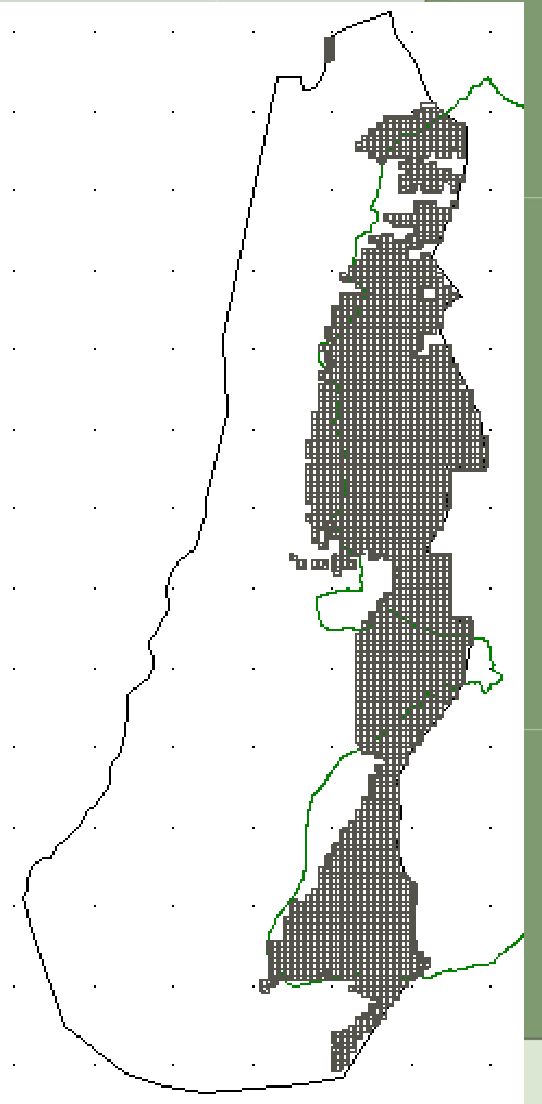
Estimation of Recharge- *Continued*

- Discretized the recharge areas into small cells.

- Assign rainfall estimation for each cell.



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Estimation of Recharge- *Continued*

- Implement the rainfall equation to achieve the recharge distribution (mm/yr)
- The volume of recharge over the aquifer is:

$$R_v = \sum_{i=1}^{n} (R_d)_i \times A_i$$

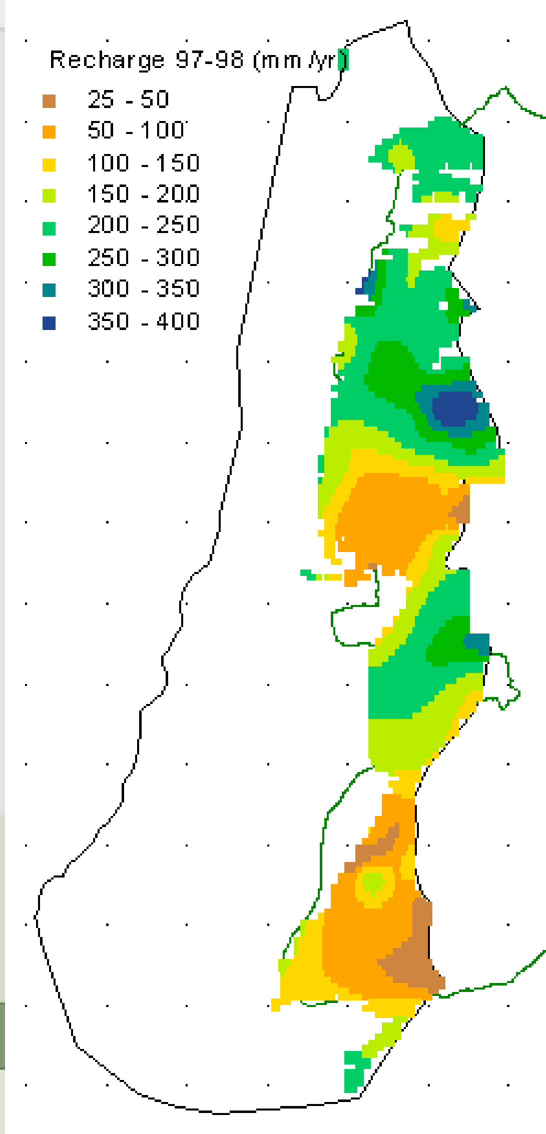
Where : R_v: Recharge volume in $\left(m^3/Yr\right)$

