# Water and Development

## Part 2a: Water in perspective and the Hydrological Cycle

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# Water

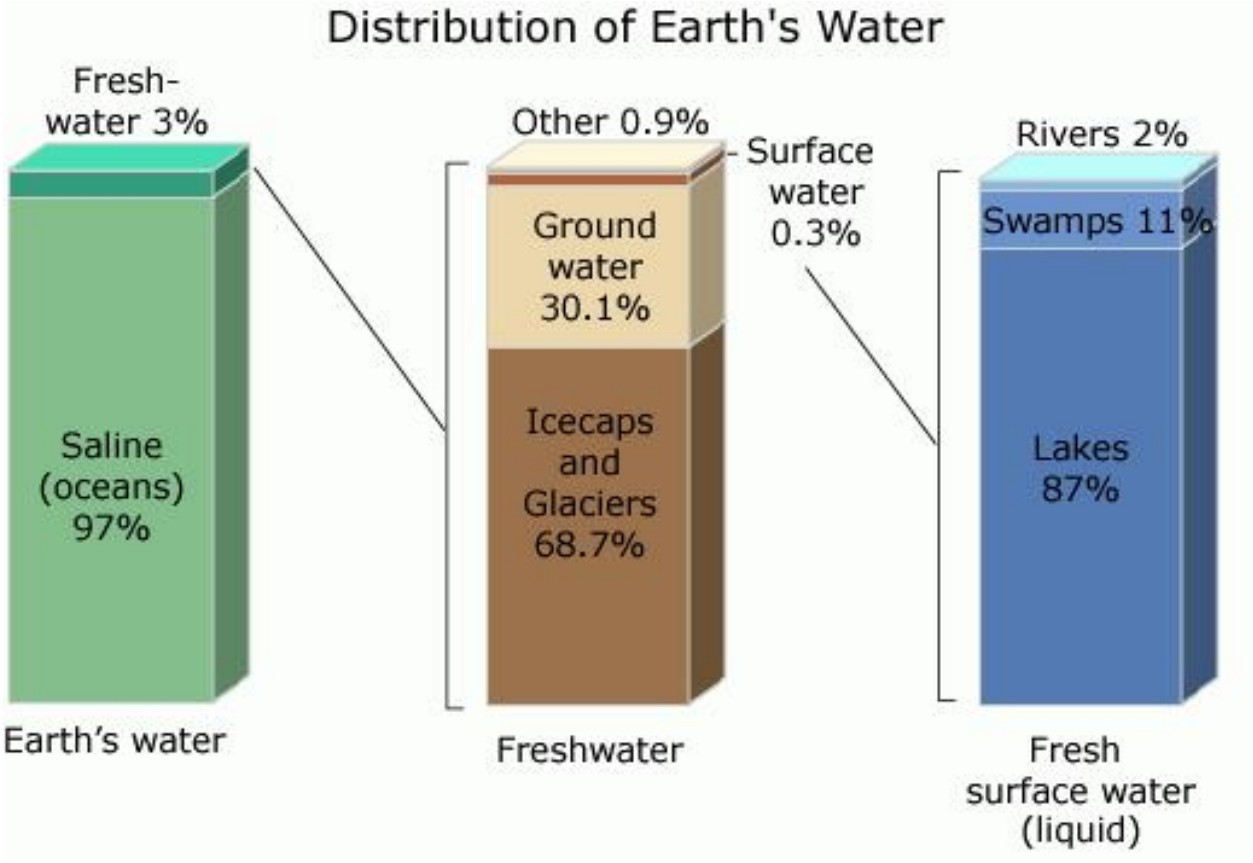
- Chemical formula $H_20$. The existence of strong *hydrogen bond*
- Exists in nature as Ice, water and vapour. Melting point 0 C, boiling point 100 C.
- Specific heat (water): 1 calorie/gm/degree C. Second highest!
  - very important for temperature regulation
- Density (water) 1gm/ml, maximum at 4 C. Ice floats on water.
  - very important for the existence of marine life.
- High surface tension and therefore strong capillary action.
  - very important for the sustenance of plants.
- Coefficient of thermal expansion (linear): $70 \times 10^{-6}$ /C.
  - Roughly 5mm of sea-level rise due to thermal expansion alone. Can we explain this?

# Life and water

- Roughly 60% of body weight is water.
- Water-key ingredient in most life processes-photosynthesis, energy transfer in animals, and so on.
- Life as we know it is water-centric (and organic carbon-centric).
- Water in the solar system:
  - Mercury atmosphere- roughly 4%
  - Enceladus (a moon of Saturn)- 91 %
  - recently-traces on the Moon.
- In general, earth is the only body which is (i) at the right distance from the sun, (ii) has a strong enough gravity to retain an atmosphere, and (iii) has water.
- Besides, early civilizations also revolved around water.

# Water on Earth

- Roughly 71 % of earth's area are the oceans, i.e., about 36 b.Ha.
  - Average depth of oceans: 3790m.
  - Salt content: 3%




source:Wikipedia

# Water availability

Total renewable (defined using the water cycle) per-capita, per year.

| Country | cu. m. |
|---|---|
| Congo | 275,000 |
| Canada | 94,000 |
| Brazil | 48,000 |
| Mongolia, Indonesia | 13,000 |
| Japan, Italy, Iraq | 3300 |
| Pakistan | 2700 |
| China | 2200 |
| Germany , Ethiopia | 1800 |
| India , Netherlands | 1200 |
| Israel | 275 |

Roughly 4000 cu.km fall on India, of which roughly 690 cu.km. are used as surface water and about 430 cu. km. as ground water.

# The main sectors

| Use | India | Developed Countries |
|---|---|---|
| Agricultural | 85% | 25 % |
| Industrial | 8 % | 60 % |
| Domestic | 7 % | 15 % |

Indian Hall-marks:

- Very low charges for agricultural water (Rs. 0.10 /cu.m.). Roughly Rs. 10 per cu.m. for domestic use, and Rs. 50 for industrial use.
- Investment of Rs. 150-200 required to develop a cubic meter of renewable resource.
- Poor domestic use network.
- Limited use of water saving practices in agricluture.

# Agriculture

- 330 m.Ha, total, 180 m. Ha cultivable area. 110 m.Ha. irrigation potential, 54 m. Ha actually under irrigation.
- Only 25-30 % irrigation through canals.
- More than 50 % through tube-wells and open-wells.
- indication of poor canal infrastructure.
- Two typical water allocation systems, *shejpali* (pre-bid allocation), and *wadabandi*, fixed rotation.
- Typical billing, if at all, is per crop-acre and not volumetric.

# Water needs

| Substance | Needs (in liters) |
|---|---|
| 1kg Rice | 1900 |
| 1kg Chicken | 3300 |
| 1kg Wheat | 1000 |
| 1kg Wool | 150 |
| 1kg Sugar | 3000 |
| 1kg Gur | 1000 |

- The numbers depend on the technology used. Drip Irrigation will typically reduce consumption by about 25-30 %.
- So why is there so much ruckus about sugarcane?

# Fishing

Besides being a food, Fish is also an important source of protein. Here is the fishing data for 2004 (F.A.O). Amounts are in million tonnes.

| Country | Wild | Farms | Per-Capita/year (kg) |
|---|---|---|---|
| World | 94 | 45 | 23 |
| India | 3.4 | 2.8 | 6.2 |
| Iceland | 1.8 | 0 | ?? |

Here is the consumption data (in kg. per capita/year):

| | | | |
|---|---|---|---|
| France | 28 | Japan | 60 |
| China | 28 | Brazil | 6 |
| USA | 21 | UAE | 27 |
| Yemen | 7 | India | 5 |

India is thus a fish-exporter!

- Wild production: 3kg/Ha. Farm: 2000 kg/Ha.

# Industrial Use

- 40,000 million cubic meters were consumed by indian industry in 2001.
- Thermal Power plants consumed 87% of this water.
- Engineering, Paper and Textiles consumed 5% , 2 % and 2% respectively.
- Poor industrial productivity per cubic meter: $ 7 /cu.m.
- 10-80 cu.m. per tonne of steel, no water recycling. In US 10 cu.m./tonne, full recycling.
- In power generation, again 80 cu.m. per Mwh, while global norm is 10-20.

http://www.cseindia.org/dte-supplement/industry20040215/non-issue.htm

# Domestic Use

- Rough International Urban norm: 200 lpcd.
- Mumbai, roughly that, or a bit higher. Bangkok, London similar.
- Delhi, Chennai lower. Most cities in India plan for 150 lpcd or higher.

