A Lecture on

Groundwater Monitoring with Optimization Technique

Faculty Development Programme on 24/09/08

IRDT Kanpur

by

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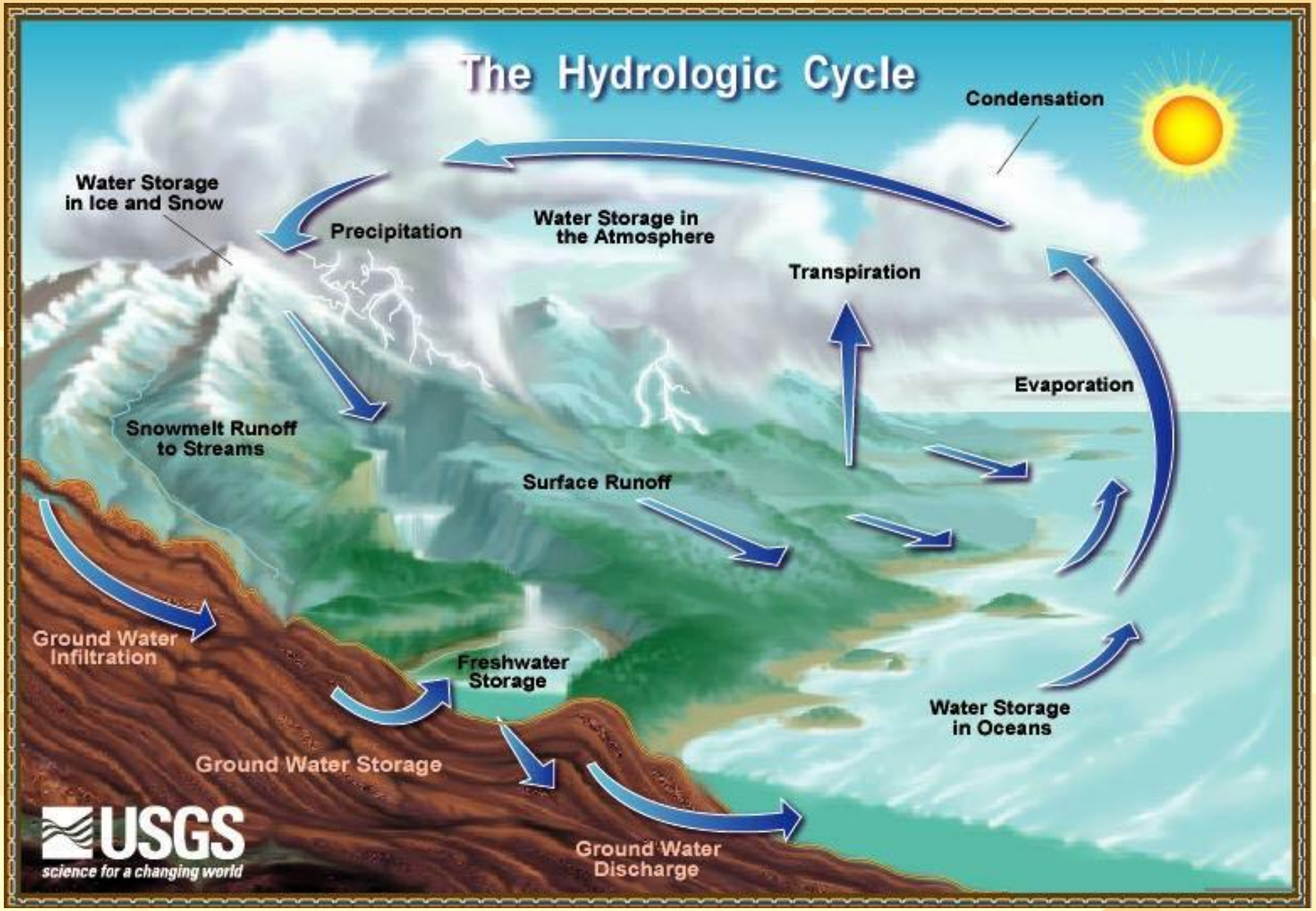


Source:piru.alexandria.ucsb.edu

Beneficial Use of Groundwater

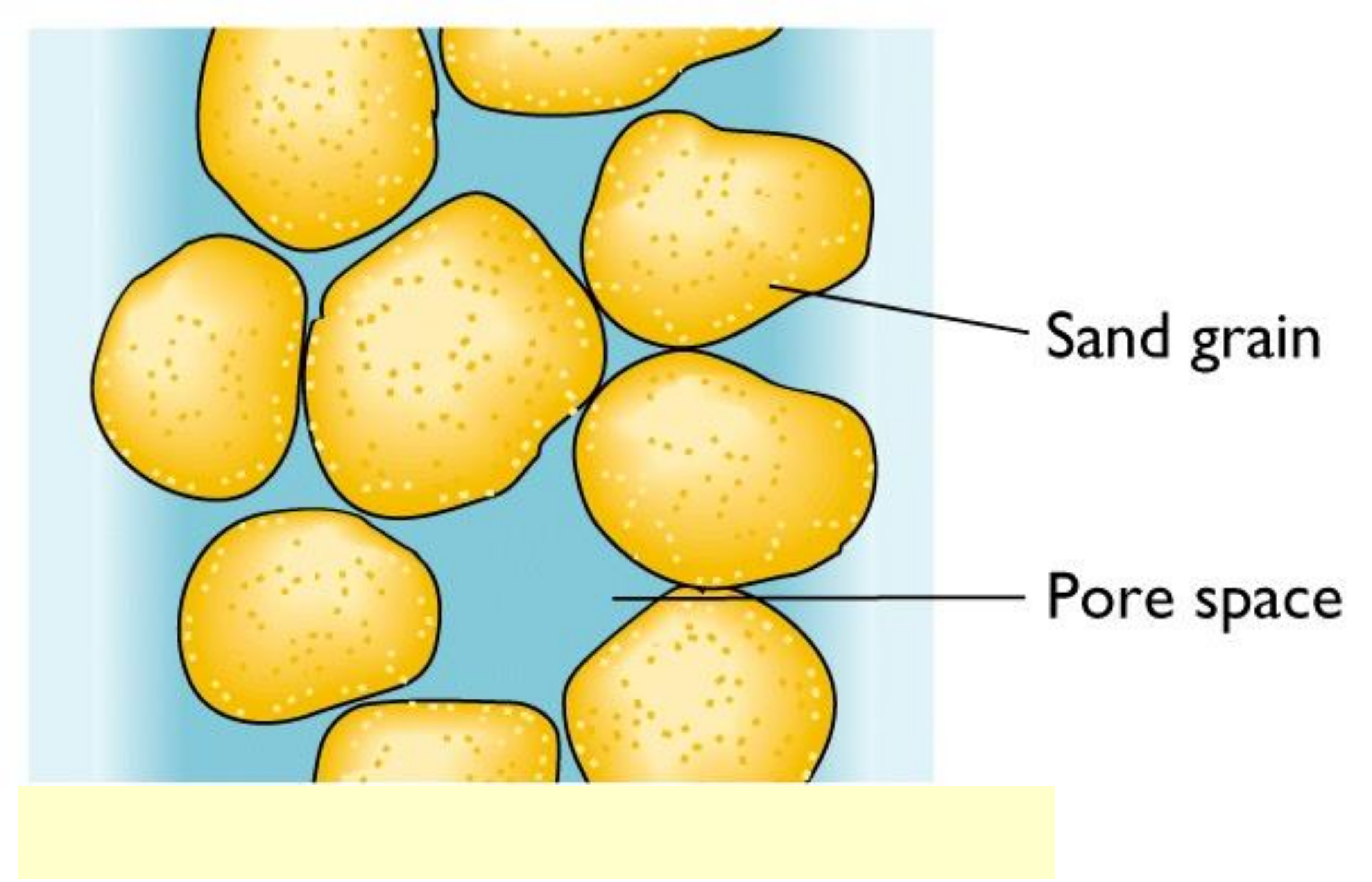
- Drinking Water
- Aesthetic/Recreational
- Irrigation
- Livestock Watering
- Ecosystem Protection

Why bother?

Groundwater is

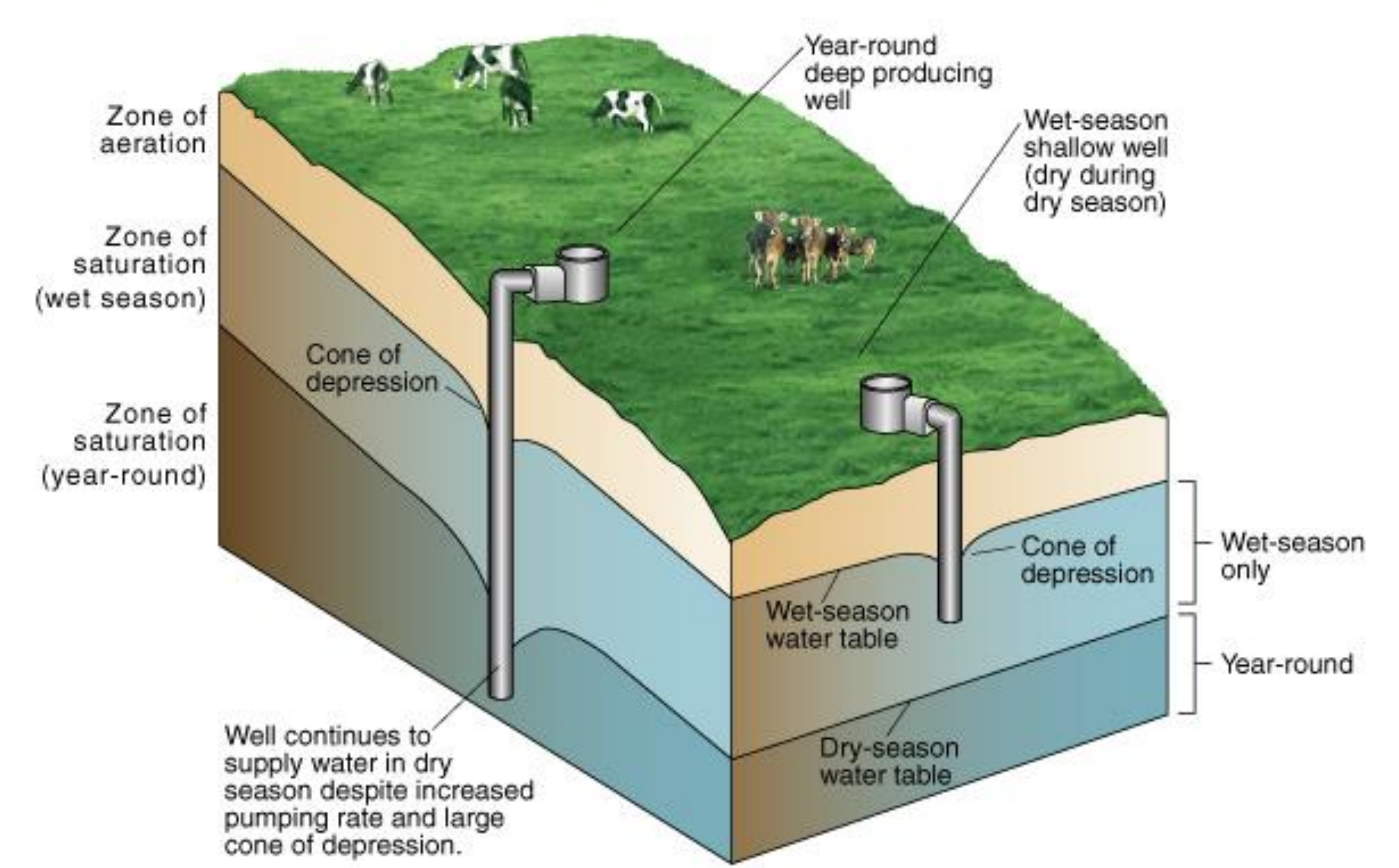
- **drinking water** for more 50% of all people
- 40% of **irrigation** water
- important for **livestock** & **industry**
- an **overused** resource resulting in:
  - water shortages
  - land subsidence
  - contamination

Porous Sandstone



Wells

- Wells can supply water - if they intersect the water table.
  - Pumping a well at a rate faster than water can flow in the aquifer creates a cone of depression.



Source:

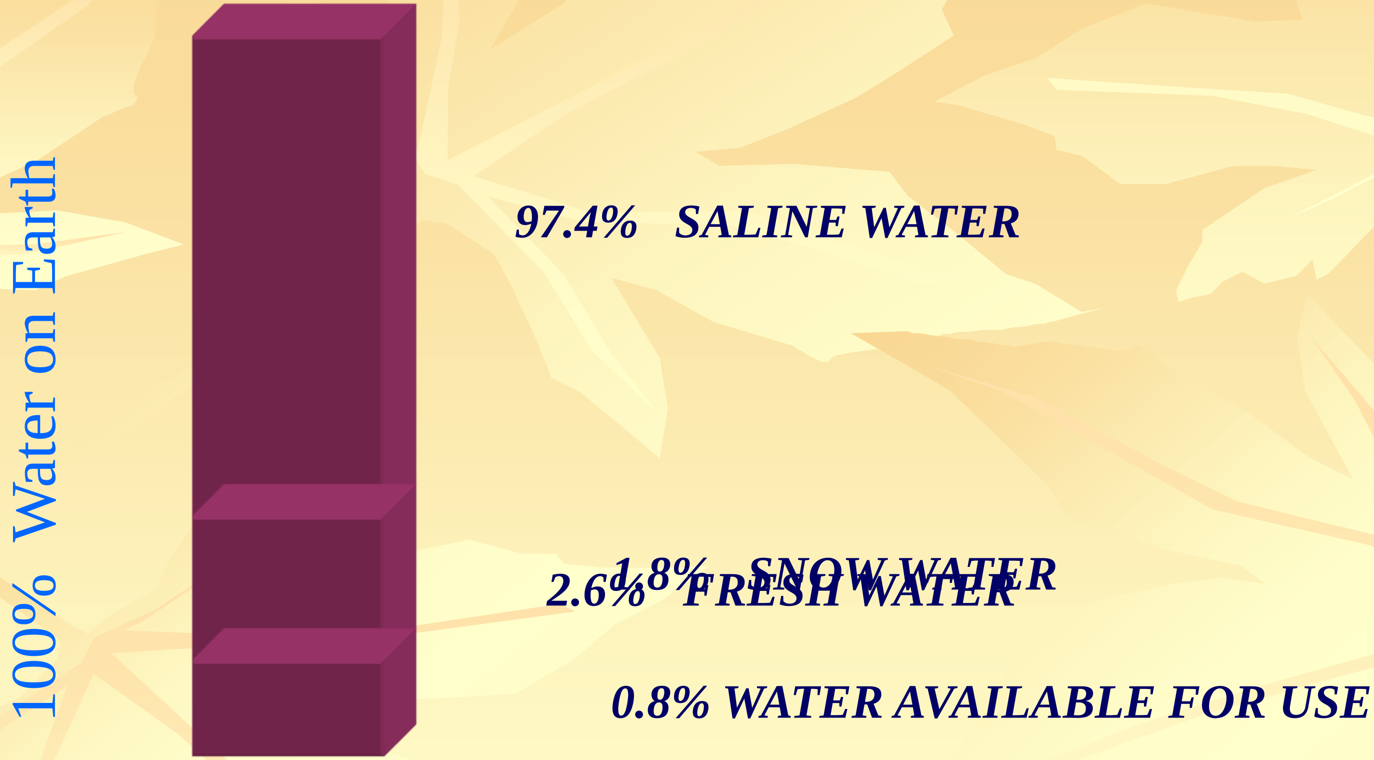
GROUND WATER POLLUTION IN INDIA

Pollutant	State	Place of occurrences
Salinity (Inland)	Maharashtra	Amravati, Akola
	Bihar	Begusarai
	Haryana	Karnal
	Rajasthan	Barmer, Jaisalmer, Bharatpur, Jaipur, Nagaur, Jalore & Sirohi
	U.P.	Mathura
Salinity (Coastal)	Andhra Pradesh	Vishakapatnam
	Orissa	Puri, Cuttak, Balasore
	West Bengal	Haldai & 24 Pargana
	Gujarat	Junagarh, Kachch, Varahi, Banskanta & Surat
Flouride	Kerala	Palaghat Krishna, Ananipur, Nellor, Chittoor.
	Andhra Pradesh	Cuddapah, Guntur and Nalgonda
	Gujarat	Banskanta, Kachch & Amreli
	Haryana	Hissar, Kaithal & Gurgaon
	Orissa	Bolangir, Bijapur, Bhubaneshwar and Kalahandi
	Punjab	Amritsar, Bhatinda, Faridkot, Ludhiana & Sangrur
	Rajasthan	Nagaur, Pali, Sirohi, Ajmer & Bikaner
	Tamil Nadu	Chengalput, Madurai
	U.P.	Unnao, Agra, Aligarh, Mathura, Ghaziabad, Meerut & Rai Baraili