R_d: Recharge depth in $\left(m/Yr\right)$

A : Area in $\left(m^2\right)$

i : cell i

n : number of cells



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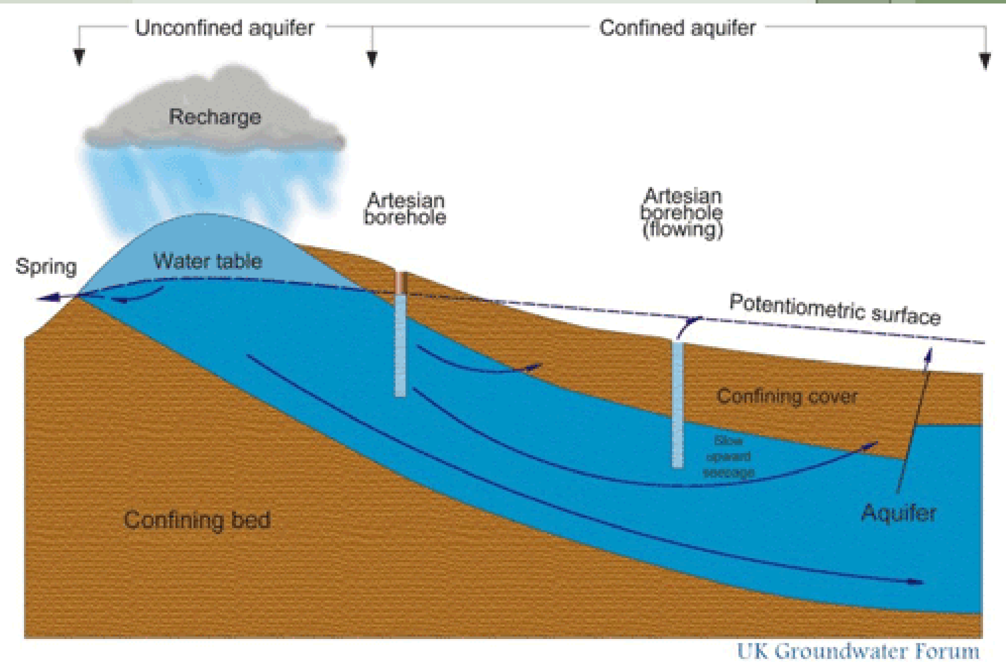
Definitions:

- **Confined Aquifer:** A layer of water beneath the surface of the earth that is trapped below an impermeable upper layer. The confining layer is usually composed of clay.
- **Unconfined Aquifer:** (water table aquifer) is the saturated formation in which the upper surface fluctuates with

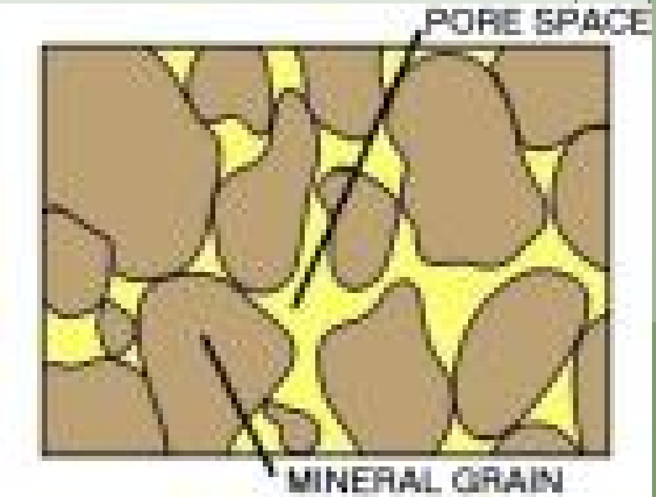
  addition or subtraction of water.



