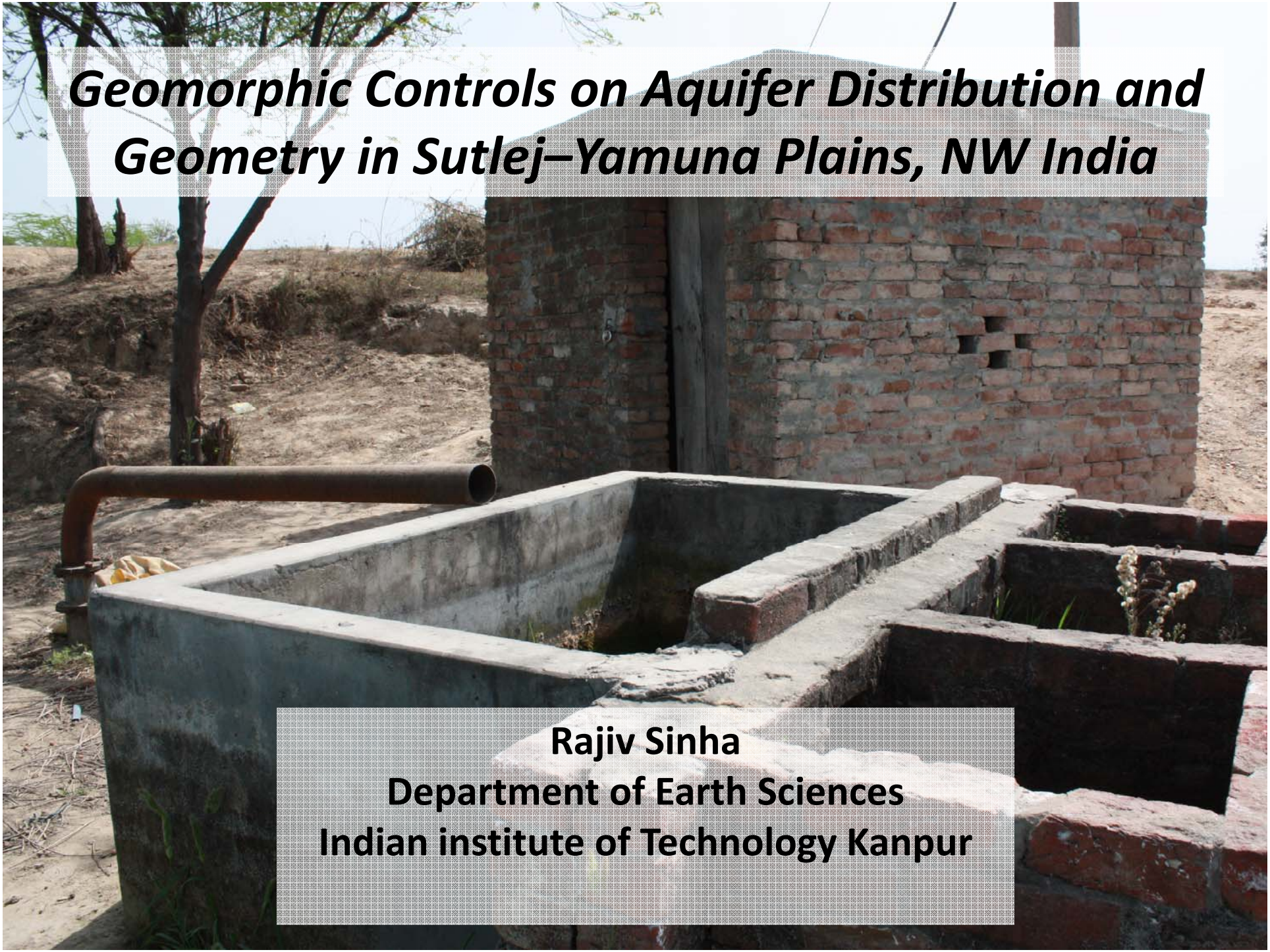
Geomorphic Controls on Aquifer Distribution and Geometry in Sutlej–Yamuna Plains, NW India



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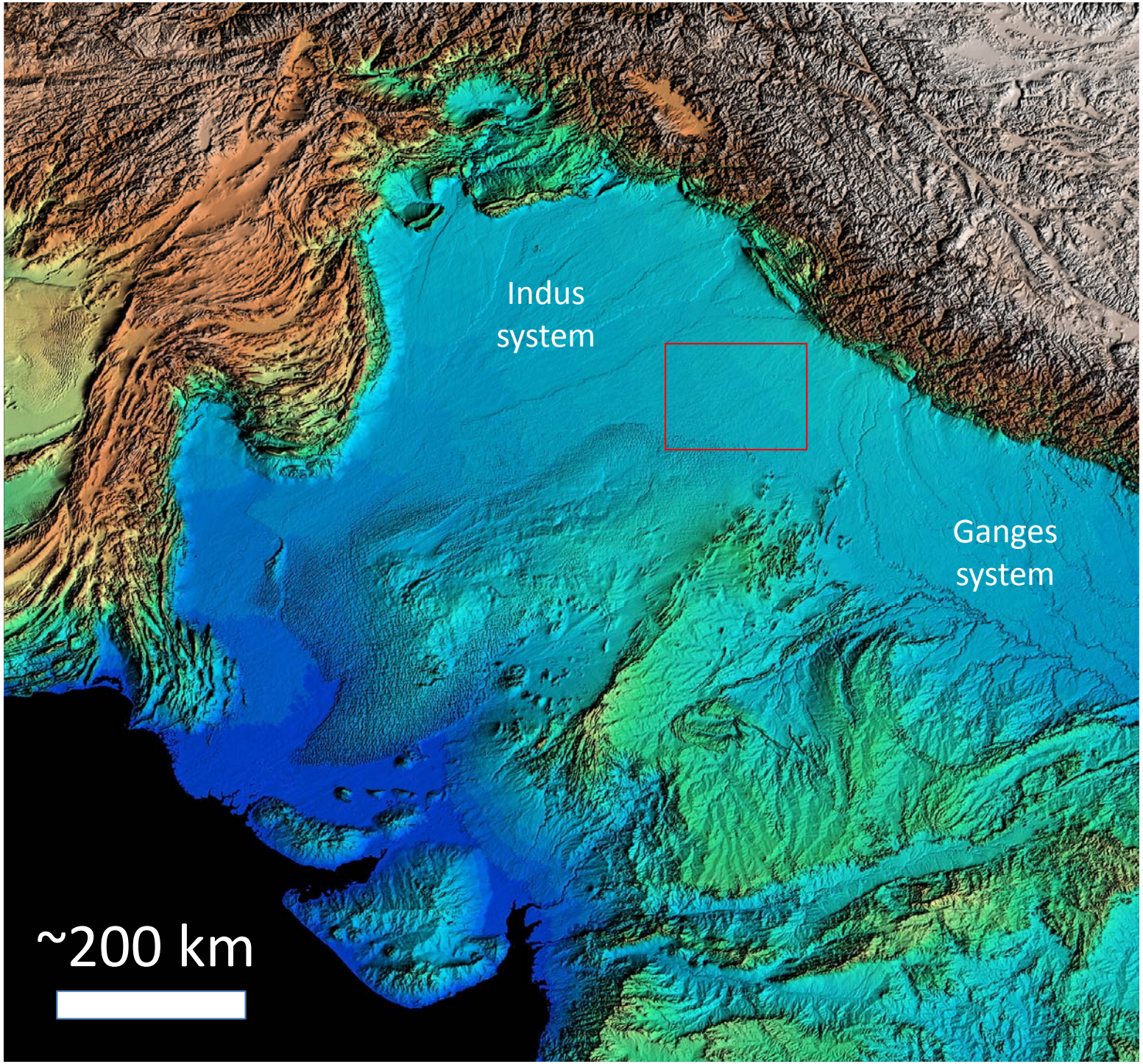
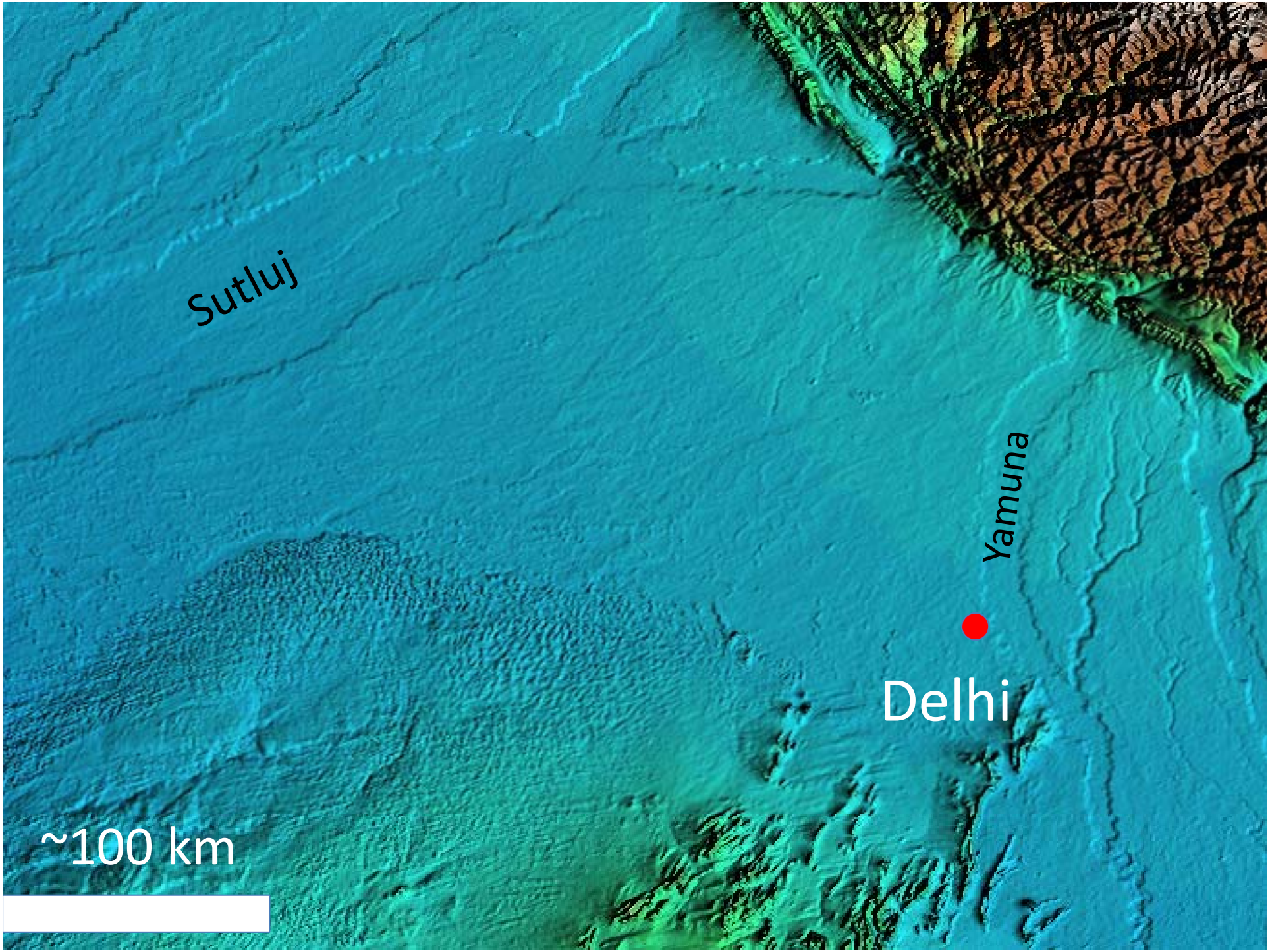
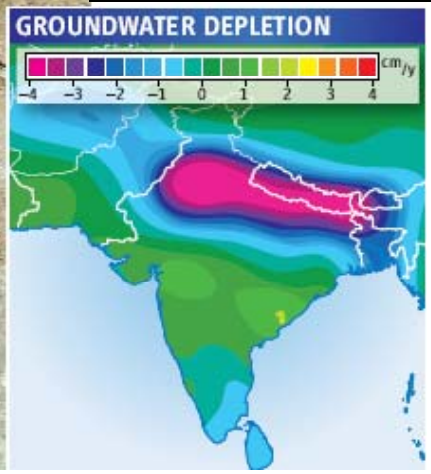

