Water and Development

Part 2c: Sub-surface and Groundwater

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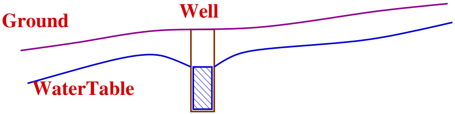
Objectives

Sub-surface and Groundwater: Stocks and Flows.

- How does GW and SSW function as stocks?
- Sub-surface water (a.k.a. Soil Moisture) in the top few meters. Groundwater: deeper, *saturated.*
- Complex interaction between SSW and GW.
- What are the basic mechanisms (laws and models) by which they work?
- What are the key parameters to describe these and how are these measured?

Groundwater

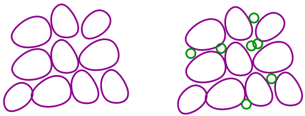
- Deep. Accessed through wells and bore-wells.
- Water-Table: important concept.
- How much water is available through-out the year? Specific Yield
- Does it depend on the nature of soil/rock underneath? Aquifer
- How do different wells interact? Conductivity



Porosity: Soil as a container

Porosity: The fraction of empty space with a soil. em Depends on configuration.

- Porosity depends on the regularity of particle size.
- The more sorted the particles, the higher the porosity.
- May change across different areas and different depths.

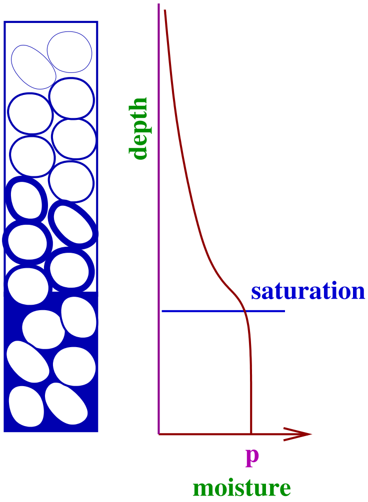


Sand	0.1mm-1mm
Silt	0.005mm-0.1mm
Clay	< 0.005mm

Moisture

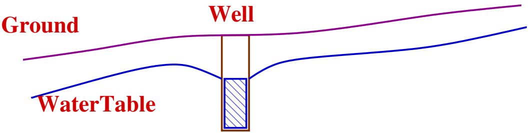
Moisture: The volume fraction of wet soil which is water.

- Water exists in within the voids and is either (i) loosely held, or (ii) tightly held by soil particles.
- Soil moisture n increases with depth and reaches its theoretical maximum of proposity p. This is called saturation.
- At this point, soil moisture equals porosity.



Saturation

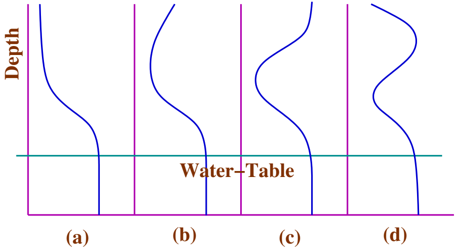
- The region below is called the saturated region.
- The region above is the unsaturated region.
- This depth is called the *depth of the water-table*.
- At this depth, water appears spontaneously in a dug-well.
- Saturated water can be extracted easily. Unsaturated region: important for plants and microbes.
- Groundwater also flows just as ordinary water, albeit at different rates.
- Groundwater flows eventually go to streams, rivers and oceans.



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.



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.

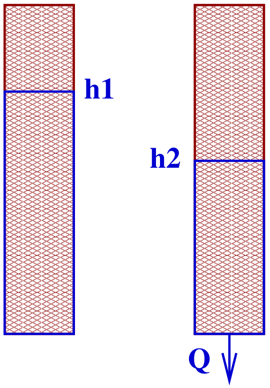
$$Porosity\ p = \frac{W_w - W_d}{\rho V}$$

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

Porosity and Specific Yield

- Porosity: The volume fraction of void to solid in dried sample.
- Saturation: When these voids are fully filled with water.

Specific Yield S_y: the ration of the colume of water that drains from a rock owing to gravity, to the total rock volumne.



- h_1, h_2 resp., are the heights of the saturated layer.
- Q is the volume of the water discharged to reach h_2 from h_1.
- $S_y = \frac{Q}{(h_1 - h_2)A}$

Caution: rock above h_i is wet, but unsaturated.