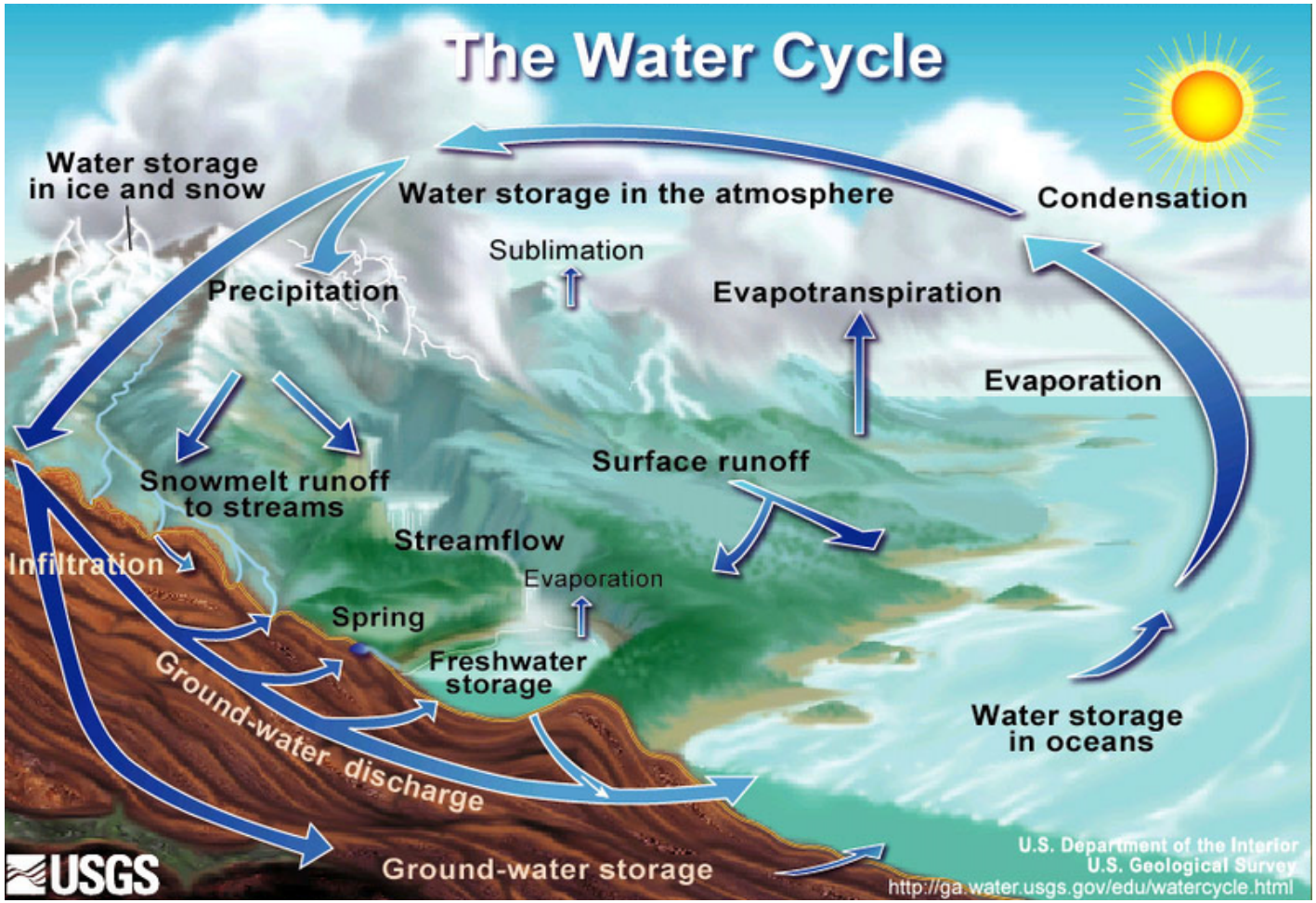
Surprisingly, rural design norm is 40 lpcd!

- Habitation is in stress if 40 lpcd is not met at any point of time within 2 km of the habitation.

## What is domestic use

- Ablutions, Washing clothes, vessels, cleaning house.
- Drinking, cooking.
- Cattle?
- Livelihoods?

# The basic movement of water




source: USGS.

# The basic process

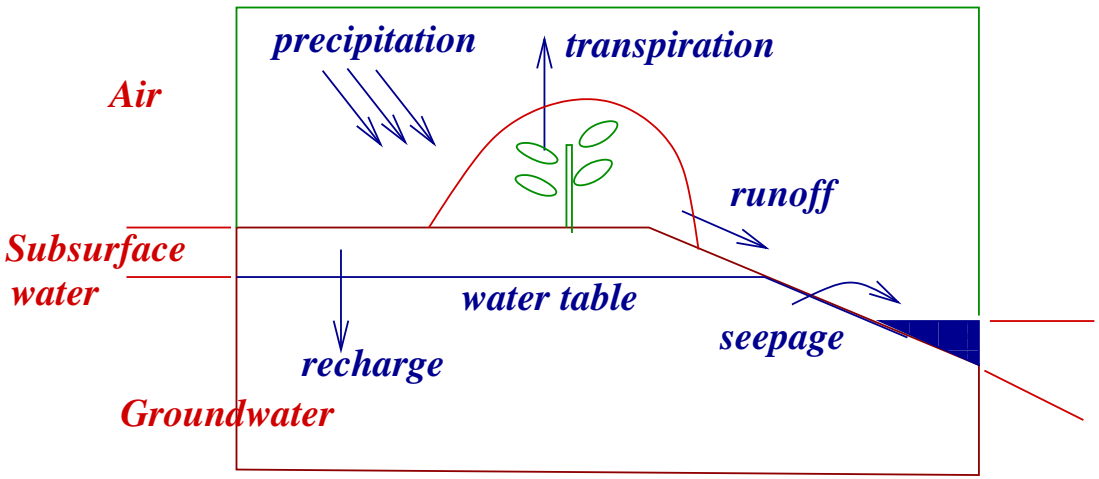
## Going Up

- 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

# What happens when it rains




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

# Evapo-transpiration

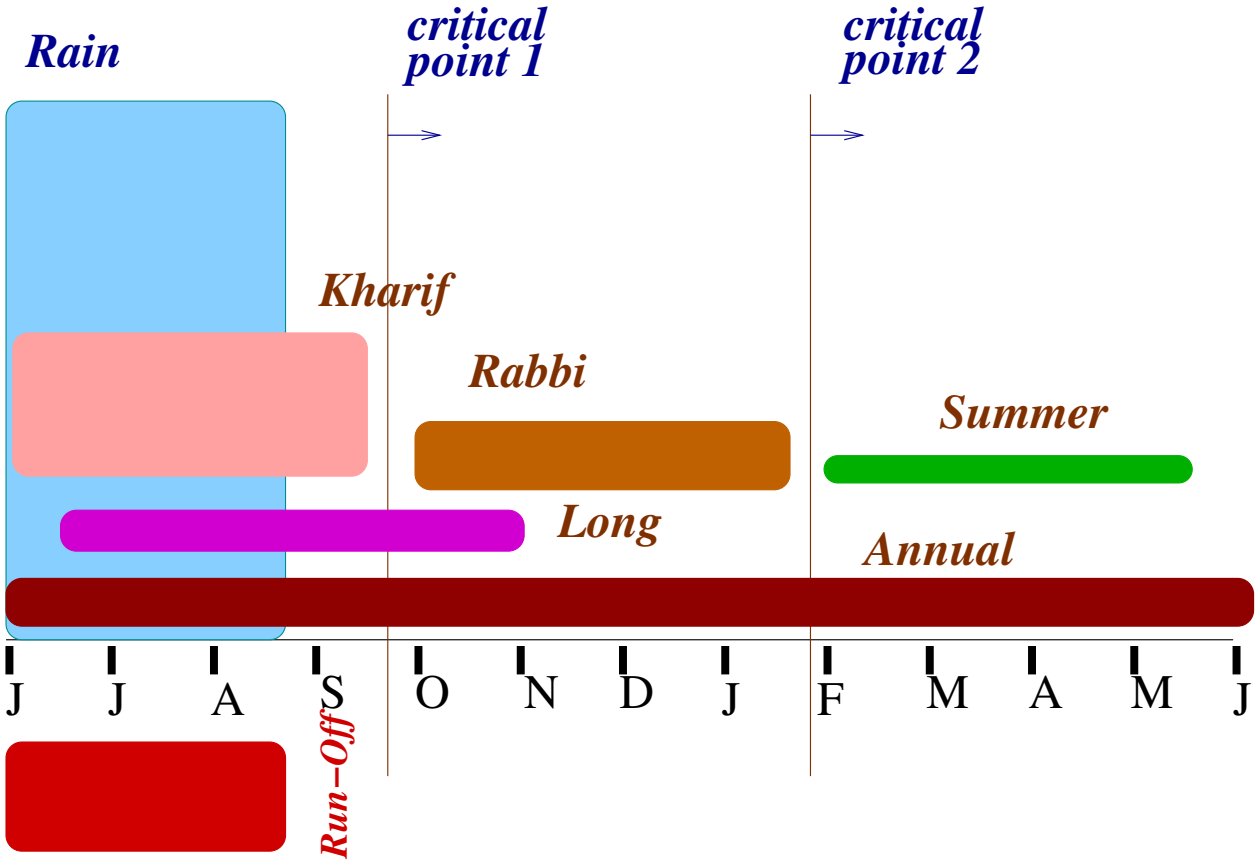
Photosynthesis: The process by which a plant grows, coverting water and CO2. This as well as loss of water through leafs is called *evapo-transpiration*.

