TD 603
Water Resources

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Lecture 7: Regional Groundwater Flow

Regional Analysis

Typical groundwater flows are more complicated than the unit situations that we saw.

- Surface water/Groundwater interactions.
  - lakes and streams
  - springs (seepage)
- Ambient water-table movements
  - Seasonal changes
  - Inteference with other water end-users.
- Inherent Complexity
  - aquifer characteristics
  - extraction and use, rain, surface cover etc.

Typical First Step:

A gross qualitative understanding. This may be done by plotting regional iso-head lines, flow-lines and water-table heights. This will help uncover the basic structure of the regional water flows.

- iso-head: surfaces of constant head h.
- flowlines: curves which are perpendicular to all iso-heads.

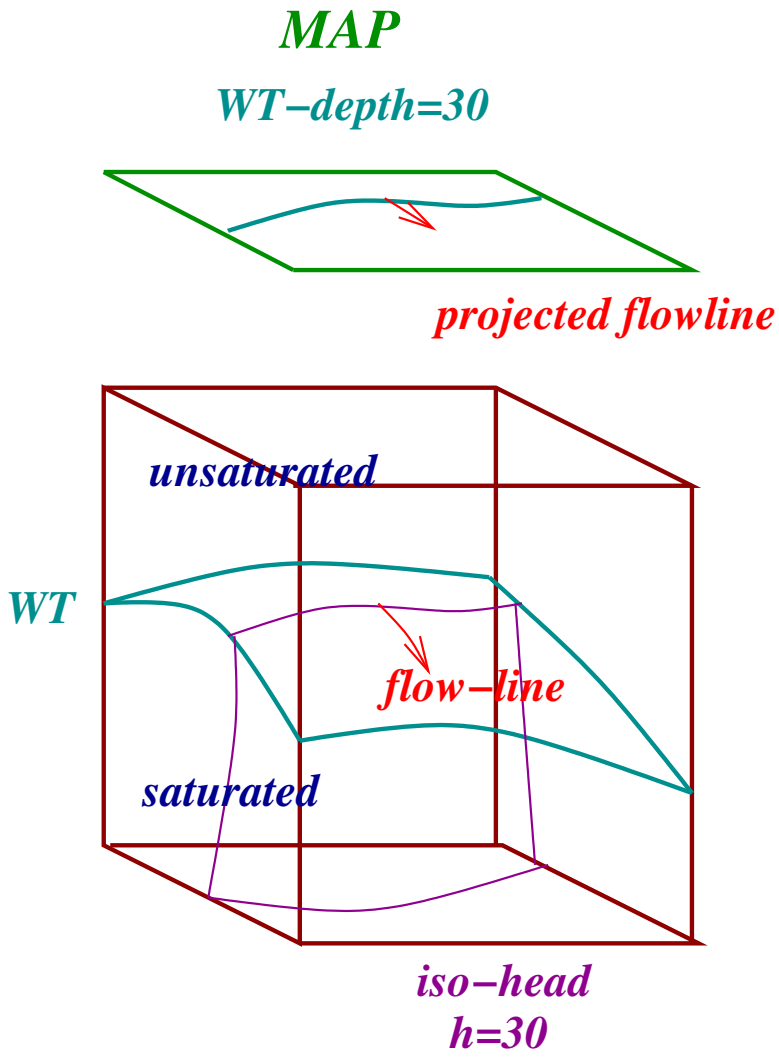
Basic Procedure

- Data: Well water levels, soil conductivity samples. GSDA
- Mathematical model: GIS systems.

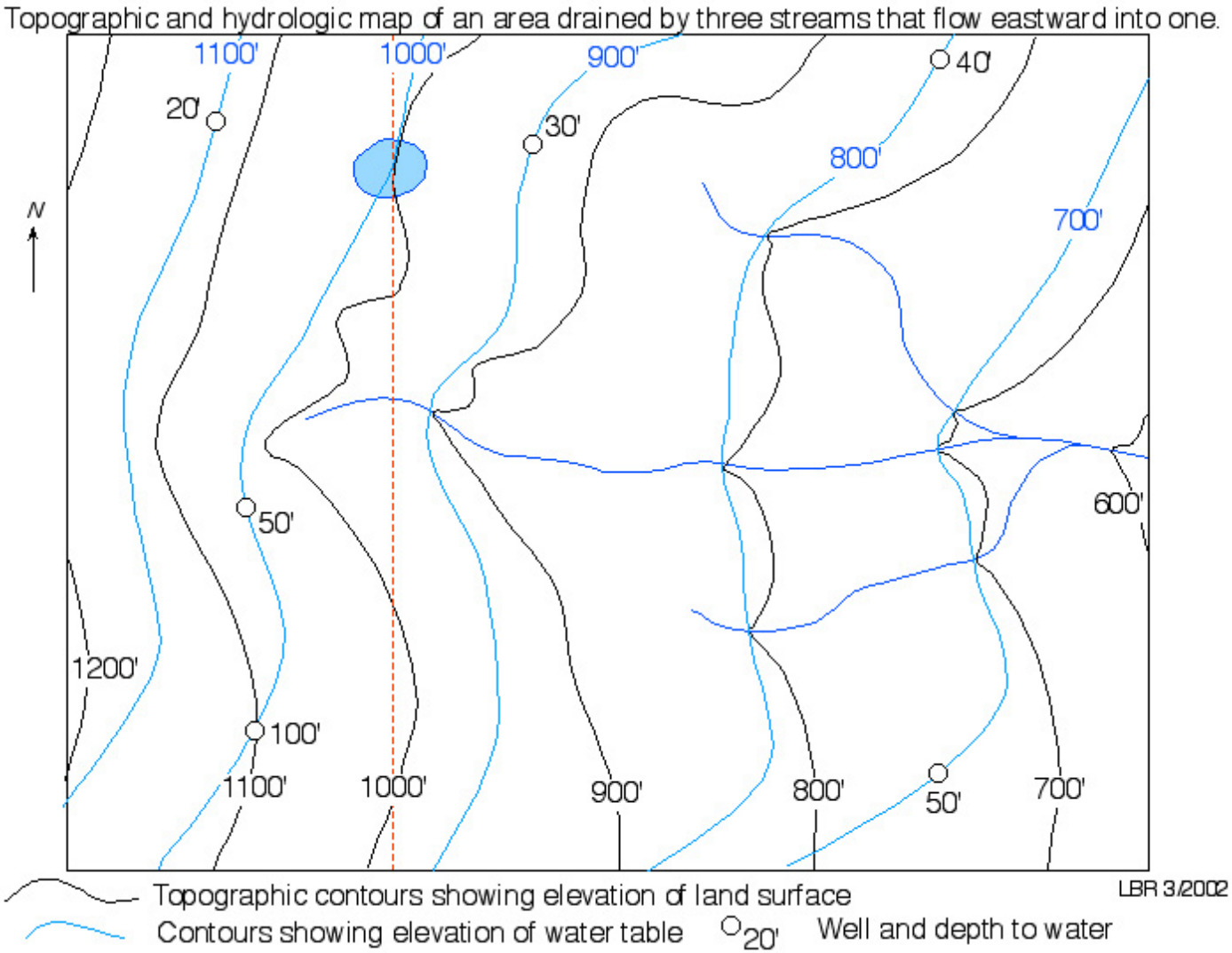
Flowlines and the Water-table

The equations $\partial h/\partial n = 0$ and $h - z = 0$ at the WT table ensures:

- The flowlines on the water-table stay on the water-table.
- The iso-head surfaces intersect the WT at 90-degrees.
- The curve of intersection has the same altitude and is a curve on the WT-map.
- The projection of the flowline on the map is perpendicular to this curve.
- The region above the WT has no flow-lines.