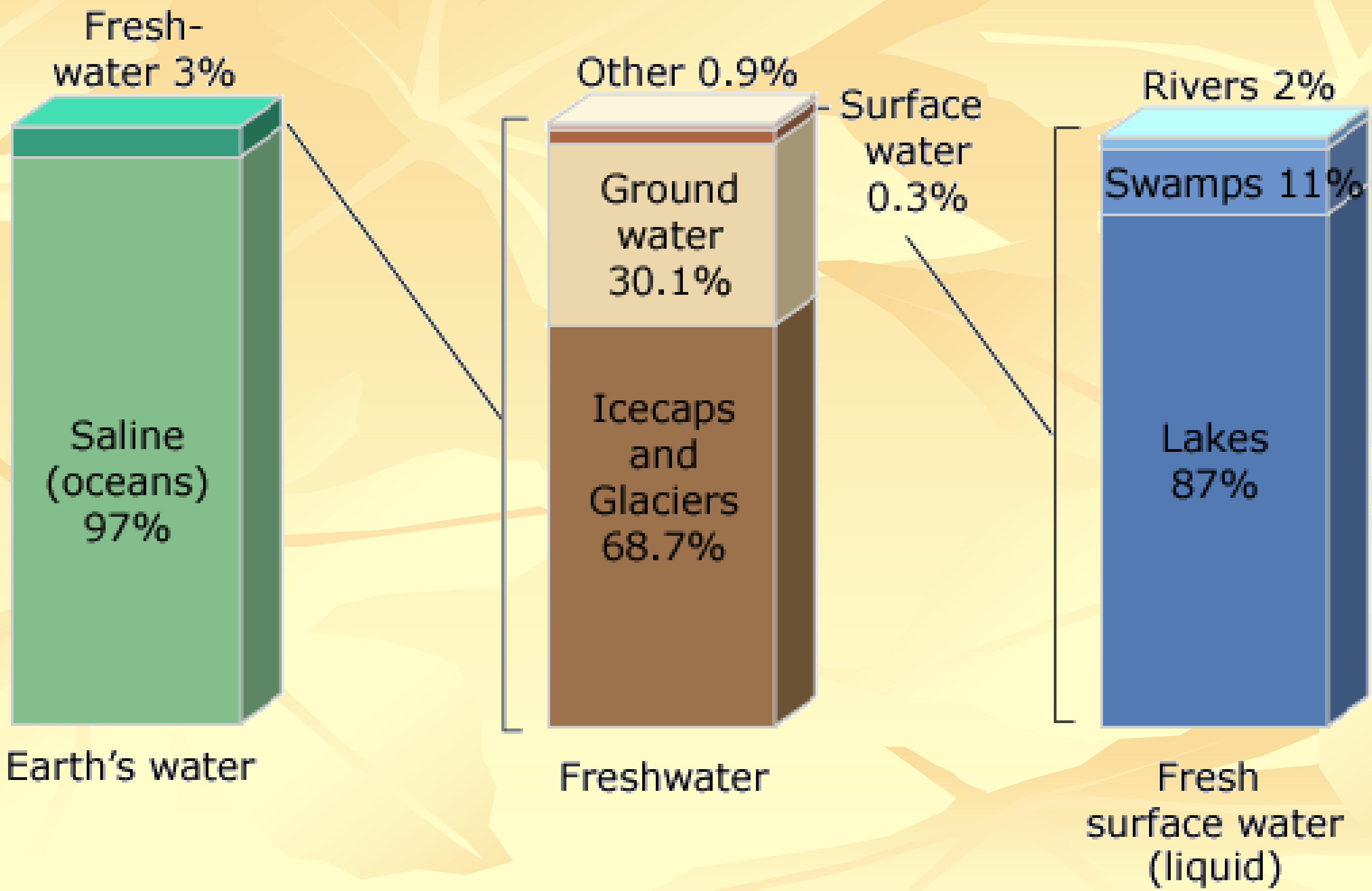
Sulphide	**Orissa**	**Balasore, Cuttak & Puri**
Iron	**U.P.**	**Mirjapur**
	Assam	**Darrang, Jorhat, Kamrup**
	Orissa	**Bhubaneshwar**
	Bihar	**E. Champaran, Muzaffarpur, Gaya, Manger, Deoghar & Madubani**
	Rajasthan	**Bikaner, Alwar, Bharatpur**
	Tripura	**Dharmnagar, Kailasanar, Ambasa, Amarpur & Agartala**
	West Bengal	**Madnipur, Howrah, Hoogly and Bankura**
Maganese	**Orissa**	**Bhubaneshwar, Athgaon**
	U.P	**Muradabad, Basti, Rampur & Unnao**
Arsenic	**West Bengal**	**Malda, Murshidabad, Nadia, 24 Pargana**
Nitrate	**Bihar**	**Patna, East Champaran, Palamu, Gaya, Nalanda, Nawada and Banka**
	Andhra Pradesh	**Vishakapatnam, East Godvari, Krishna, Prakasam, Nellor, Chittoor, Anantpur, Cuddapah, Kurnool, Khamam and Nalgonda**
	Delhi	**Naraina, Shehadr (Blocks)**
	Haryana	**Ambala, Sonepat, Jind, Gurgaon, Faridabad & Hissar**
	Himachal Pradesh	**Kulu, Solan, Una**
	Karnataka	**Bidar, Gulbarge and Bijapur**

	Madhya Pradesh	**Sehore, Bhopal & (West & Central Part of state)**
	Maharashtra	**Jalna, Beed Nanded, Latur, Osmanabad, Solapur Satara, Sangli and Kolhapur**
	Punjab	**Patiala, Faridkot, Firozpur, Sangrur & Bhatinda**
	Rajasthan	**Jaipur, Churu, Ganganagar, Bikaner, Jalore, Barmer, Bundi and Sawaimadhopur**
	Tamil Nadu	**Coimbatore, Penyar and Salem**
	West Bengal	**Uttar Dinajpur, Malda, Birbhum, Murshidabad, Nadia, Bankura and Purulia.**
Chloride	**Karnataka**	**Dharwad, Belgaum**
	Madhya Pradesh	**Bhind, Shagapur and Sehore**
	Maharashtra	**Solapur, Satara, Amravati, Akola & Buldana**
	Rajasthan	**Barmer, Jaisalmer, Jodhpur & Jalore**
	West Bengal	**Contai, Digha, Haldia**
Zinc	**Andhra Pradesh**	**Hyderabad, Osmania University campus**
	Delhi	**R.K. Puram**
	Rajasthan	**Udaipur**
Chromium	**Punjab**	**Ludhiana**

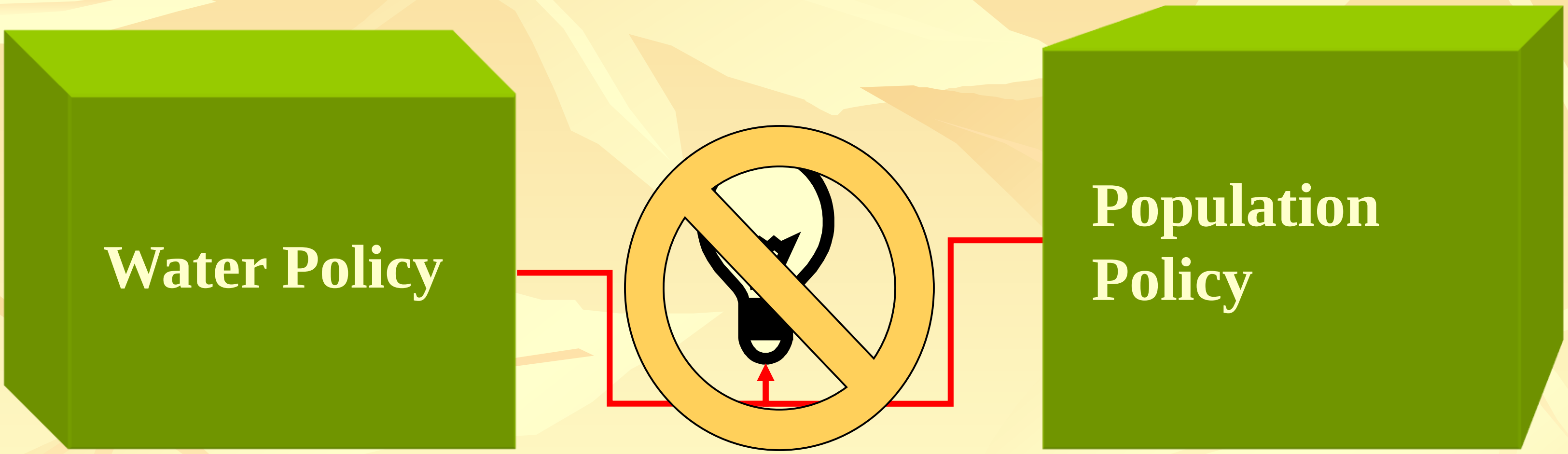
What we HAVE??