| | | | |
|---|---|---|---|
| Rice (Kharif) | 800mm | 100 days | Well-drained |
| Wheat (Rabbi) | 500mm | 100 days | Well drained |
| Cotton (K. Long) | 700mm | 140 days | Black |
| Bajri (Rabbi) | 350mm | 110 days | Black |
| Sugarcane | 1800mm | 15 mo. | All |
| Pomegranate | 1200mm | 12 mo. | Well drained |
| Seasonal Grass | 200mm | 2 mo. | All |
| Scrub | 400mm | 12 mo. | All |
| Forest | +700mm | 12 mo. | All |

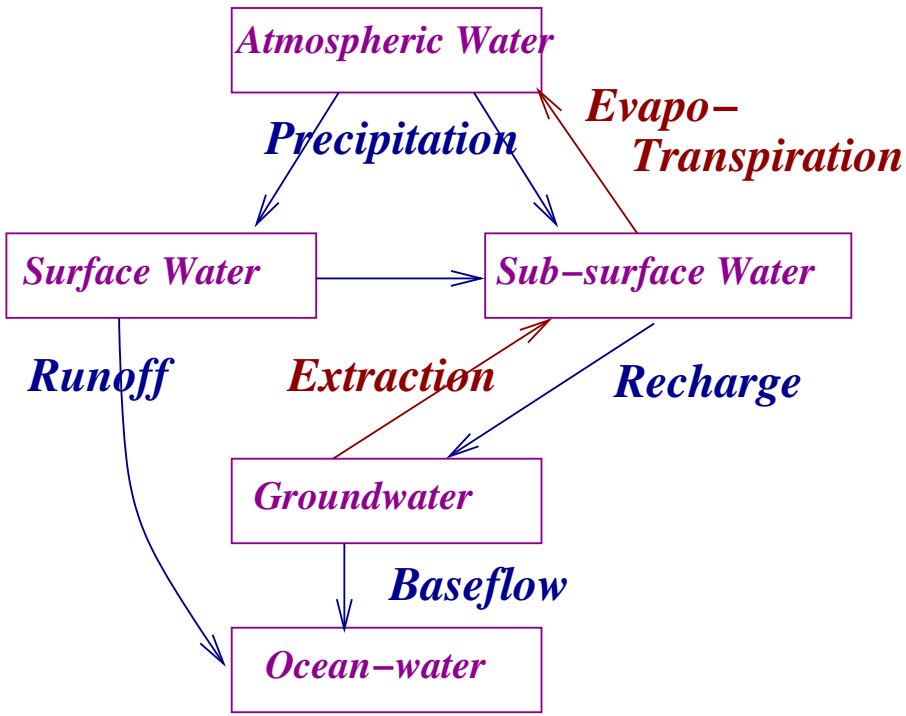
# ET loads

- 1 Ha. of Wheat will require a minimum of 5000 cu. m. of water.
- ET loads depend on planting method, row-width and climate. The above is indicative.
- It *does not* depend on irrigation method. It essentially is the water a healthy plant will require.
- Excess watering will either (i) drain, (ii) go into the ground, or (iii) evaporate from moist soil.

# ET load graphically



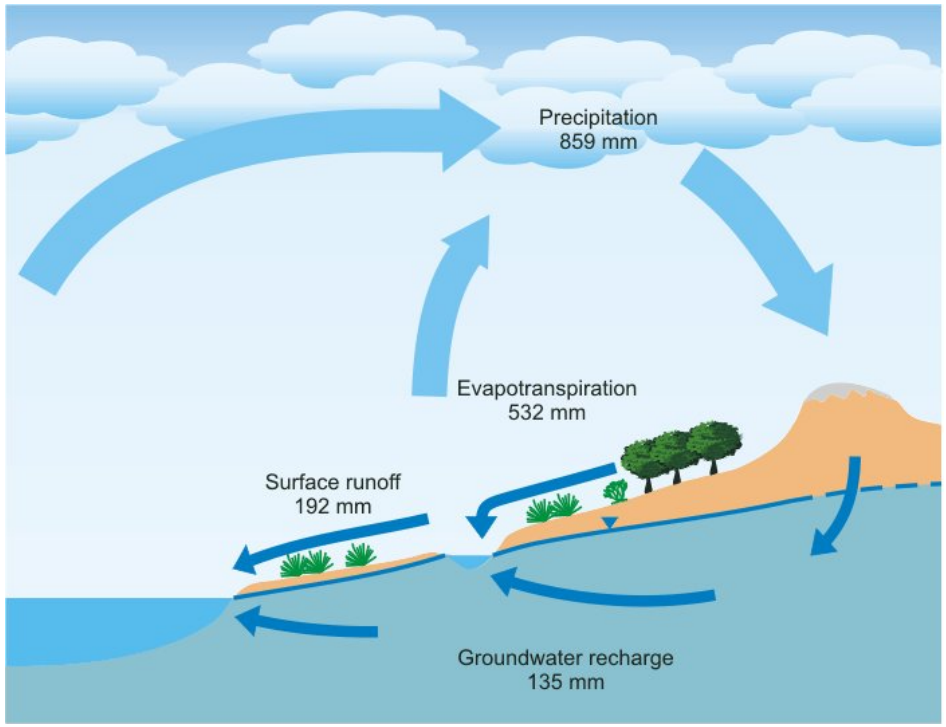
# The basic stocks and flows




- 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*.

# A toy model-Germany

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



# Basic Stocks

Sub-surface water: water in the top 1m of soil. Equivalent to 20-50 mm of water.

- Infiltration after rain.
- Water application for agriculture.
- Recharge into GW, Evapo-transpiration.

Groundwater: Below sub-surface.

- Recharge from sub-surface.
- Recharge from rivers, lakes and reservoirs.
- Baseflows into sea, rivers and streams.
- Extraction.

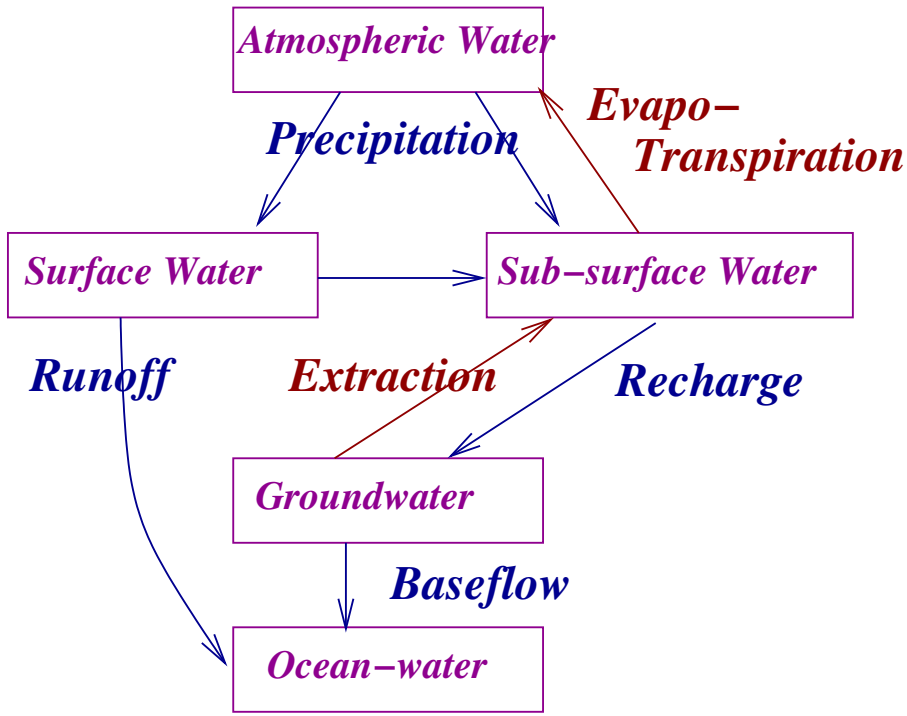
# The Water-balance

Key Stocks $S$, incoming $i$and outgoing flows $o$

$$\frac{dS}{dt} = i - o$$

Precipitation+Extraction= Recharge+Evapo-Transpiration+ Runoff+$\Delta$ Soil Moisture