Lab. setup: Takes a lot of time for water to drip.

Specific Yield

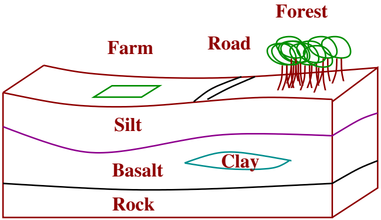
- Importance: This is actually the fraction which is accessible.
- Note 1: In accessible voids are NOT counted in porosity.
- Note 2: To access full n-fraction, oven heating was required.
- Clearly $S_y \leq n$, the porosity and

$$S_r = n - S_y$$

  S_r is called the Specific Retentivity.
- S_r is largely due to the adhesion of water molecules to the rock layer.
- Specific Yield of a well : to be done later.

Some Specific Yields			
Clay	2	Sandy Clay	7
Silt	18	Fine Sand	21
Medium Sand	26	Fine Gravel	25

How much GW in a region?



- regional features impact water balance
- surface features affect infiltration.
- underground features affect the accumulation and movement

Soil parameters:

- Porosity, specific yield n, S_y: the maximum available volume fraction
- Conductivity K: The ability of the soil to allow the movement of water.

Aquifer

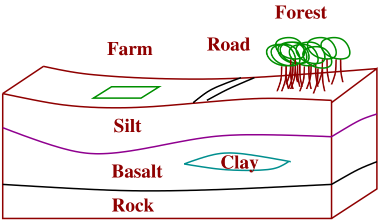
An aquifer is an underground soil-strata which allows storage and movement of water.

- $K > 0.1 cm/s$ and $S_y > 0.1$
- Roughly coarse silts and sands.

Larger Picture

In general, we would like to

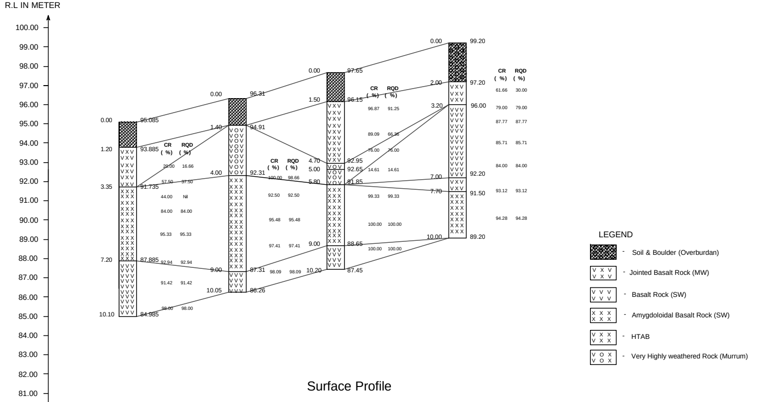
- analyse groundwater and surface water
- prescribe corrective measures
- understand sustainable use



A real-life scenario

- Various surface features such as farmslands, forests, built-up areas, which affect infiltration.
- Similar soils appearing as layers, and their geological properties.
- climactic data such as rainfall, evaporation, etc.
- Water requirements and usage, such as for irrigation, domestic use.

Bore-logs



BH. NO	BH -1	BH- 2	BH -3	BH- 4
Depth	10.10 m	10.05 m	10.20 m	10.00 m
RL. M.	95.085 m	96.31 m	97.65 m	99.20 m
Chainage	15.00 m	35.00 m	55.00m	75.00 m

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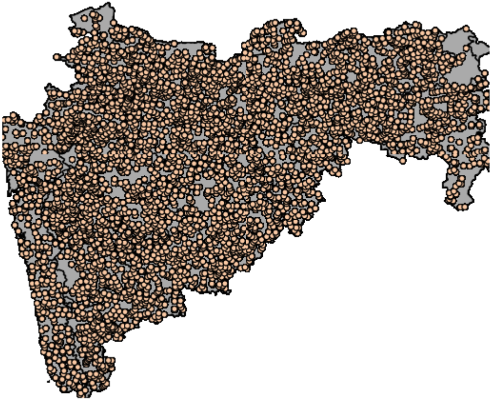
Project :- Soil Investigation at Gudvanwadi Check Dam.