Indus
system
Ganges
system
~200 km


Sutluj
Yamuna
Delhi
~100 km

Northern India's Groundwater Is Going, Going, Going …

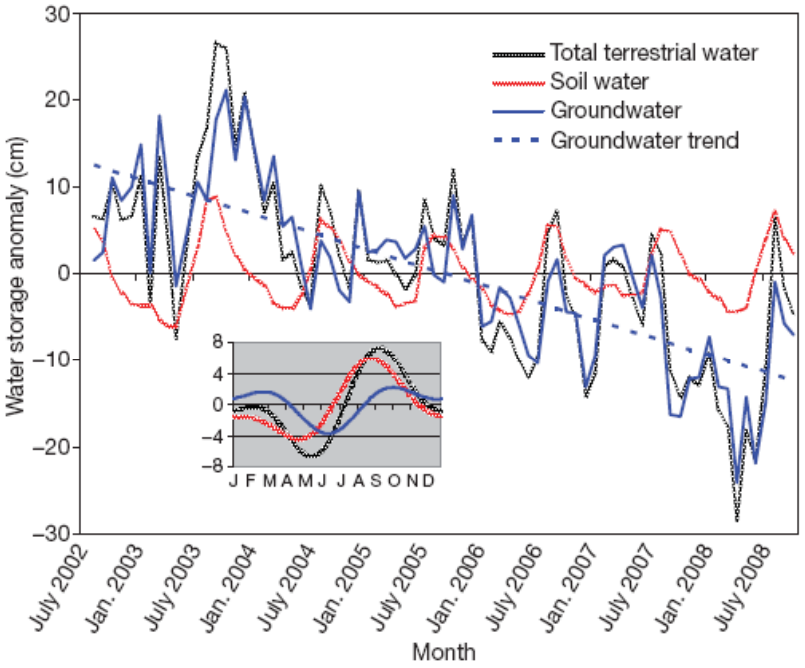
Total loss: 109 km^3 (Aug'02 – Oct'08)
Rate of decline:17.2 $\pm$ 4.5 km^3/yr
Mean water table decline: 0.33 m/yr
Local rates > 10m/yr
No shortage of rainfall (except 2002)



"Groundwater is NOT bottomless and when we hit the bottom, the situation could get very scary……." (Kerr, 2009, Science)

=> GW declines were not caused by natural climate variability

Monthly time series of water storage anomalies in northwestern India (based on GRACE data)

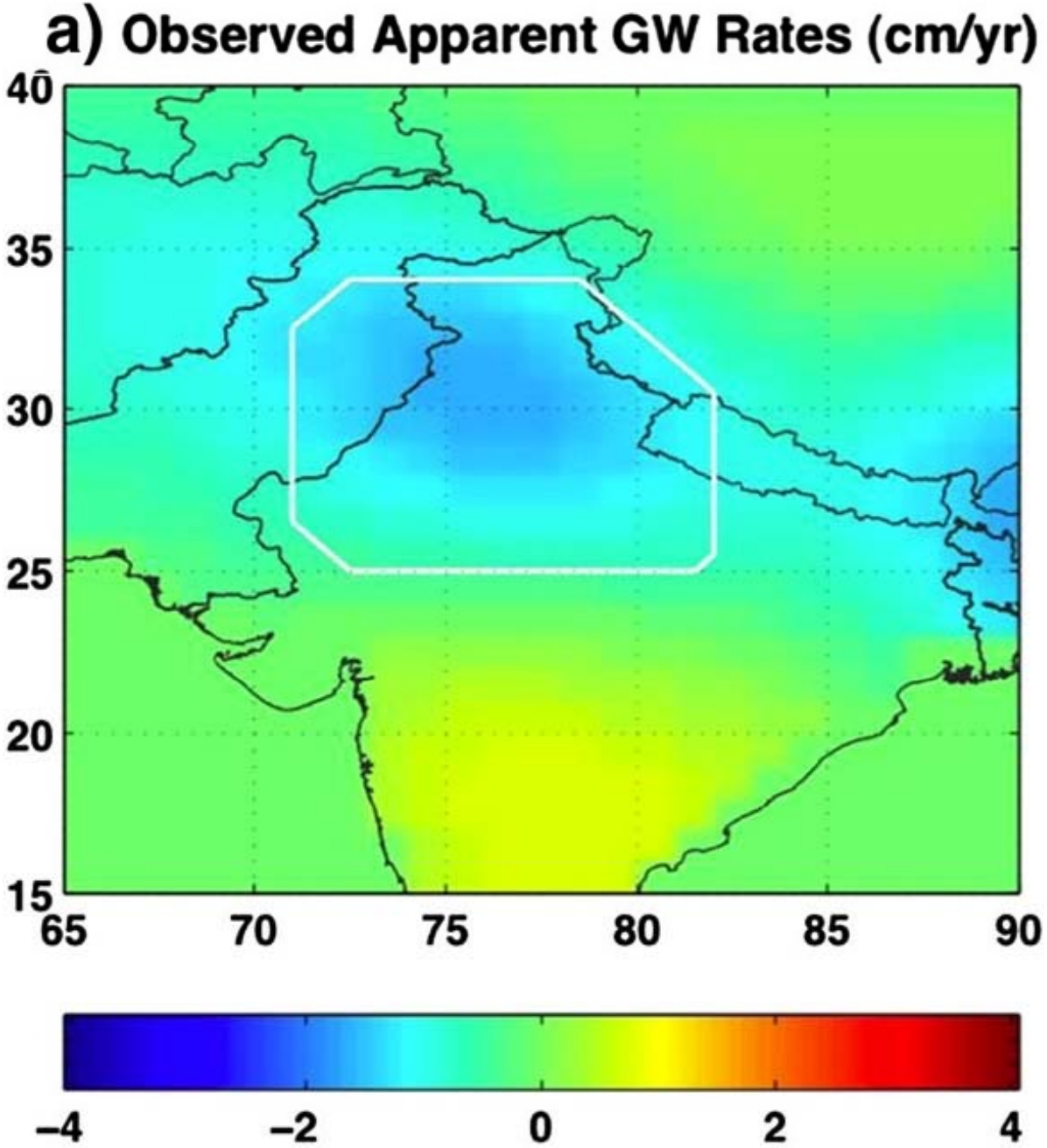


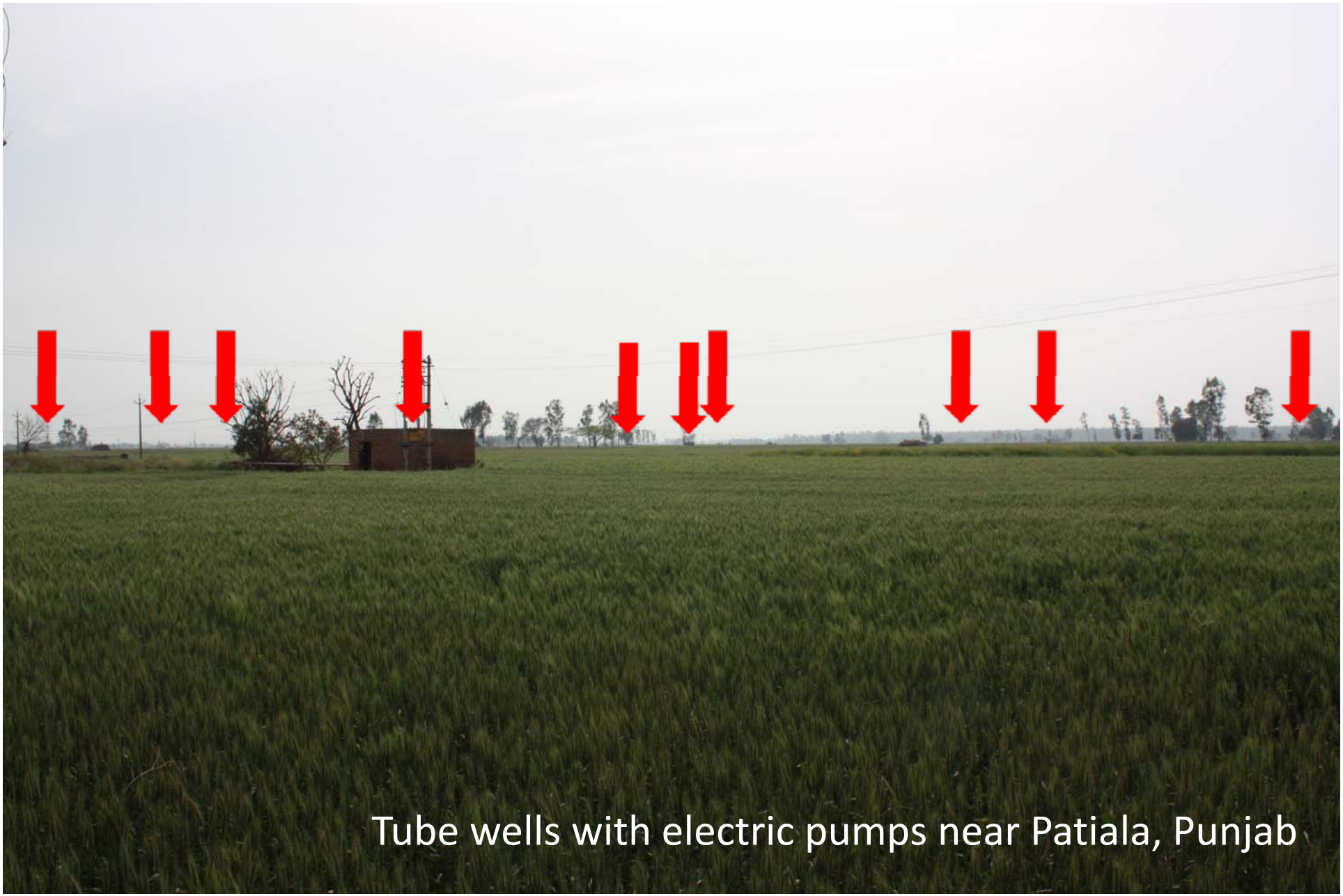
(Rodell et al., Nature, 18 Aug., 2009)

Chen et al 2014

10 year GRACE data
- 2003 - 2012

Pronounced groundwater depletion in NW India
- but what does this look like in high resolution?