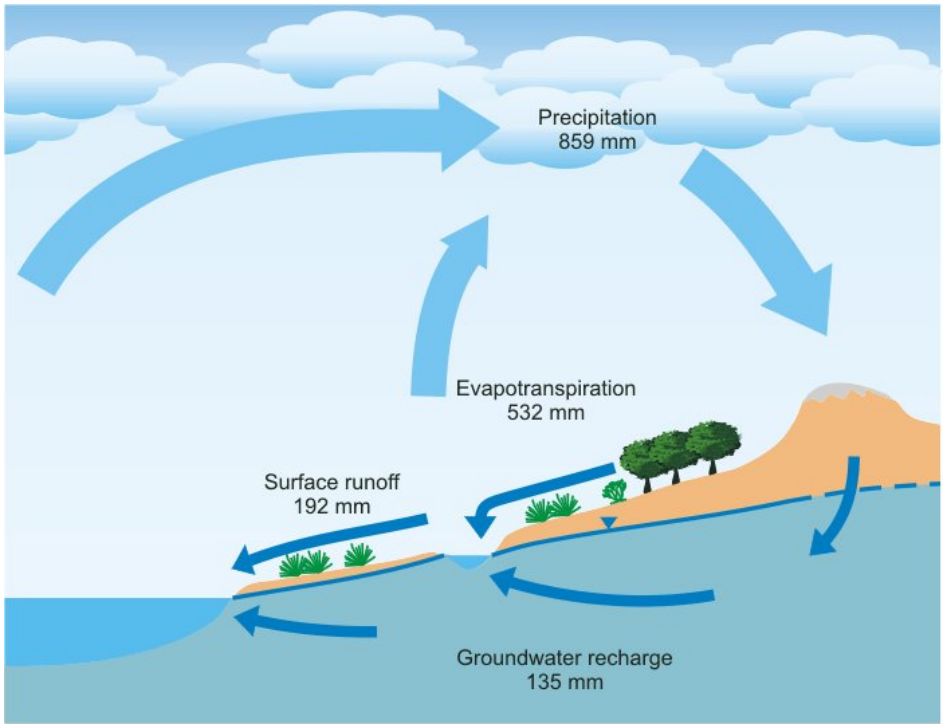
Recharge=Baseflow+ Extraction+$\Delta$ Groundwater.



# Some Δs

- Δ Soil Moisture= -5mm/day (ET)+ Infiltration-2mm (Recharge to GW).
- Daily Rainfall =Infiltration+Runoff-Sea +Δ Storage

# MyWatershed-Water Balance Exercise



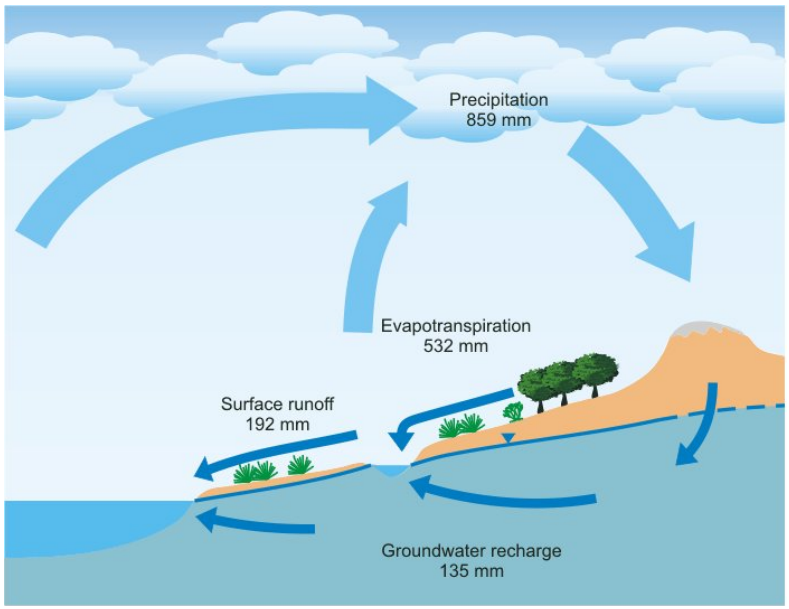

Suppose that we have the following data (per year):

| | |
|---|---|
| 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

- What will happen if we build a check-dam and a reservoir?




Flows:

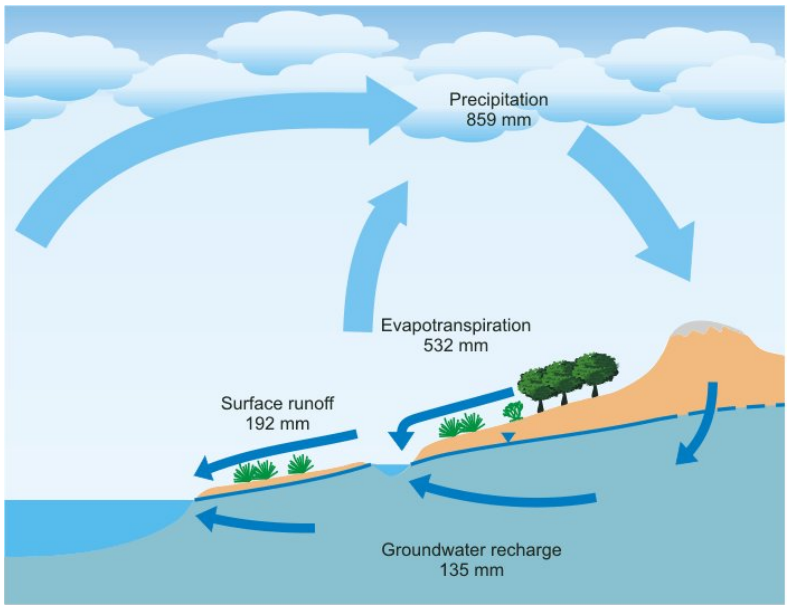
| | | |
|---|---|---|
| Rainfall | 859 mm | |
| Runoff | 192 mm | ↓ |
| Evapo-transpiration | 532mm | |
| Groundwater flows | 135mm | ↑ |

Stocks:

| | |
|---|---|
| Surface Water | ↑ |
| Groundwater | ↑ |

# MyWatershed-Water Balance Exercise

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




Flows:

| | | |
|---|---|---|
| Rainfall | 859 mm | |
| Runoff | 192 mm | ↑ |
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Stocks:

| | |
|---|---|
| Surface Water | ↑ |
| Groundwater | ↓↓ |

# Regional Picture

| Village Ghotewadi | |
|---|---|
| Total Land | 3000 Ha. |
| Forest | 1200 Ha. |
| Commons | 100 Ha. |
| Wastelands | 300 Ha. |
| Agricultural | 1500 Ha. |
| Rainfall ($f$) | 520mm |

## Crop Choice

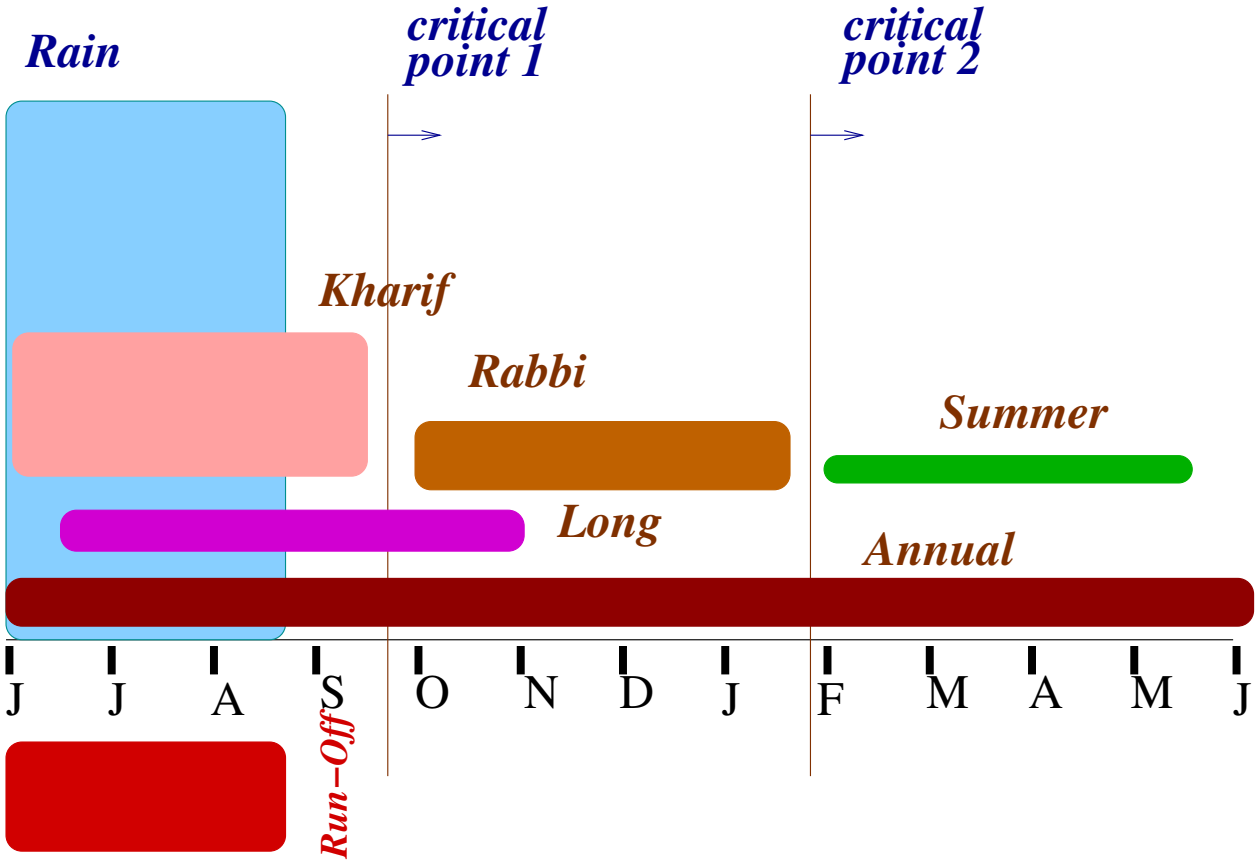
What is a feasible cropping pattern?