Definitions:

- **Porosity (*n*):** [dimensionless] is the fraction of void space in a volume of rock

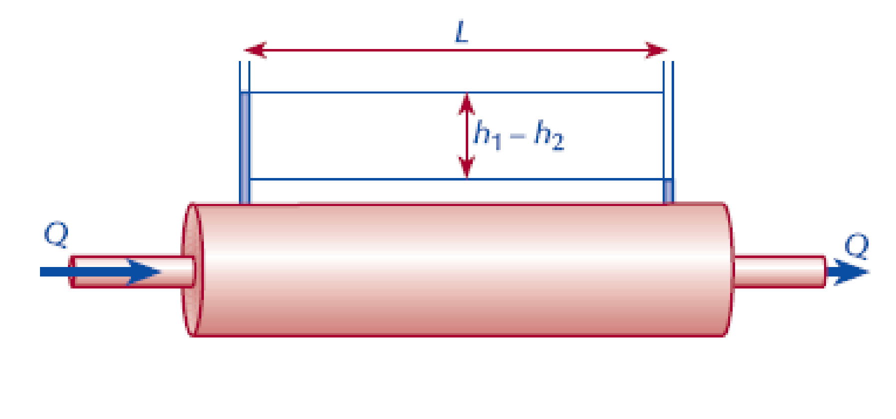
$$Porosity = \frac{\text{Total volume of void space}}{\text{Total volume}}$$



Definitions:

- **Darcy's law:** says that the discharge Q of water through a column of sand is proportional to the cross-sectional area A of the sand column, and to the difference in piezometric head between the ends of the column, h1– h2, and inversely proportional to the length of the column L.

$$Q = KA\frac{h_2 - h_1}{L}$$



- **K=Hydraulic conductivity (m/day)**: Describe the ease with which water moves through soil or a saturated geologic material.

Estimating water stored within Confined Aquifer

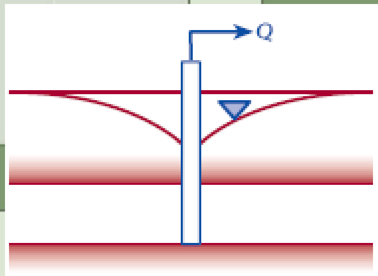
- When water is pumped from a well in a confined aquifer, the piezometric head in the aquifer is lowered close to the well. Since flow is towards the well, Darcy's law demands that the head in the rock must increase with distance from the well and the piezometric surface then forms a **cone of depression** around the well.

- The extent of the cone of depression increases laterally with time as the pumping continues, but at any particular time there is a distance at which the **drawdown** in head, i.e. the change in head from its original value, is effectively zero.

- At any time, there is a distance from the well beyond which there is no flow in the direction of the well.

- Since the aquifer is confined, there is limited vertical recharge to it from above or below. At this time, there is still water being abstracted from the well.

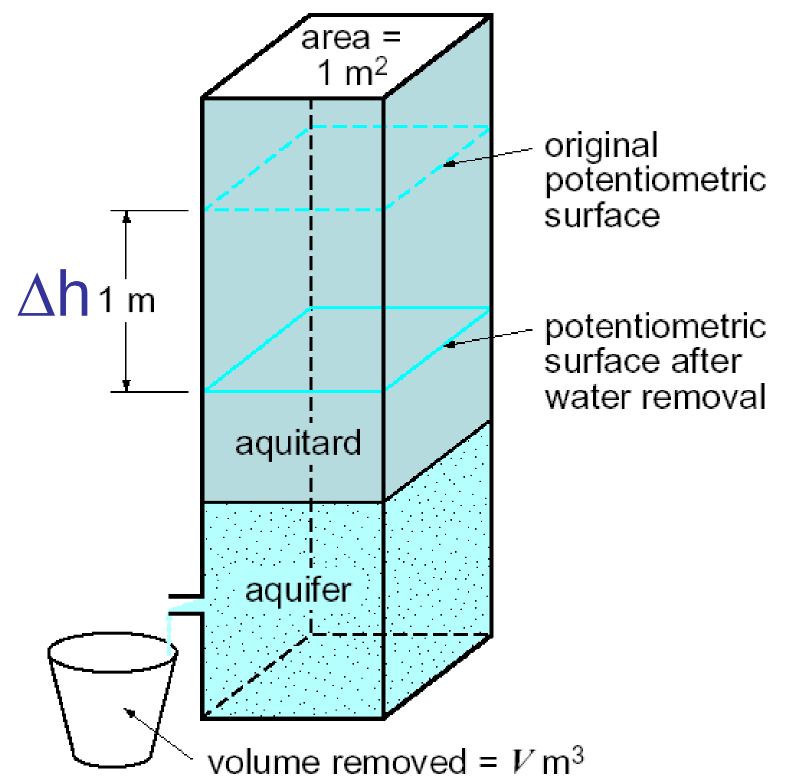
- When water is pumped from the rock, the water pressure is lowered (i.e. water is released from elastic storage, the aquifer remains saturated.



