TD 603
Water Resources

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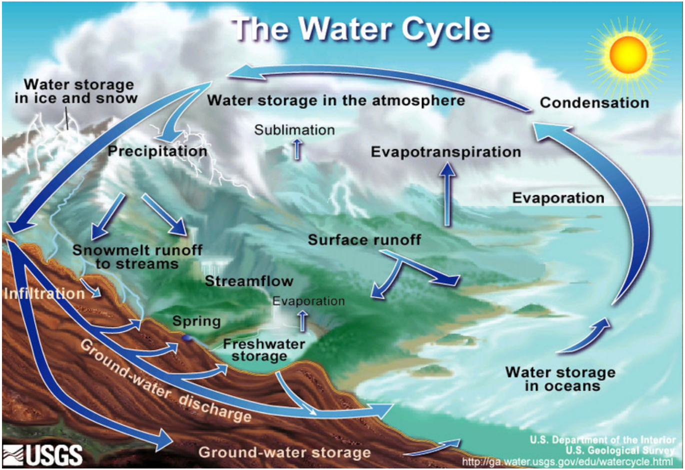
Lecture 2: Water cycle, stocks and flows

The basic movement of water



source: USGS.

The basic process

Going Up

- Oceans, Lakes and streams to Atmosphere-Evaporation
- Direct loss of moisture from the soil-Evapo-Transpiration
- Loss from vegetation-Transpiration
  - depends on solar intensity, humidity and air flow.
- Formation of liquid-water in the Atmosphere-Cloud-Formation

Coming Down

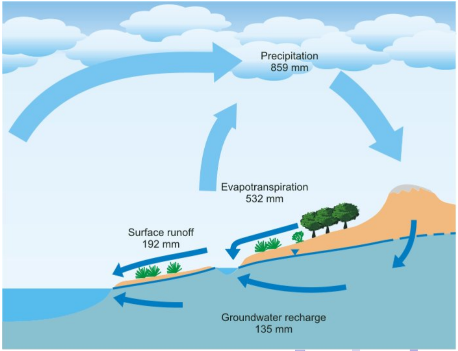
- Rain/Snow-Condensation and Precipitation
- Drainage of rainwater into streams and rivers-Runoff
- Seepage of rainwater into the ground -Infiltration/Recharge

The basic stocks and flows

- Air Moisture: Clouds end in the Troposphere (about 35,000 ft).
- Surface: Rivers, streams and glaciers. Man-made reservoirs.
  - Subsurface: Soil Moisture.
- Groundwater: under the *water table*.

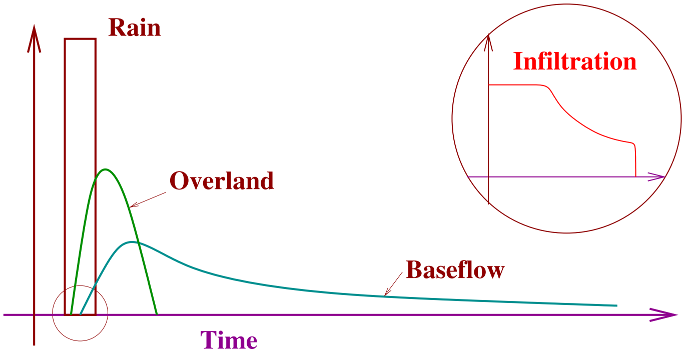
- Precipitation: world average of about 800mm annual.
- Evaporation, Transpiration: from surface to air.
- Recharge: surface to ground
- Seepage, Baseflow: from ground to surface

Germany's water balance (courtesy: BGR)



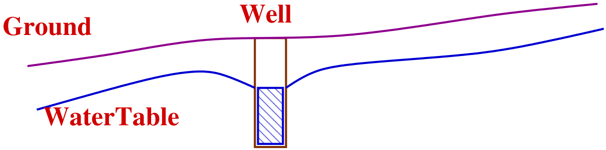
What happens when it rains

Suppose we observe a stream...