100% Water on Earth
97.4% SALINE WATER
1.8% SNOW WATER
2.6% FRESH WATER
0.8% WATER AVAILABLE FOR USE

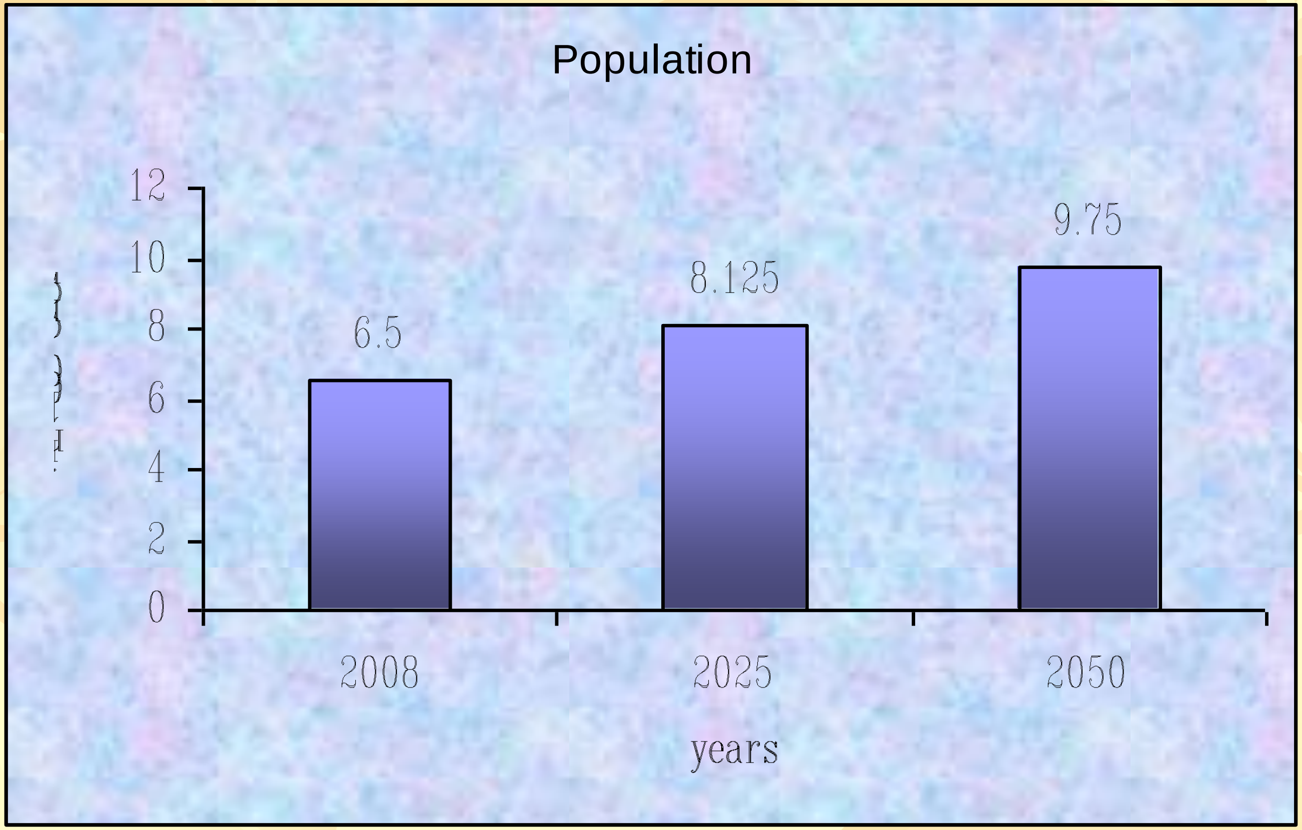
Distribution of Earth's Water

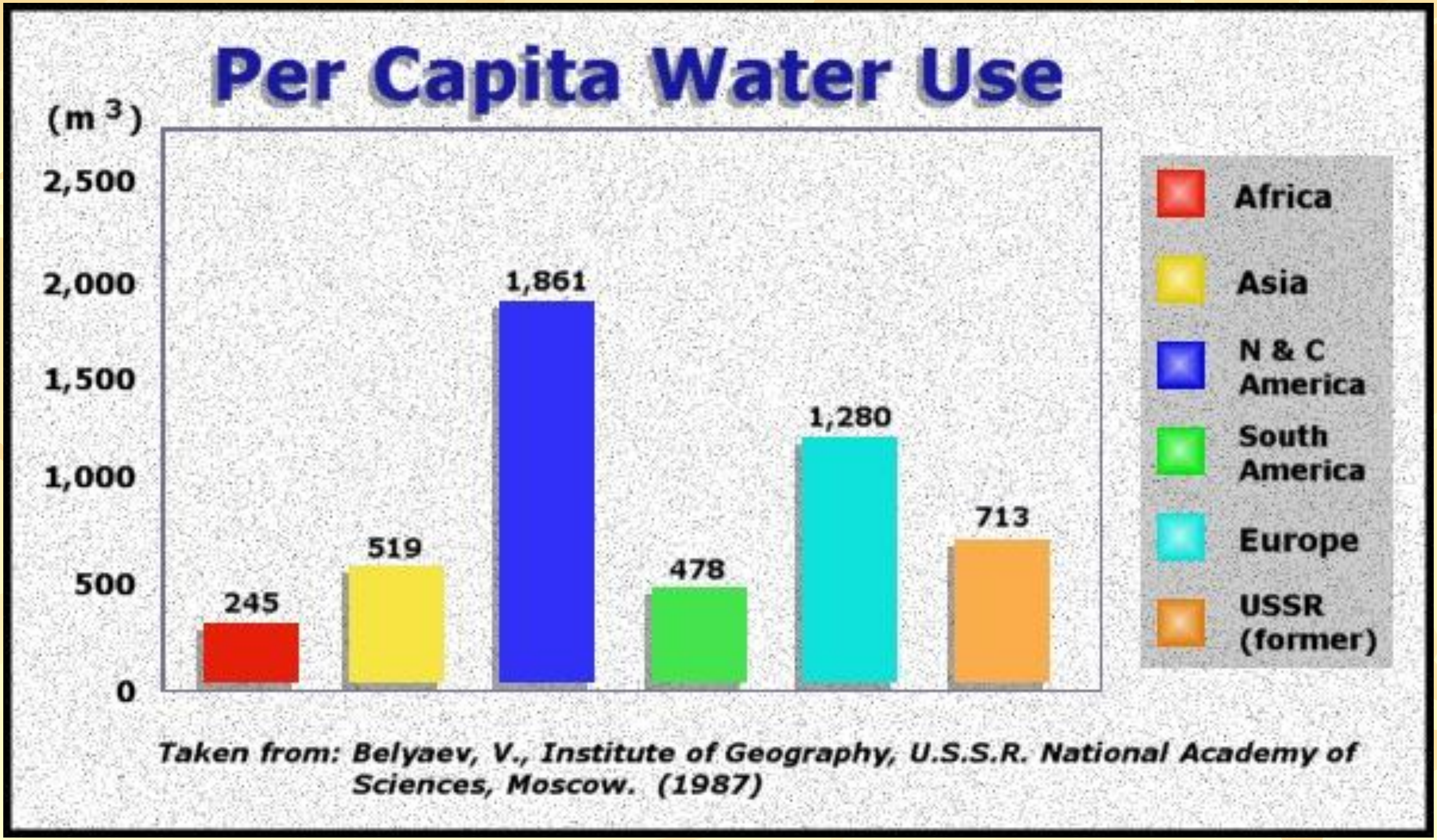


Indian Association of Parliamentarian Population and Development



We are going to have….




Per Capita Water Use
(m 3)
2,500
2,000
1,500
1,000
500
0
245
519
1,861
478
1,280
713
Africa
Asia
N & C America
South America
Europe
USSR (former)
Taken from: Belyaev, V., Institute of Geography, U.S.S.R. National Academy of Sciences, Moscow. (1987)

Dark Facts

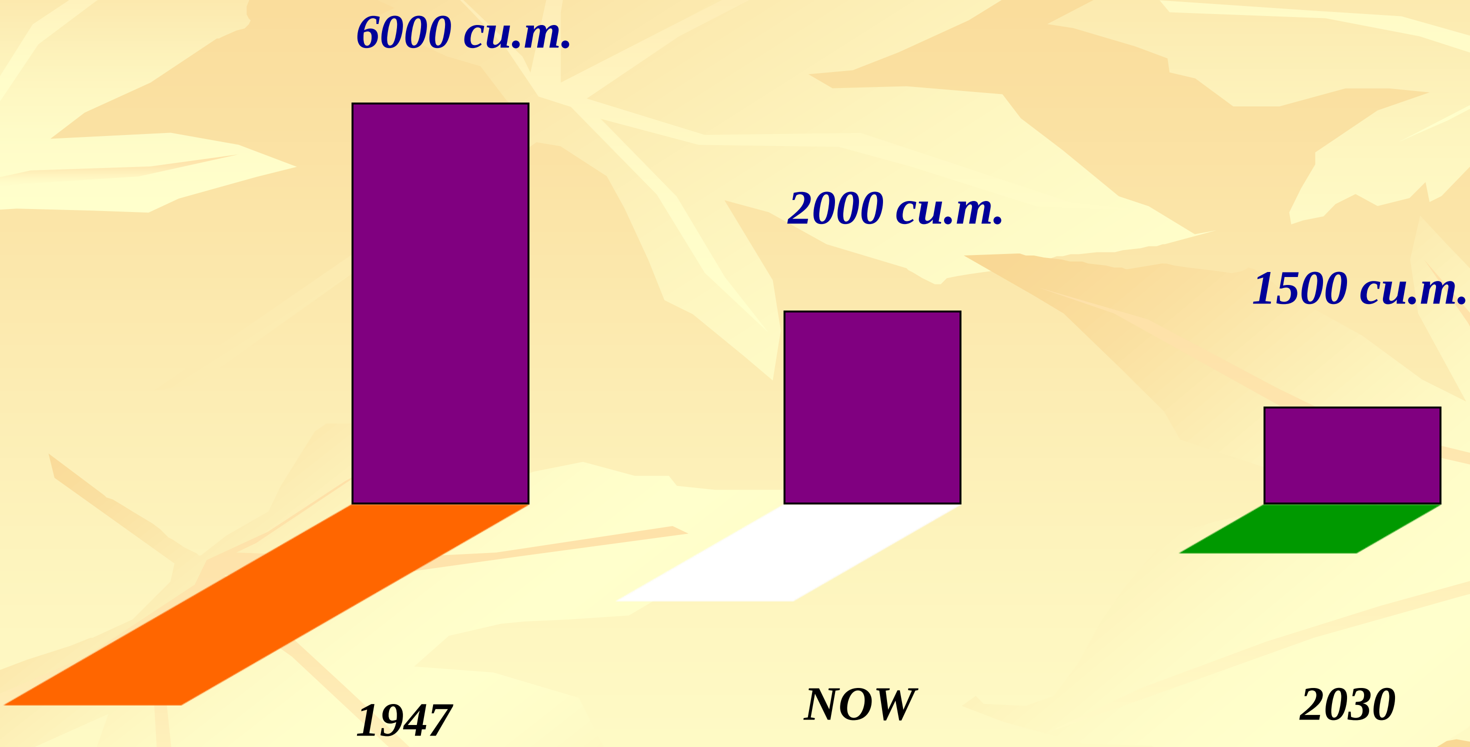
200 crores people do not have proper drinking water

Water demand goes up by **TWO times** in each decade

23 countries are facing severe problem of drinking water

Out of which **18 countries** are facing drought conditions

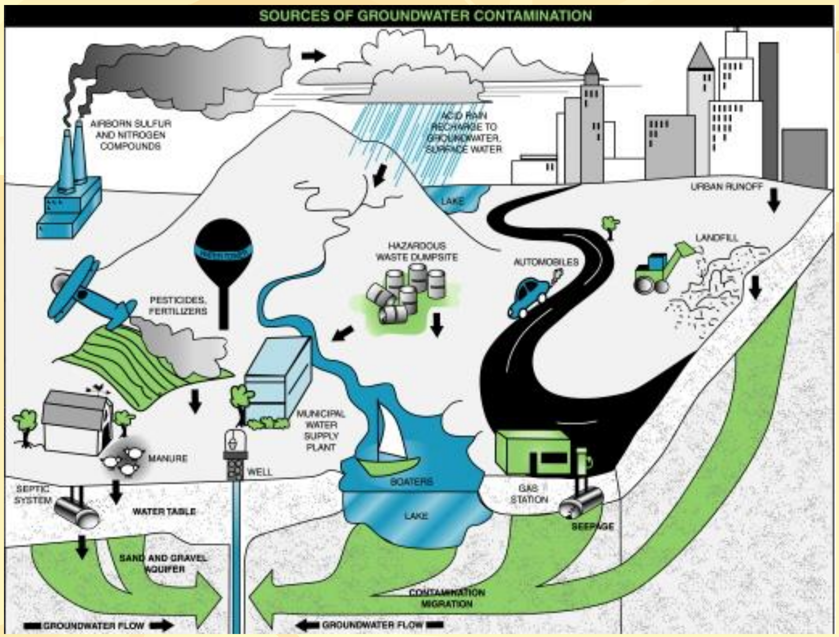
Water Resources per Capita

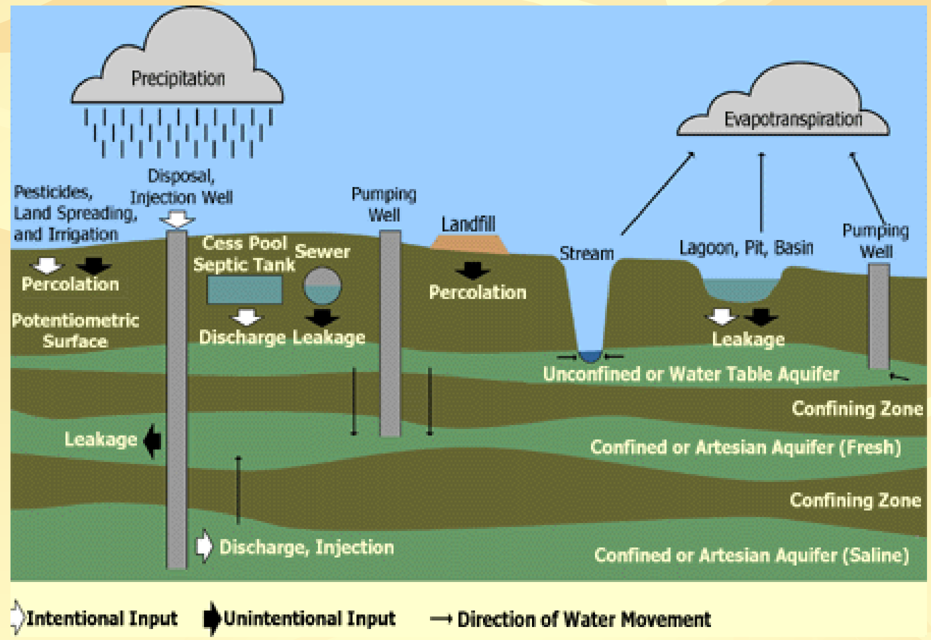


Contamination can enter the water bodies through one or more of the following ways:

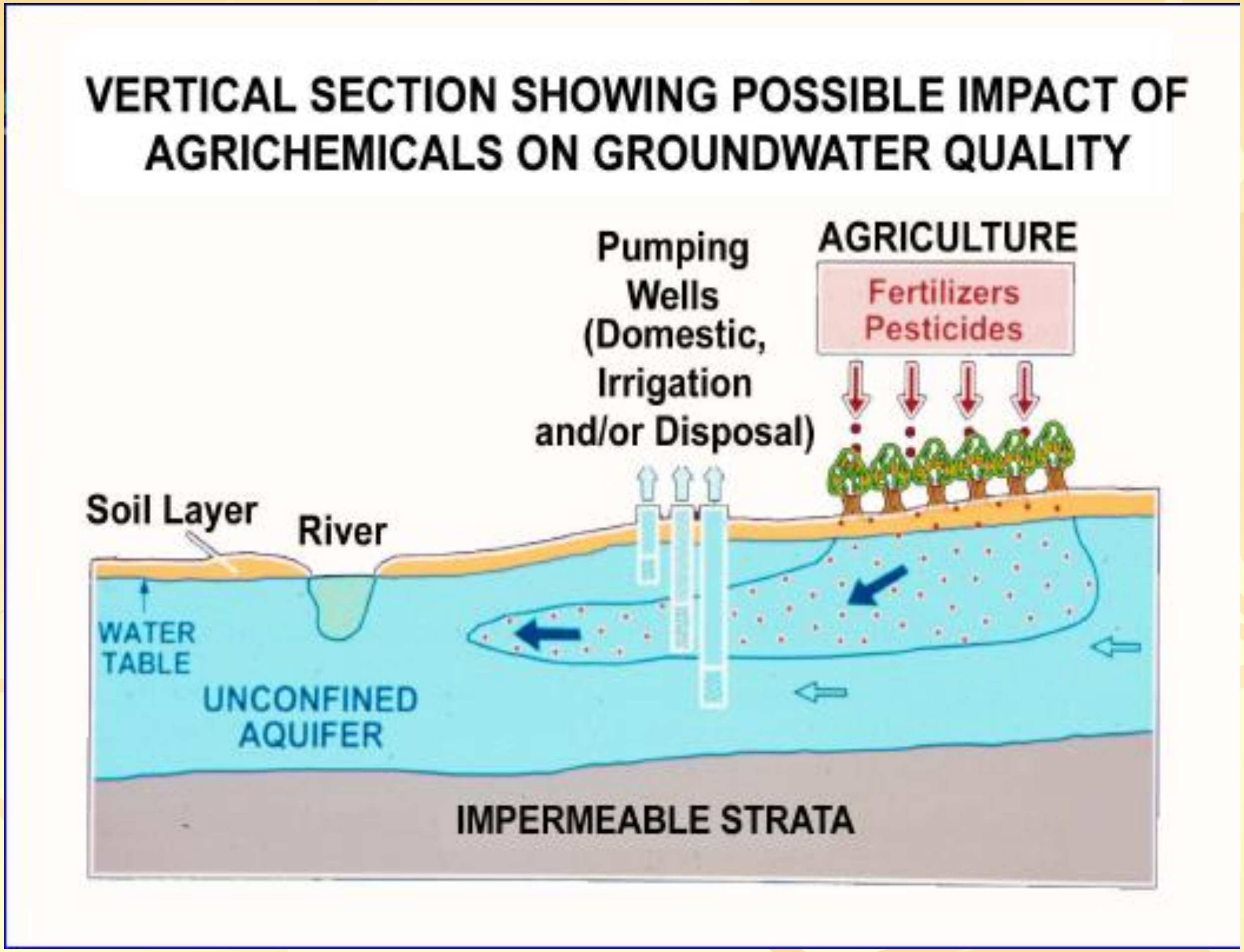
- Direct point sources: Transfer of pollutants from municipal industrial liquid waste disposal sites and from municipal and household hazardous waste and refuse disposal sites.
- Diffuse agricultural sources: Wash off and soil erosion from agricultural lands carrying materials applied during agricultural use, mainly fertilisers, herbicides and pesticides.
- Diffuse urban sources: Run off from city streets, from horticultural, gardening and commercial activities in the urban environment and from industrial sites and storage areas.