Subject :- Surface Profile

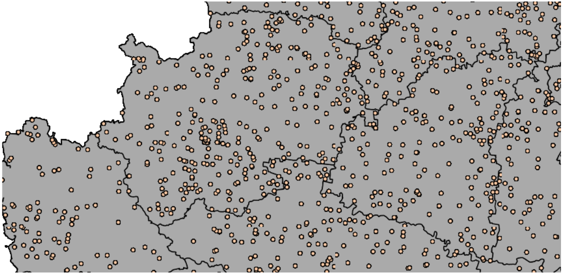
DATE : 11 / 05 / 2009 | DRN. BY : Ulhas | APPROVED BY:

Measuring Groundwater stocks



- Groundwater Survey and Development Agency (GSDA), Over 5000 observation wells.
- Dug-wells observed quarterly, Bore-wells monthly.

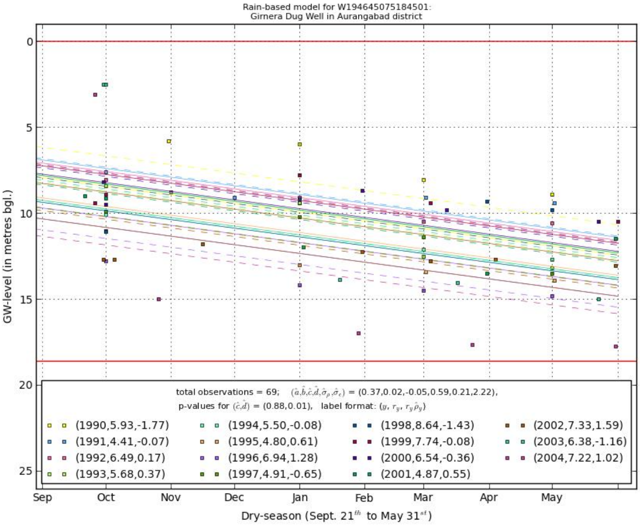
Close-up-Nasik



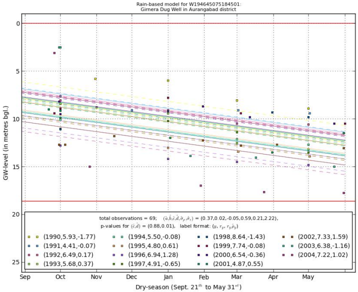
What is available

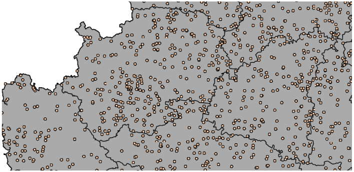
- Levels in various times of the year, nearby rainfall, depth of well.
- Specific yield? Depth of aquifer?

Water-table at a well (Rahul Gokhale)



Water-table at a well (Rahul Gokhale)

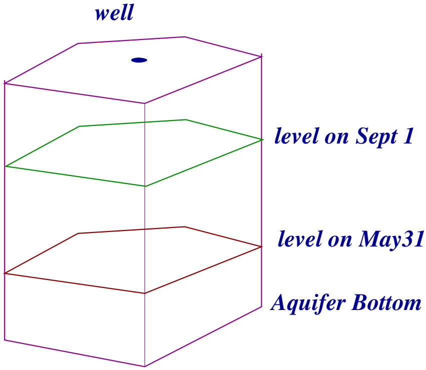




- The model $WT(p,t,r)$: The water-table at the point p on date t (i.e., days after September 1, in year with annual rainfall r.
- $WT(p,t,r) = a_p + b_p t + c_p r \pm \sigma_p$
- The numbers $(a_p, b_p, c_p, \sigma_p)$ computed for all observation wells.

A calculation

Depth of well	18m-bgl
September 15	8m-bgl
May 31st	14m-bgl



- $S_y = 2\%$. This implies that 1m of water-table=20mm of water.
- September stock $= (18 - 8) \cdot 0.02 = 200mm$. May stock $= (18 - 14) * 0.02 = 80mm$.
- Comsumption =120mm. Total GW stock $= Area \cdot 200mm$.