Is $(A * f) - (\sum_i A_i r_i)$ positive?

But what is $A$?

| Crop | Area $A_i$ (Ha.) | Req. $r_i$ (mm) | Season |
|---|---|---|---|
| Grapes | 100 | 1200 | Annual |
| Soyabean | 300 | 500 | Kharif |
| Maize | 200 | 700 | Kharif |
| Tomato | 200 | 650 | Summer |

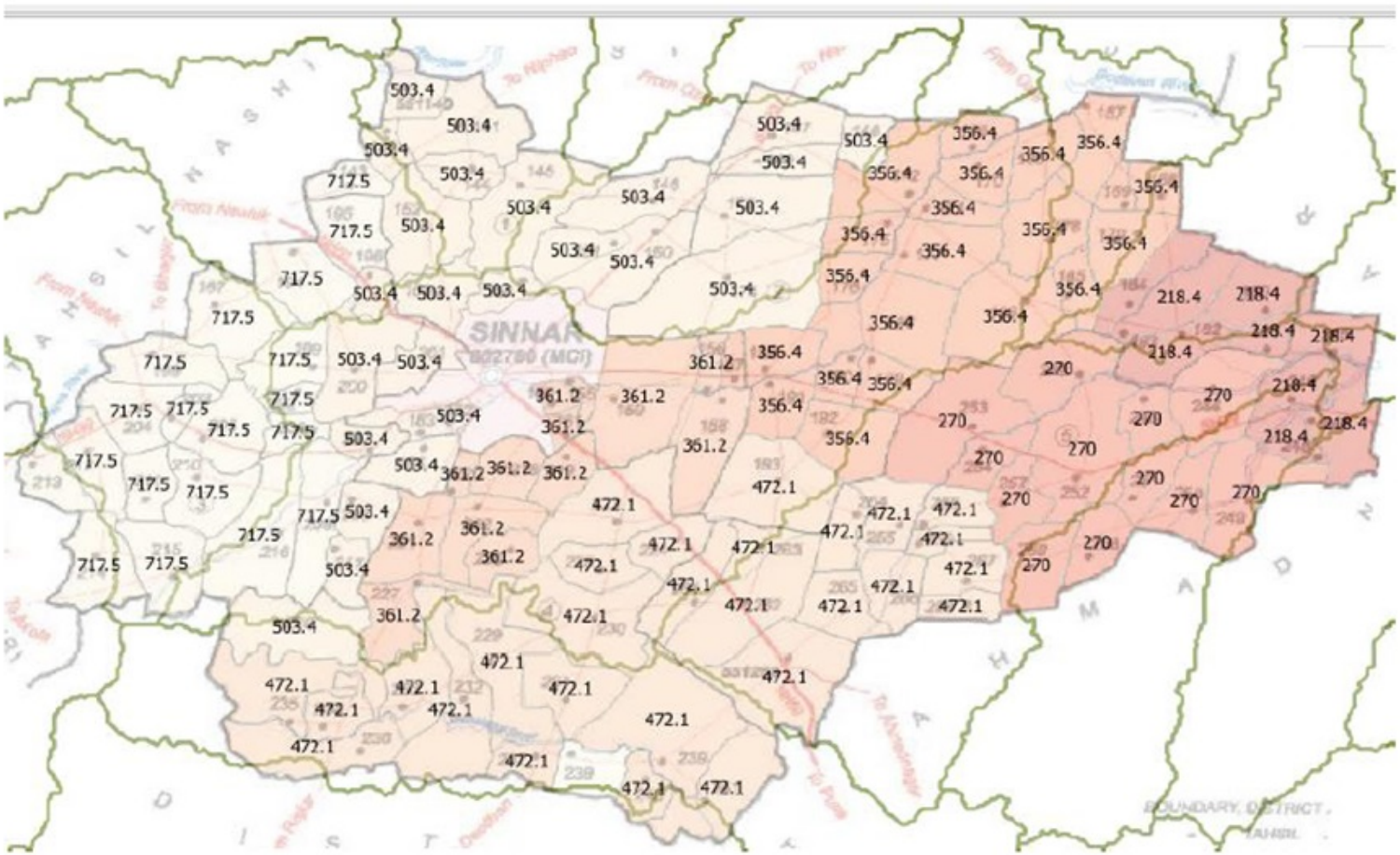
# ET load graphically



# Rains

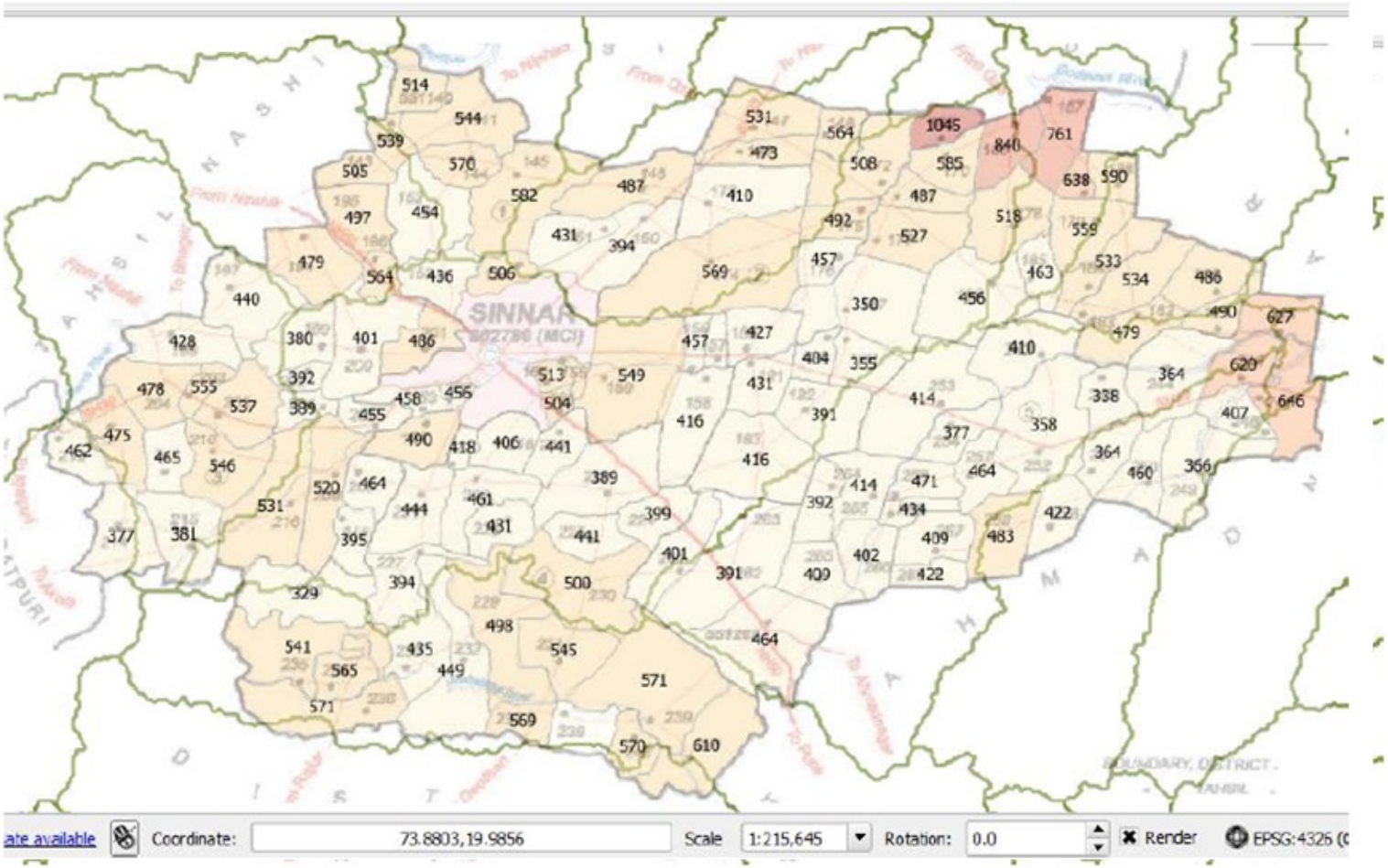
## mm rainfall assigned

(each village assigned to closest circle)