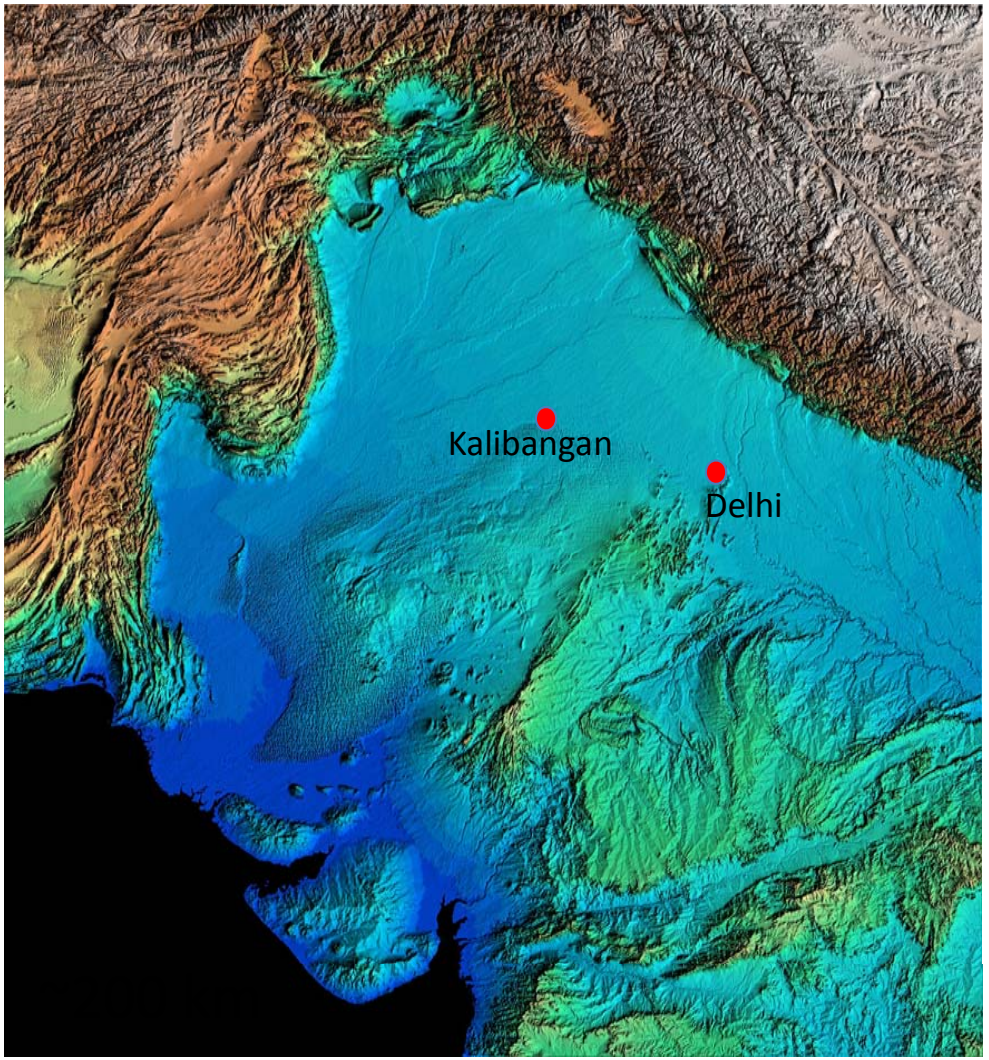


Tube wells with electric pumps near Patiala, Punjab

Motivation and Rationale

- NW India - a 'hotspot' of groundwater depletion
- Situation is likely to get worse in climate change scenarios
- People completely unaware of this grave situation
- No serious plan in place to remedy or arrest this situation
- Groundwater largely hosted within buried channels
- Need to describe their location, age and 3D structure

NW India



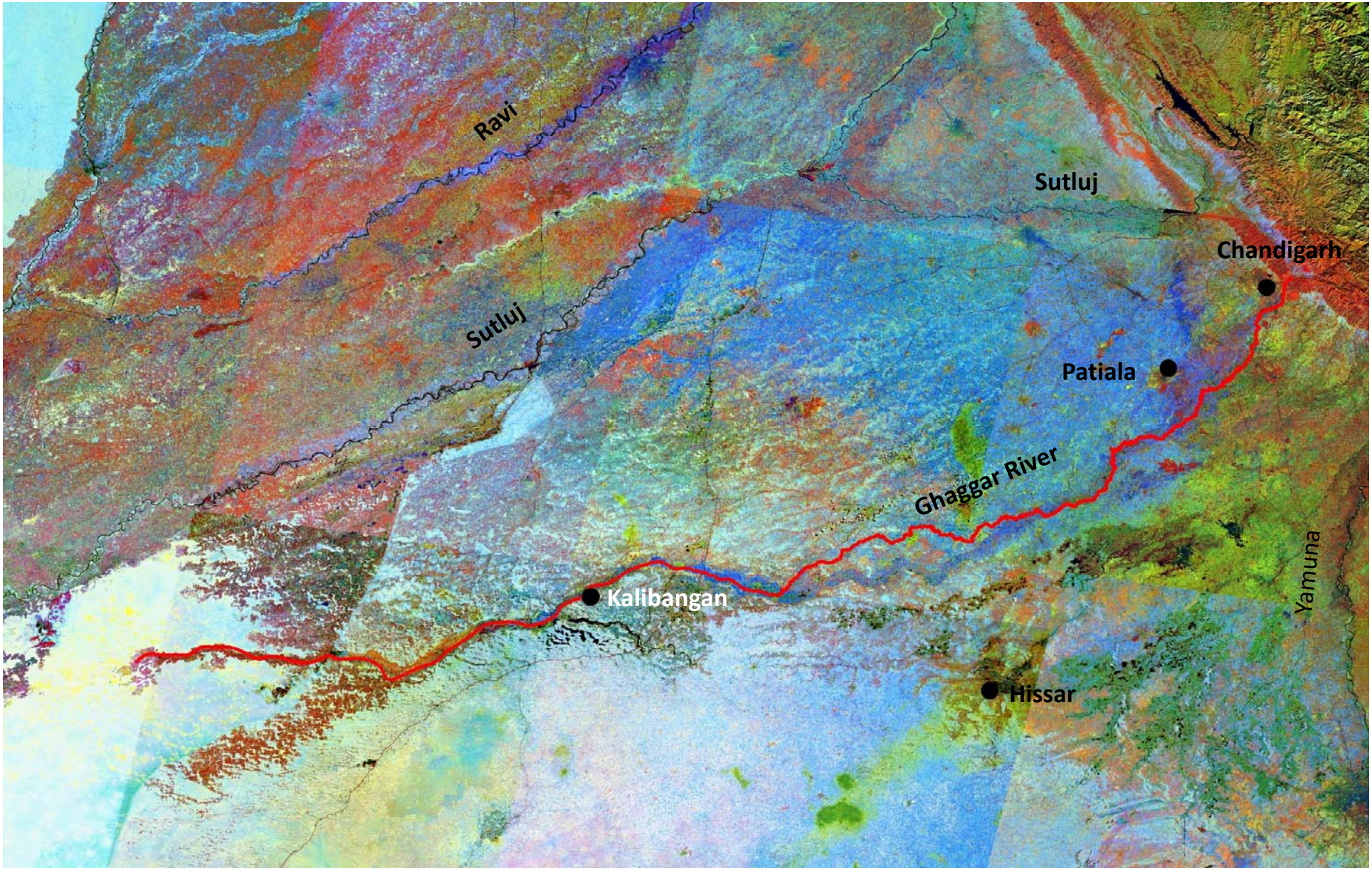
Outstanding Science Questions

- What is the spatial distribution of groundwater depletion?
- What controls the spatial distribution of groundwater aquifers in northwestern India?
- What is the source of the groundwater and what is the residence time of groundwater?
- How connected are the aquifers, and how has connectivity changed in recent geological time?

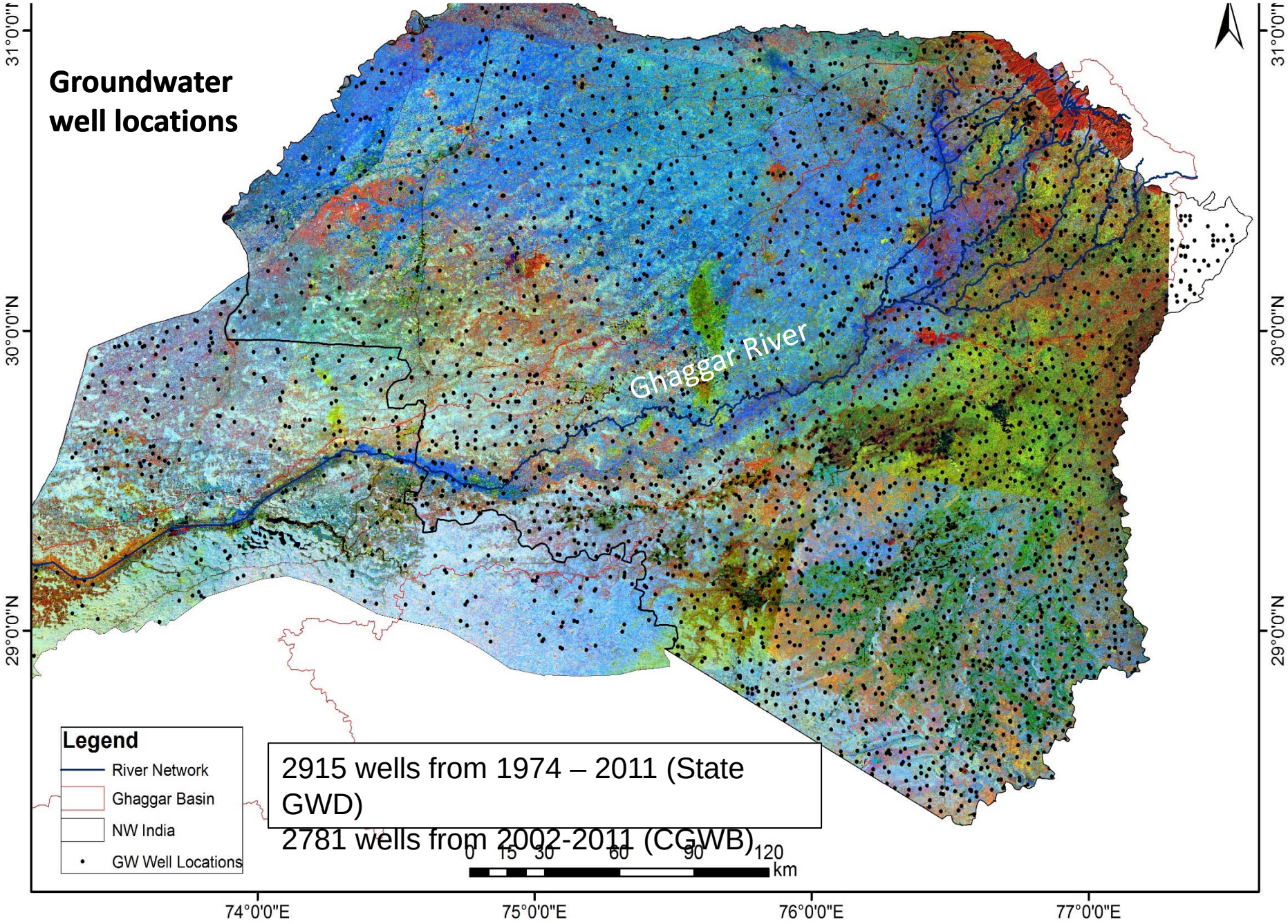
And then:

- How might the groundwater system respond to future changes in monsoon precipitation patterns?