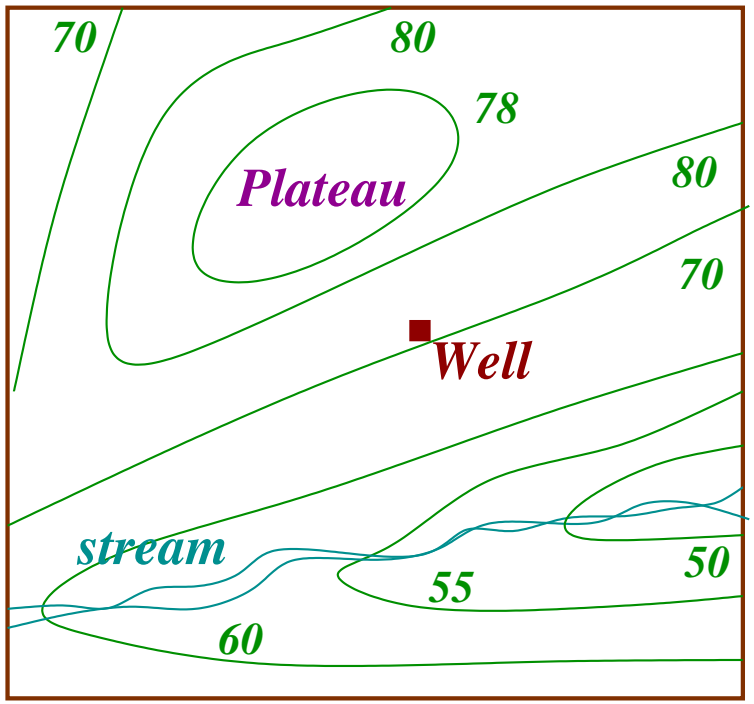


WT and Elevation contours

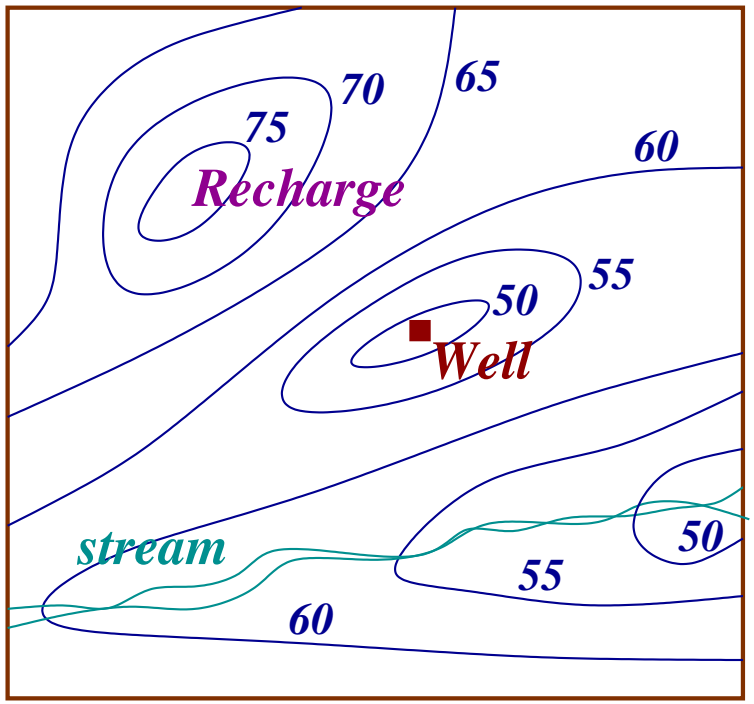


from: Prof. Bruce Railsback
http://www.gly.uga.edu/railsback/GeologicalDiagrams2.html.

Another Example



Topography



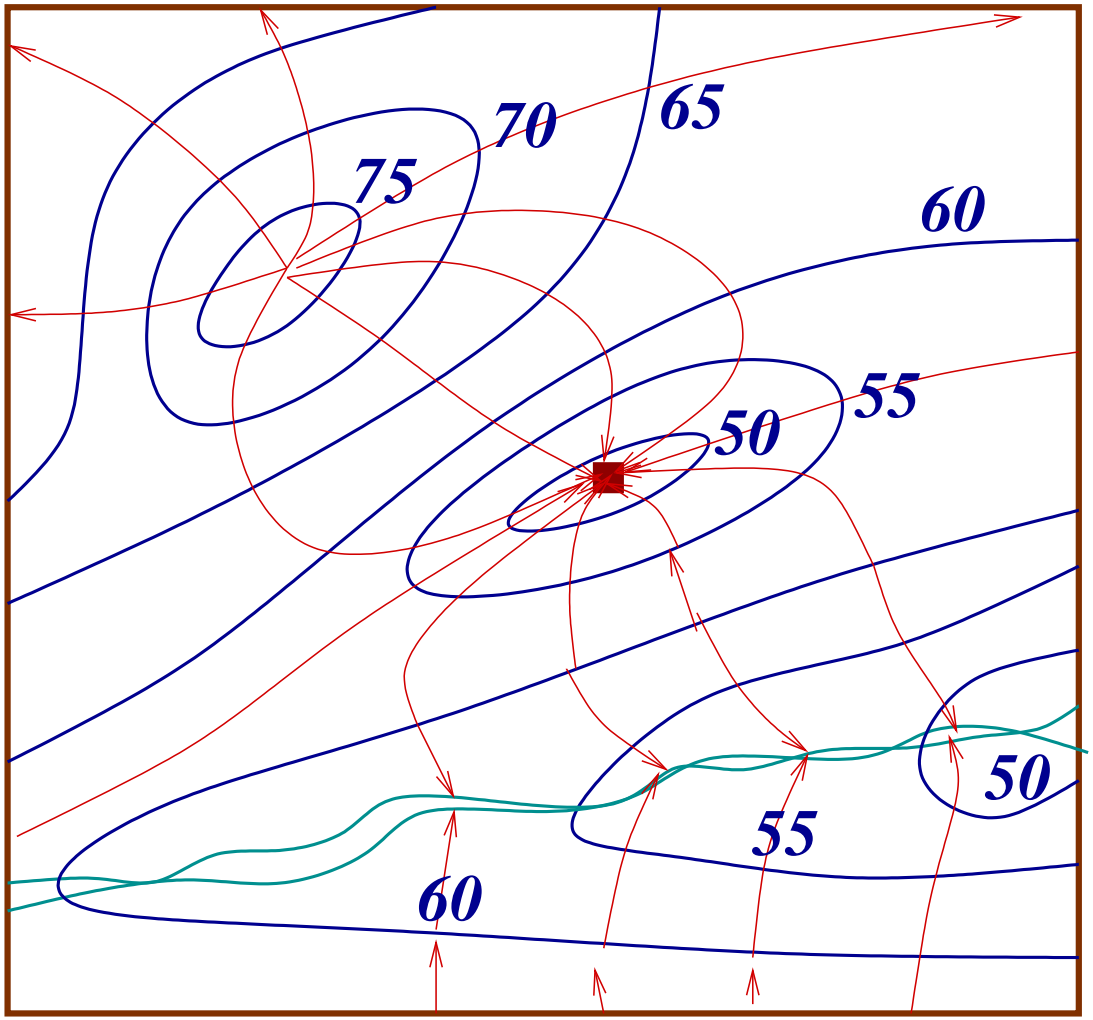
Water Table Elevation

- A region 1 sq.km., with stream, well and plateau.
- Note difference between water-table elevation and altitudes.
- Note discharge and recharge areas.

WT-map

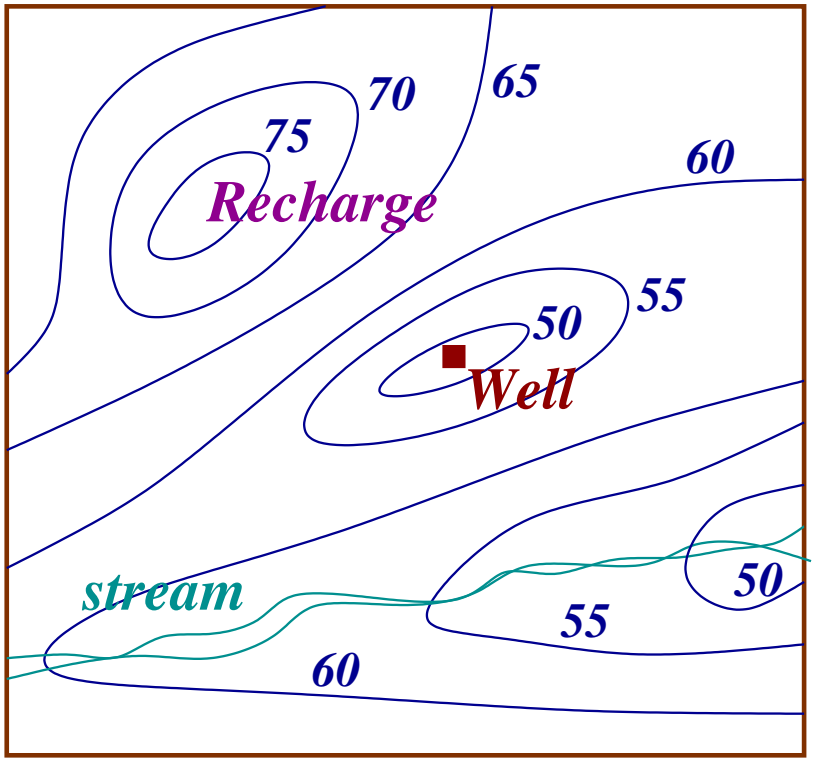
Note...

- Flow-separation.
- Behaviour at source and sinks.
- Location of the well.
- Source of well-recharge.
- A possible decomposition of the region.