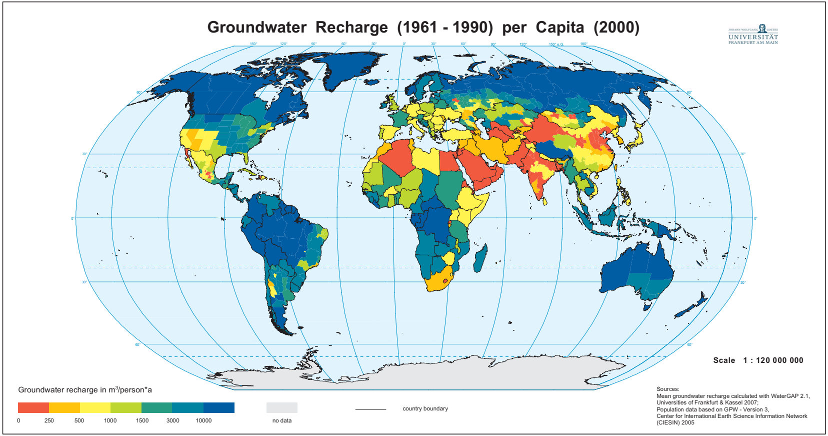


Groundwater

- Moisture in the soil is ground-water.
- This moisture is acted upon by gravity and *settles*.
- Beyong a certain depth, all soil pores are full of water. This is called the saturated zone.
- This level is called the water table.
- Groundwater also flows just as ordinary water, albeit at different rates.
- Groundwater flows eventually go to streams, rivers and oceans.

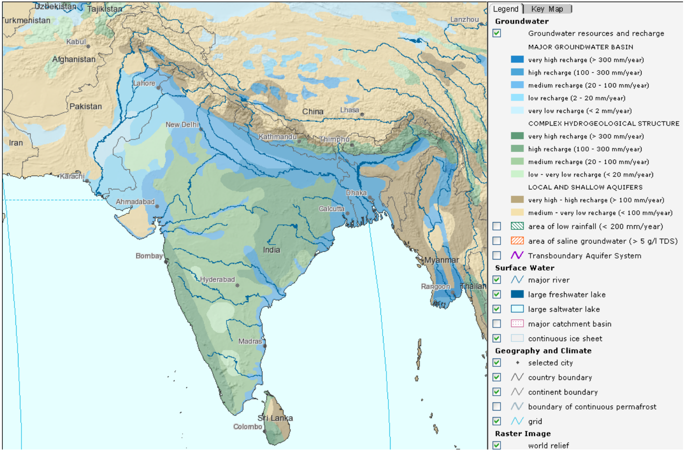


Recharge



source: `whymap.org`, BGR-Unesco.

Recharge/Geology-India



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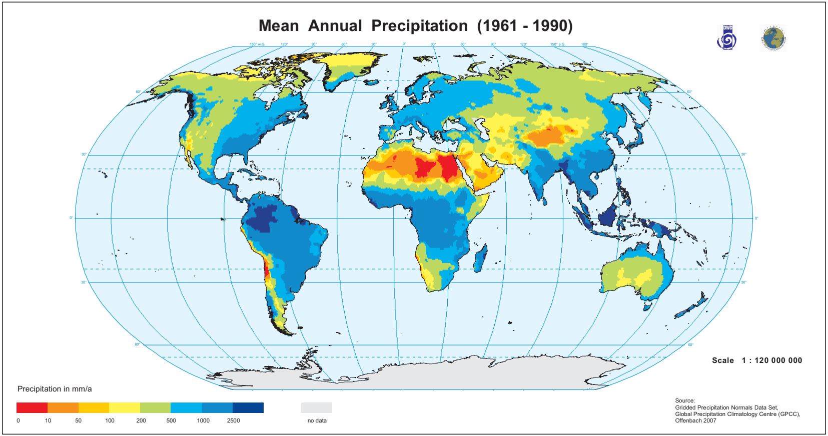
Rainfall



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Precipitation

- Precipitation is the most visible component of the Hydrological cycle.
- Rains in India are the most important cultural and economic event of the year. 15 wets days supply 50% of annual rains!
- India receives most of its rains (of about 900 mm/year average) in the form of three monsoons:
  - South-west (for W. and C. India, May 1st-Oct. 1st)
  - South-east (for E. and N. India, June 1st-Oct. 1st)
  - South (south-east coast of India, Oct. 1 Dec. 1st)
- In any watershed, this is the most important data which needs to be collected.
- Typically observed by rain-guages at suitable points in the watershed.