Estimating water stored within Confined Aquifer

- **Specific storativity:**[1/m] of the rock is defined as *the volume of water released from (added to) storage per unit volume of rock per unit decrease (increase) in head*.

- The specific storativity is given by: $$S_s = \rho g\left(\alpha + n\beta\right)$$



where:

S_s : specific storativity $[{}^{1}/_{m}]$

α : coefficient of compressibility of the rock $[{}^{m^2}/_{N}]$

β : coefficient of compressibility of Water $[{}^{m^2}/_{N}]$

ρ : Density of water $[{}^{Kg}/_{m^3}]$

n : Porosity

Coefficient of compressibility of water:

$4.678\times10^{-10}\ [{}^{m^2}/_{N}]$ at 10°C.

Rock type	α (m^2N^{-1})
Clay	$10^{-8} - 10^{-6}$
Sand	$10^{-9} - 10^{-7}$
Gravel	$10^{-10} - 10^{-8}$
Jointed rock	$10^{-10} - 10^{-8}$
Sound rock	$10^{-11} - 10^{-9}$

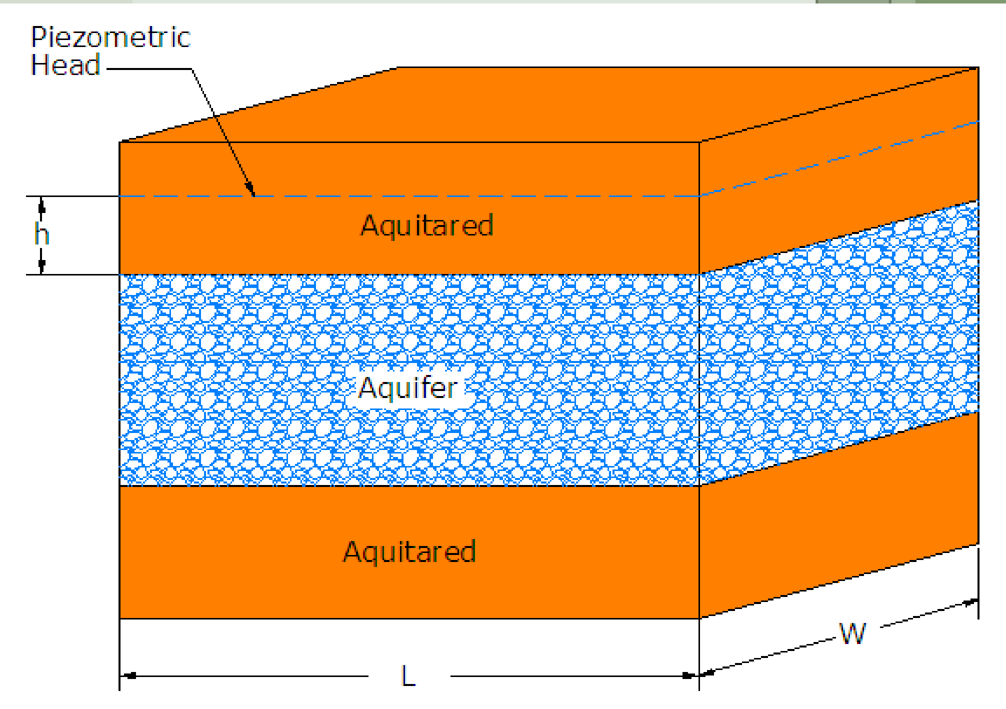
Estimating water stored within Confined Aquifer

- **Based on the definition of Specific storativity, the volume of water stored (Q) equal to:**

$$Q = S_s \times Volume \times Head$$

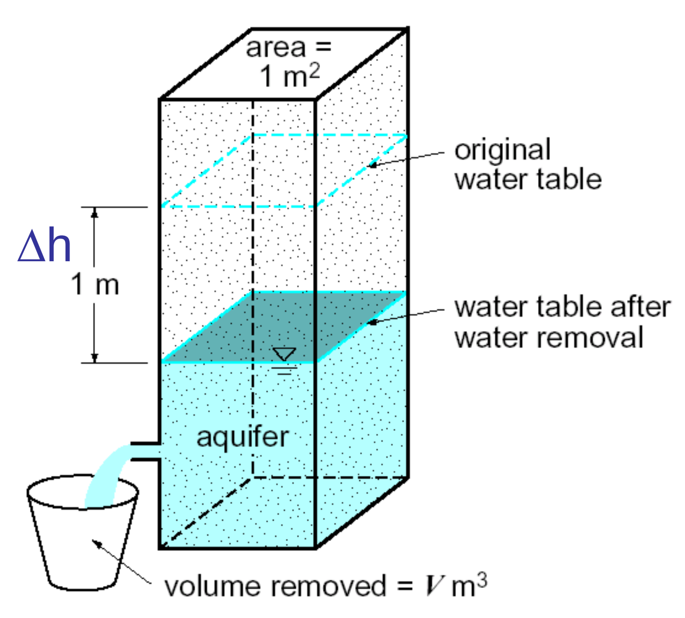
$$Q = S_s \times (W \times L \times h) \times h$$