# Demand

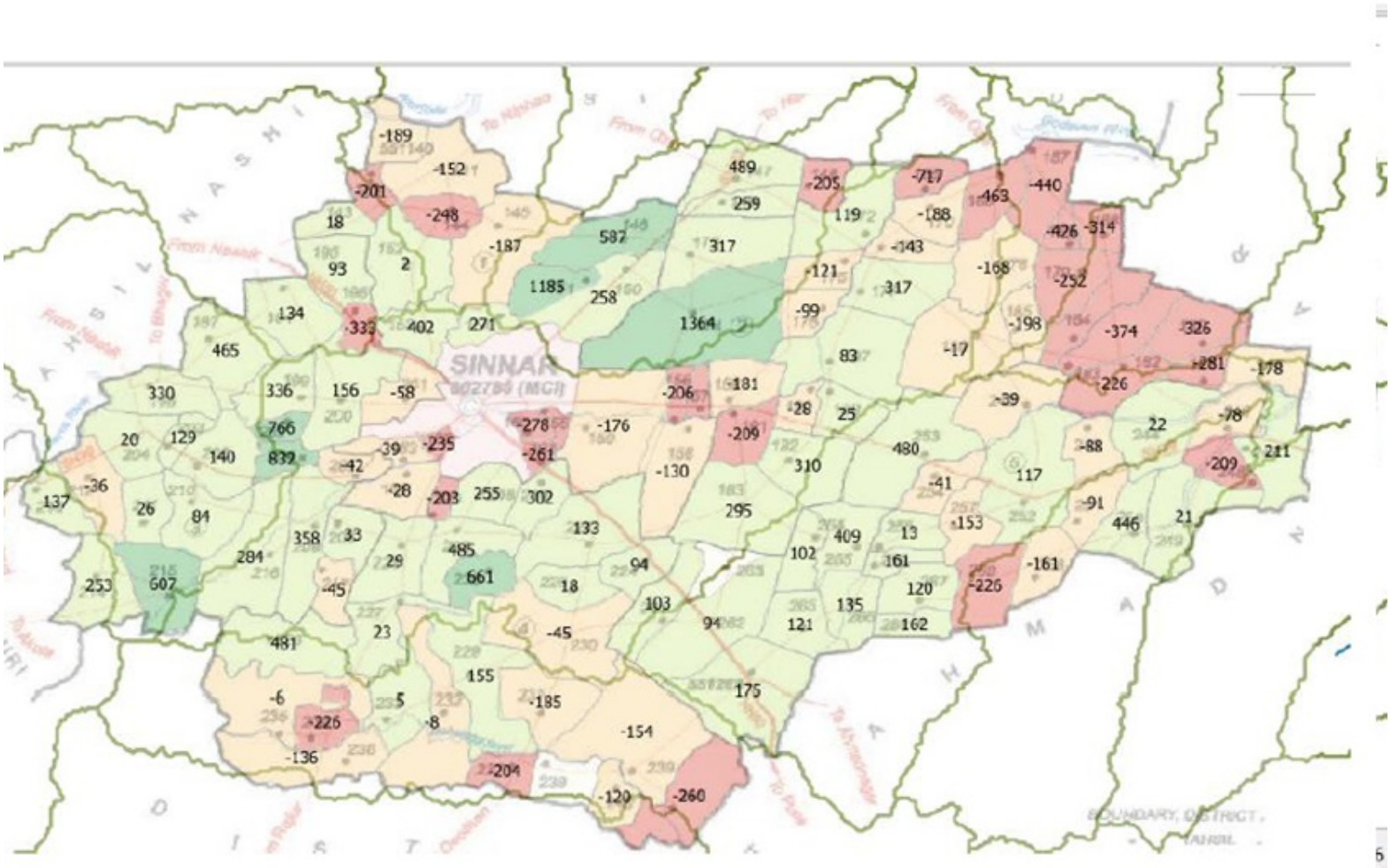
Total mm crop water requirement based on village cropping (denominator is the cropped area)



# Deficit

## mm water use beyond rain in cultivable area

(rain*cultivable area – water use*cropped area)/cropped area

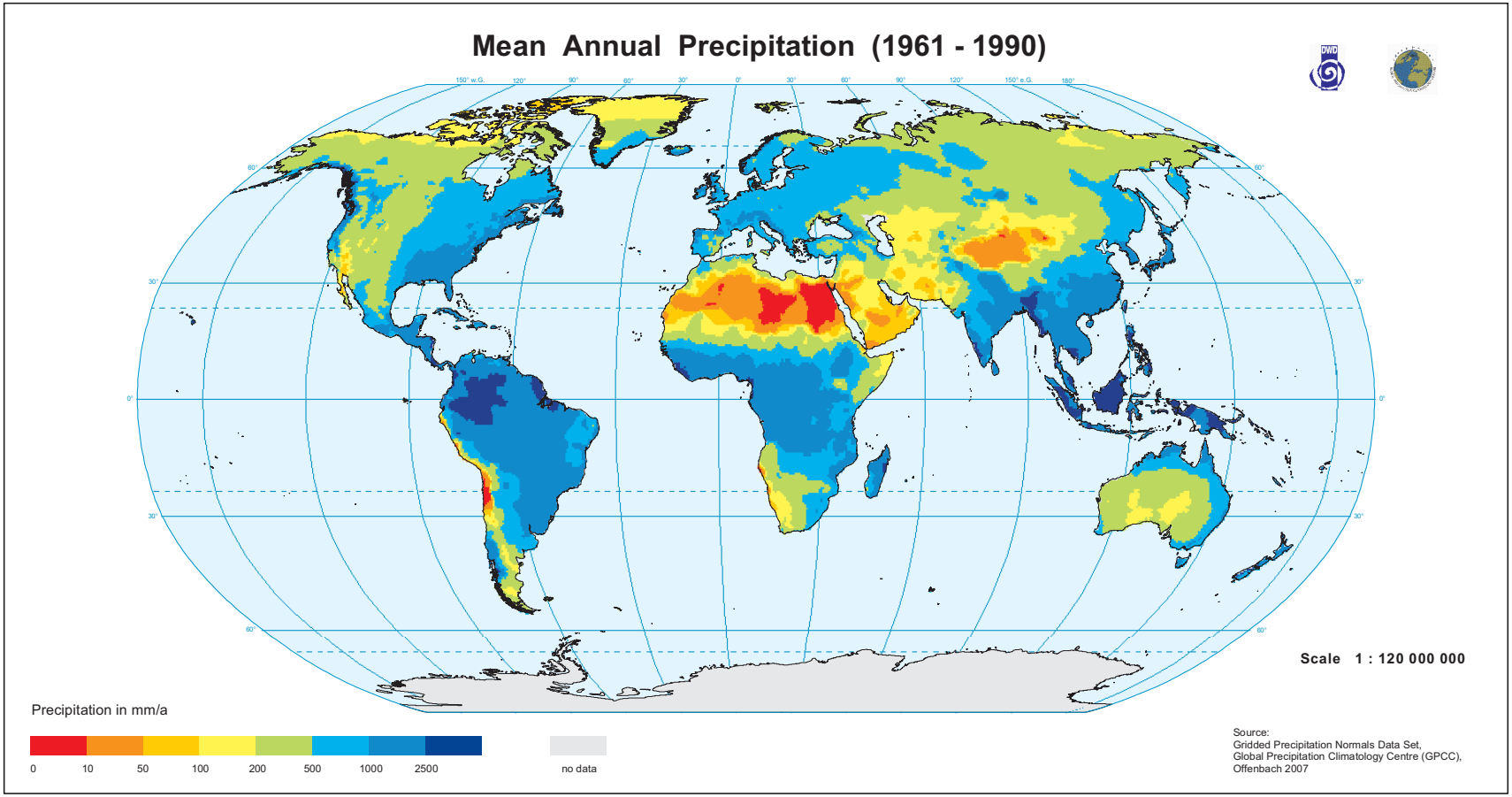


# Precipitation

- 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)
- Most important regional data.
- Observed by network of rain-guages.