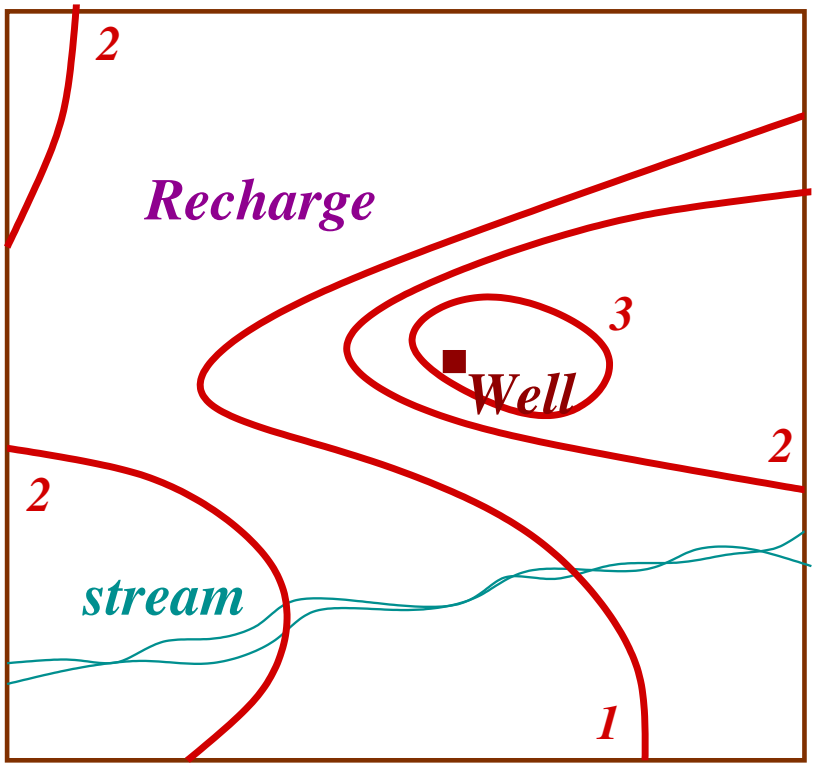


Flow–Lines

Seasonal variations

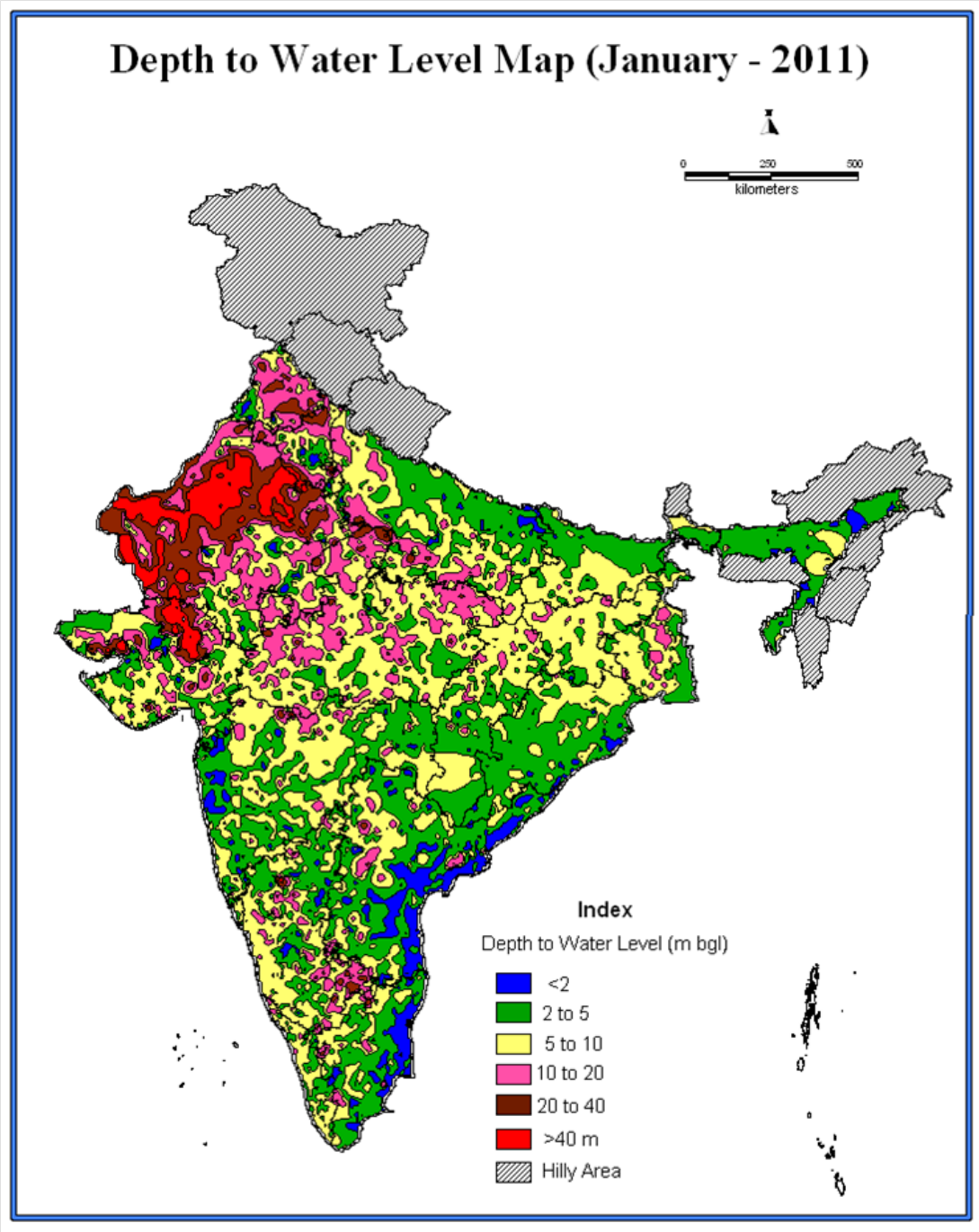


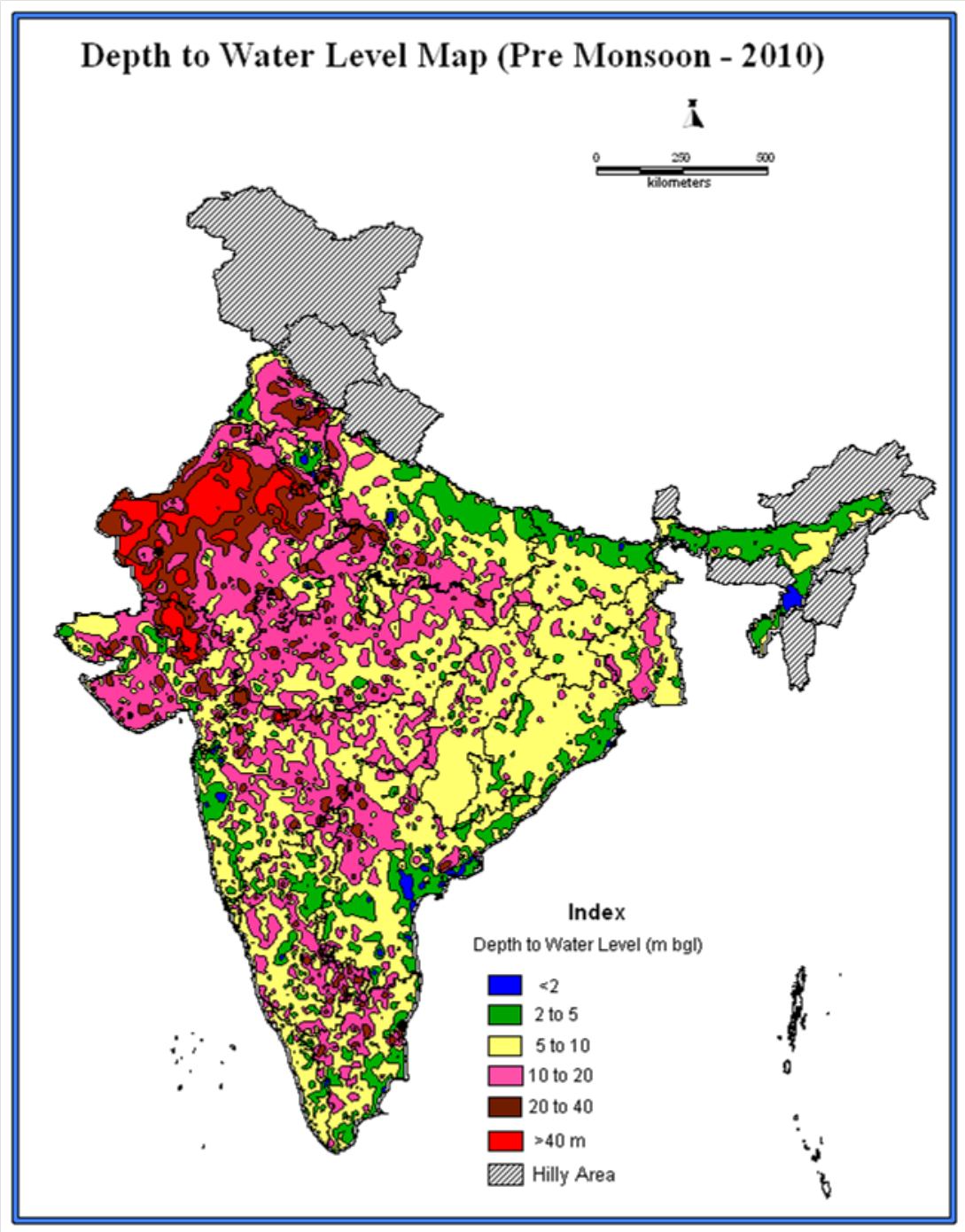
Water Table Elevation



Seasonal Drop in WT

- Typically, WT varies with seasons.
- Regional WT maps will also have the maximum summer-time drop in WT.
- Note, here excessive drop near well, due to continued use.