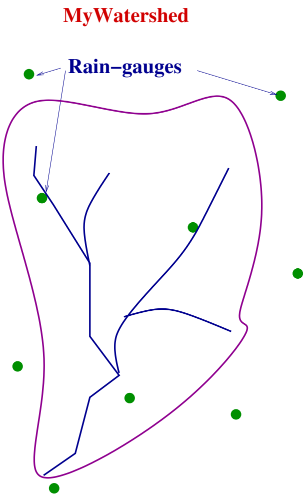
Daily Rainfall	mm/day
Season Total	mm
Rainfall Intensity	mm/day
Rainy Days	No.

Rain-gauges (wikipedia)

Standard : Funnel-top, and a measuring cylinder.

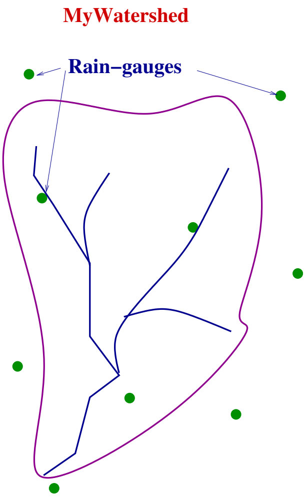
Tipping bucket : Funnel, with water falling on a see-saw. Pulse generated every 0.2mm. Now standard in India.

MyWatershed-estimating total rainfall



- Shown here is my watershed with the locations of rain-gauges.
- Estimate the total rainfall over my watershed (**in cubic-meters** .

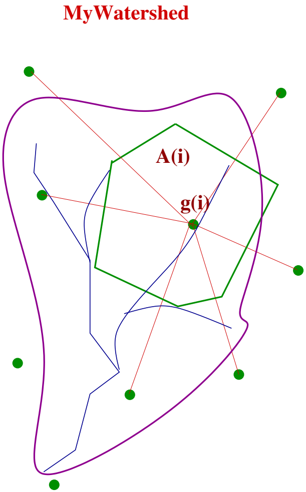
MyWatershed-estimating total rainfall



- Shown here is my watershed with the locations of rain-gauges.
- Estimate the total rainfall over my watershed (**in cubic-meters** .

- Question: What should I assume as the rainfall at point p?
- Heuristic: Assign to each point p, the rainfall at the closest gauge.

MyWatershed-the construction



- Draw your watershed on a graph-paper.
- Let $g(i)$ be a gauge and let the reading at $g(i)$ be $r(i)$.
- We want to find all points p for which the closest point is $g(i)$.

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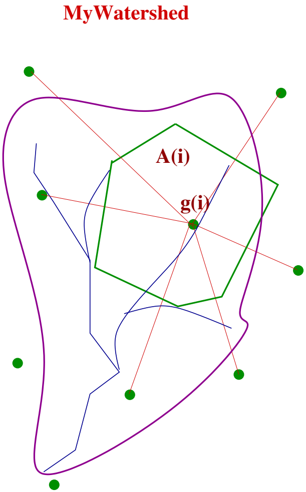

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- Compute the polygon $P(i)$ by the method of bisectors.
- Let $A(i)$ be the fraction of the area lying inside my waterhsed.