Sources of Groundwater Contamination

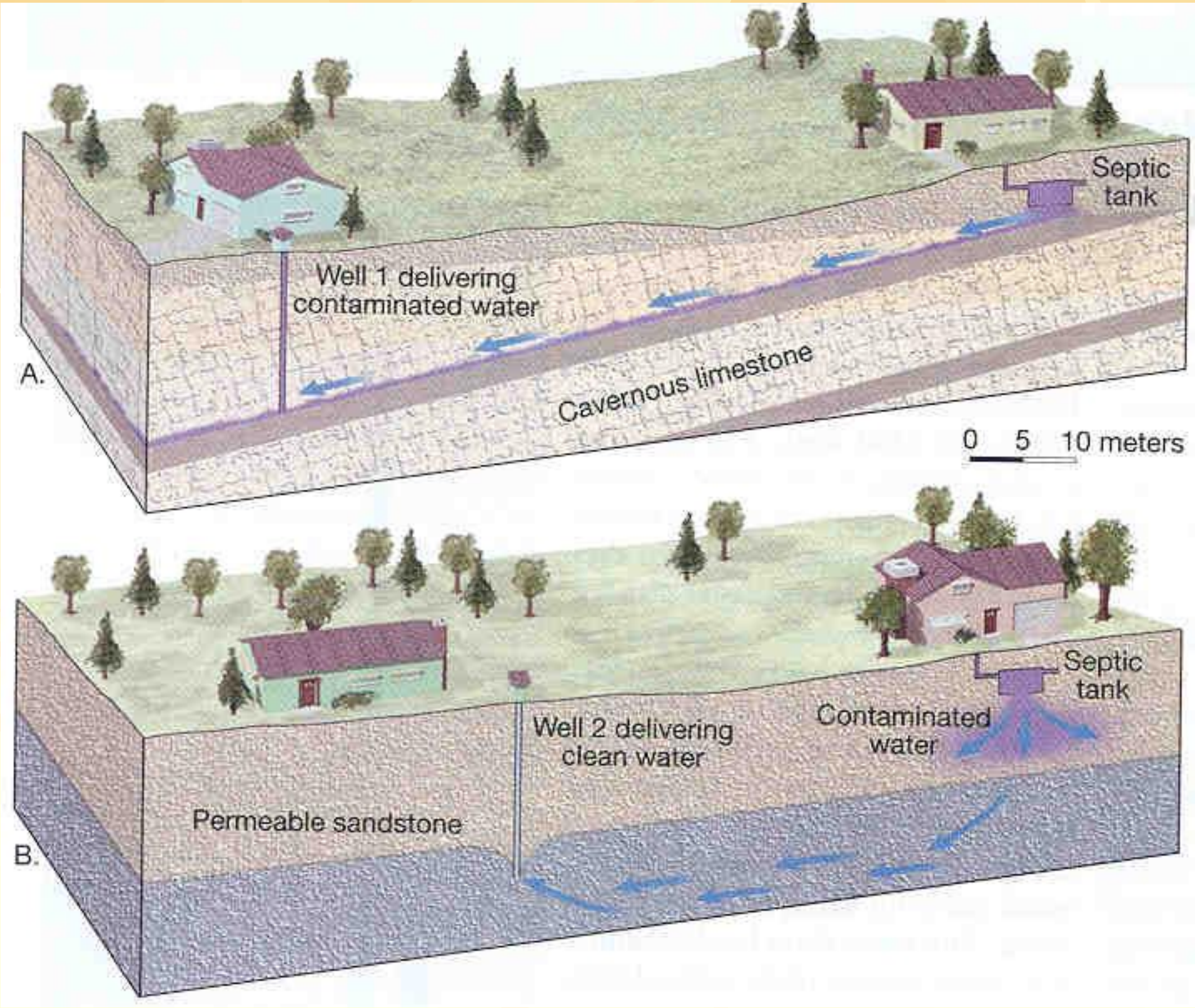




Source: www.woodstockconservation.org

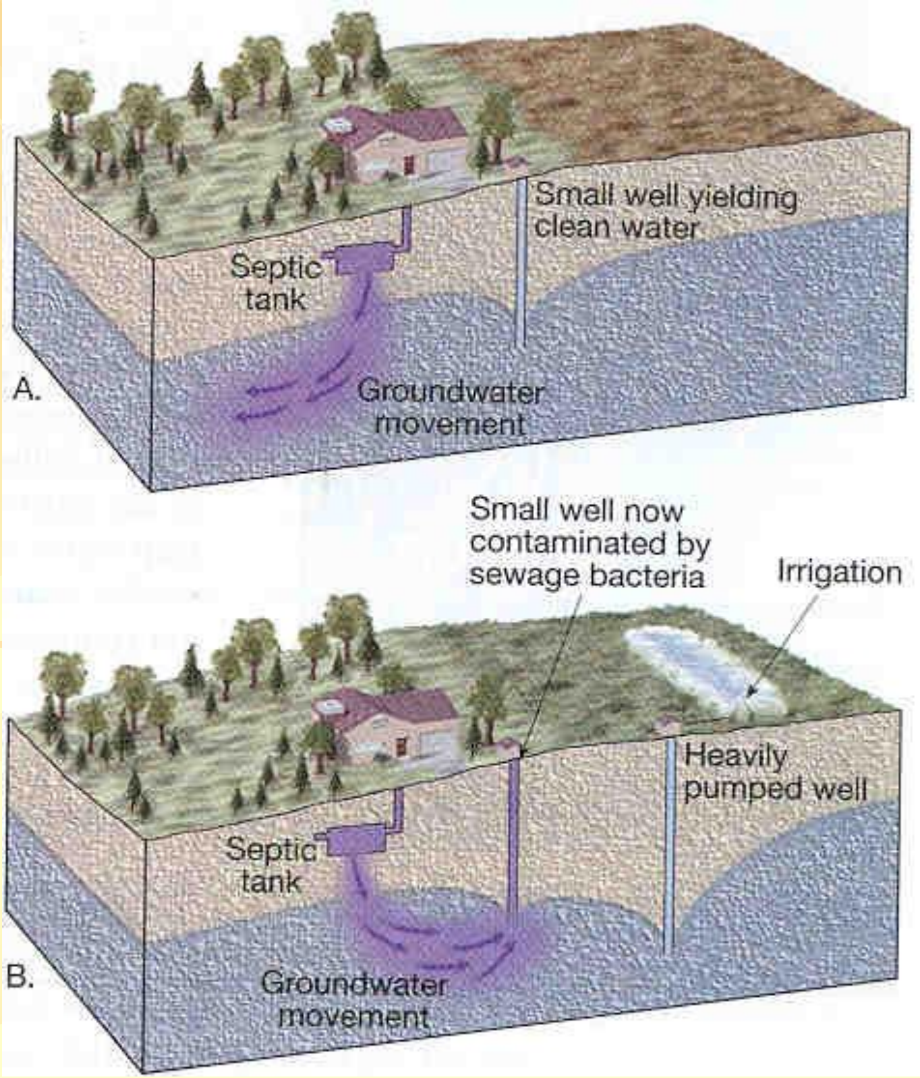

VERTICAL SECTION SHOWING POSSIBLE IMPACT OF
AGRICHEMICALS ON GROUNDWATER QUALITY
Pumping
Wells
(Domestic,
Irrigation
and/or Disposal)
AGRICULTURE
Fertilizers
Pesticides
Soil Layer
River
WATER
TABLE
UNCONFINED
AQUIFER
IMPERMEABLE STRATA

Groundwater contamination (due to human causes)



Source: **http://fouch101.asu.edu**

- Groundwater contamination (due to human causes)



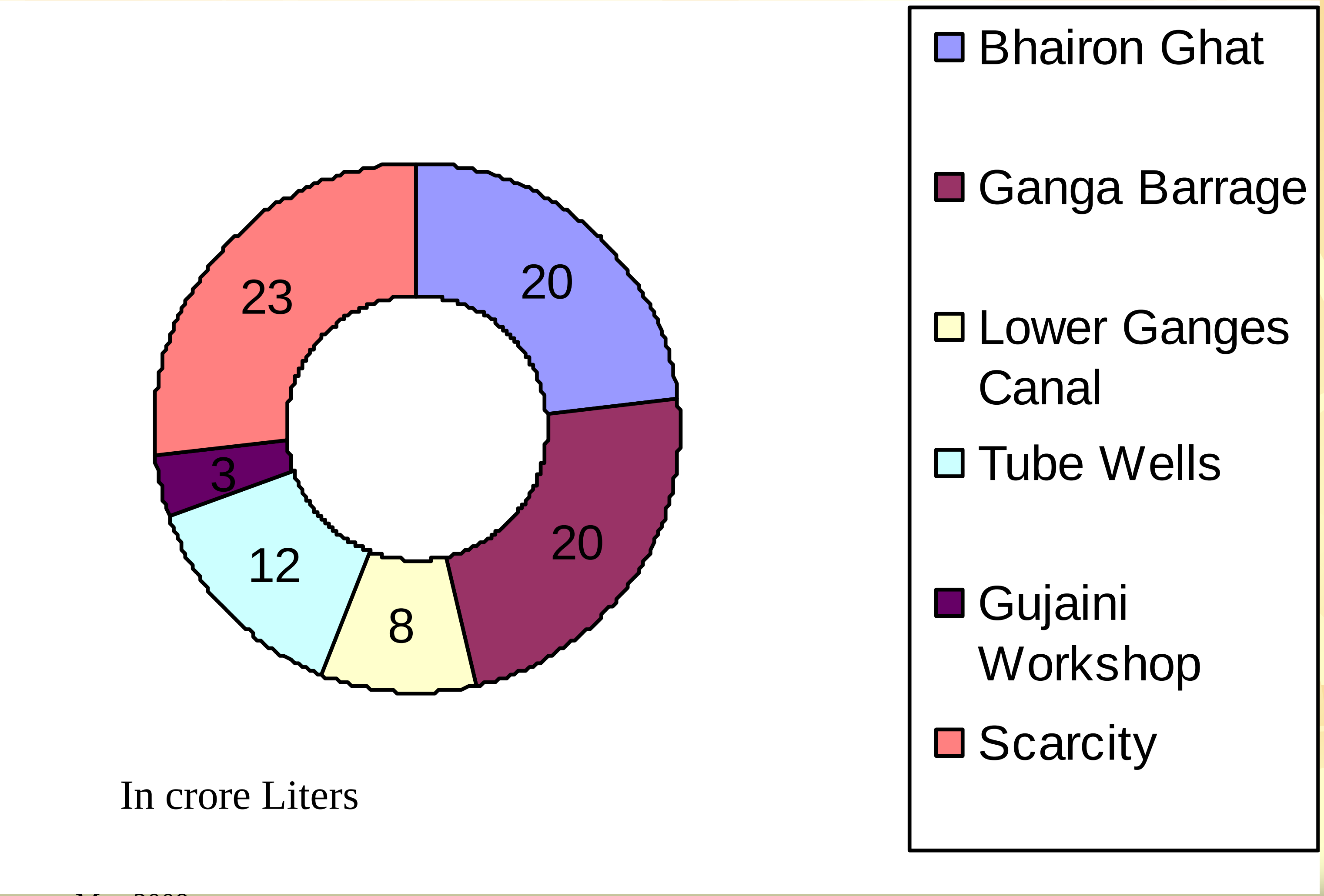
Source: **http://fouch101.asu.edu**

- Groundwater contamination (due to human causes)

Source: **http://fouch101.asu.edu**

Our Kanpur City

Our Daily Need :



Source: Dainik Jagran, May 2008

Reality

Ganga Barrage – Scarcity of 18 cr. Lts

Lower Ganga Canal – Scarcity of 2 cr. Lts.

Gujaini Workshop – Scarcity of 1.8 cr. Lts.

- Leakage of 8 cr. Lts.
- Due to Power cut 2 cr. Lts.

TOTAL LOSS: 41 Lts.

Source: Dainik Jagran, May 2008

Problems and contamination

Land subsidence

- The removal of water allows the aquifer sediments to compact.
- Once compacted, the overlying unsaturated zone sediments will also drop in elevation.

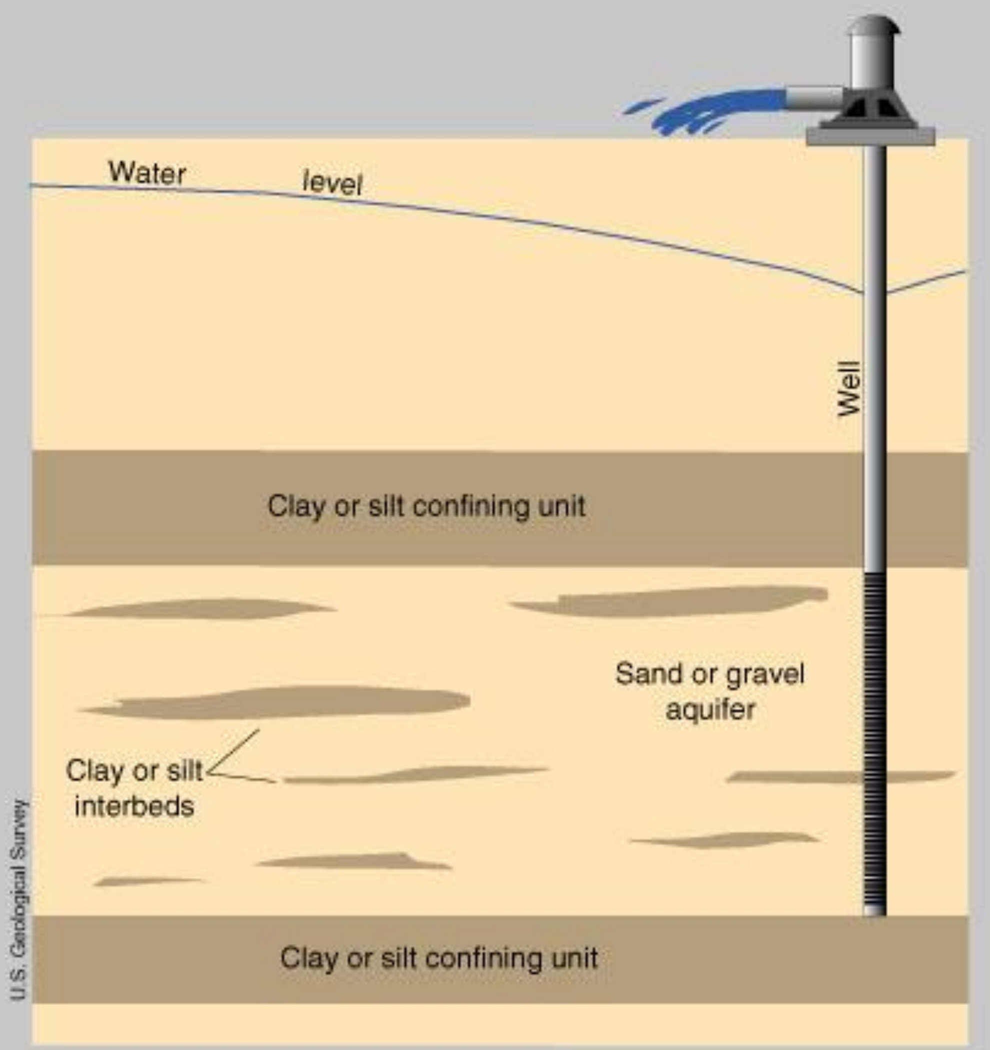
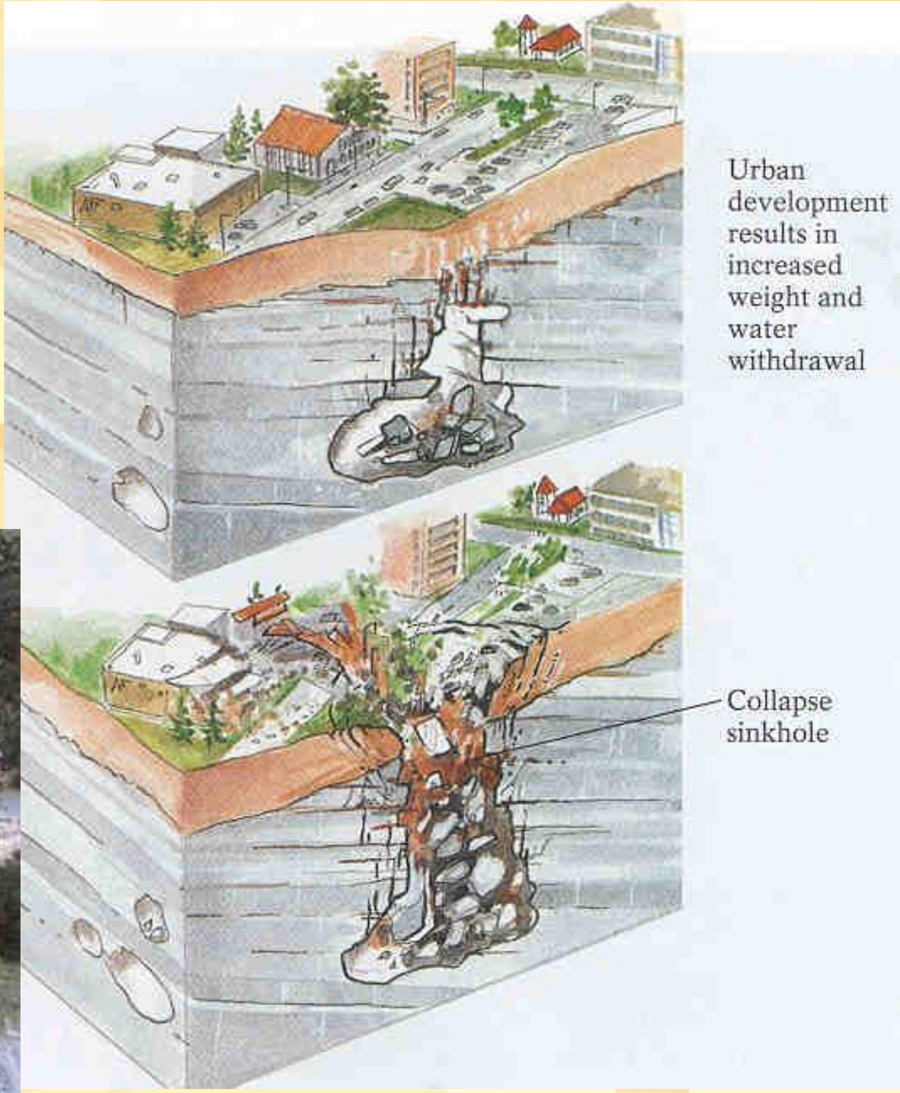