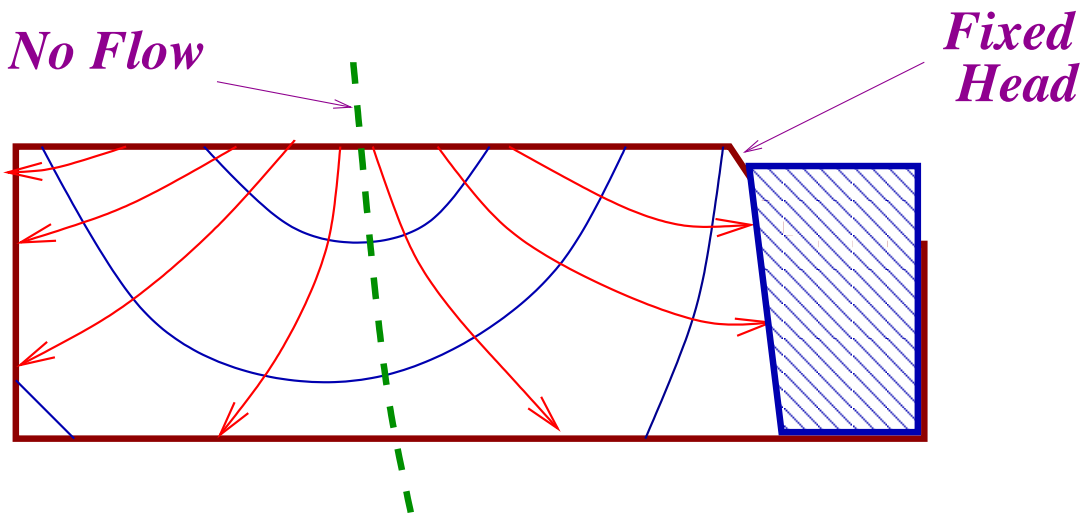

Depth to Water Level Map (January - 2011)
N
0
250
500
kilometers
Index
Depth to Water Level (m bgl)
<2
2 to 5
5 to 10
10 to 20
20 to 40
>40 m
Hilly Area

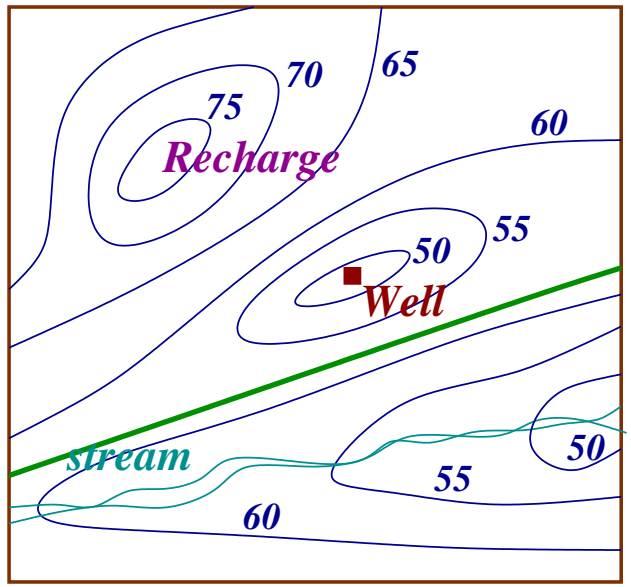

Depth to Water Level Map (Pre Monsoon - 2010)
0
250
500
kilometers
Index
Depth to Water Level (m bgl)
<2
2 to 5
5 to 10
10 to 20
20 to 40
>40 m
Hilly Area

Subproblem Definition

Regional groundwater analysis : helps in identifying subproblems and their boundary conditions.

- helps define regions and adjacencies (boundaries)
- helps locate no-flow and fixed head



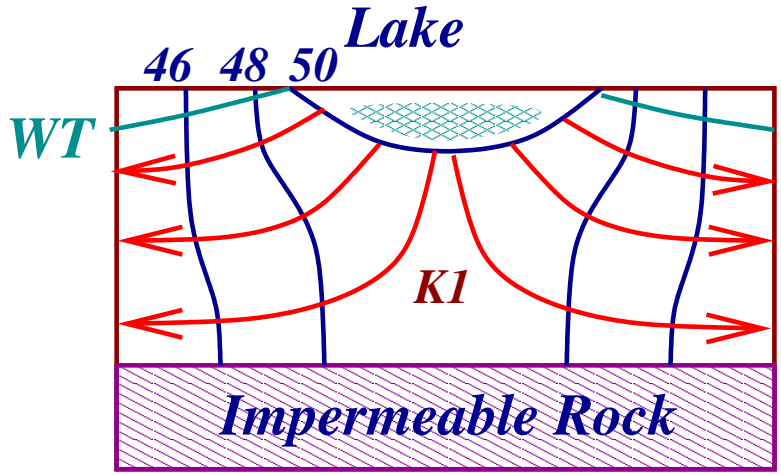


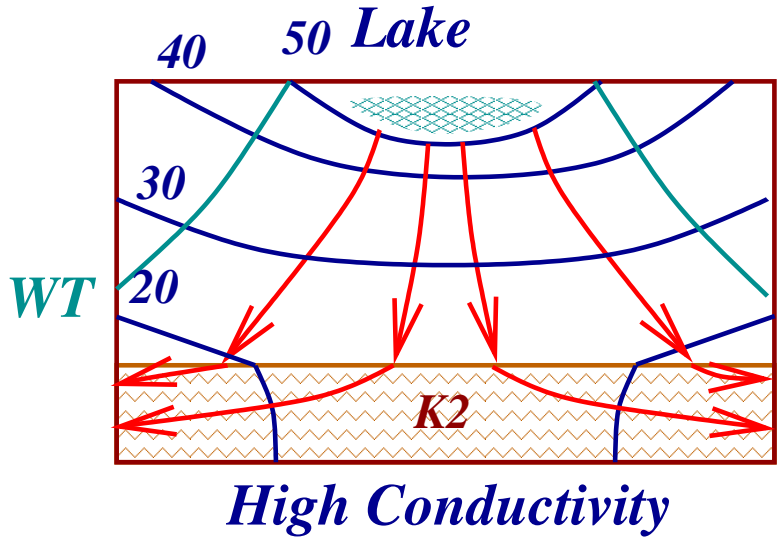
No–Flow boundary

- helps define time-varying ambient head boundary condition.