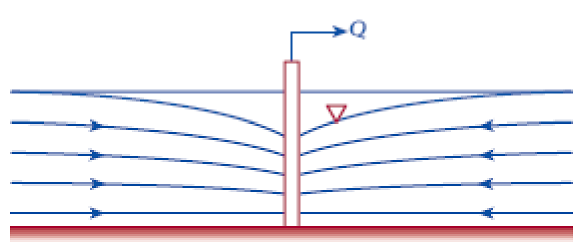
$$Q = S_s \times W \times L \times h^2$$



Estimating water stored in UnConfined Aquifer

- Lowering the water table in unconfined aquifer leads to the dewatering of the upper part of the aquifer by vertical drainage.
- The drainage process is characterized by two parameters: the **specific yield** and the **specific retention**:
  - The **specific yield** SY [dimensionless] is defined as the volume of water released by drainage from a (horizontal) unit area of a phreatic aquifer due to a unit fall in the water table. When the water table falls.





Estimating water stored in UnConfined Aquifer

- The **specific retention** *SR* [dimensionless] which is defined as the difference between total porosity and the specific yield. (The volume of water remaining in the zone above the water table that was previously fully saturated)

- Specific yield is a function of the rock in the upper portion of the aquifer which represents an integrated effect over the entire aquifer thickness.

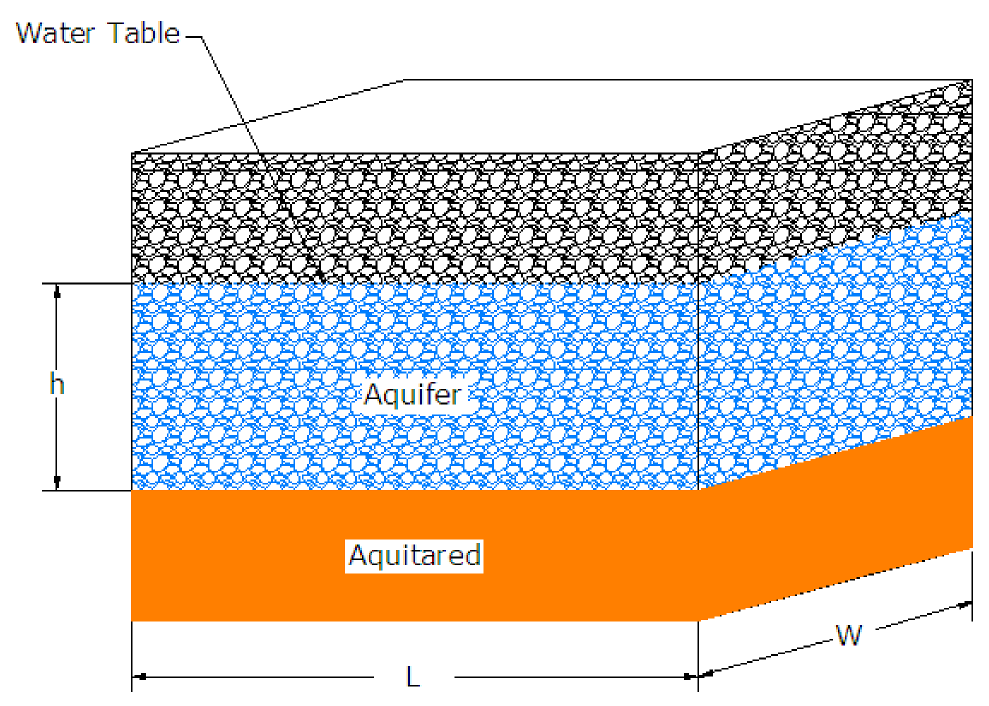
Estimating water stored within Unconfined Aquifer