Figure 2. An aquifer system susceptible to compaction that results in land subsidence. Release of water from clay and silt confining units and interbeds causes a reduction in thickness of these compressible sediments.

Sink holes

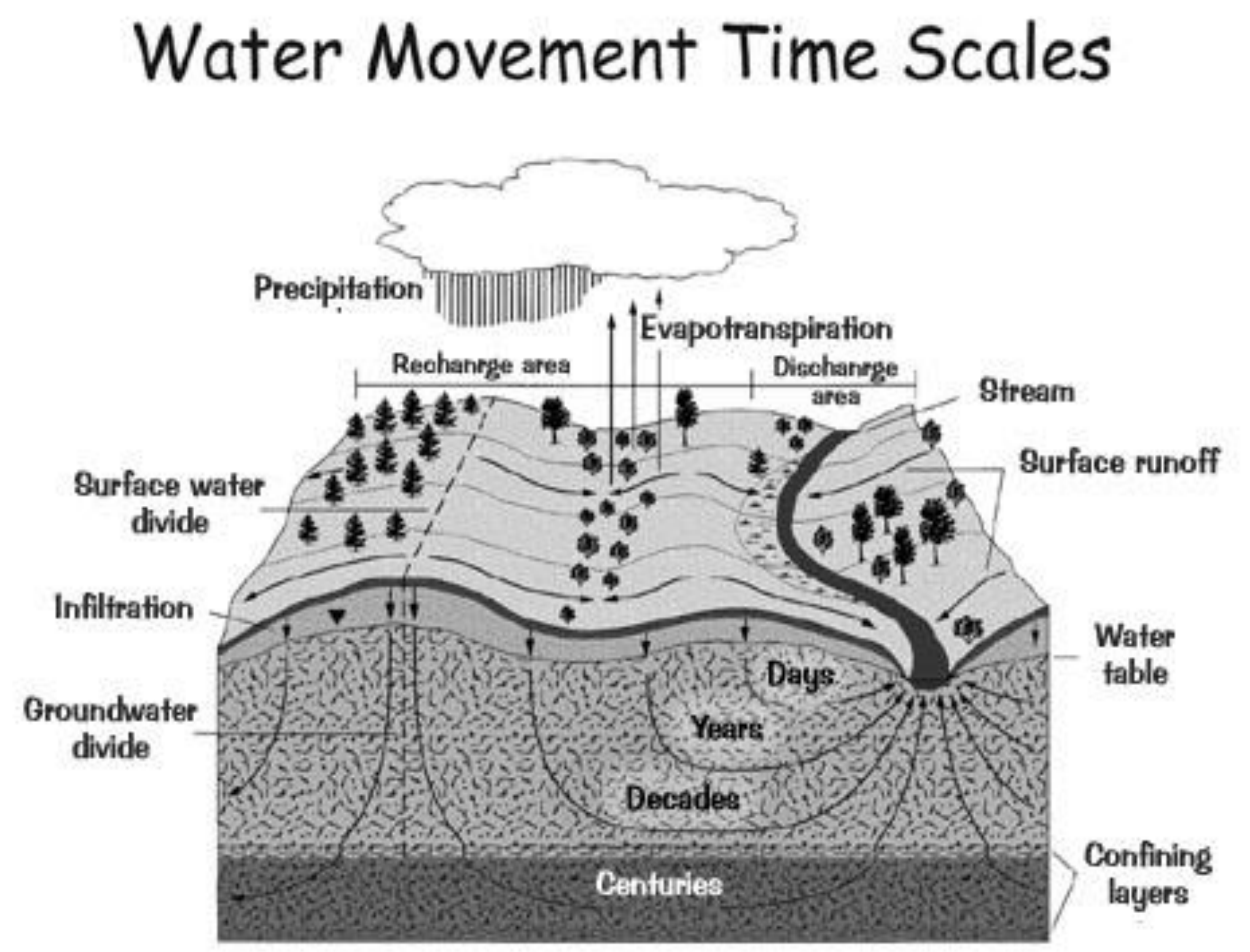
Source: **http://fouch101.asu.edu**

Sink holes


Urban development results in increased weight and water withdrawal
Collapse sinkhole

Groundwater recharge and discharge takes time

- The rate of movement of groundwater depends on many factors including the flowpath.



Source: **http://fouch101.asu.edu**

EFFECT OF DECREASING GROUND WATER

- ❖ Installation of tube well and water lifting devises will be costlier.
- ❖Irrigation cost will increase.
- ❖More consumption of electricity and diesel.
- ❖Adverse effect on crop production and productivity.
- ❖Scarcity of water for domestic and industrial use.
- ❖Imbalance of Ecology and environment .
- ❖Decrease in Bio-mass production.

Nat. Conf. Rabi, Dept. of irrigation U.P., 2004

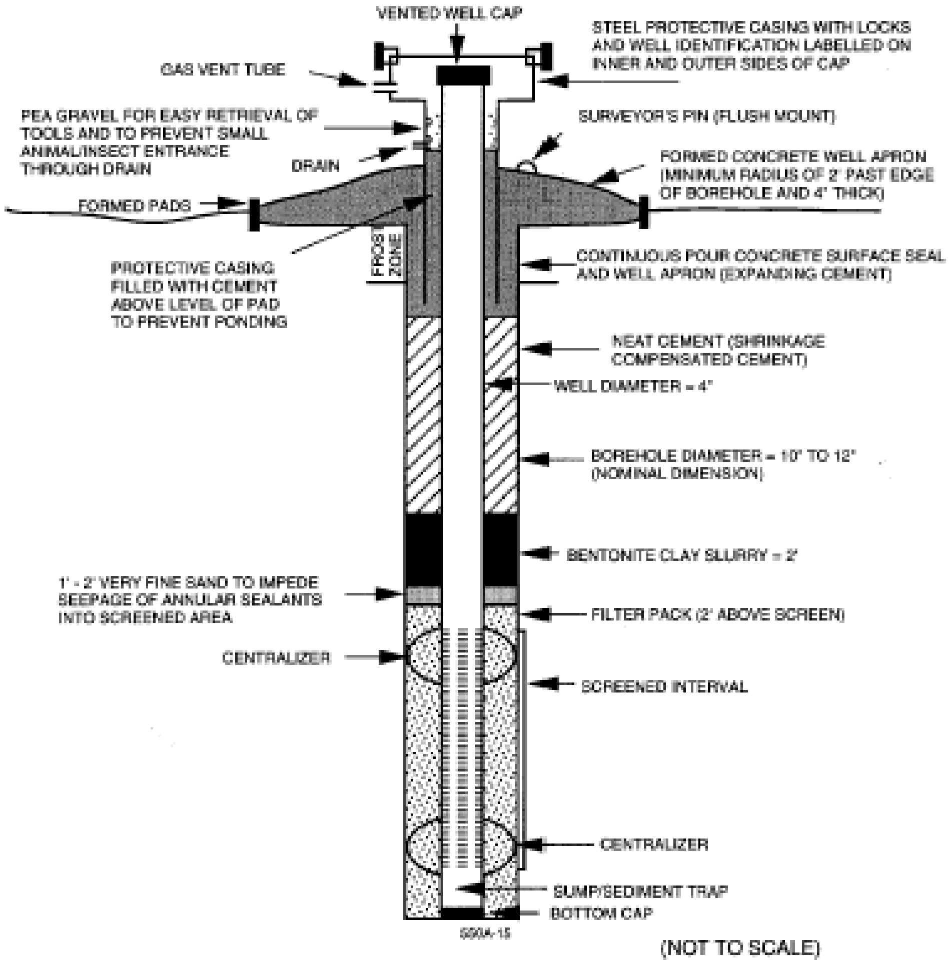
Groundwater Monitoring

- Selection of sampling points and
- Temporal sampling frequency

To determine:

physical, chemical, and
biological characteristics of groundwater.

MONITORING WELL



CROSS-SECTION OF TYPICAL MONITORING WELL

Motivation

- Designing effective and efficient LTM plans can be difficult, especially at sites with any of the following:
  - Many wells
  - Many possible constituents that could be sampled
  - Different types of samples with different costs and effectiveness
    - Traditional well-based samples
    - Indicator samples
    - Sensor data
- Mathematical optimization can help in identifying effective plans

Why Optimize?

- The number of possible sampling plans in one monitoring period is

$$2^m$$

where m is the product of

  - Number of possible sampling locations
  - Number of constituents at each well
  - Number of types of samples

Why Optimize (Contd.)?

- For example, a site with 10 wells and 3 possible constituents to measure at each well would have

  2^{30} or 1 billion!

  possible sampling plans
- Any trial-and-error method is unlikely to identify the most effective sampling plans
- Mathematical optimization can efficiently identify the most effective sampling plans to satisfy any monitoring objective that can be quantified

Components of an optimization formulation

- **Decision Variables:**

  What we are determining optimal values for?

- **Objective function:**

  1. Values can be computed once the value of each decision variable is specified.
  2. The mathematical equation being minimized or maximized.
  3. Serves as the basis for comparing one solution to another.

- **Constraints:**

  Limits on values of the decision variables, or limits on other values that can be calculated once the value of each decision variable is specified

Global Optimization Technique: SIMULATED ANNEALING

SA method resembles the cooling process of molten metals through annealing.

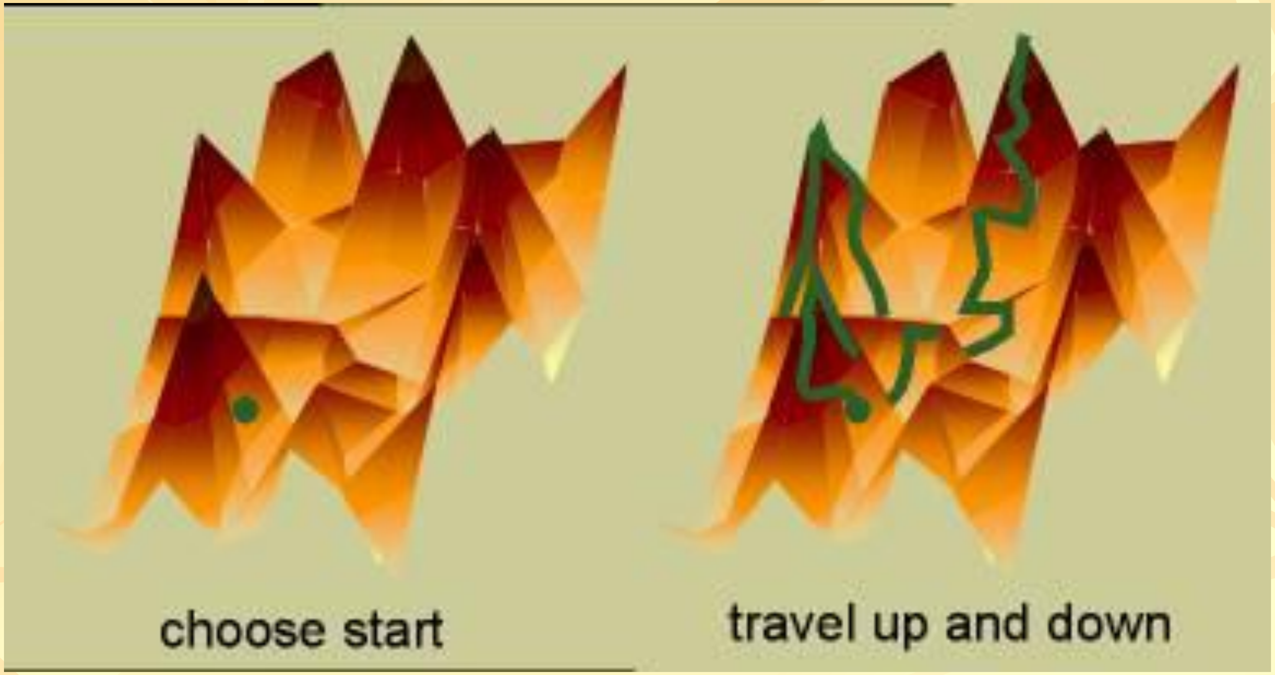
At HIGH Temperature:

Atoms in molten metals can move freely (Random)

At LOW Temperature:

Atoms get ordered; form Crystals having minimum possible energy.