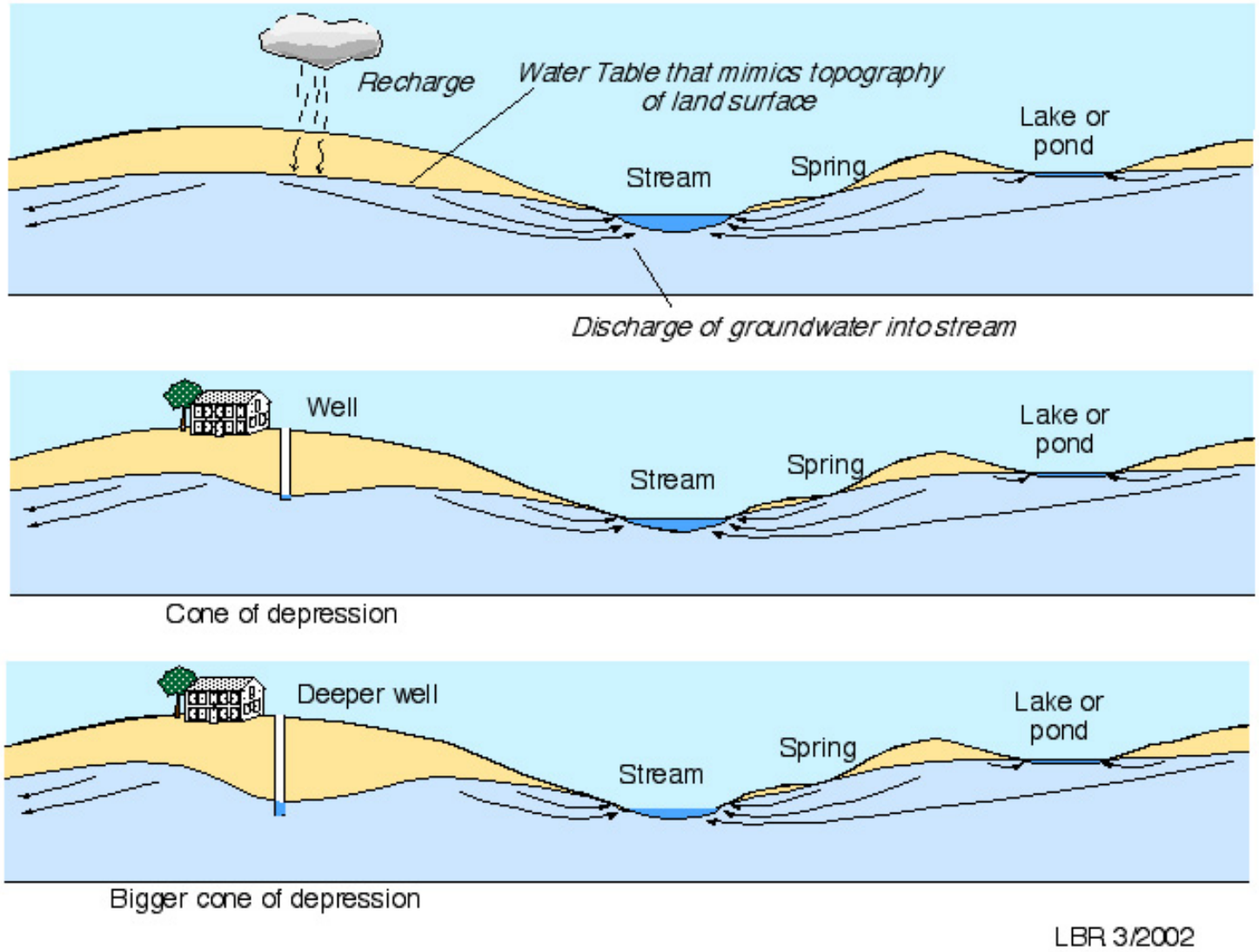
An example: Lake

- Two situations:
  - On impermeable rock base.
  - On high conductivity base. $K2 >> K1$
- Iso-head lines.
  - Slowly moving.
  - Rapidly moving.
- Flow-lines
  - Small sideways.
  - Large downward.
- **Watch WT**
- Lake loses water roughly at $K1$.
- Lake loses water roughly at $K2$



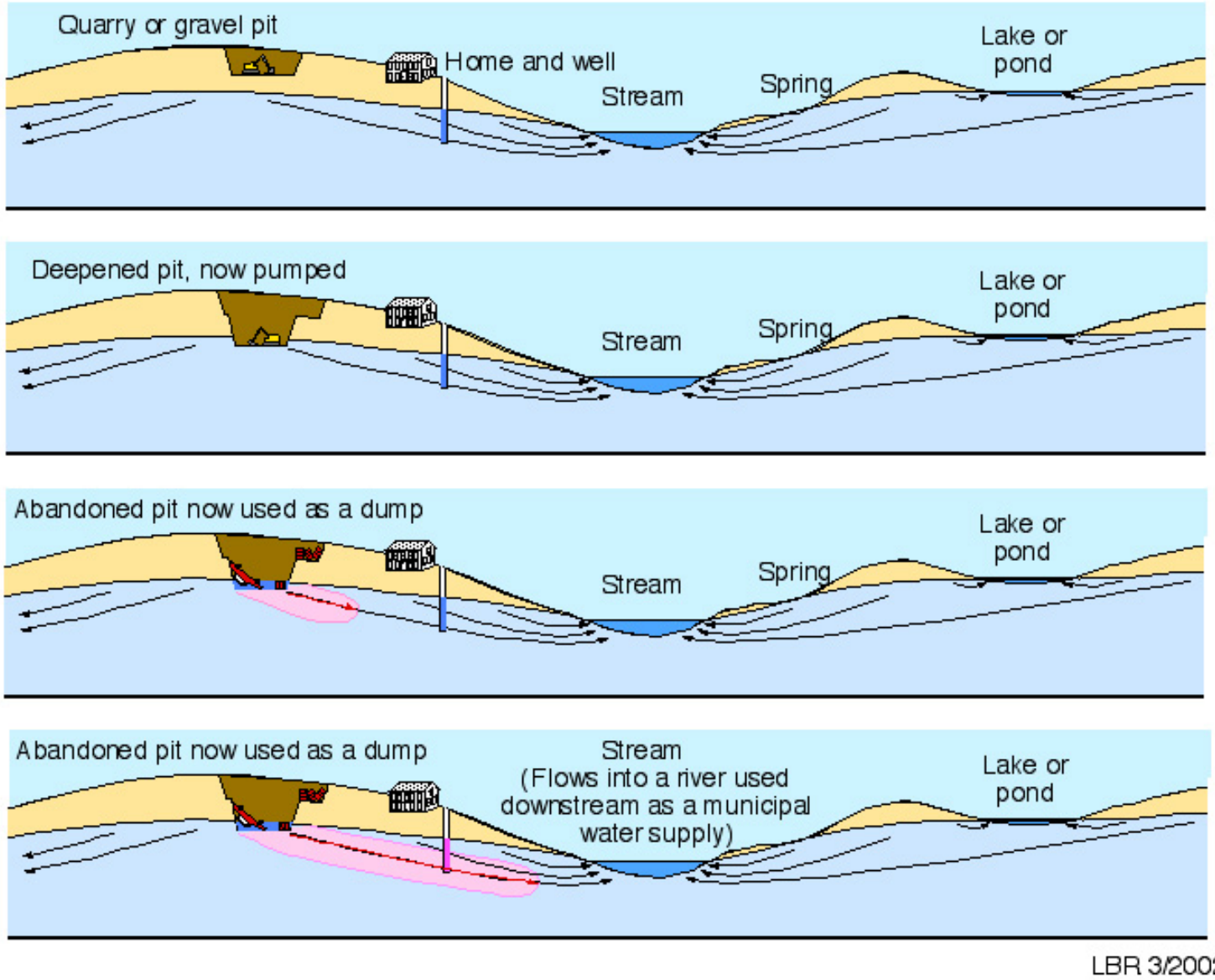


More situations



courtesy: Bruce Railsback again!

More situations



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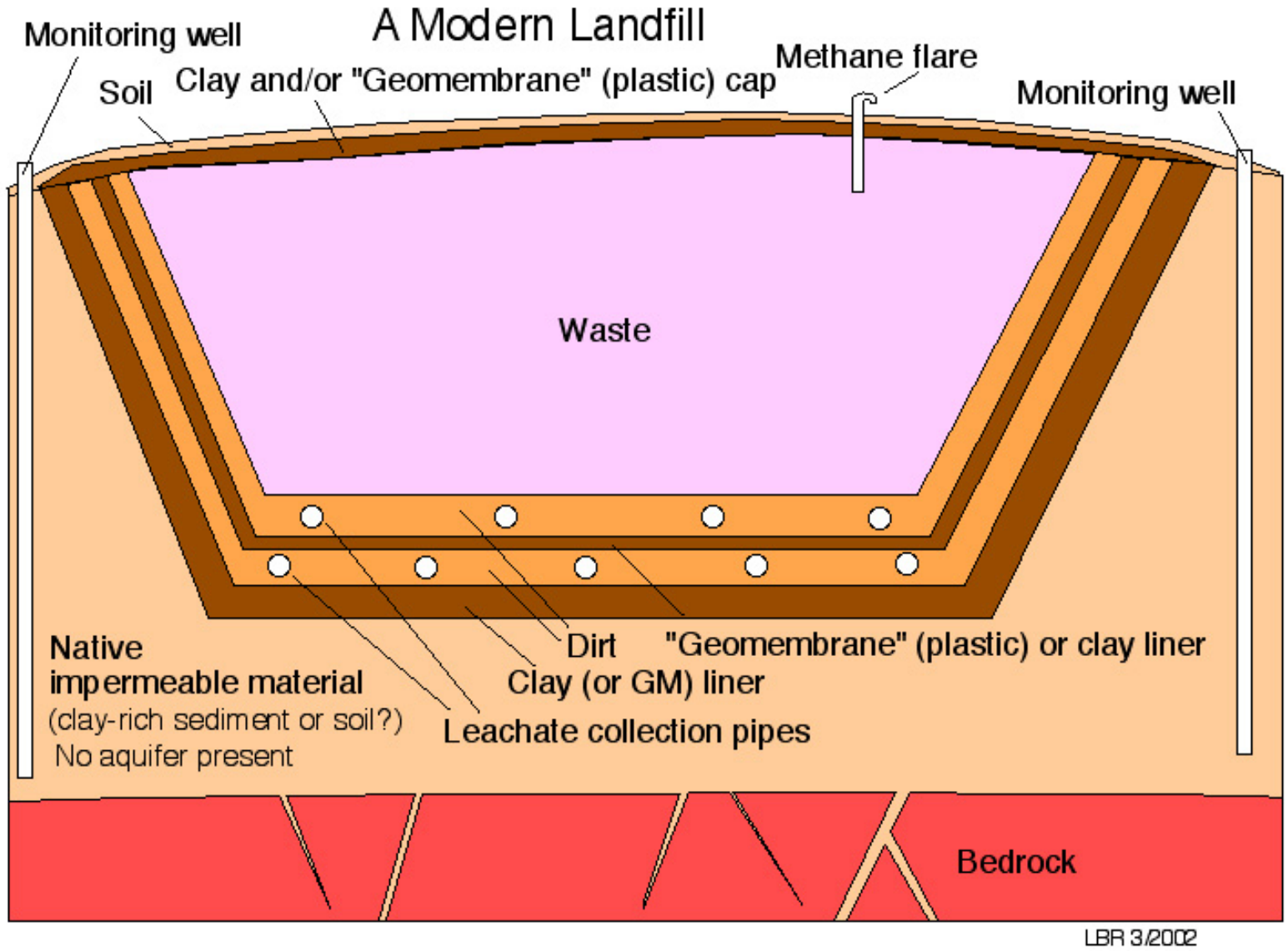
More situations