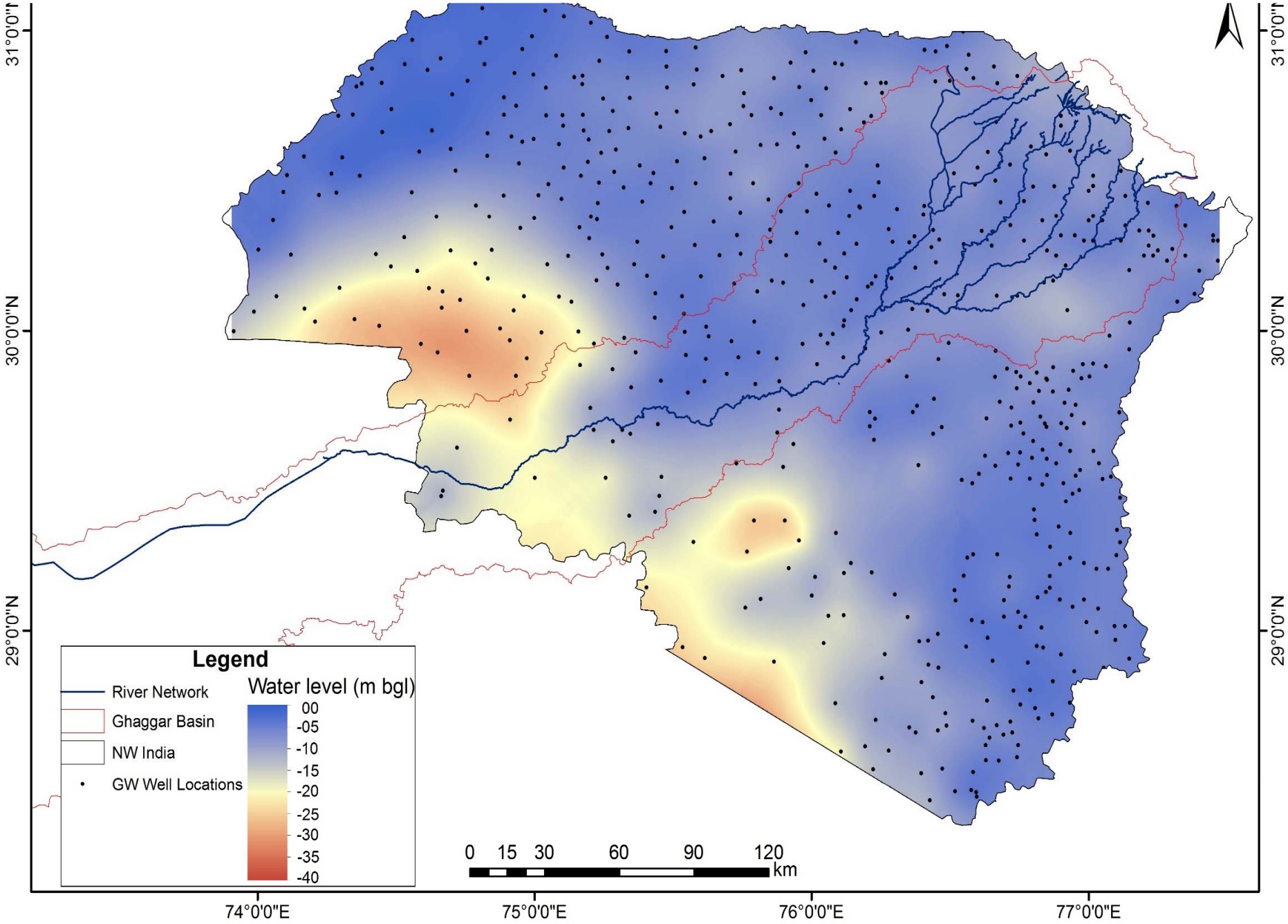
Regional Context



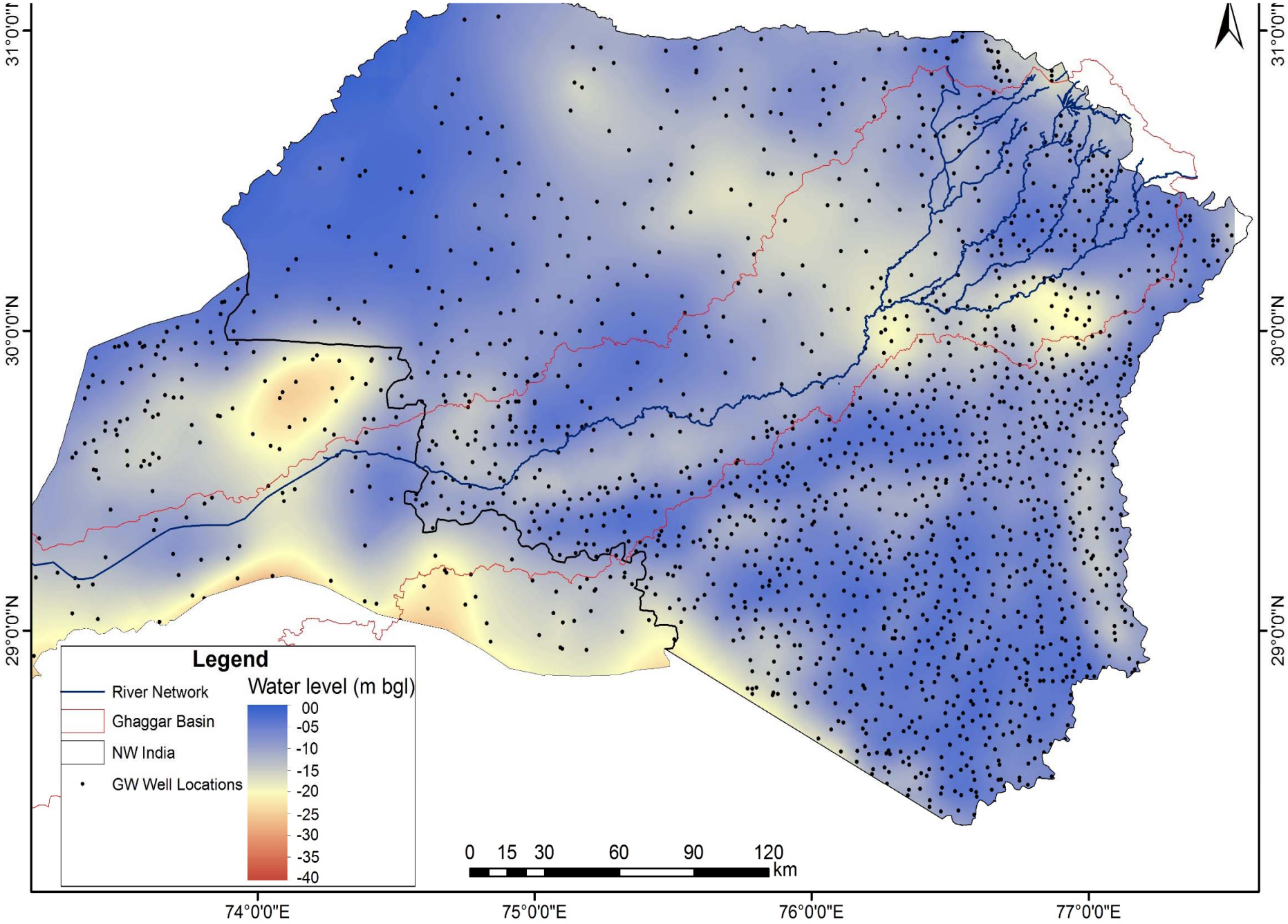
Spatial trends of groundwater depletion



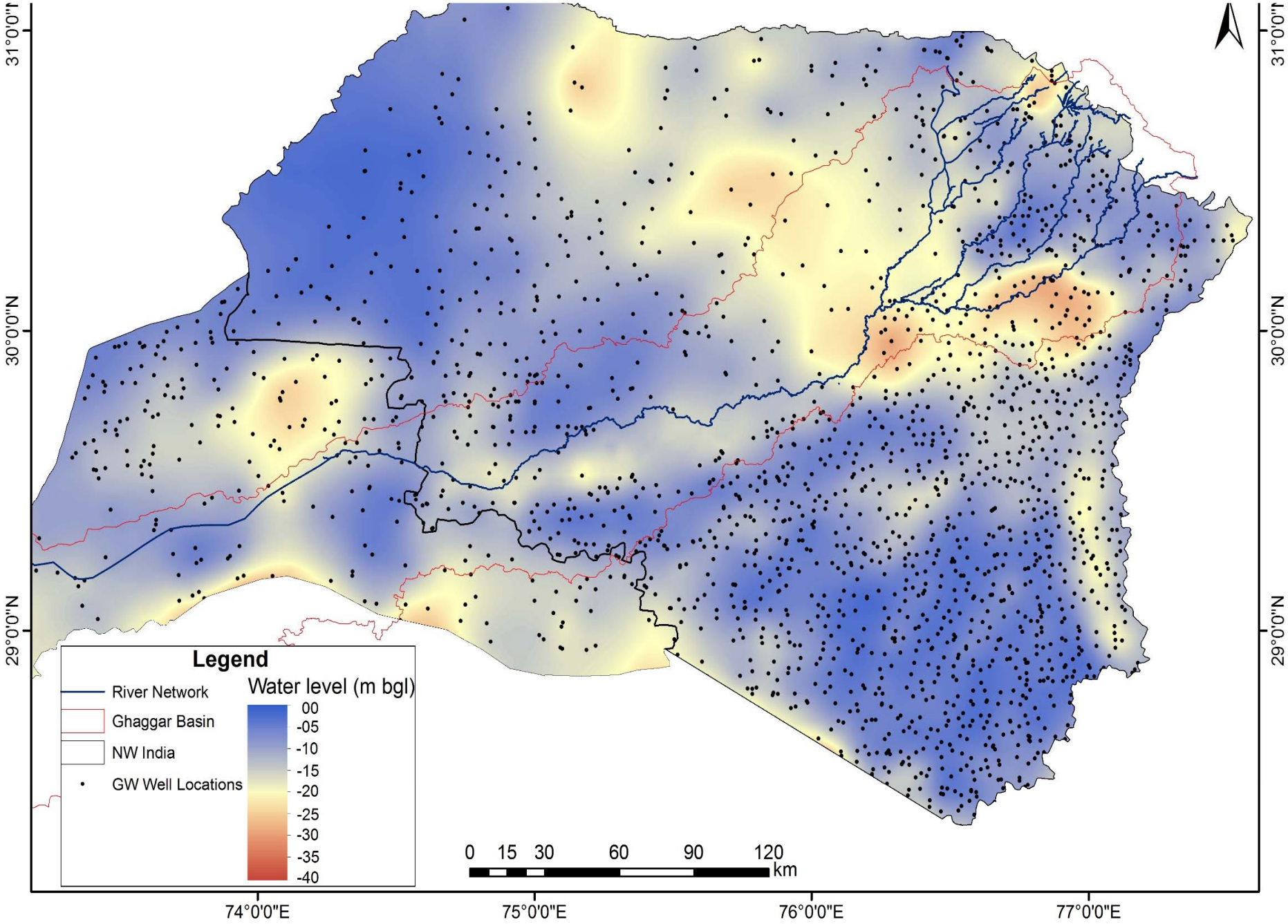
Depth to water level 1975



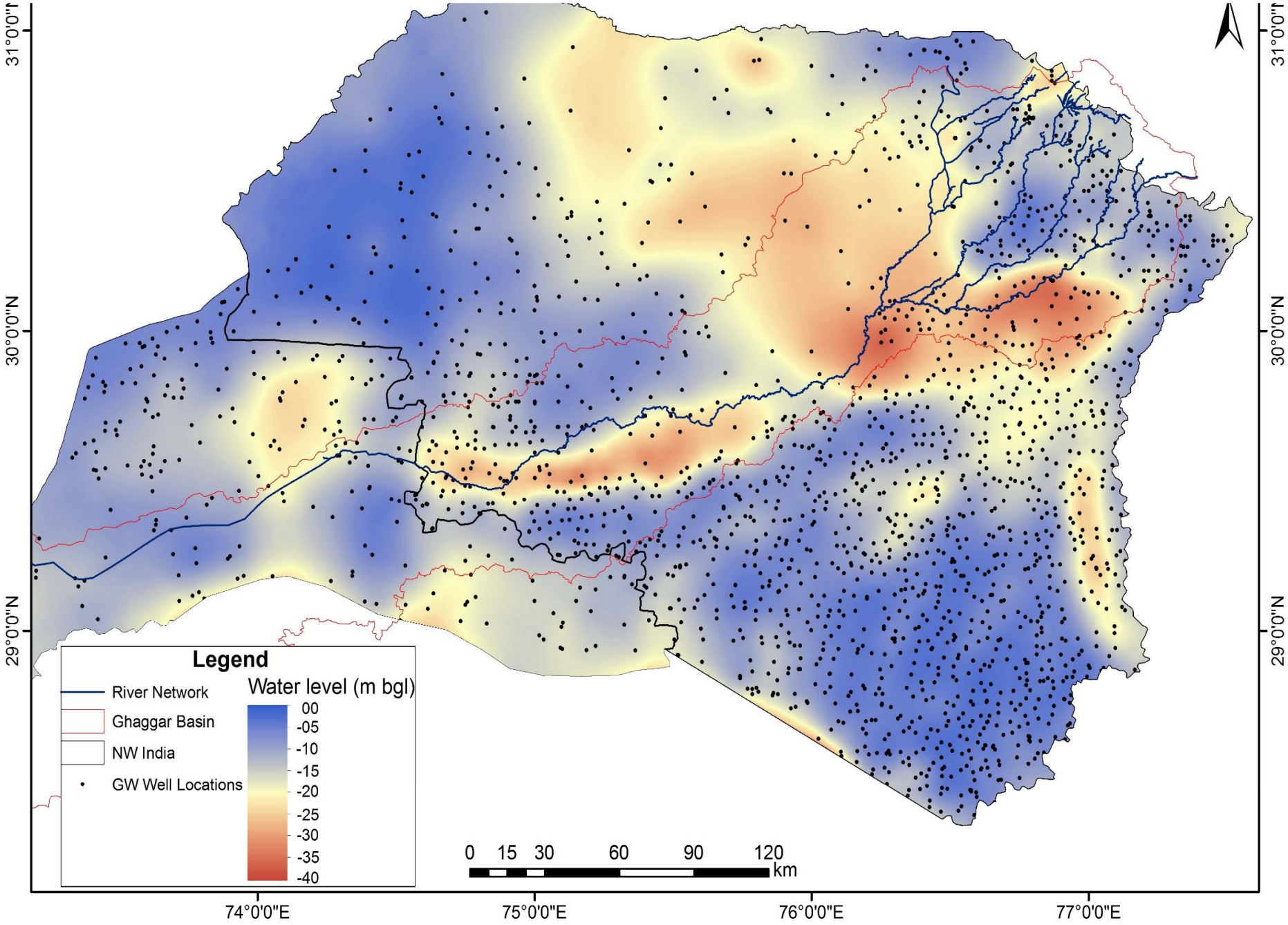
Depth to water level 2000



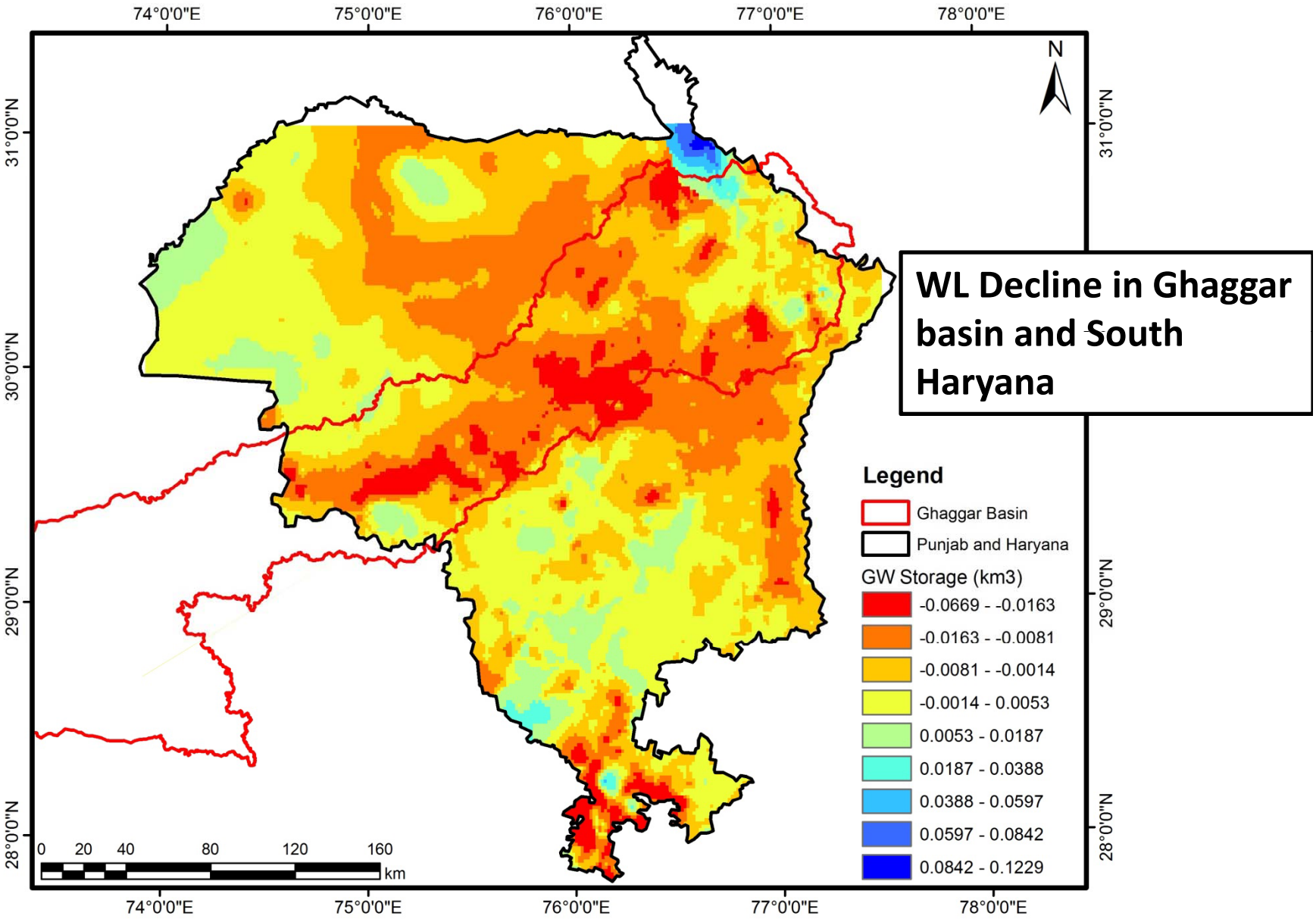
Depth to water level 2005



Depth to water level 2010



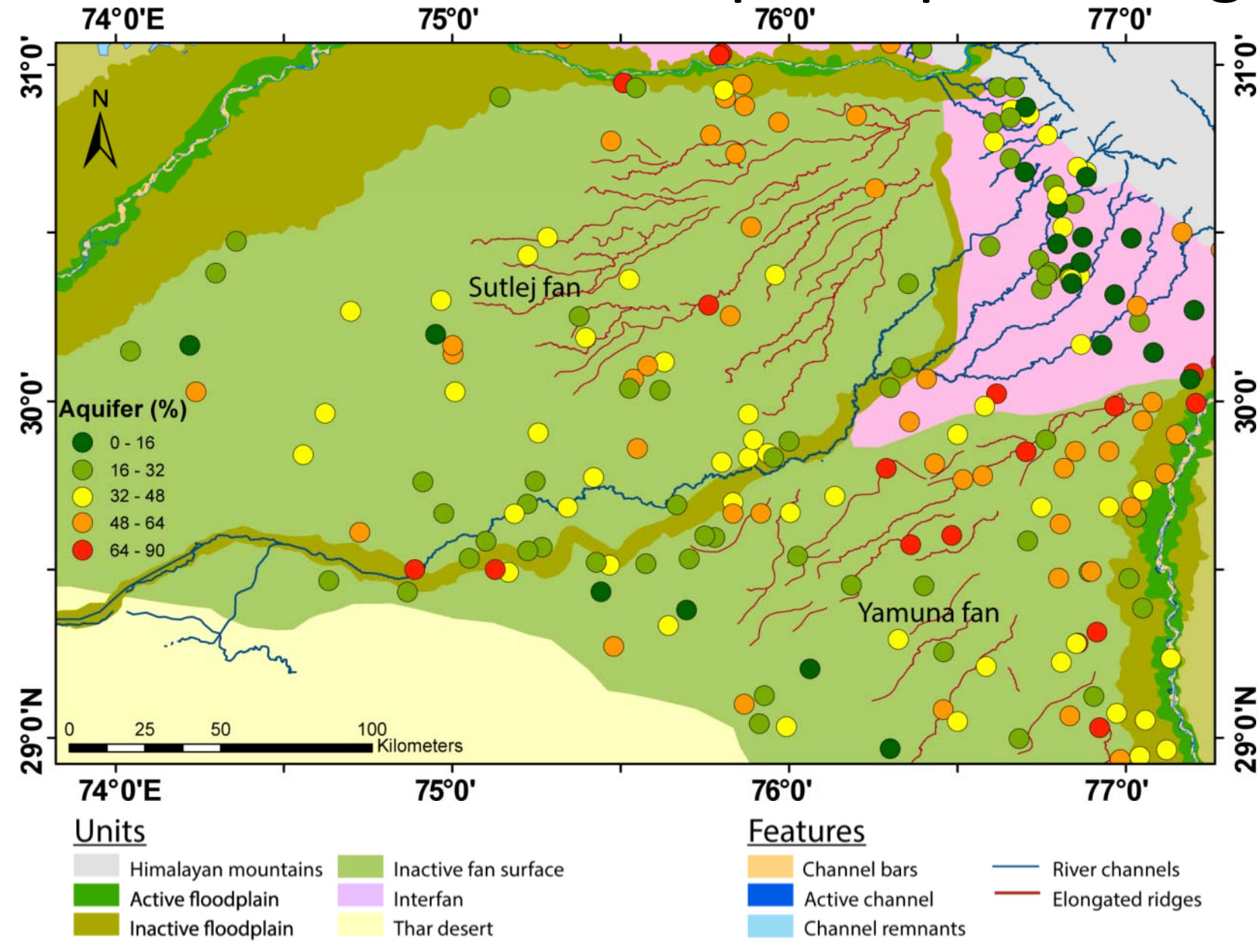
GW Storage Change (from 1995 to 2010)



Characterisation of Aquifer bodies – most crucial but very challenging