Search Process



Boltzmann Probability : $P(E) = \exp(-E/kT)$

Source:biology.st-andrews.ac.uk/.../simanneal.png

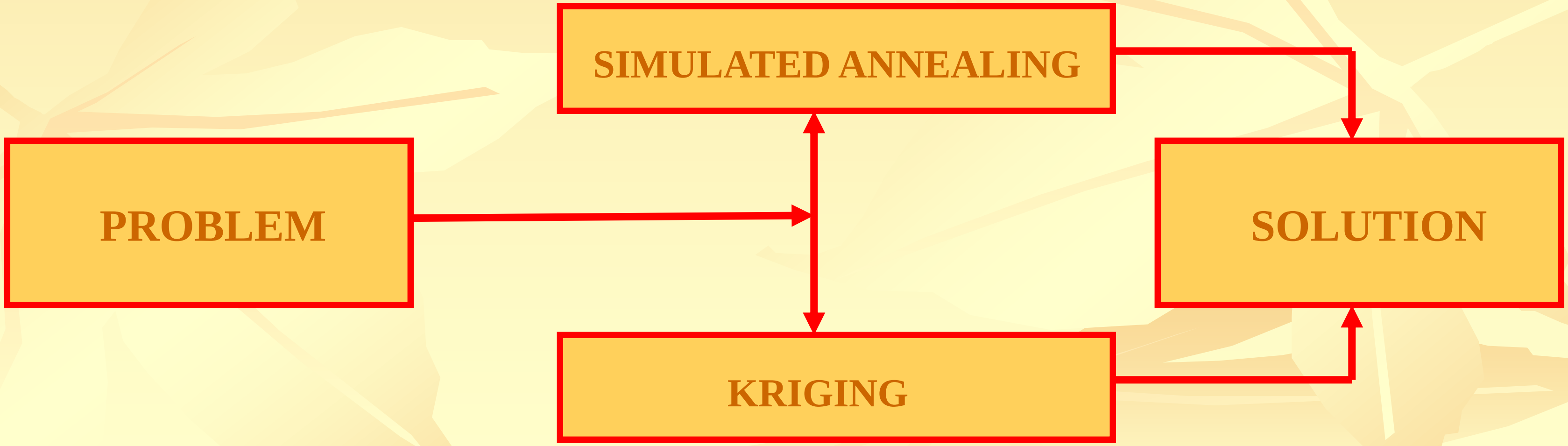
Geostatistical Kriging

What's Spatial interpolation

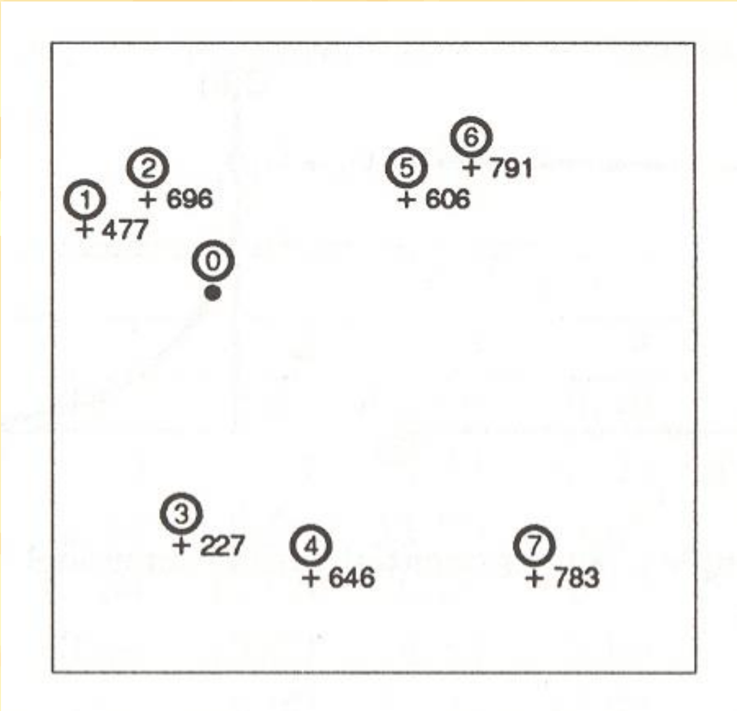
- Spatial interpolation is the process of using points with known values to estimate values at other points.
- Spatial interpolation is therefore a means of creating surface data from sample points.

Linked SA and Kriging Technique

This technique is developed by
Prof. Bithin Datta
Indian Institute of Technology, Kanpur
and
Dr. Deepesh Singh
Harcourt Butler Technological Institute, Kanpur



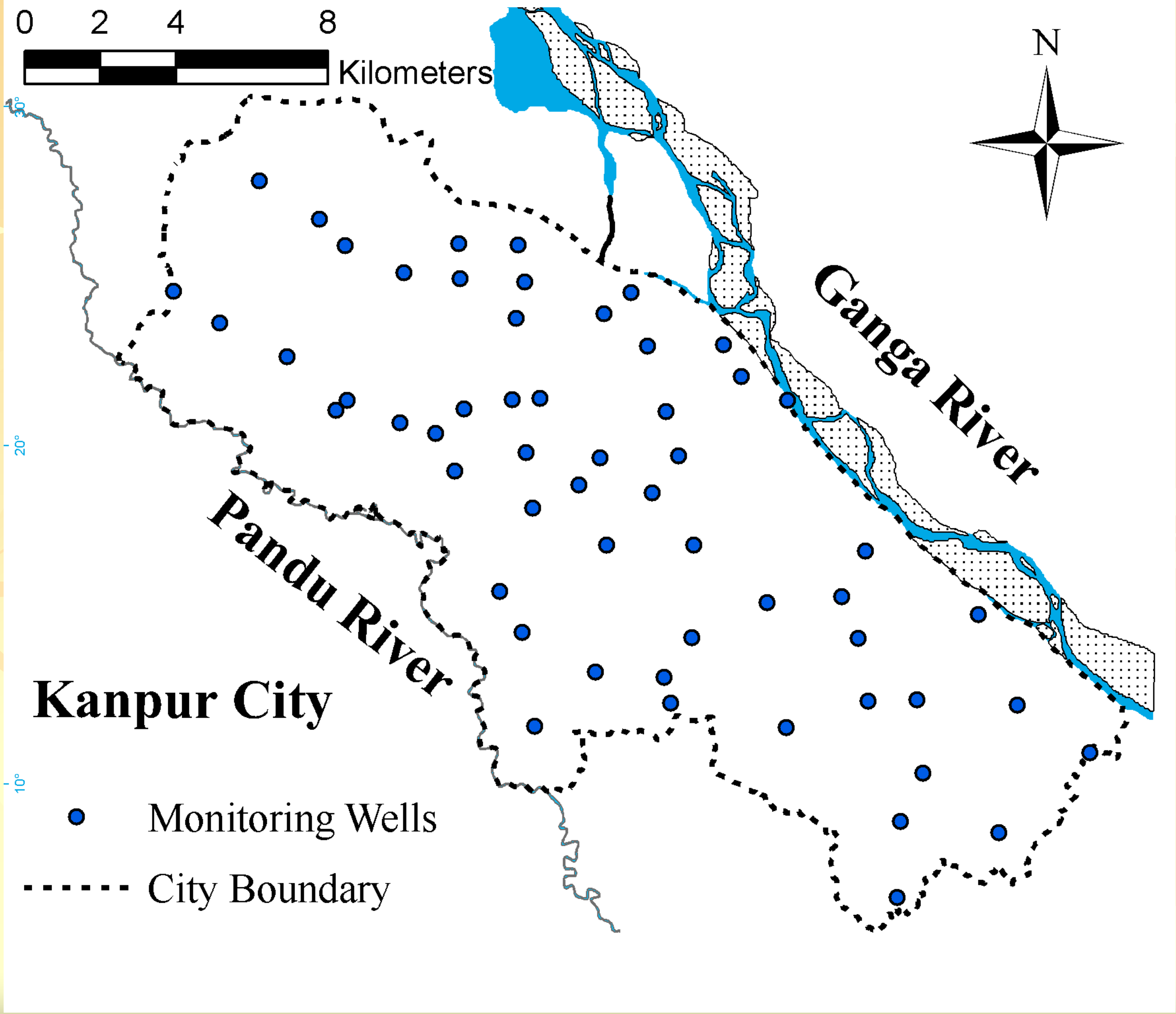
Numeric example of kriging



	Sample No.	X	Y	V	Distance from 65E,137N
1	225	61	139	477	4.5
2	437	63	140	696	3.6
3	367	64	129	227	8.1
4	52	68	128	646	9.5
5	259	71	140	606	6.7
6	436	73	141	791	8.9
7	366	75	128	783	13.5

In this example, we want to estimate a value for point 0 (65E, 137N), based on the 7 surrounding sample points. The table indicates the (x,y) coordinates of the 7 sample points, their corresponding values of V (which is the variable we are interested in) and their distance to point 0.

Kanpur


0 2 4 8
Kilometers
N
Ganga River
Pandu River
Kanpur City
Monitoring Wells
City Boundary

Groundwater Pollution in Kanpur

Large number of industries: Leather, Textile, Jute and Chemical

Unplanned disposal:

- Domestic Waste and

- Discharge of untreated or partially treated effluents by the industries directly on land or in Ganga river are resulting into pollution of surface and sub-surface water.

The ranges of chromium concentration in water of phreatic aquifers in these localities are as below.

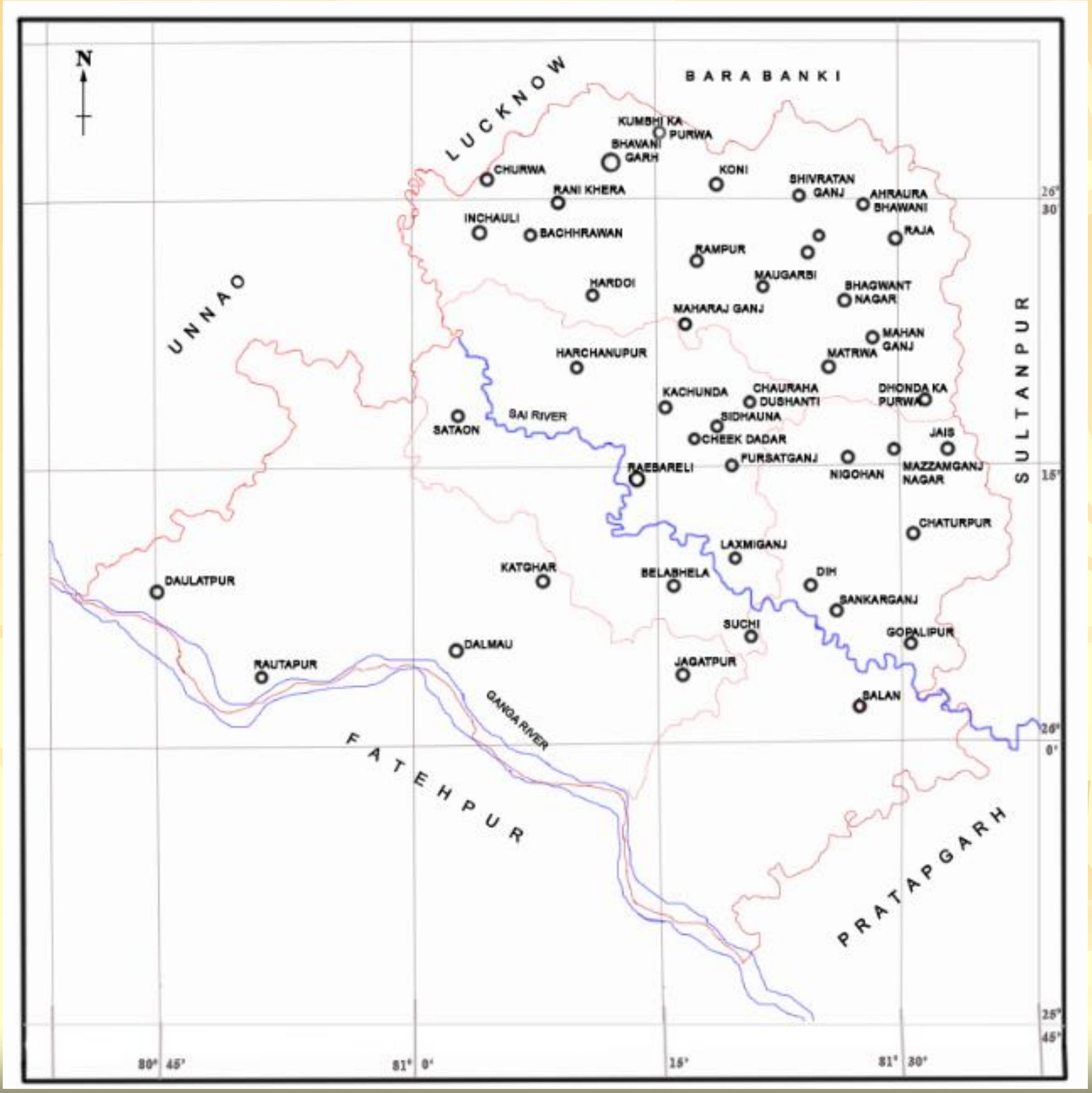
- Baburia : 0.510-7.223 mg/l
- Rakhi Mandi : 0.007-10.00 mg/l
- Fazalganj : 0.005-6.35 mg/l
- Jajmau : 0.003-0.132 mg/l
- Nauriya Khera : 0.008-8.00 mg/l (Panki Thermal)

The main source of chromium concentration in ground water being the industrial effluents from Leather, Textile etc.