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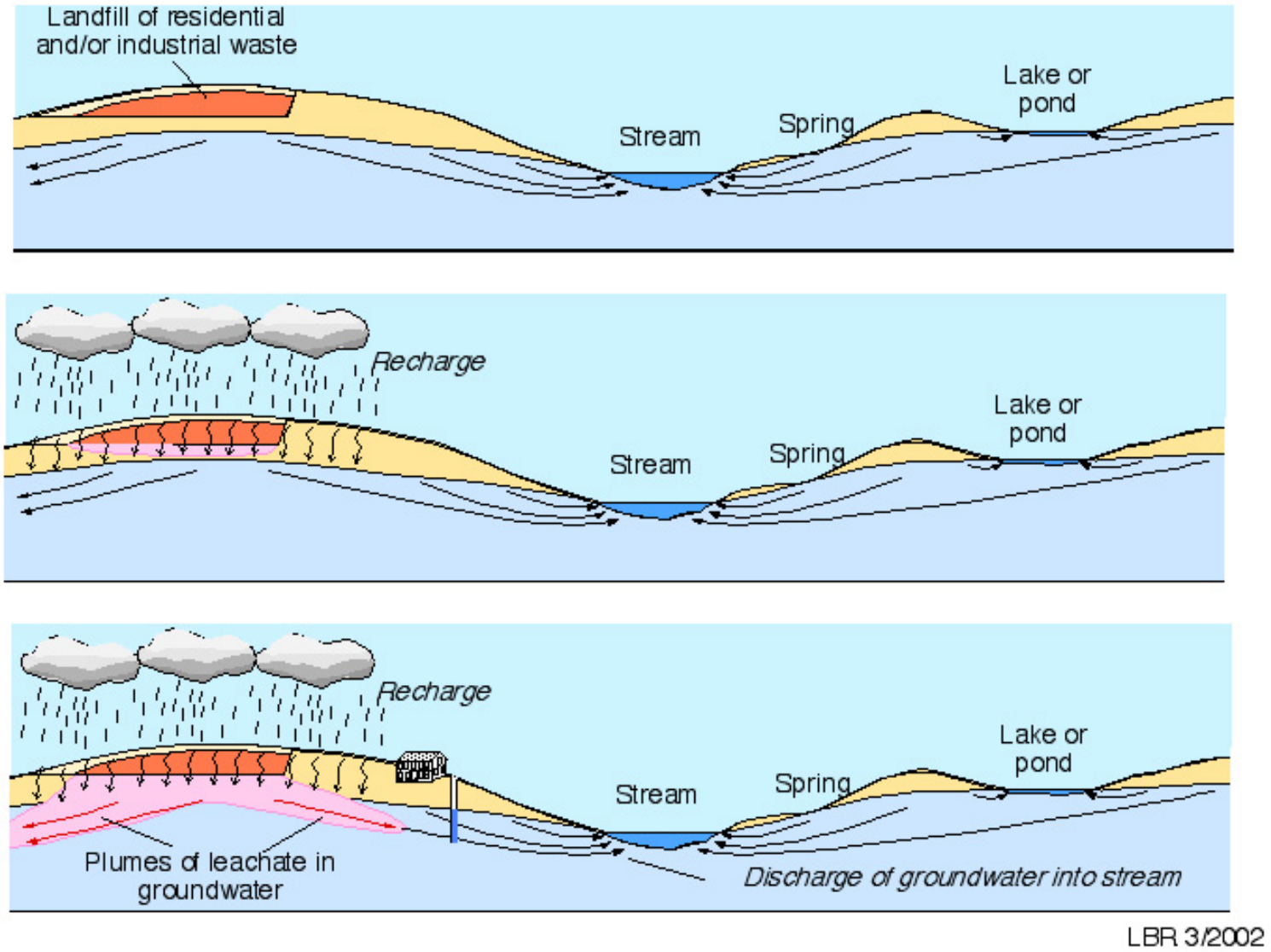
More situations



courtesy: Bruce Railsback again!

Maharashtra-GSDA

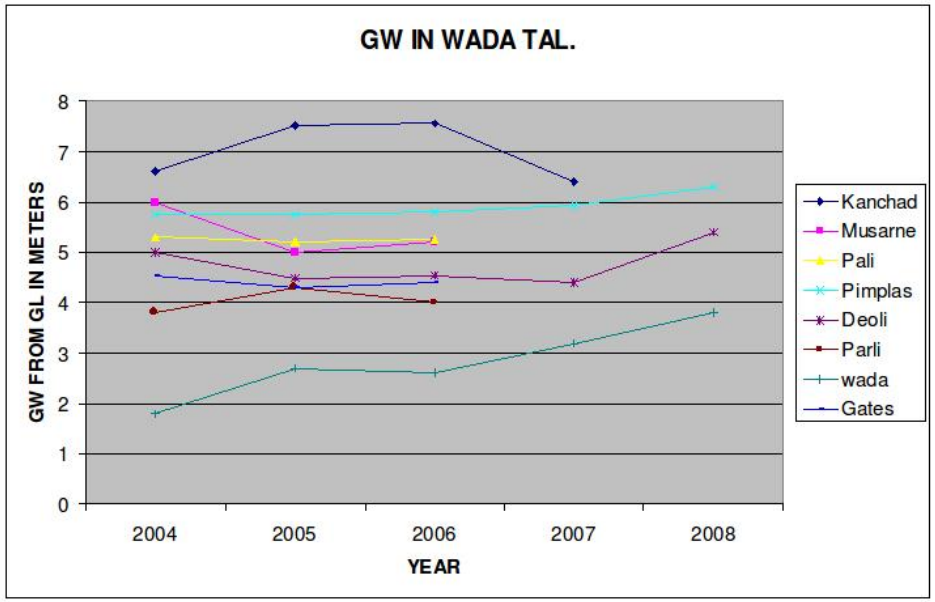
- Water is a state-subject, and so is Groundwater.
- In Maharashtra: Groundwater Surveys and Development Agency

  `http://mahagsda.org`

  under the Water Supply and Sanitation Department
- Groundwater extraction and utilization falls under the MWRRA.
- Functions:
  - Generate and supply data related to ground-water.
  - Undertake studies and advise the govt. and people.
  - Implement and execute acts and laws related to ground-water.
- Infrastructure:
  - Thousands of observations wells (WT) and piezo-meters (heads).
  - field-offices, weather, topographical and geological data.
- Example : Thane district of area 9500 sq. km. has 92 observation wells (i.e., one observation per 100 sq. km.!), which are monitored quarterly.