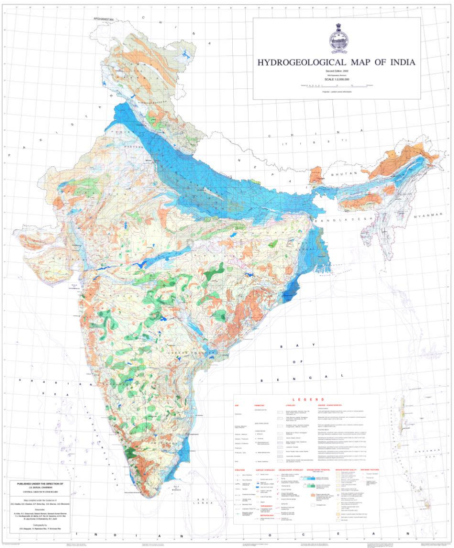
India's Aquifers

blue	high-porosity
green	porosity due to fractures
beige	little/no porosity

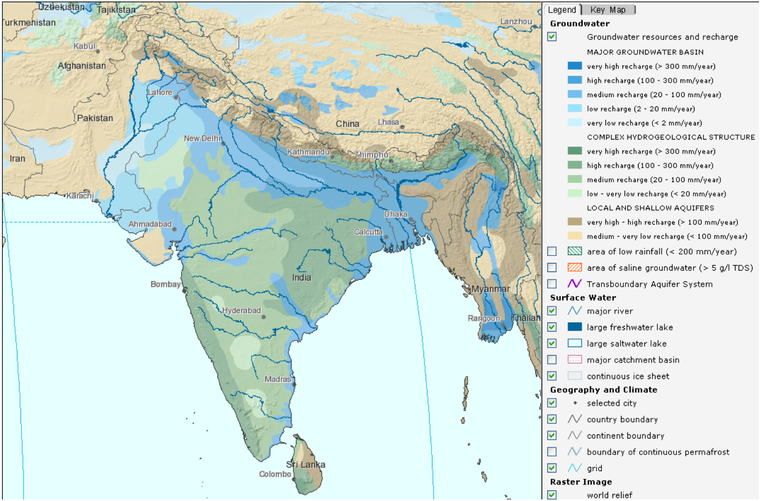
Indian aquifers:

- The Gangetic Plain: porous, shallow aquifer.
- The Deccan Trap: moderately deep and fractured.
- The Kutch: Silt/Clay shallow.

Mostly unconfined

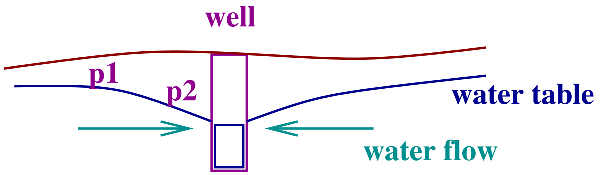


Groundwater and Recharge source: UNESCO and whymap.org (BGR)

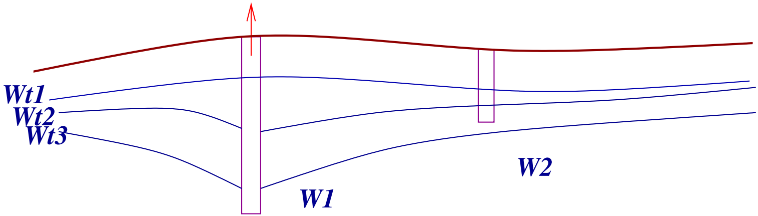


Movement of GW

- Let p_1 and p_2 be points on the water table.
- Thus $h(p_1) > h(p_2)$ and groundwater flows from p_1 to p_2.
- A well from which water is drawn causes a *dip* in the water table, called the *draw-down cone*.
- This cone causes the well to recharge. The strength of the recharge is given by the angle of attack.
- If the water-table falls below the well-bottom the well runs dry.