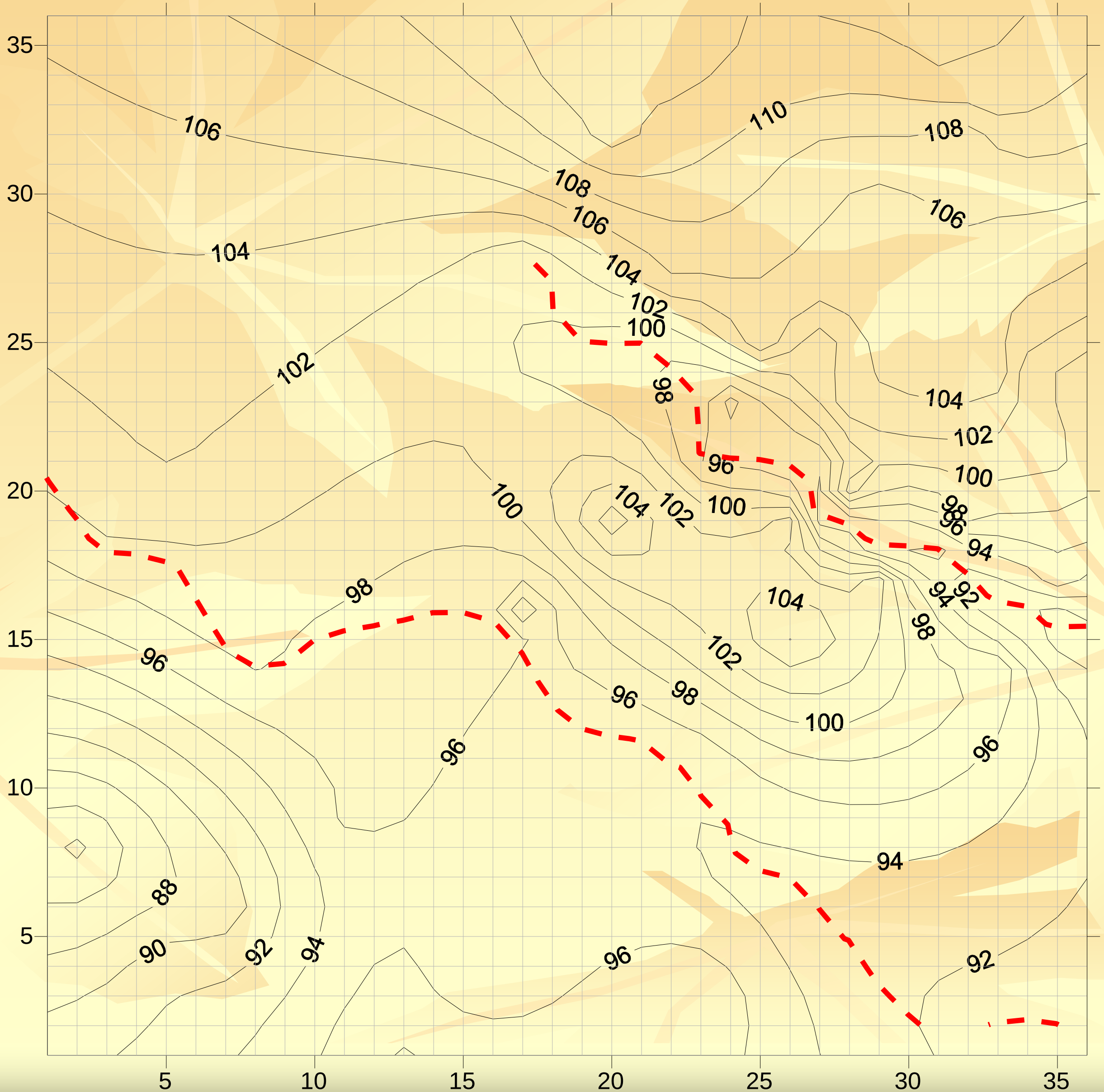
ALARMING !!

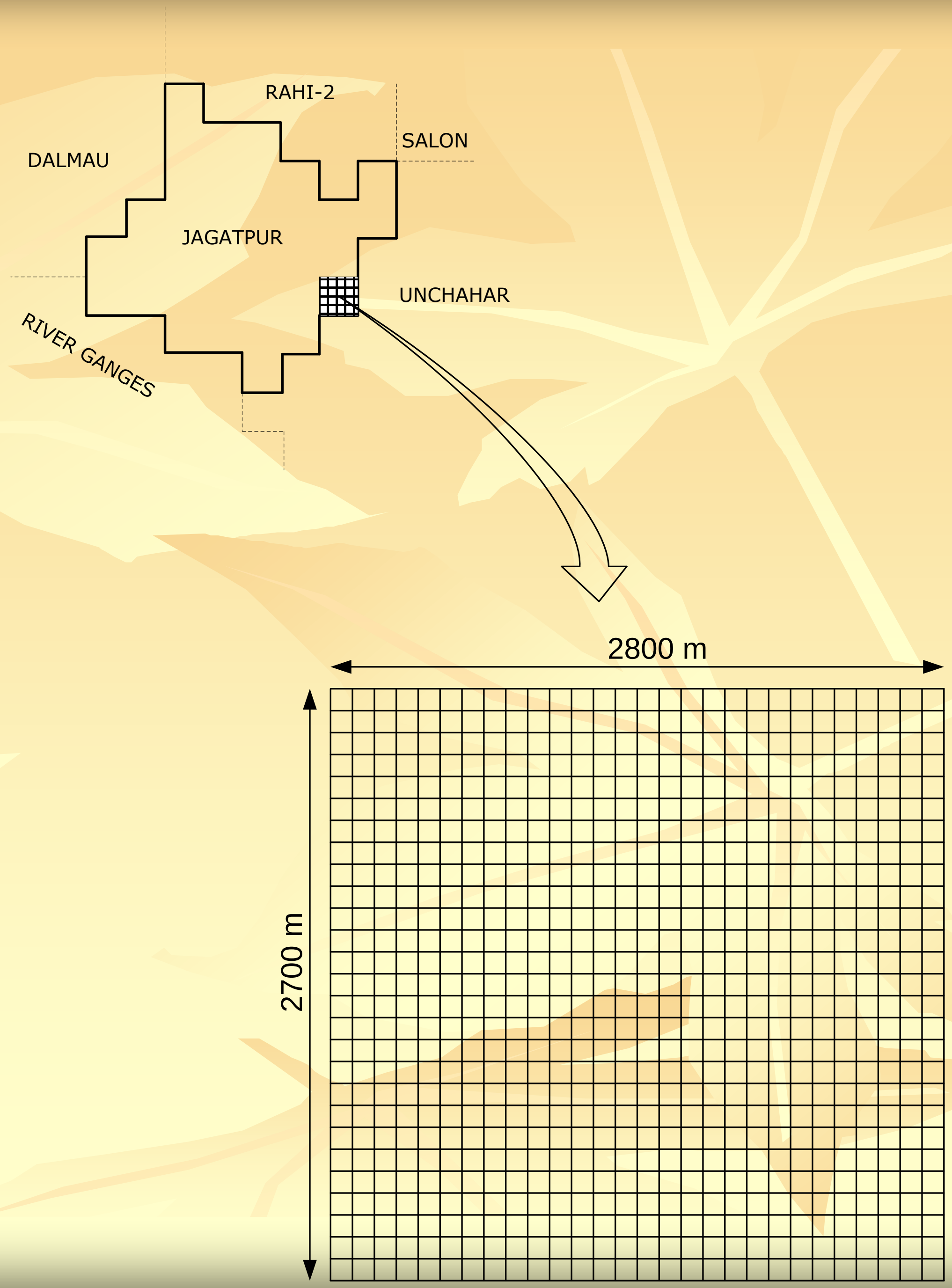
- Chromium is the most toxic water pollutant.
- The concentration above 0.05 mg/l in drinking water may prove detrimental to human health.
- The higher concentration of chromium may cause cancer of lungs, nasal cavity and paranasal sinus, stomach and larynx. Skin decolourization and peptic ulcer are common disease in the inhabitants of this area.

Case Study

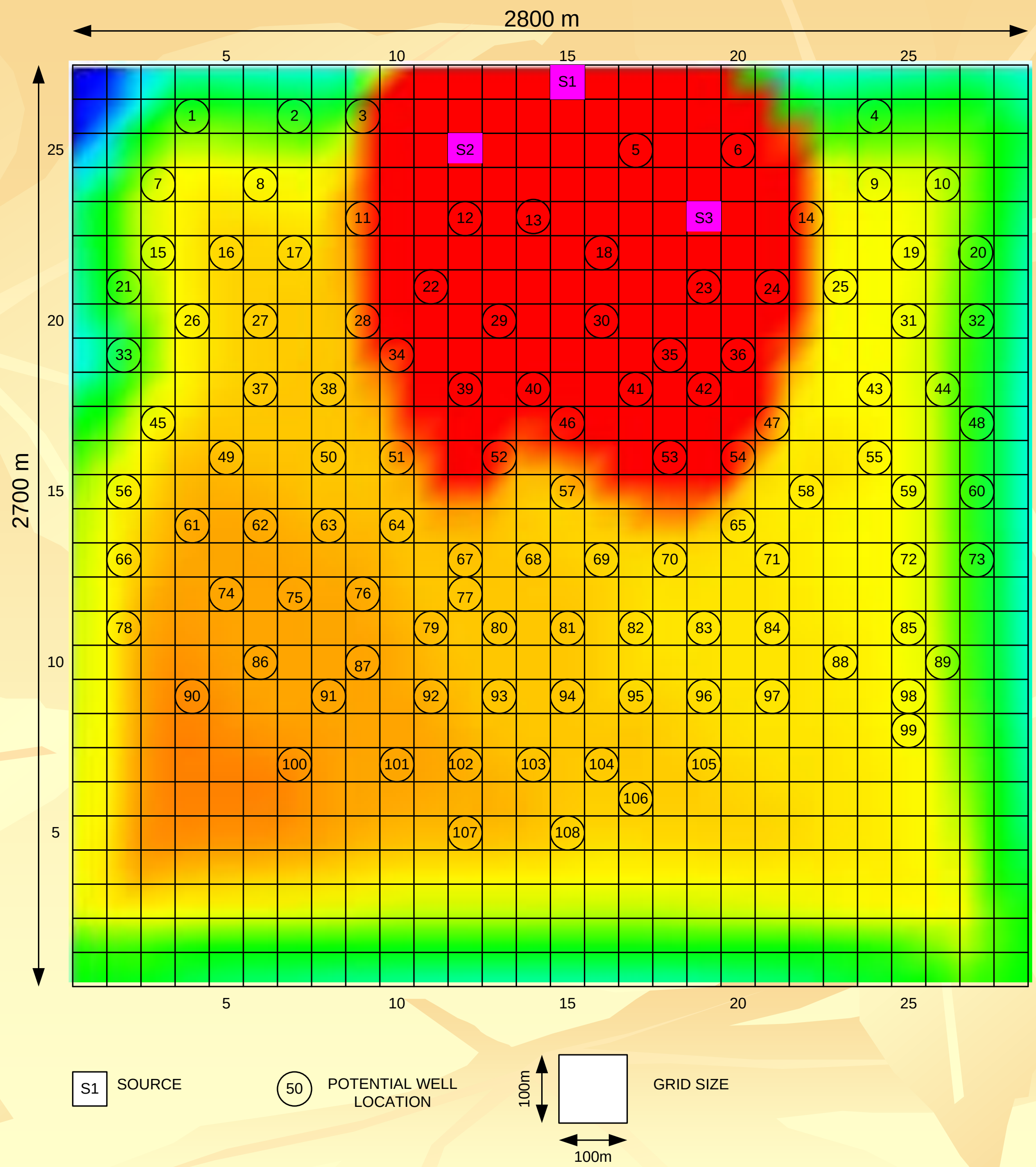

N
LUCKNOW
BARABANKI
UNNAO
SULTANPUR
FATEHPUR
PRATAPGARH
KUMBHI KA PURWA
BHAWANI GARH
CHURWA
RANI KHERA
KONI
SHIVRATAN GANJ
AHRAURA BHAWANI
INCHAULI
BACHHRAWAN
RAJA
RAMPUR
MAUGARBI
HARDOI
BHAGWANT NAGAR
MAHARAJ GANJ
MAHAN GANJ
MATRWA
HARCHANUPUR
KACHUNDA
CHAURAHA DUSHANTI
DHONDA KA PURWA
SATAON
SAI RIVER
SIDHAUNA
CHEEK DADAR
JAIS
RAEBARELI
FURSATGANJ
NIGOHAN
MAZZAMGANJ NAGAR
CHATURPUR
LAXMIGANJ
KATGHAR
BELABHELA
DIH
DAULATPUR
SANKARGANJ
SUCHI
GOPALIPUR
DALMAU
RAUTAPUR
JAGATPUR
GANGA RIVER
BALAN
80° 45'
81° 0'
15'
81° 30'