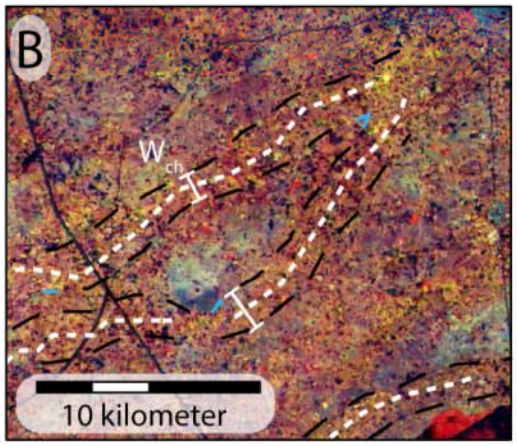
- Highest rates of global groundwater extraction
- Very sparse information on aquifer distribution, – no geological model
- Very poor stratigraphic constraints, vey large area (44,000 km^2)
- Standard stratigraphic methods for reconstruction aquifer geometry inadequate
  - Structure imitating
  - Process imitating
  - Descriptive
- Need simple flexible, predictive models that can be easily adapted as new data become available

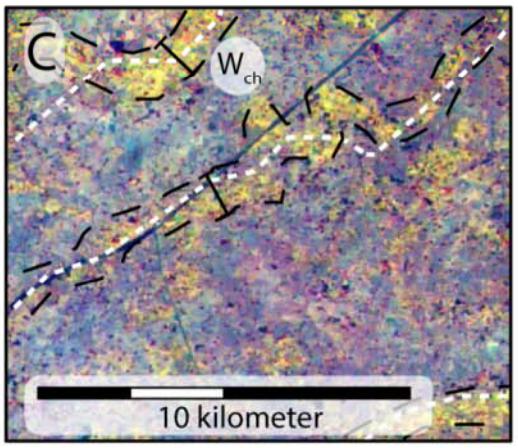
Spatial distribuiton of aquifer percentage

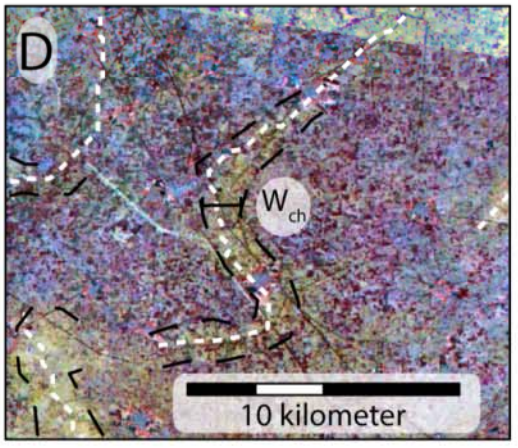


Channel width characteristics

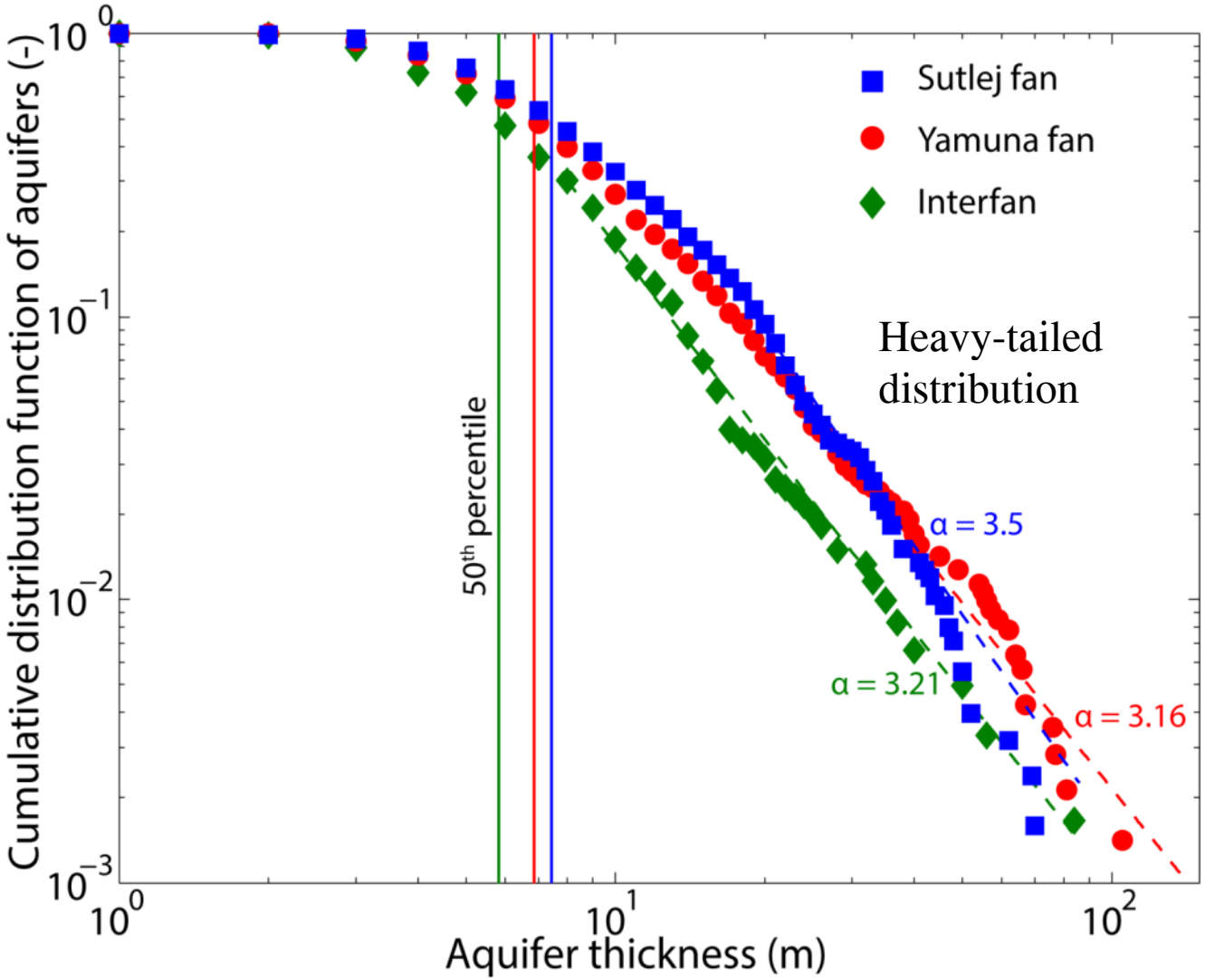
Basin	Feature	Width (m)
Sutlej river	Valley	7000-50000
	Channel belt	1600-5000
	Current channel	300-900
Yamuna river	Valley	15000-20000
	Channel belt	4000-10000
	Current channel	900-1500
Ghaggar	Paleochannel	5000-8000
	Current channel	60-100
Sutlej fan	Ridges	650-2300
Yamuna fan	Ridges	740-1790