GSDA-Organization and Reports

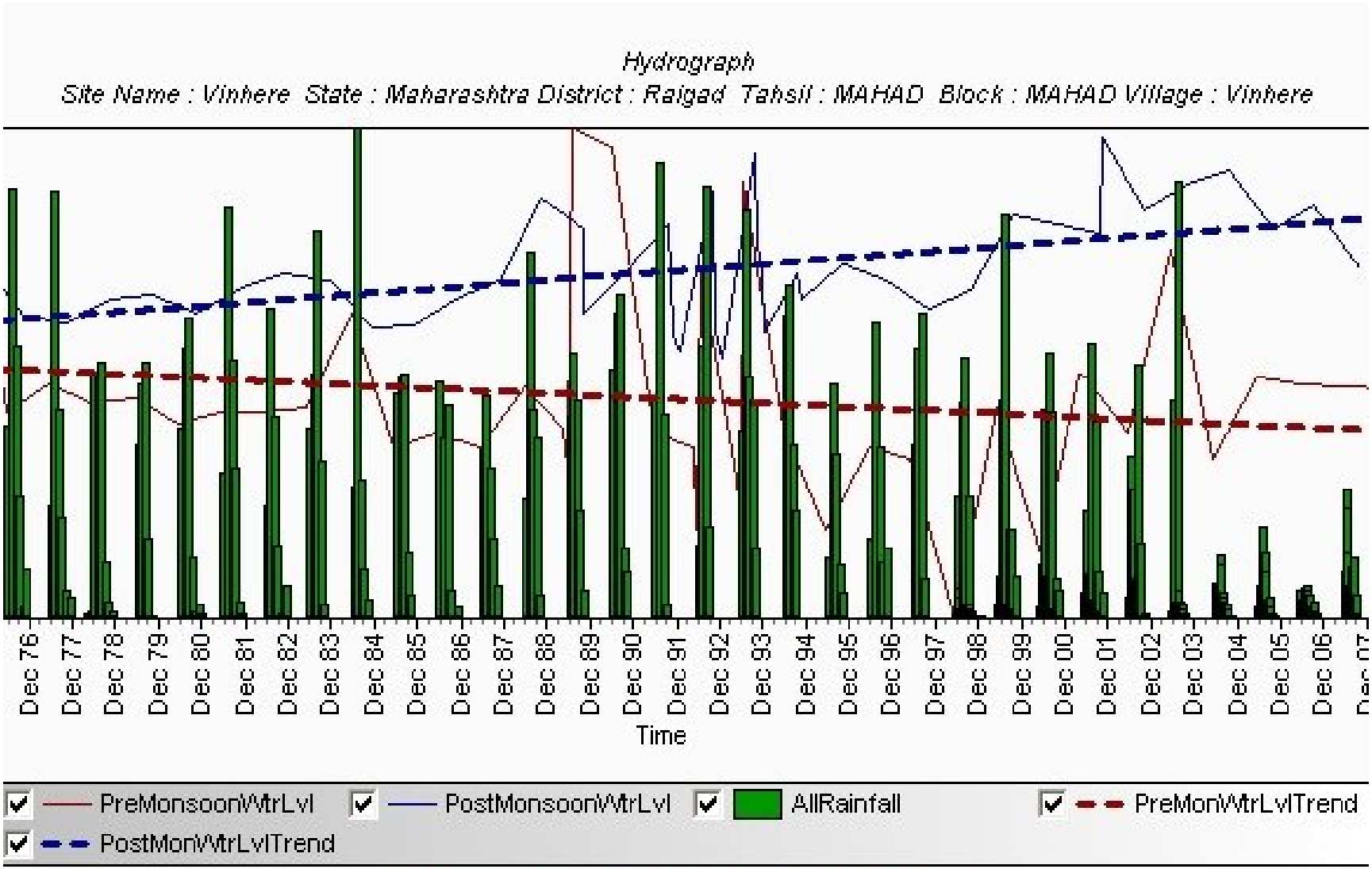
- HQ at Pune , 6 branches (Amravati, Nagpur, Nashik, Kokan, Aurangabad, Pune).
- Each branch with a Senior Geologist, Deputy Engineer with a jurisdiction of roughly 5 districts.
- Organization of Maharashtra into basins and sub-basins.



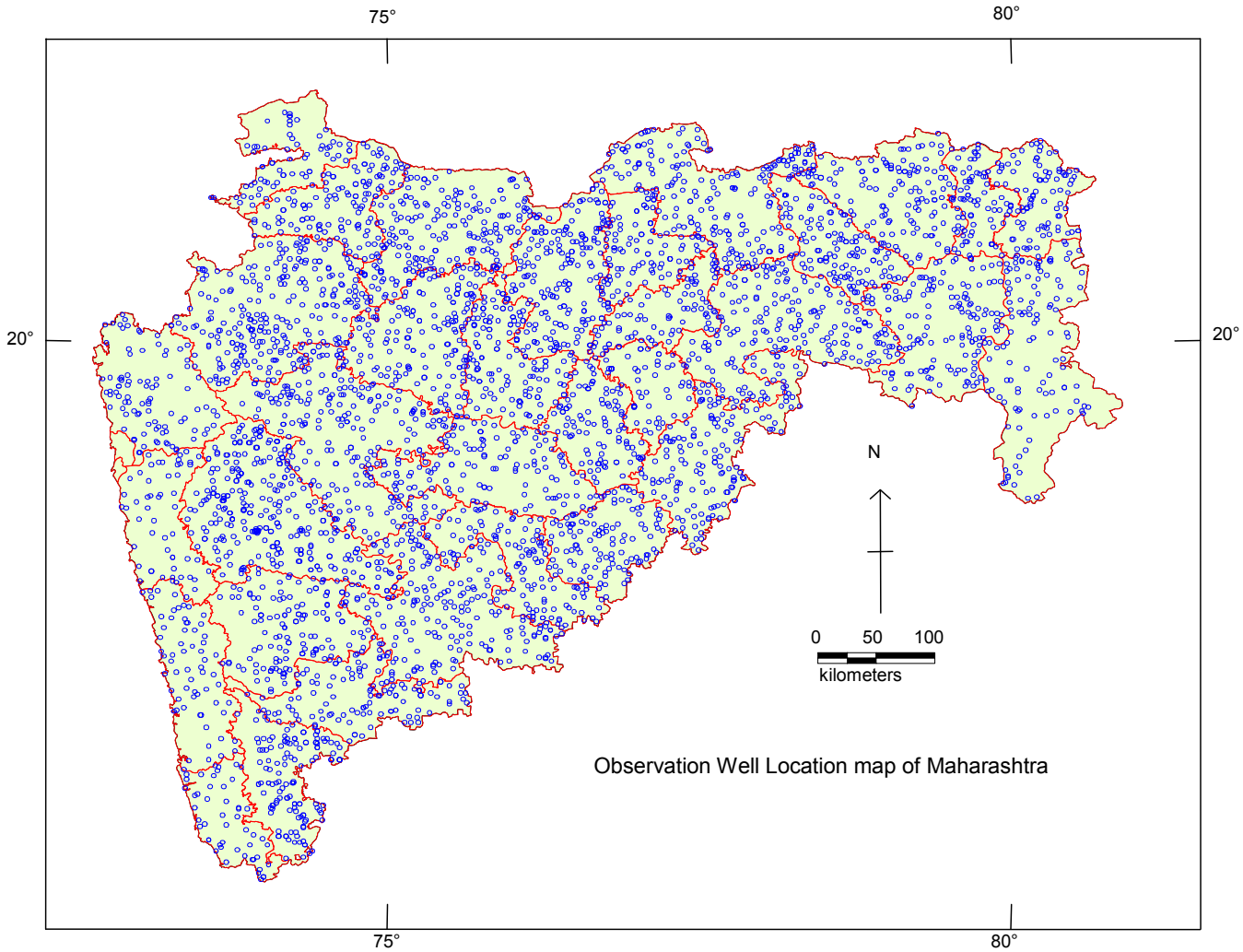
Observation well data for Summer of Wada taluka, Thane district.

- Construction of Summary data on Water-balance.
  - rainfall, wells, borewells, extraction, recharge.
  - borewell success rates, subsidies.
  - groundwater potential, scarcity, over-exploitation, regional hydrographs.

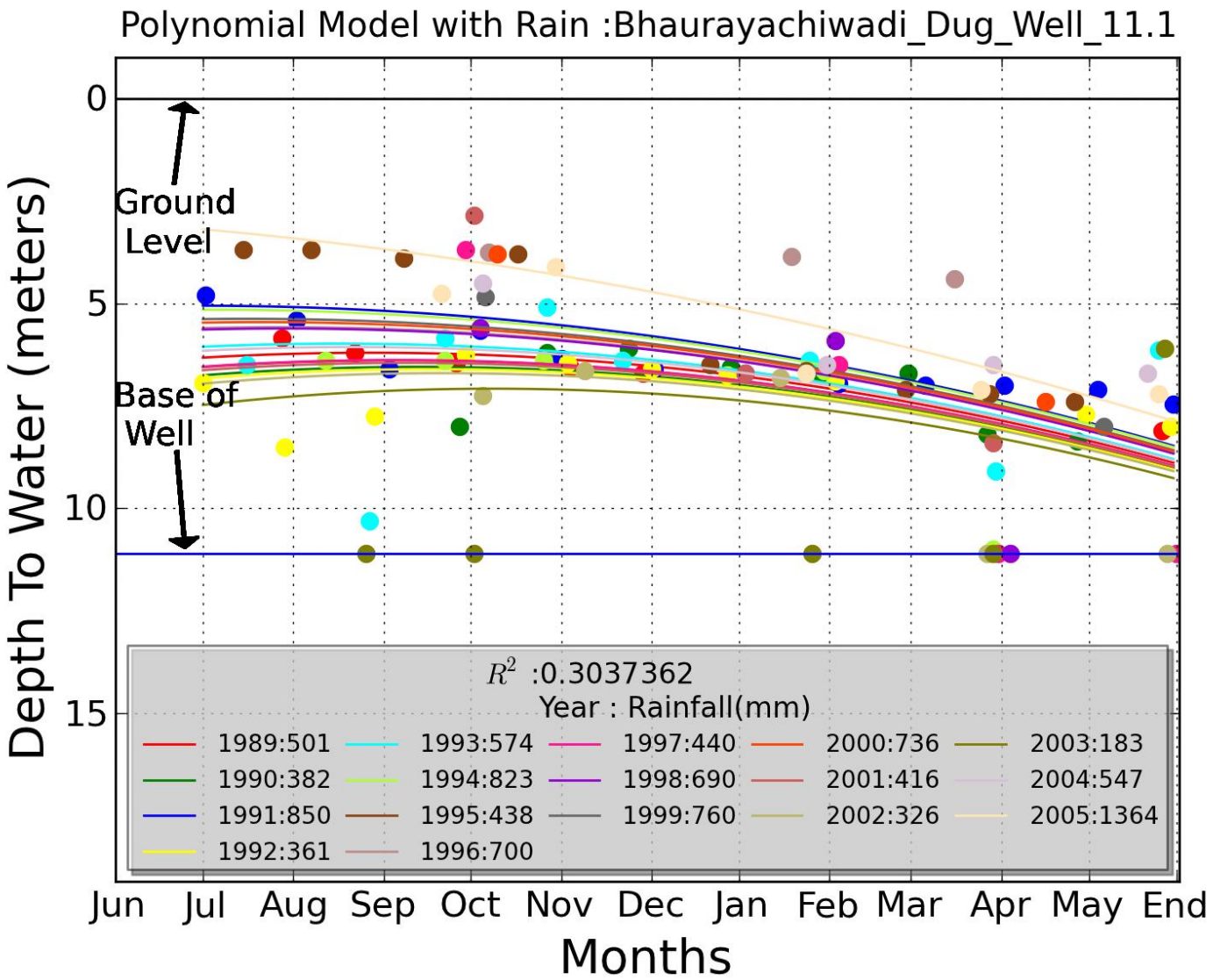
Raigad district Hydrograph (source GSDA)