Groundwater Table

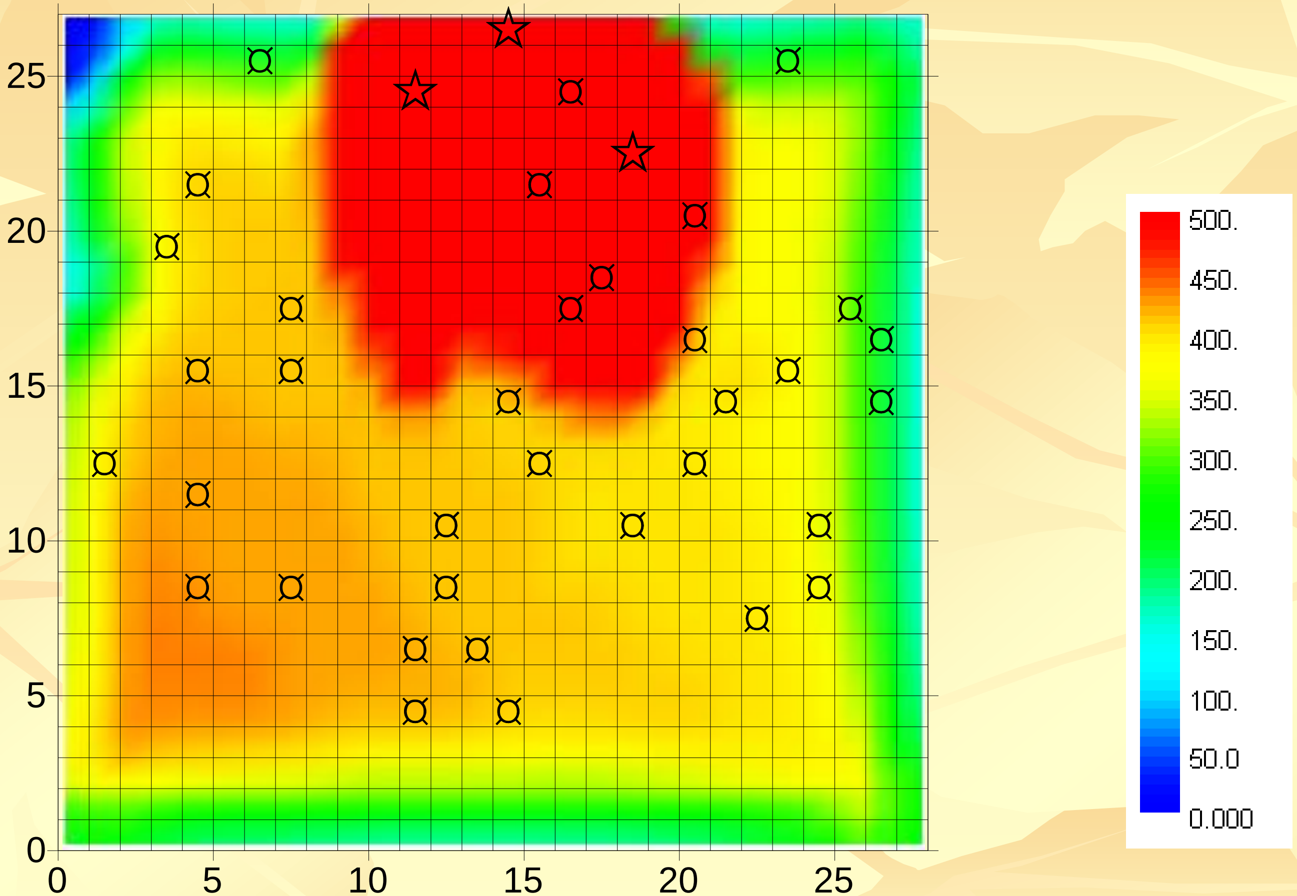



RAHI-2
SALON
DALMAU
JAGATPUR
UNCHAHAR
RIVER GANGES
2800 m
2700 m

Study Area

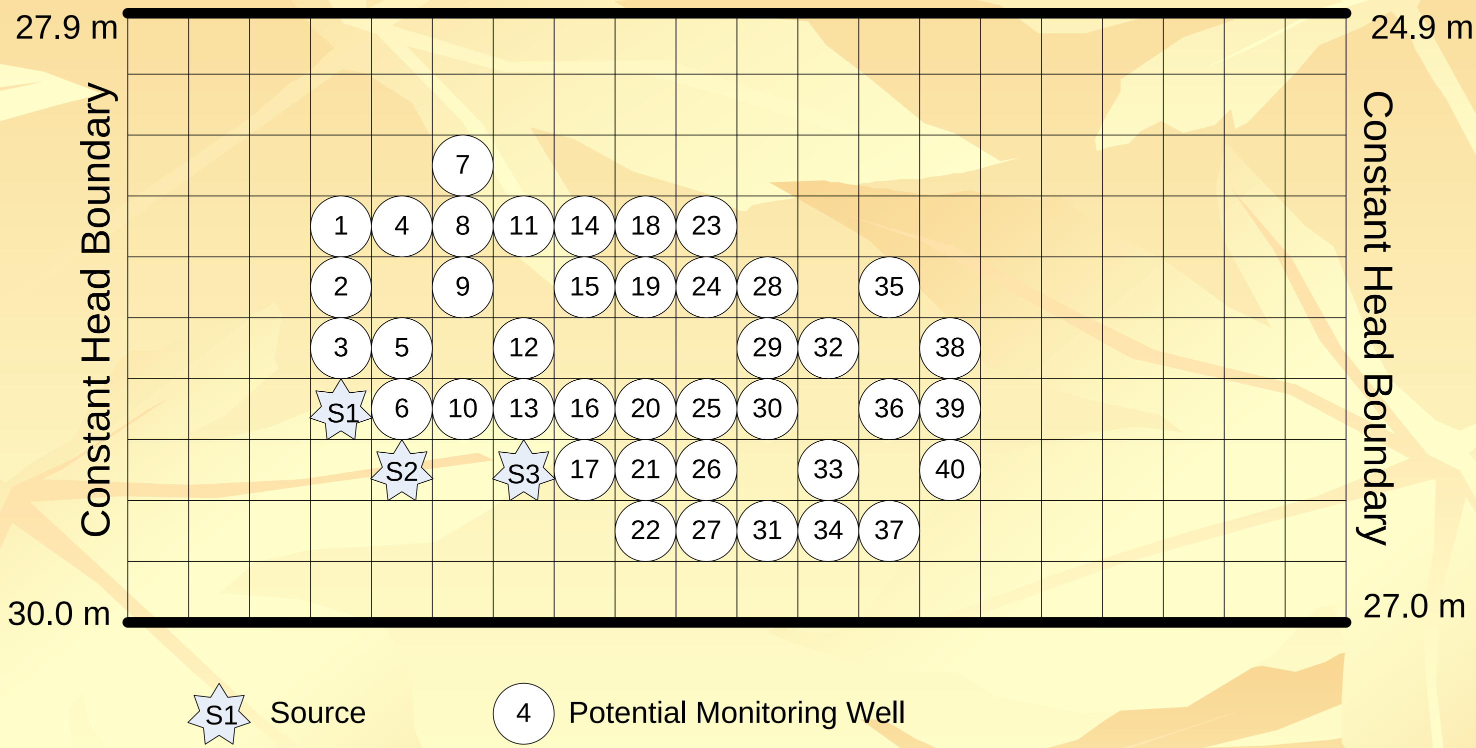


Study area showing locations of sources and potential monitoring wells



Optimal location of monitoring wells for design set of 35 wells

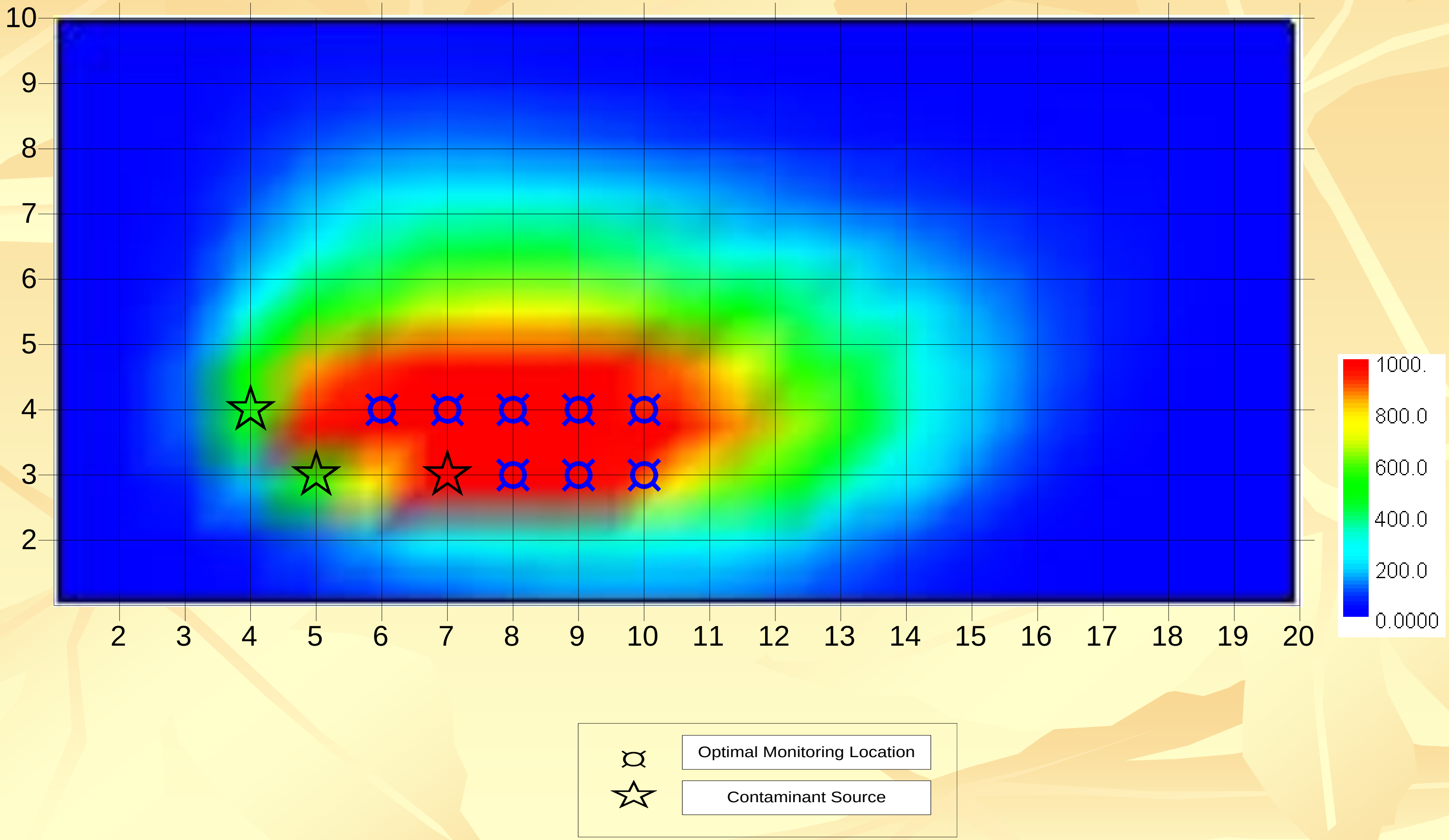
Another Study Area for Analysis



Data Required for Dynamic Design

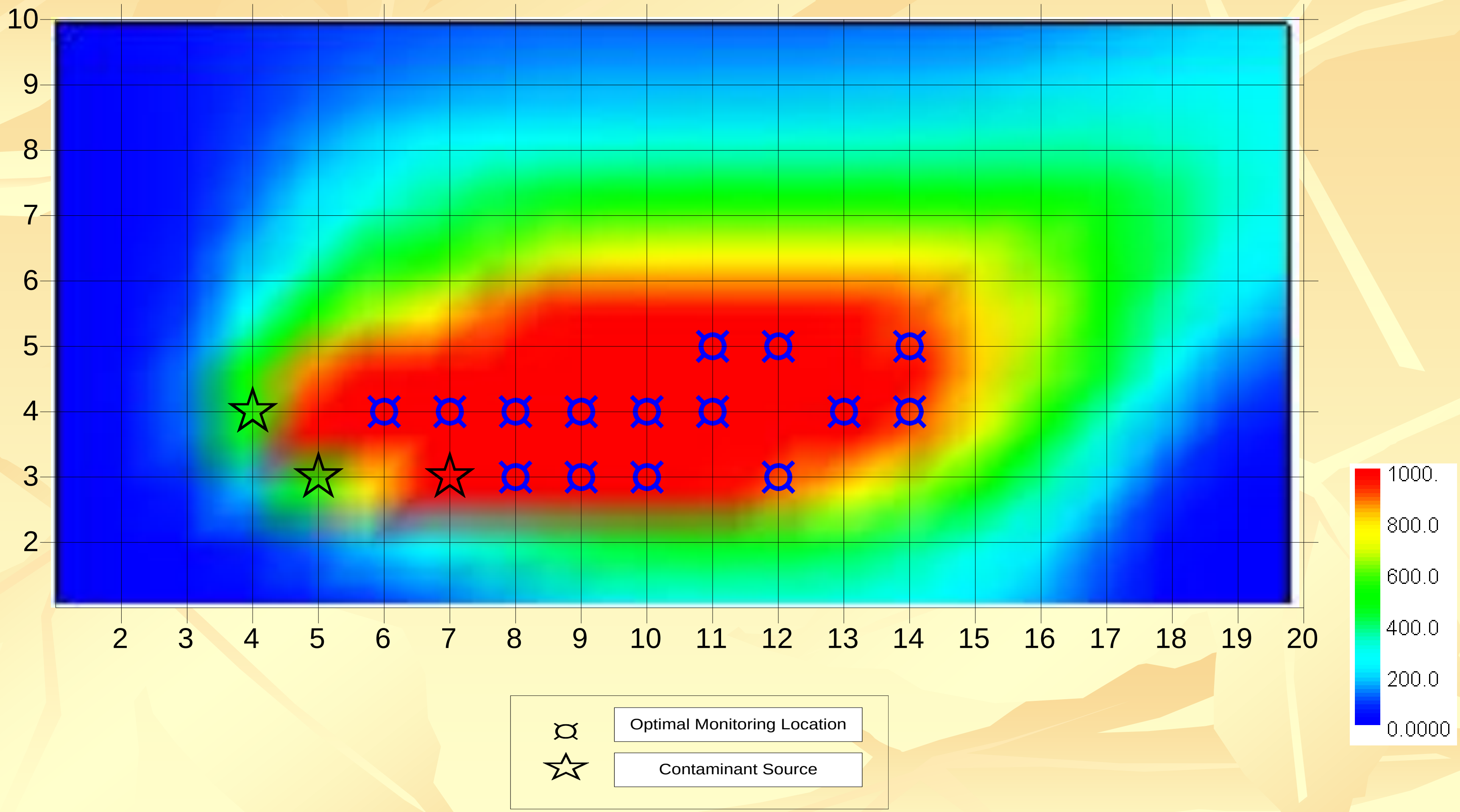
Parameter	**Value**
Initial concentration	0.0 mg/l
Storage coefficient	0.001
Ratio of transverse dispersivity to longitudinal dispersivity	0.30
Hydraulic conductivity	1×10^{-3} m/s
Aquifer thickness	20 m

management period I



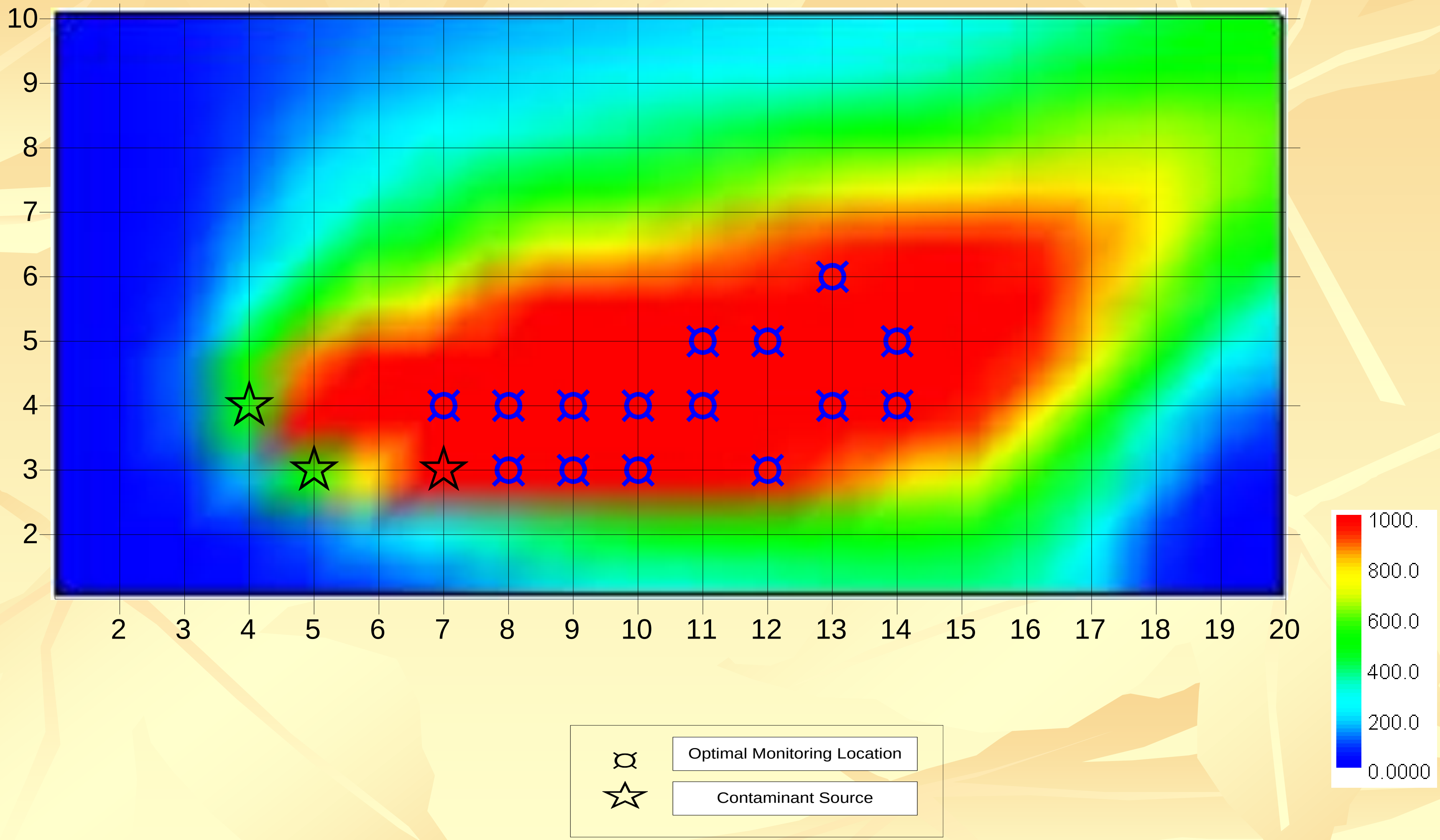
Optimal location of 8 wells

management period II



Optimal location of 15 wells

management period III



Optimal location of 15 wells

Conclusions

- Broad application of technique, on Groundwater Quality Modeling.
- The objective function can cover the desired input to the plans.
- The Optimization technique gives the best possible solution.

THANKS !!