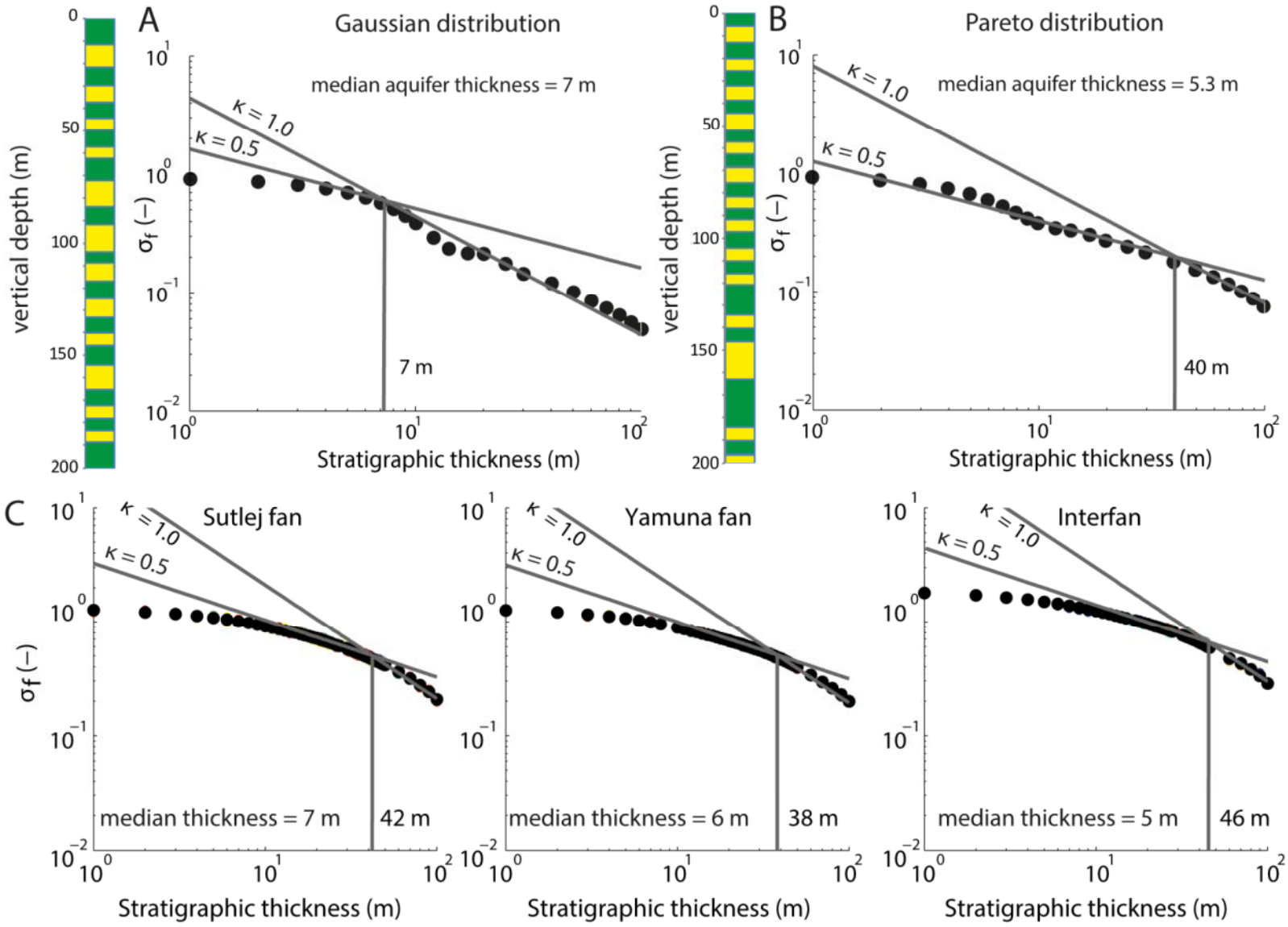




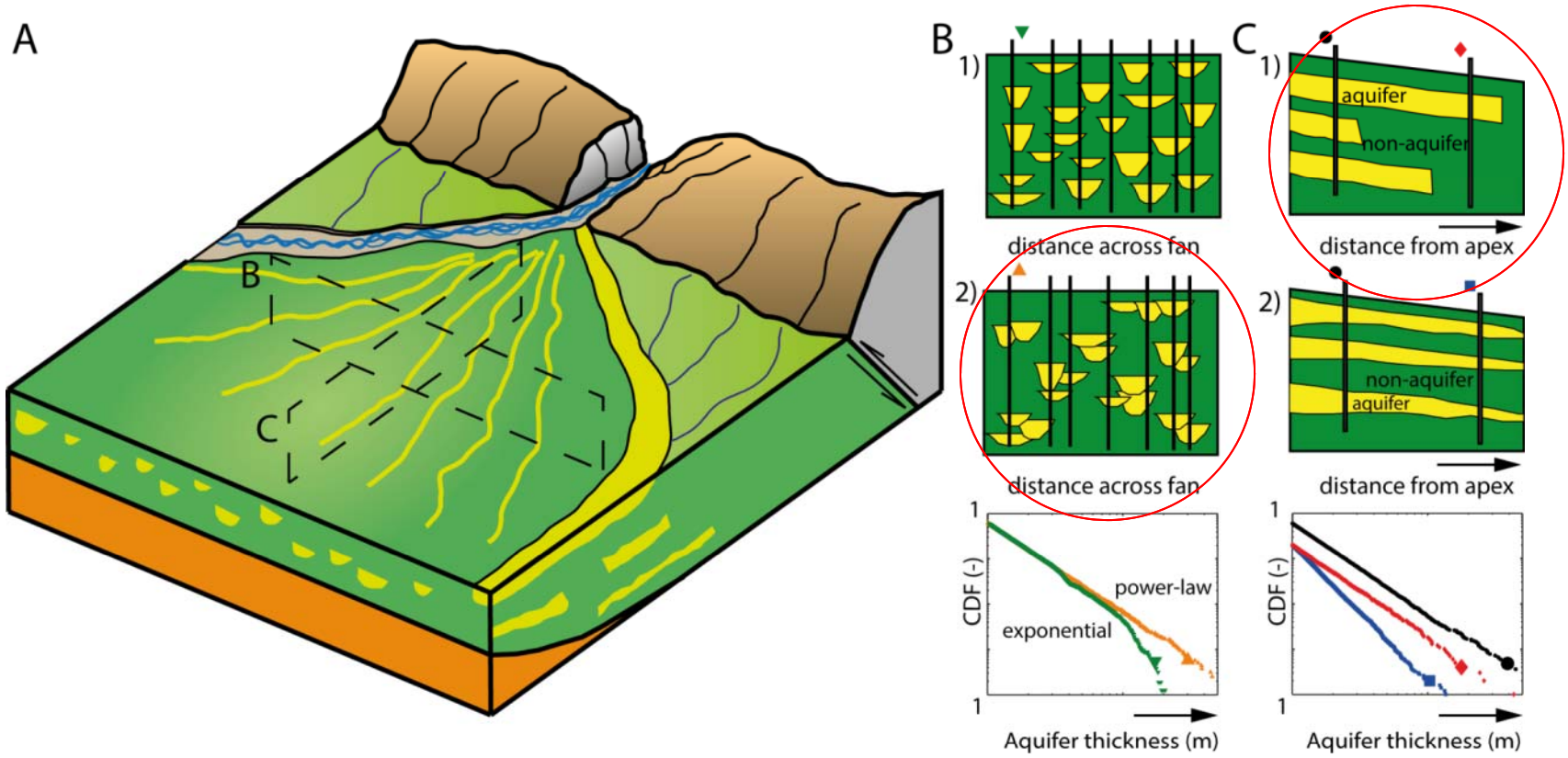
Aquifer thickness distribution



Compensational filling

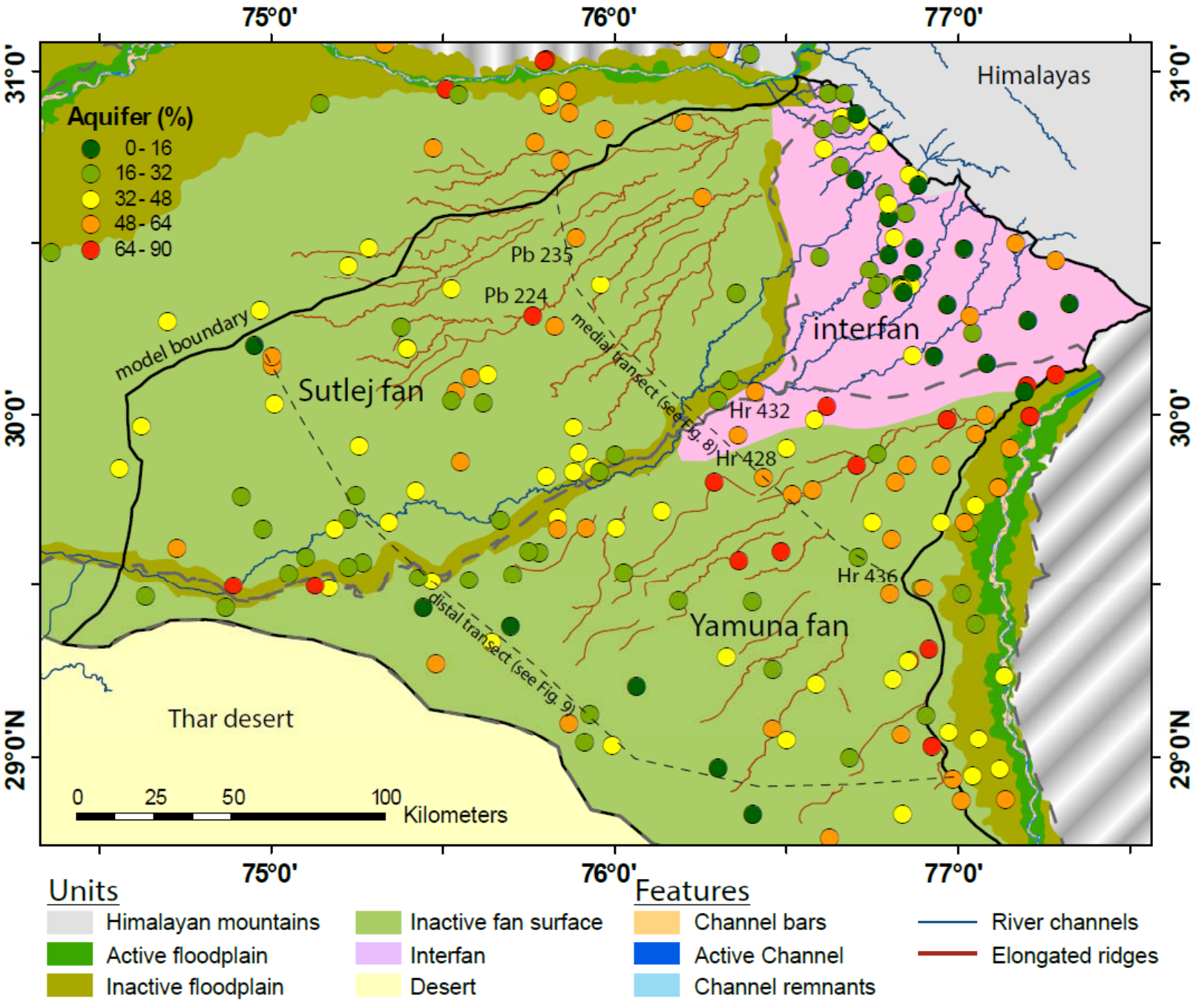


Conceptual model

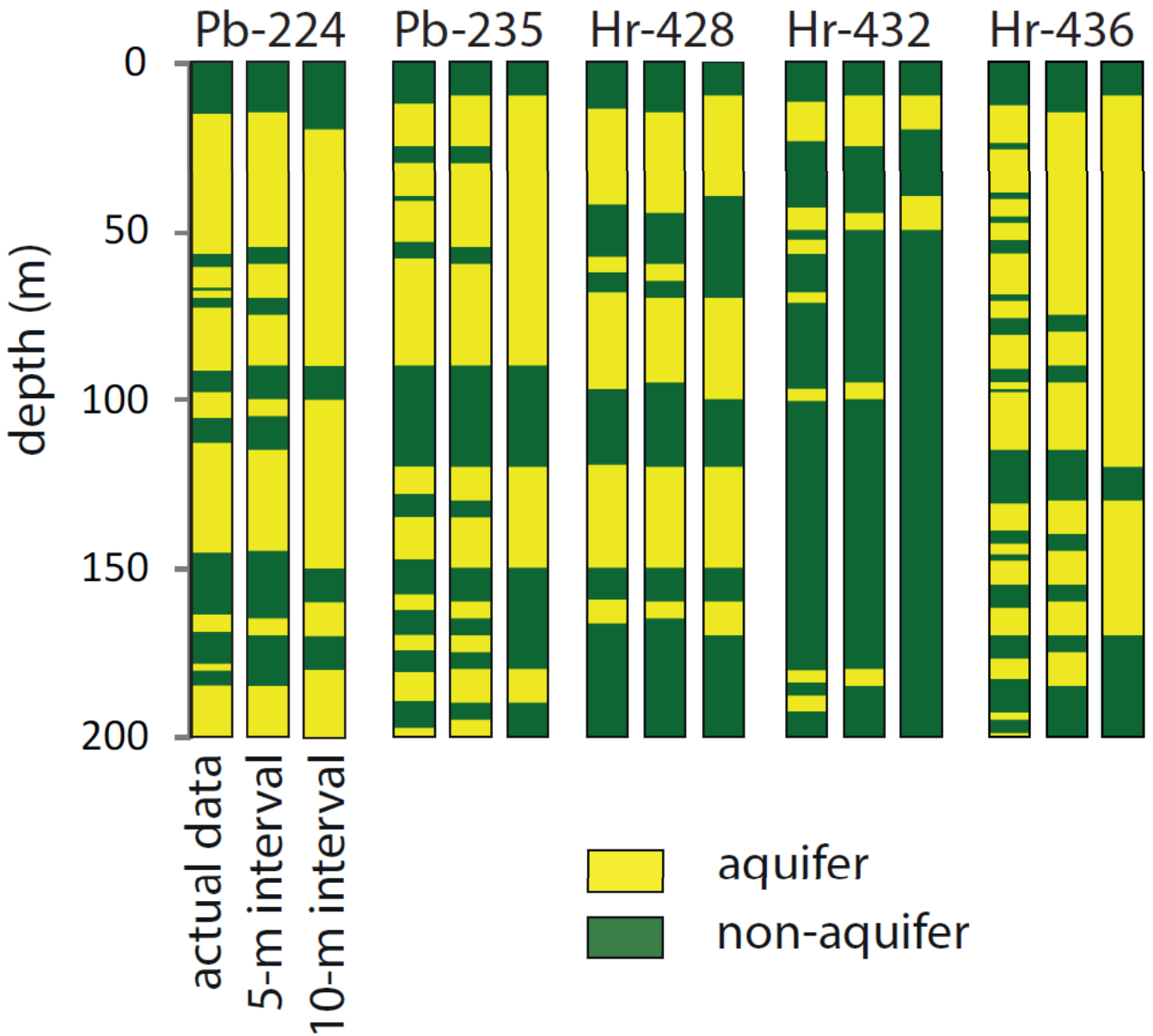


B) anti-compensational filling (2) leads to thicker aquifers (power law) compared to compensation filling (1).

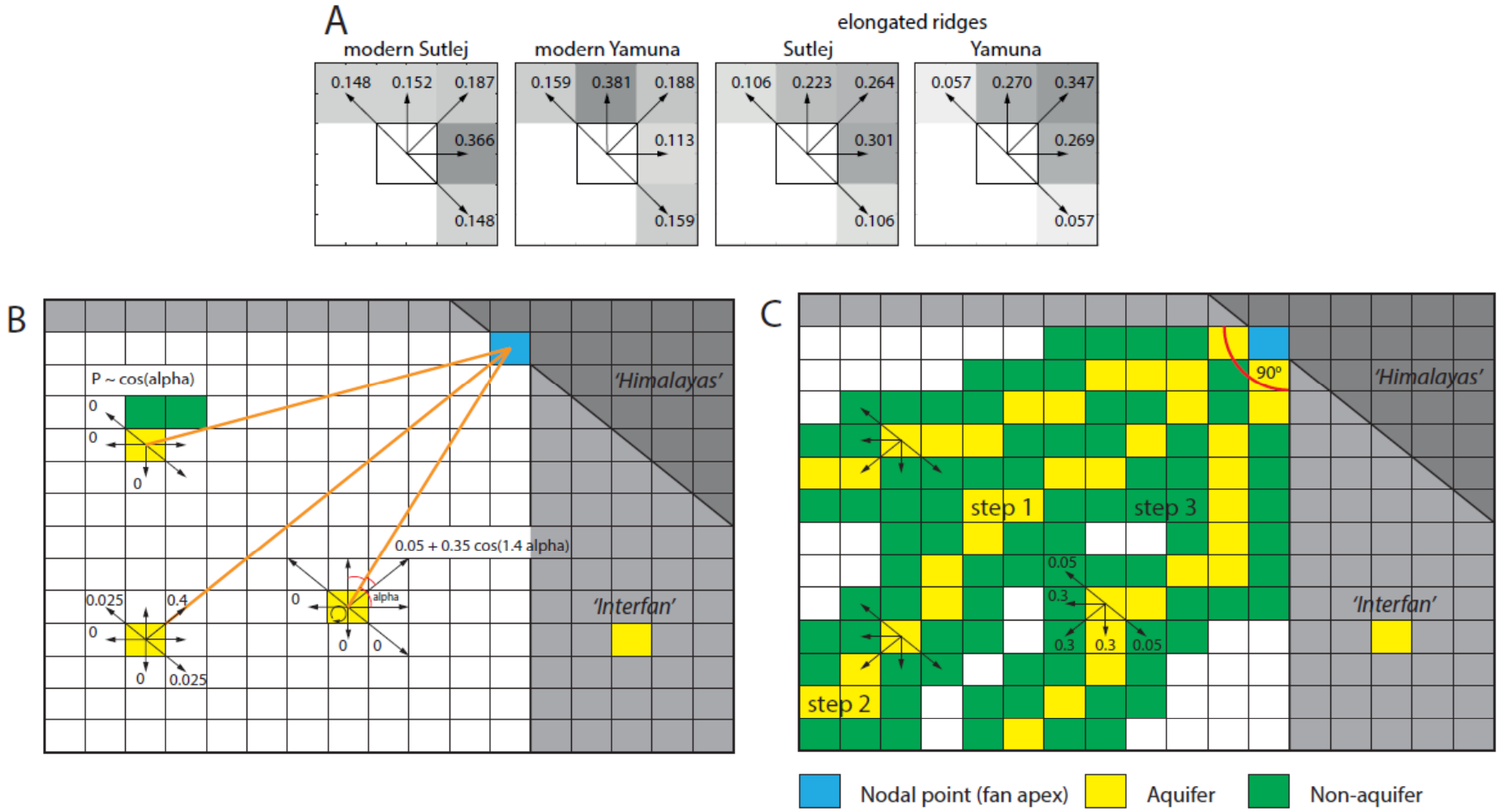
C) decrease in number of aquifers down fan (1) but do not thin appreciably (2).


75°0'
76°0'
77°0'
31°0'
30°0'
29°0'N
Aquifer (%)
0 - 16
16 - 32
32 - 48
48 - 64
64 - 90
Himalayas
Pb 235
Pb 224
model boundary
Sutlej fan
medial transect (see Fig. 8)
interfan