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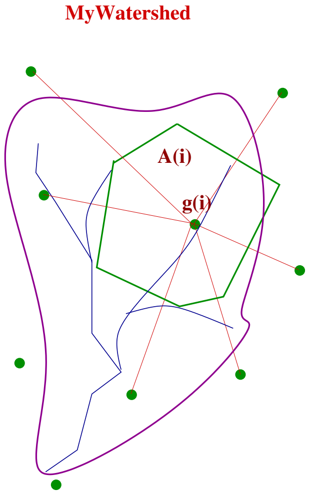

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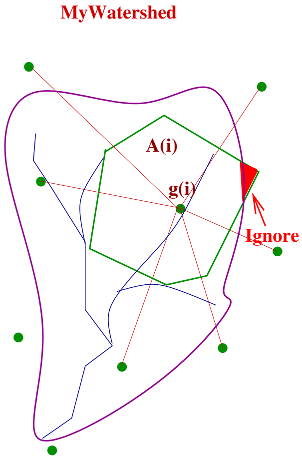
- Compute the polygon $P(i)$ by the method of bisectors.
- Let $A(i)$ be the fraction of the area lying inside my waterhsed.
- The area $A(i)$ *belongs* to $g(i)$.

MyWatershed-the construction



- Measure $A(i)$ using the graph paper. Ignore area outside the watershed.
- The sum $\sum_i A(i) = A$ the total area of the watershed.
- Average rainfall

$$r = \frac{\sum A(i) r(i)}{\sum A(i)}$$

Finally...

Total Volumne= $A.r$

Measuring Stream-flows

V-notch weir.

- Suitable for small streams.
- A V-notch is inserted in the stream so that there is sufficient head behind the V-notch.
- Measurements are taken on the height of the stream-level on the V-notch.
- Flow: cu.m./s is given by an empirical relationship. For a 90-degree V-notch:

$$Q = 2.5H^{5/2}$$

where Q in cu.ft/s, and H is ht. of head above crest.

Example: If $H = 0.25ft$ then $Q = 0.078$ cu.ft/s.

Measuring Stream-flows

For larger streams

- Use a stick-mounted flow-meter.
- Select a stream cross-section.
- Follow a schedule of measurements at various depths and points on the cross-section.
- Use formula to compute flow.

Flow in Open-Channel

Mannings Eqn.

$$V = (1.49R^{2/3}S^{1/2})/n$$

where

- V is average velocity in ft/s
- R is surface-area/wet-perimeter in ft.
- S is the slope of the water

and n is as below:

Mountain streams	0.04
winding stream	0.035
natural streams	0.025
unlined canals	0.02
smooth concrete	0.012

Example (Fetter) : An aquaduct is with a slope of 5ft/mile and with a rectangular cross-section of 50ft and water depth of 8ft. What is the average velocity of the water in the aquaduct?

- $R = (50 \times 8)/66 = 6.06$.
- $S = 5/(1760 \times 3) = 0.000947$.
- $n = 0.02$.
- $V = 3.048 ft/s$

Mumbai needs 3000 mega-liters/day which come from lakes about 100 km away and about 500 ft above Mumbai in elevation. Estimate the the number of pipes needed to transfer this water, if the diameter of these pipes is 2m..

Run-off

- This is the part of precipitation which flows out of the watershed through rivers and streams.
- Overall Indian average is about 83% , in Konkan its above 93 % .
- The difference
  - is stored in reservoirs and tanks.
  - recharges ground-water.
  - evaporates or is consumed.
- Run-off is a function of rain-intensity, slope, land-conditions, forest-cover, existing soil-moisture and many other things.

Key Objective

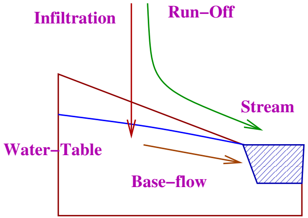
One key aim is to compute the water balance for a watershed, i.e., to estimate each quantity in the hydrological cycle. Important sub-goals:

- Estimate total precipitation.
- Estimate total Run-off.

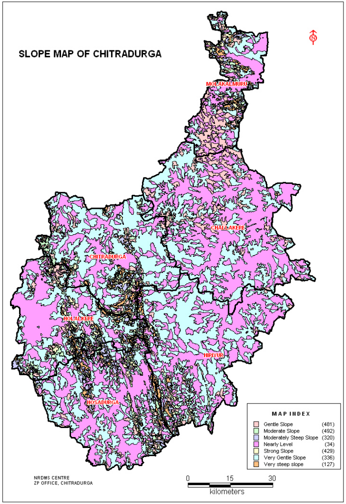
Precipitation to Run-Off

Many stages from Precipitation to Run-Off

- Interception: The contact of the raindrop with vegetation.
- Stem-Flow: Flow of water from plant to soil.
- Infiltration: Coversion of liquid-water to soil moisture.
  - Saturation: All soil pores get filled with water.
- Run-Off: Two components:
  - Overland-flow: Post saturation! Excess flow reaches streams.
  - Base-flow: Groundwater releases moisture into streams.