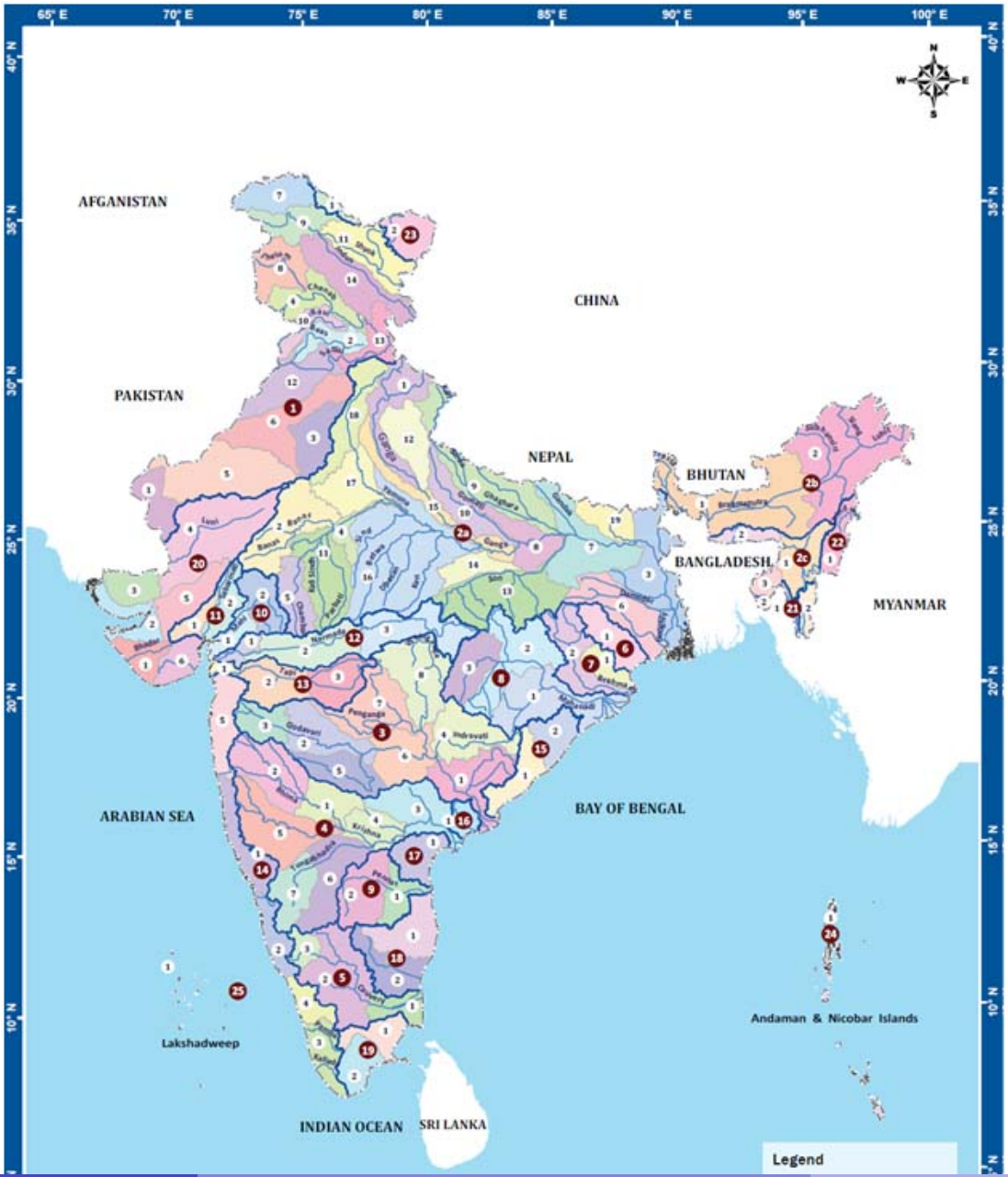
| | |
|---|---|
| Daily Rainfall | mm/day |
| Season Total | mm |
| Rainfall Intensity | mm/day |
| Rainy Days | No. |

# Rainfall

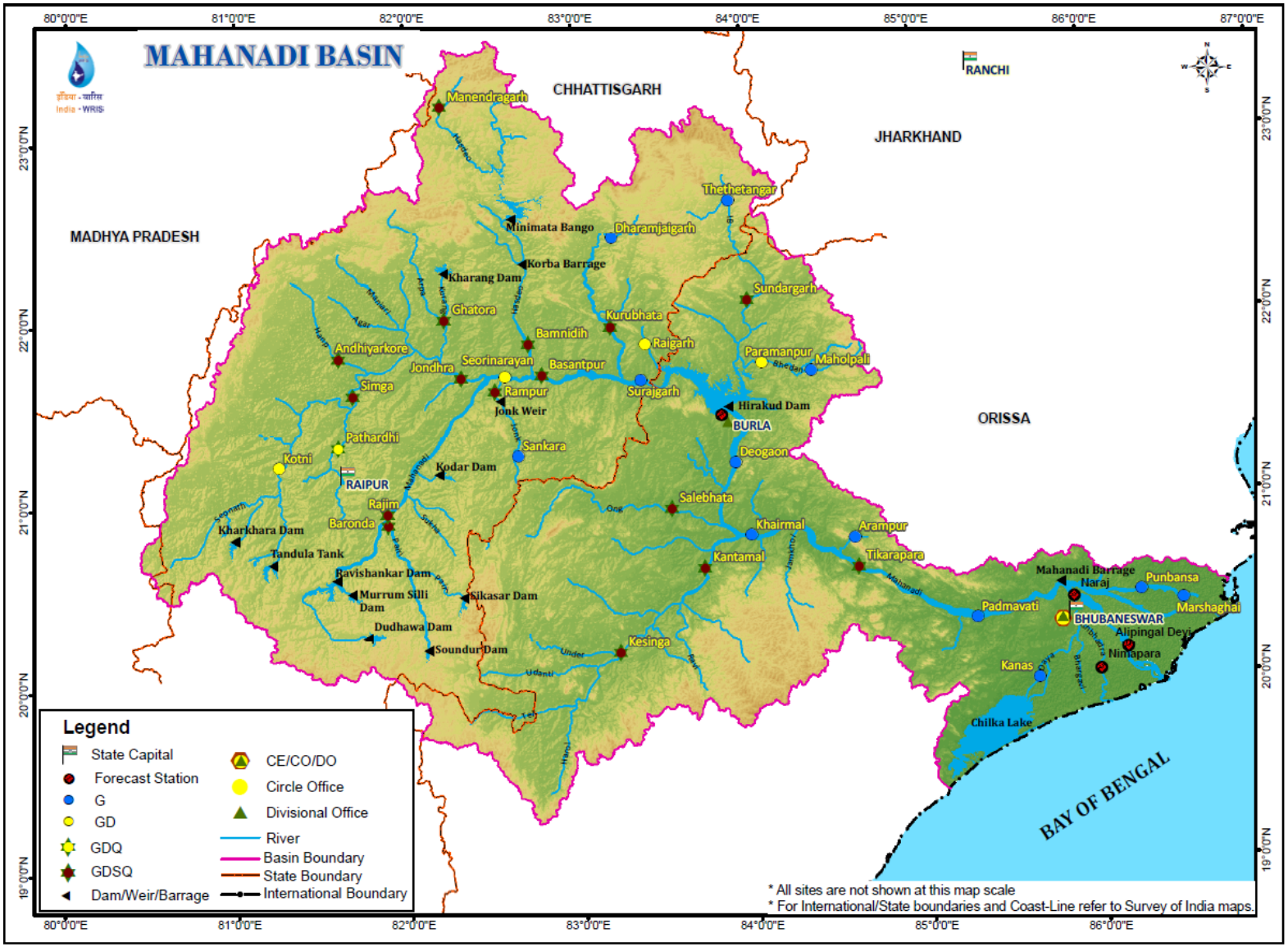



source: `whymap.org`, BGR-Unesco.

# Run-off


65° E
70° E
75° E
80° E
85° E
90° E
95° E
100° E
40° N
35° N
30° N
25° N
20° N
15° N
10° N
AFGANISTAN
CHINA
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
MYANMAR
ARABIAN SEA
BAY OF BENGAL
Lakshadweep
Andaman & Nicobar Islands
INDIAN OCEAN
SRI LANKA
Legend

# A Basin


MAHANADI BASIN
CHHATTISGARH
JHARKHAND
MADHYA PRADESH
ORISSA
RANCHI
RAIPUR
BURLA
BHUBANESWAR
BAY OF BENGAL
Manendragarh
Thethetangar
Minimata Bango
Dharamjaigarh
Korba Barrage
Kharang Dam
Sundargarh
Ghatora
Kurubhata
Bamnidih
Raigarh
Andhiyarkore
Jondhra
Seorinarayan
Basantpur
Paramanpur
Maholpali
Simga
Rampur
Jonk Weir
Suraigarh
Hirakud Dam
Pathardhi
Sankara
Deogaon
Kotni
Kodar Dam
Salebhata
Rajim
Baronda
Kharkhara Dam
Khairmal
Arampur
Tandula Tank
Kantamal
Tikarapara
Ravishankar Dam
Murrum Silli Dam
Sikasar Dam
Mahanadi Barrage
Naraj
Punbansa
Padmavati
Marshaghai
Alipingal Devi
Nimapara
Dudhawa Dam
Soundur Dam
Kesinga
Kanas
Chilka Lake
Legend
State Capital
Forecast Station
G
GD
GDQ
GDSQ
Dam/Weir/Barrage
CE/CO/DO
Circle Office
Divisional Office
River
Basin Boundary
State Boundary
International Boundary
* All sites are not shown at this map scale
* For International/State boundaries and Coast-Line refer to Survey of India maps.
80°0'0"E
81°0'0"E
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21°0'0"N
20°0'0"N
19°0'0"N