- **Based on the definition of Specific Yield, the volume of water stored (Q) equal to:**

$$Q = S_y \times Area \times Head$$

$$Q = S_s \times (W \times L) \times h$$

$$Q = S_s \times W \times L \times h$$



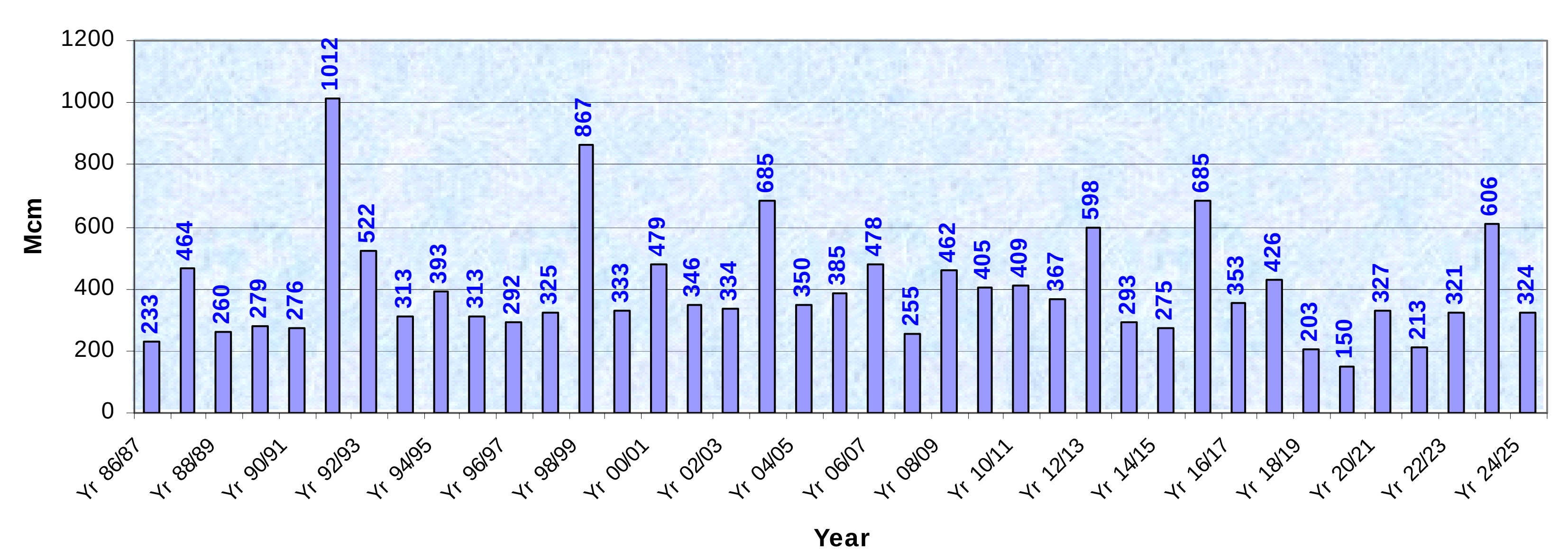
Aquifer Sustainability

- **Perennial Safe (Sustainable) Yield:** The amount of abstractions that can be safely abstracted without long or short term adverse conditions occurring.
- **Maximum Perennial Yield**: The maximum yield available annually subject to all available recharge resources being utilized at optimum level by allowing specific drop in storage on the calculation that this will be recovered during specific year circle of recharge.
- **Stressed Sustainable Yield:** The amount of water that can be extracted > Perennial safe yield over a long planning period (e.g. 25 years) on the condition that the over pumped water can be recovered over a future period in which the basin can be managed wisely.