Slope



- Both run-off and infiltration depend greatly on the slope.
- Slope-maps are an important input for developing run-off and infiltration models for the water-shed.
- Infiltration models are easier and depend on point conditions.
- Run-off models are more difficult and also must model drainage and thus, floods.

Standard models for watersheds must be developed and calibrated.

Porosity and Soil Moisture

Key Quantites
Soil Moisture: Fraction of soil-volume filled with water.
Porosity of a soil: Maximum possible value of soil moisture.

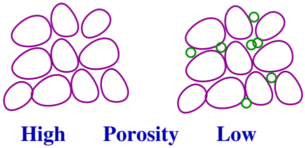
- Take a fixed volume V sample of soil.
  - Use a standard gouge, scoop, screw or core.
- Let W_s be its weight.
- Let W_d be the weight of the sample after oven-drying.
- Let W_w be the weight of the sample after immersing it in water till it gets saturated.
- Let ρ be the density of water.

$$Porosity\ p = \frac{W_w - W_d}{\rho V}$$

$$Moisture\ n = \frac{W_s - W_d}{\rho V}$$

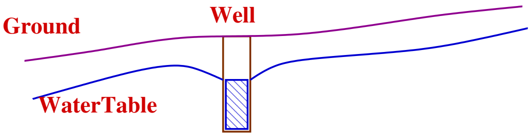
Porosity and Moisture

- Porosity depends on the regularity of particle size.
  - The more sorted the particles, the higher the porosity.
- Soil moisture n increases with depth and reaches its theoretical maximum of proposity p.



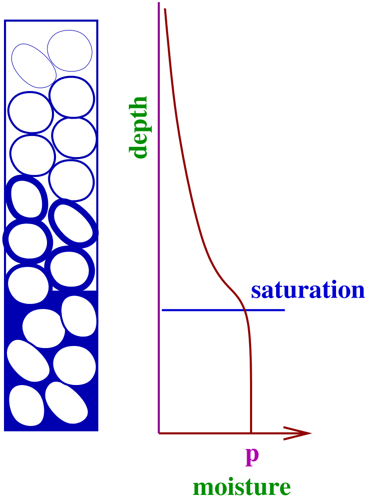
Sand	0.1mm-1mm
Silt	0.005mm-0.1mm
Clay	$<$ 0.005mm

- This depth is called the *depth of the water-table*.
- At this depth, water appears spontaneously in a dug-well.



Saturation

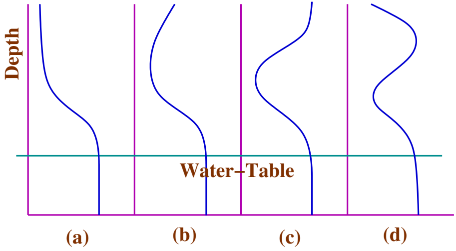
- As depth increases, soil moisture increases upto a point.
- At this point, soil moisture equals porosity.
- The region below is called the saturated region.
- The region above is the unsaturated region.
- Soil moisture remains (relatively) constant beyond the saturation point.



Moisture when it rains:

When the rain falls

(a) Before Rains: surface moisture less than porosity.
(b) Start of Rain: surface mosture starts increasing: Infiltration phase.
(c) Saturation: Surface saturates: Run-Off phase.
(d) Rain Stops: Moisture descends and joins water-table by gravity.