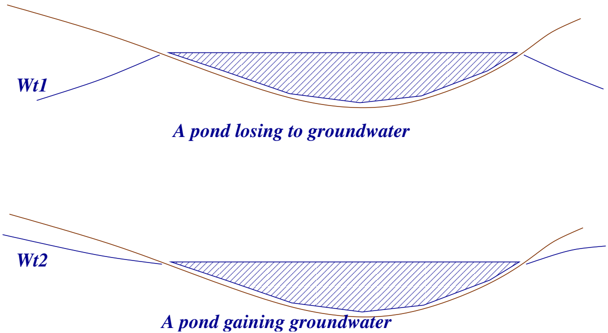


Two wells

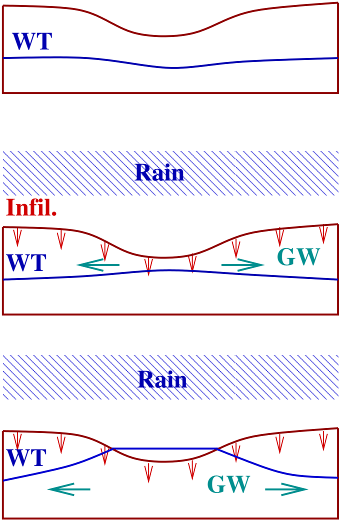


- Two wells W_1 and W_2. Well W_2 is a drinking water well and W_1 is an irrigation bore-well.
- As W_1 extracts $q_1 = 0, q_2, q_3$, where $q_1 < q_2 << q_3$, the water-table gets lower as wt_1 to wt_2 to wt_3.
- At extraction q_3, the drinking water well goes dry.

A pond in summer and after rains



Groundwater and Rains

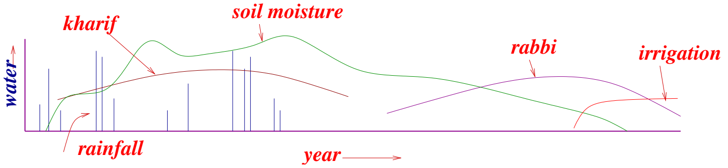


An example terrain.

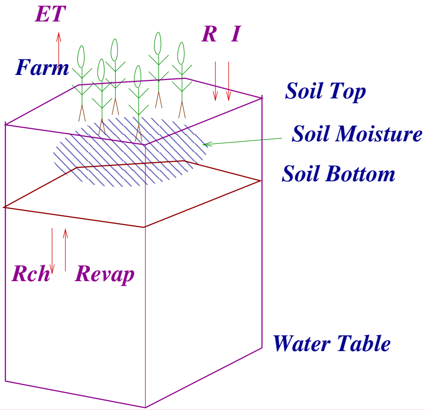
- Water Table following the topography.
- Rains cause infiltration. Since in the depression, the thickness is small, WT rises faster here. A significant Groundwater flows away from the depression.
- Still more rains causes the water-table to touch the surface and this creates a pond.
- Eventually scenario (i) returns.

Soil-Moisture

- Soil Moisture. The water-content in the top 1m of the surface.
- In farms with good soils, could be upto 20-30% by volume.
- Largely a stabilizing buffer for kharif agriculture.
- Black cotton soils: Enough water for most of the rabi crop.
- Complex interaction with Rainfall on one side, ET and GW on the other.



Soil-moisture Equations



Parameters.
L: Soil Thickness
θ: Soil Moisture Fraction.

Various Rates (mm/day)

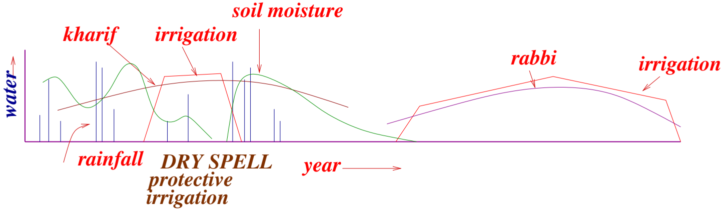
R	Rain Infiltration
I	Irrigation
ET	Evapo-transpiration
Revap	Reverse Evap.
Rch	Recharge

θ: The determinining variable.

$$L \cdot \frac{d\theta}{dt} = R + I + Revap - ET - Rch$$

Bad soil

- Thin soil ($<$ 50cm), drains quickly, large particle-size.
- Inability to hold on moisture and offer it to crops.
- Frequent irrigation required. Dry spells may cause crop loss.
- Where is irrigation water to come from? Wells, farm-ponds, lift-irrigation.



How to Analyse

Supply Side

- Soil type and soil thickness. *GSDA maps, test-pits.*
- Existence of wells, streams, seasonality-access to water. Inspection and Interview.

Demand Side

- Crop-sowing for Kharif and Rabbi. Annual crops.
- Yields (kg/hectare) and price obtained (Rs./kg). Indicative of water-stress.

Allocation

- Number of irrigations required. Coping with dry spells. Interview
- Farm-ponds, irrigation pumps and systems, wells, access to nearby *bandharas*.

The Household.

- House-hold assets. Indicative of recent history, ability to invest.
- Education levels, salaried people, number of farm-workers.
- Farm inputs. Access to market. Knowledge.

Thanks