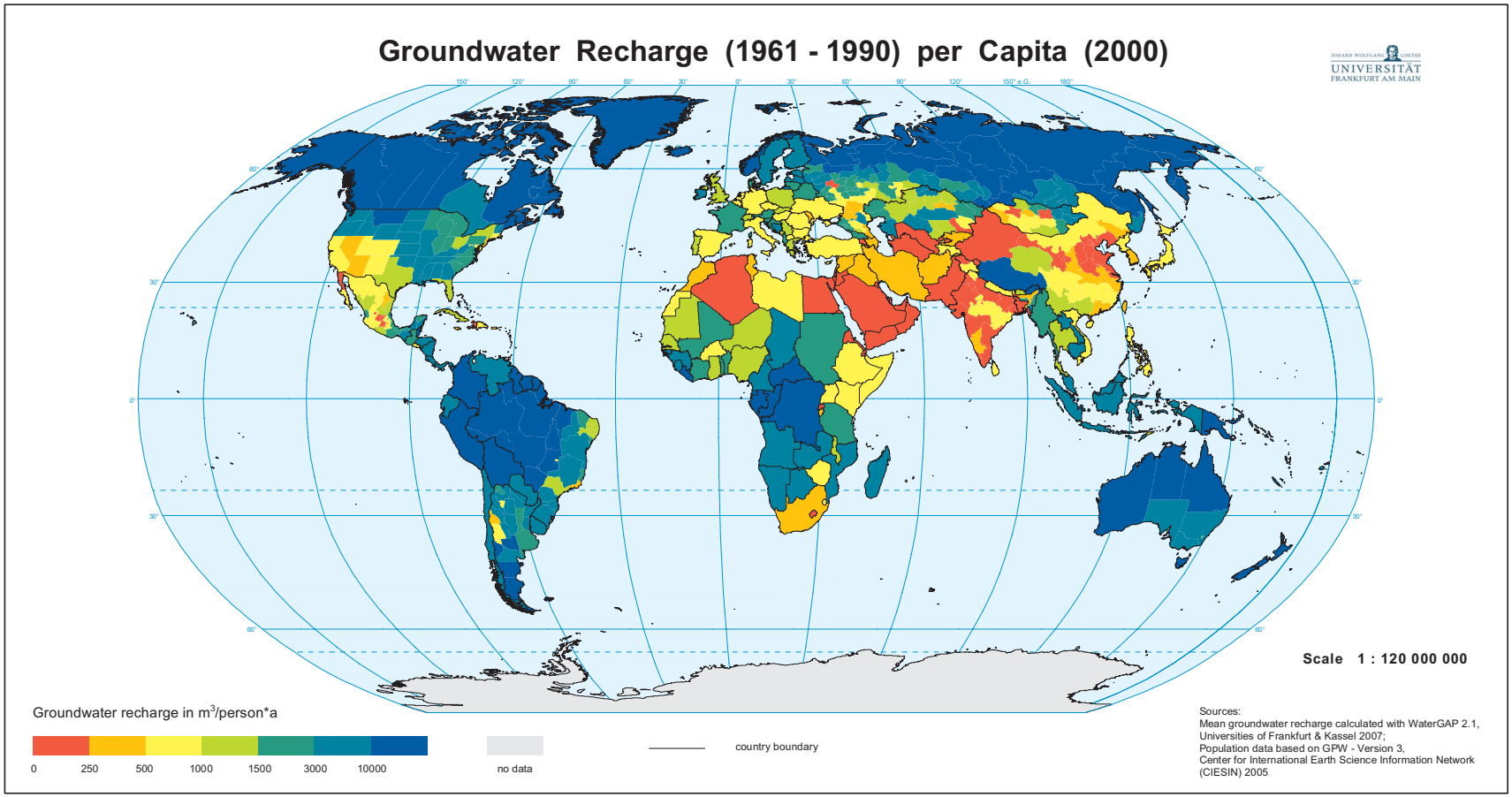
# Mahanadi Basin-Data

| | |
|---|---|
| Length of Mahanadi River (Km) | 850 |
| Catchment Area (Sq.km.) | 141600 |
| Average Water Resource Potential (MCM) | 66800 |
| Utilizable* Surface Water Resource (MCM) | 50000 |
| Total Live Storage Capacity of Projects (MCM) | 14200 |

*-utilizable: which will not directlu run off to sea, or is available within the country's boundary.

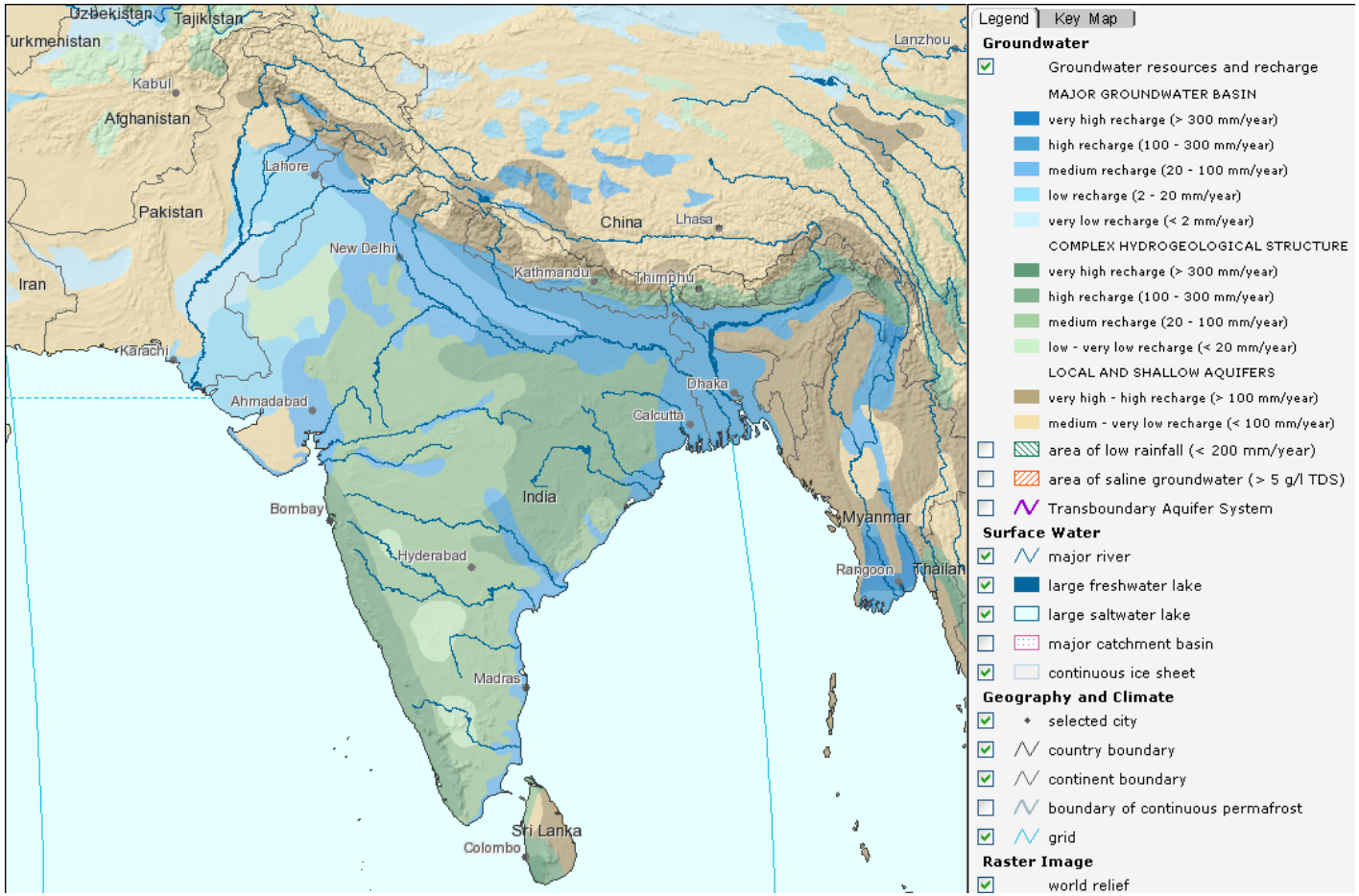
- Can you estimate the infiltration fraction?
- What is the use of storage?
- What is the connection between the two?

# Recharge




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

# Recharge/Geology-India




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

# CGWB estimates

| | |
|---|---|
| Annual Replenishable Ground Water Resources | 433 bcm |
| Net Annual Ground Water Availability | 398 bcm |
| Annual Ground Water Draft for Irrigation<br>Domestic & Industrial uses | 245 bcm |
| Stage of Ground Water Development | 62% |

# Thanks