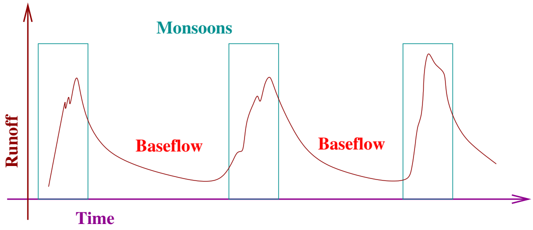


Stream-flow and Base-flow

- The stream flow is largely baseflow for most of the year.
- Only in the monsoon is there a run-off component.
- A simple exponential flow model:

$$flow = Ae^{-\alpha t} + B$$

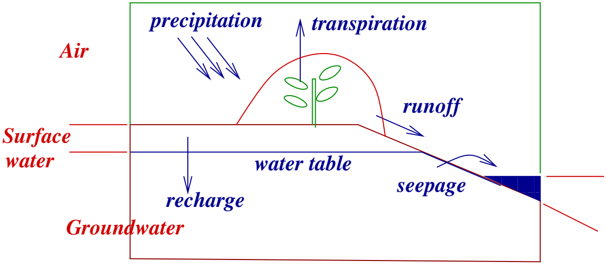
  where A, B and α are parameters of the watershed.
- A small α signifies good health.
- If flow is negative, assume it to signify that the stream is dry.



Measuring other flows

- Infiltration: Standard models. Also Infiltrometer which measures infiltration and conductivity, a hydrogeological term.
  - slope, soil properties, vegetation.
- Transpiration: Standard data from experimental plots. Also FAO and agriculture department.
  - Typically depends on wind velocity, air temperature, humidity and also plant properties.
  - Typically about 100 to 200 times of wieght gained by plant. For crops, about 3mm per day.
- Evaporation. From soil as well as water bodies. 1mm-5mm per day. Depends on air temperature, humidity and velocity.
- Seepage, Groundwater flows: Depends on conductivity and *hydraulic heads*. Darcy's law.

The Water-balance



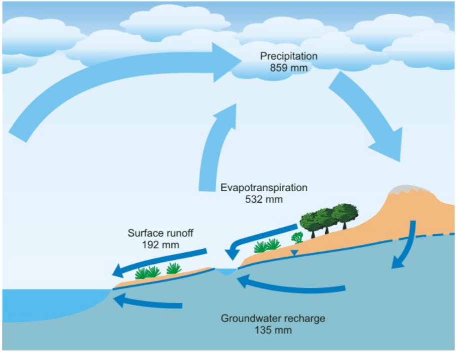
For any region and for any sector, say *Surface Water* and for any action, say *groundwater extraction for irrigation*:

Precipitation=Recharge+Evapo-Transpiration+ Runoff+Δ Soil Moisture

Any water application :

Access $\Rightarrow$ Treatment $\Rightarrow$ Use $\Rightarrow$ Treatment $\Rightarrow$ Disposal

MyWatershed-Water Balance Exercise



Suppose that we have the following data:

Rainfall	859 mm
Runoff	192 mm
Evapo-transpiration	532mm
Groundwater flows	135mm

- What will happen if we build a check-dam and a reservoir?
- What will happen if we increase groundwater extraction and use it for agriculture?

MyWatershed-Water Balance Exercise

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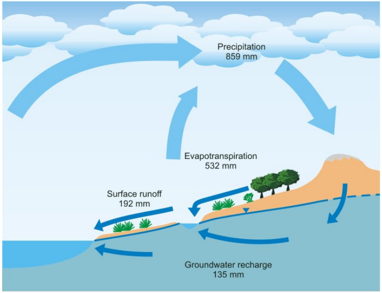


Flows:

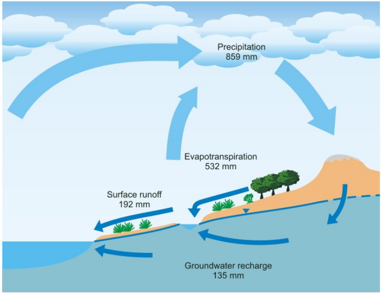
Rainfall	859 mm	
Runoff	192 mm	$\downarrow$
Evapo-transpiration	532mm	
Groundwater flows	135mm	$\uparrow$

Stocks:

Surface Water	$\uparrow$
Groundwater	$\uparrow$

MyWatershed-Water Balance Exercise

- What will happen if we increase groundwater extraction and use it for agirculture?



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