Aquifer Sustainability- WAB as A Case Study

- **Perennial Safe (Sustainable) Yield:**

(Sustainable Yield)$_i$ =(Recharge)$_i$ **where i=year**

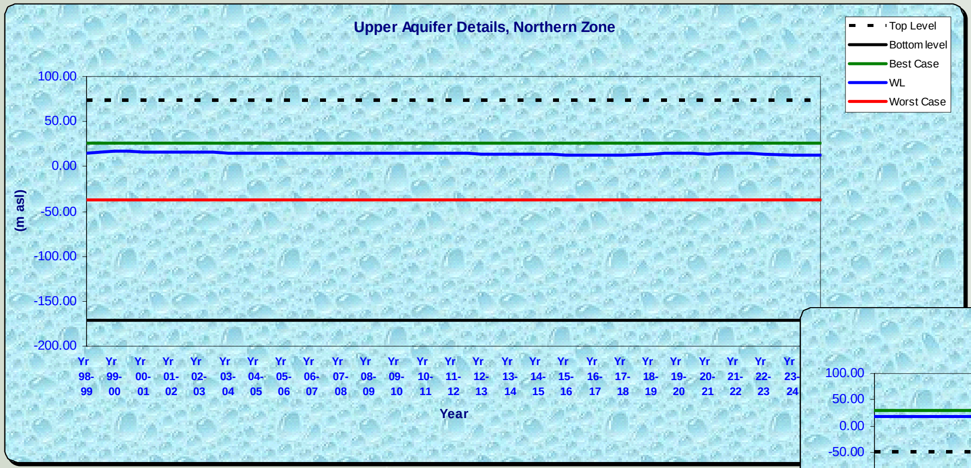


- **Example: The sustainable of year 2005/2006 is 386 Mcm**

  The sustainable of year 2006/2007 is 478 Mcm

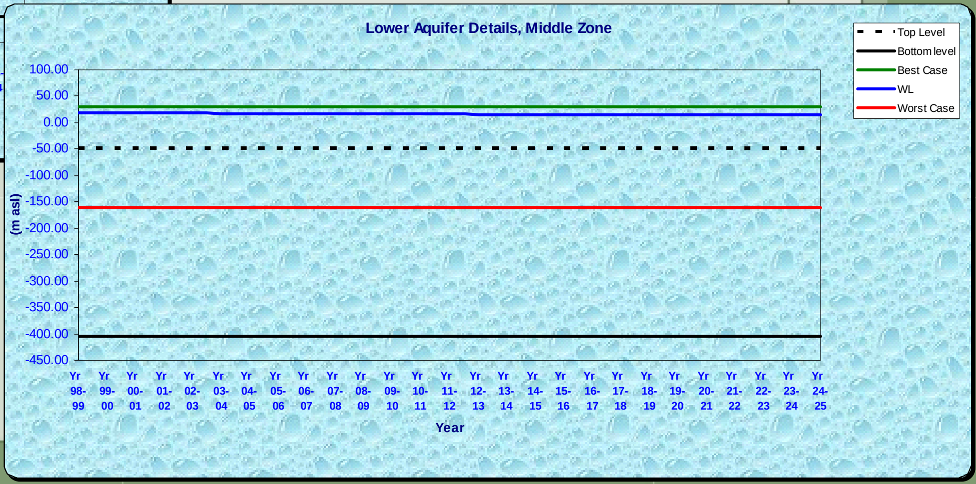
Aquifer Sustainability- WAB as A Case Study

- **Perennial Safe (Sustainable) Yield: Water levels in WAB remains constant.**



Unconfined Case

Confined Case



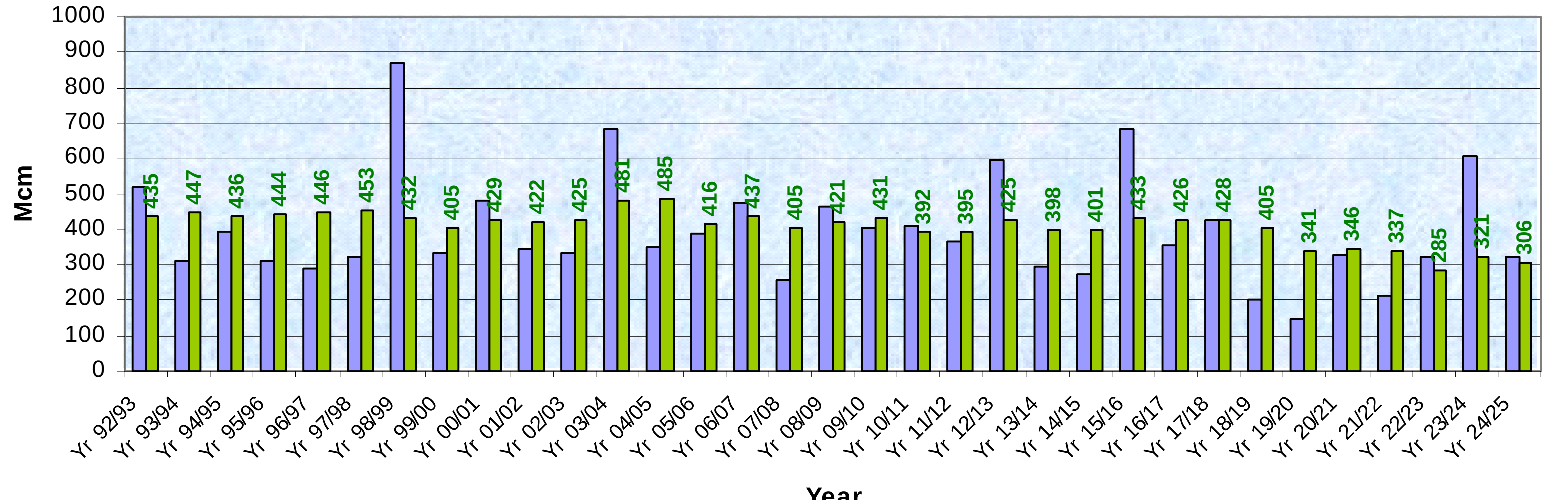
Aquifer Sustainability- WAB as A Case Study