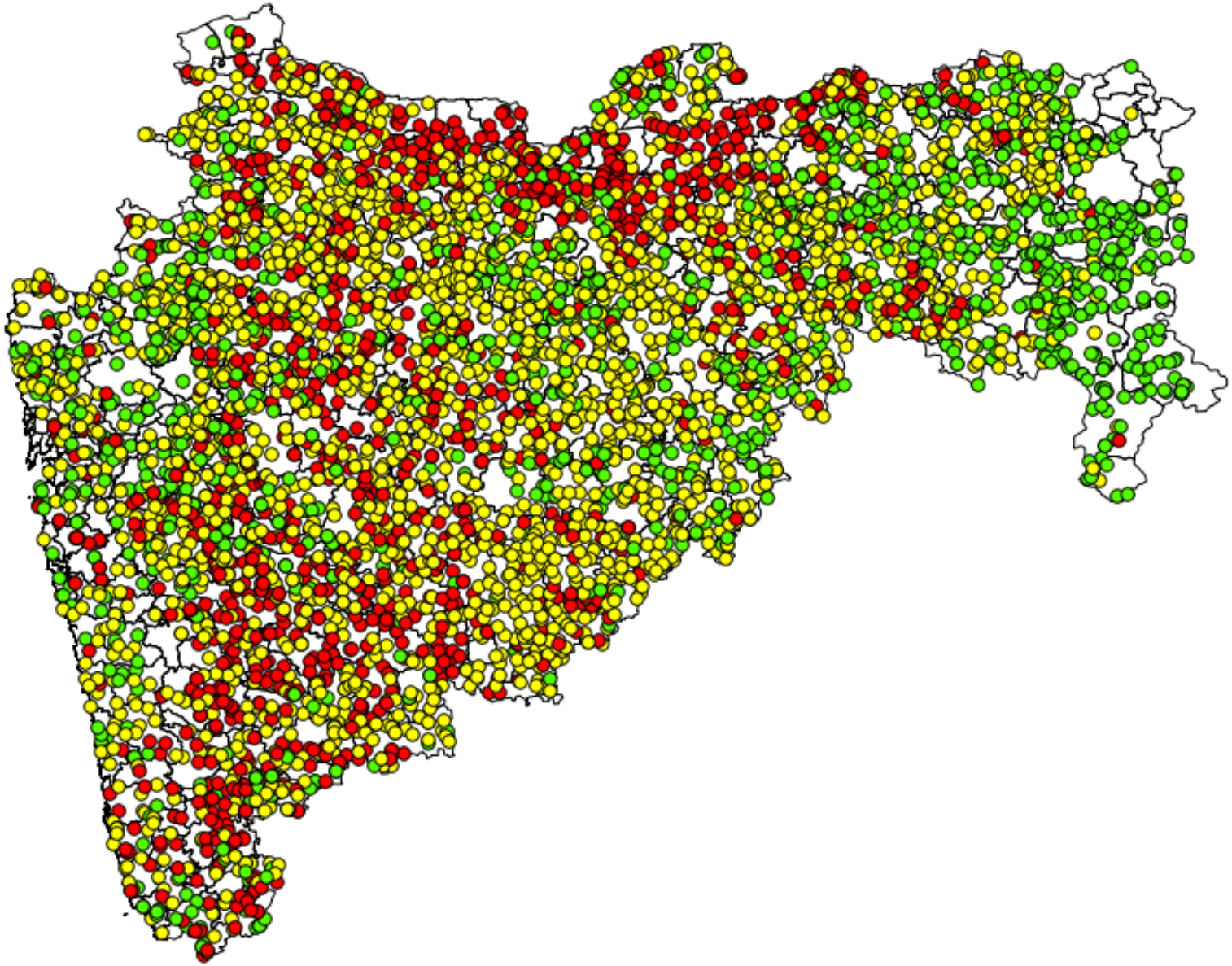
Observation Wells



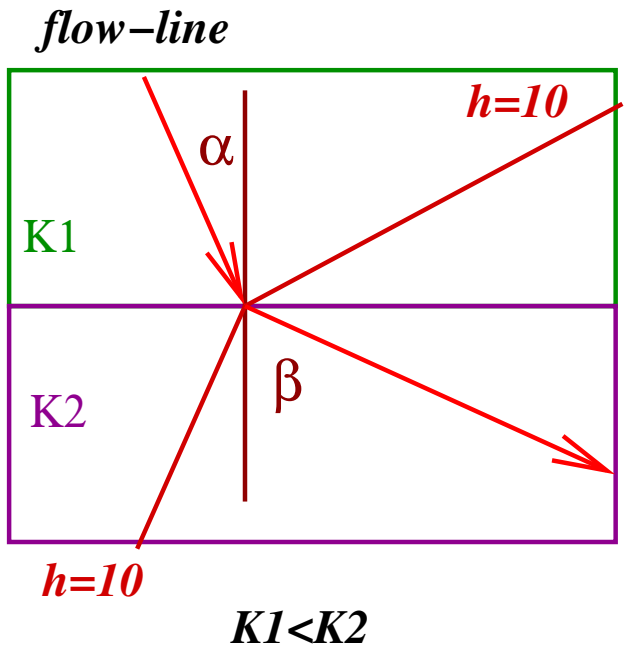
Models


Polynomial Model with Rain :Bhaurayachiwadi_Dug_Well_11.1
Depth To Water (meters)
0
5
10
15
Ground Level
Base of Well
R^2 :0.3037362
Year : Rainfall(mm)
1989:501
1990:382
1991:850
1992:361
1993:574
1994:823
1995:438
1996:700
1997:440
1998:690
1999:760
2000:736
2001:416
2002:326
2003:183
2004:547
2005:1364
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
End
Months

Quality of fit



Refraction

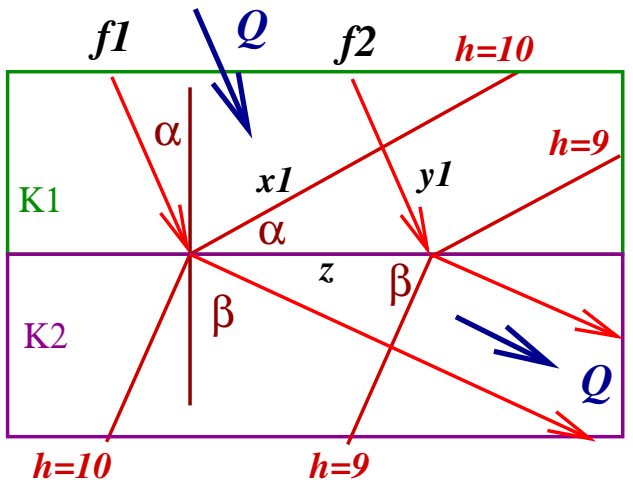


Situation : The junction between two materials of different conductivities.

- Let $K1 < K2$ and let flow-line go from material 1 to 2.
- Let angle of arrival be α and departure be β.

then...

$$\frac{\tan\alpha}{\tan\beta} = \frac{K1}{K2}$$



- Continuity of h.
- Conservation of mass (Q).

$$Q = x1 \cdot K1/y1 = K1/\tan\alpha$$

- This proves the result!

Discussion

1. What happens to the perpendicularity relationship of flowlines to iso-heads when the medium is anisotropic?
2. Draw a lake, WT, iso-heads and flow-lines, where the surround grounds are actually charging the lake.
3. Discuss the difference flowline and light refraction.
4. How would you actually implement a time-varying boundary conditions? Are there any other examples?
5. What do you think would typical ground-water laws be like, and what would be the difficulties in enforcing groundwater laws.
6. Look at hydrographs of other locations put up on the GSDA website. What are your comments on the trend-lines?