- **Maximum Perennial Yield**:

$(\text{Sustainable Yield})_i = (\text{Moving Average of Recharge})_i^T$

where i=year

T=Return Period (7-10 years)

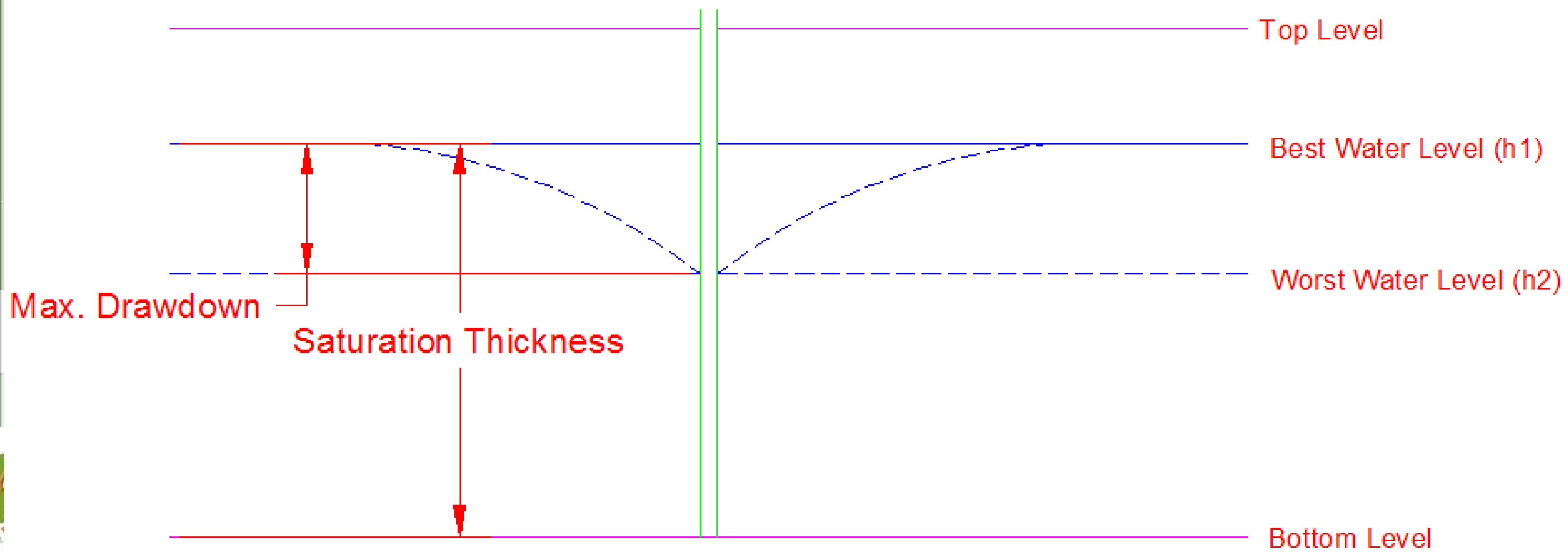


- **Example: The sustainable of year 2005/2006 is 416 Mcm**

  The sustainable of year 2006/2007 is 437 Mcm

Aquifer Sustainability- WAB as A Case Study

- **Stressed Sustainable Yield** : Calculation based on:
  - Rainfall Scenario
  - 30 % of the saturation thickness as a maximum drawdown in the unconfined aquifer.
  - Iterative procedure, i.e. increase the abstraction in steps until the aquifer reaches the worst limit.
  - Groundwater flow model



Aquifer Sustainability

- **Stressed Sustainable Yield** : It has been shown that **760 Mcm/yr** can be extracted from the basin till 2025 when the basin starts to reflect averse conditions.