Hr 432
Hr 428
Hr 436
Yamuna fan
distal transect (see Fig. 9)
Thar desert
0 25 50 100
Kilometers
Units
Himalayan mountains
Active floodplain
Inactive floodplain
Inactive fan surface
Interfan
Desert
Features
Channel bars
Active Channel
Channel remnants
River channels
Elongated ridges

Examples of logs with aquifer and non-aquifer

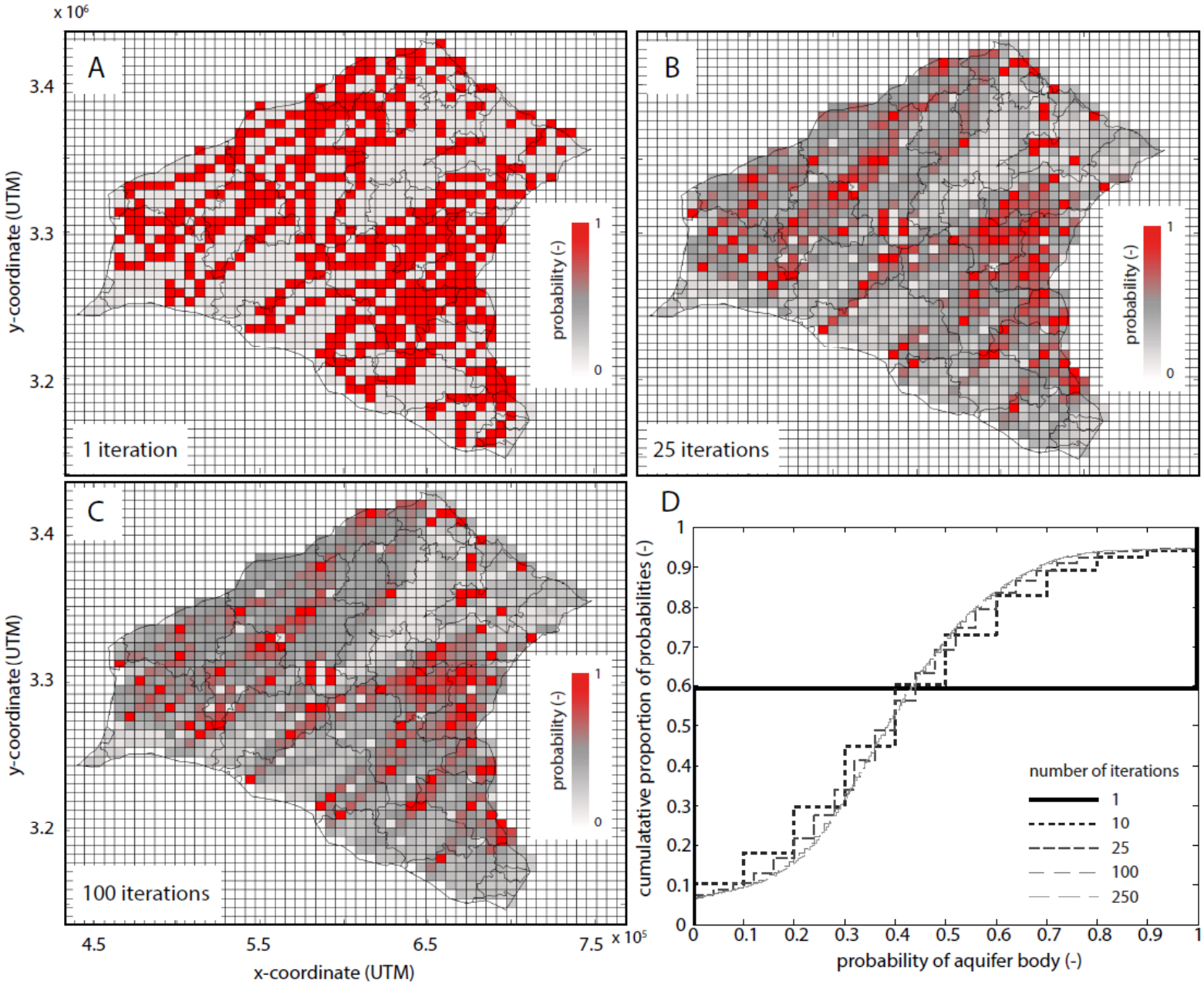


Weighted Random Walk Approach



- A continuous channel that connects aquifer location on the fan with the fan apex
- Paleochannels set the weighting for routing direction
- Elongate channel bodies enclosed within non-aquifer material
- Well data determine net-to-gross for the whole system

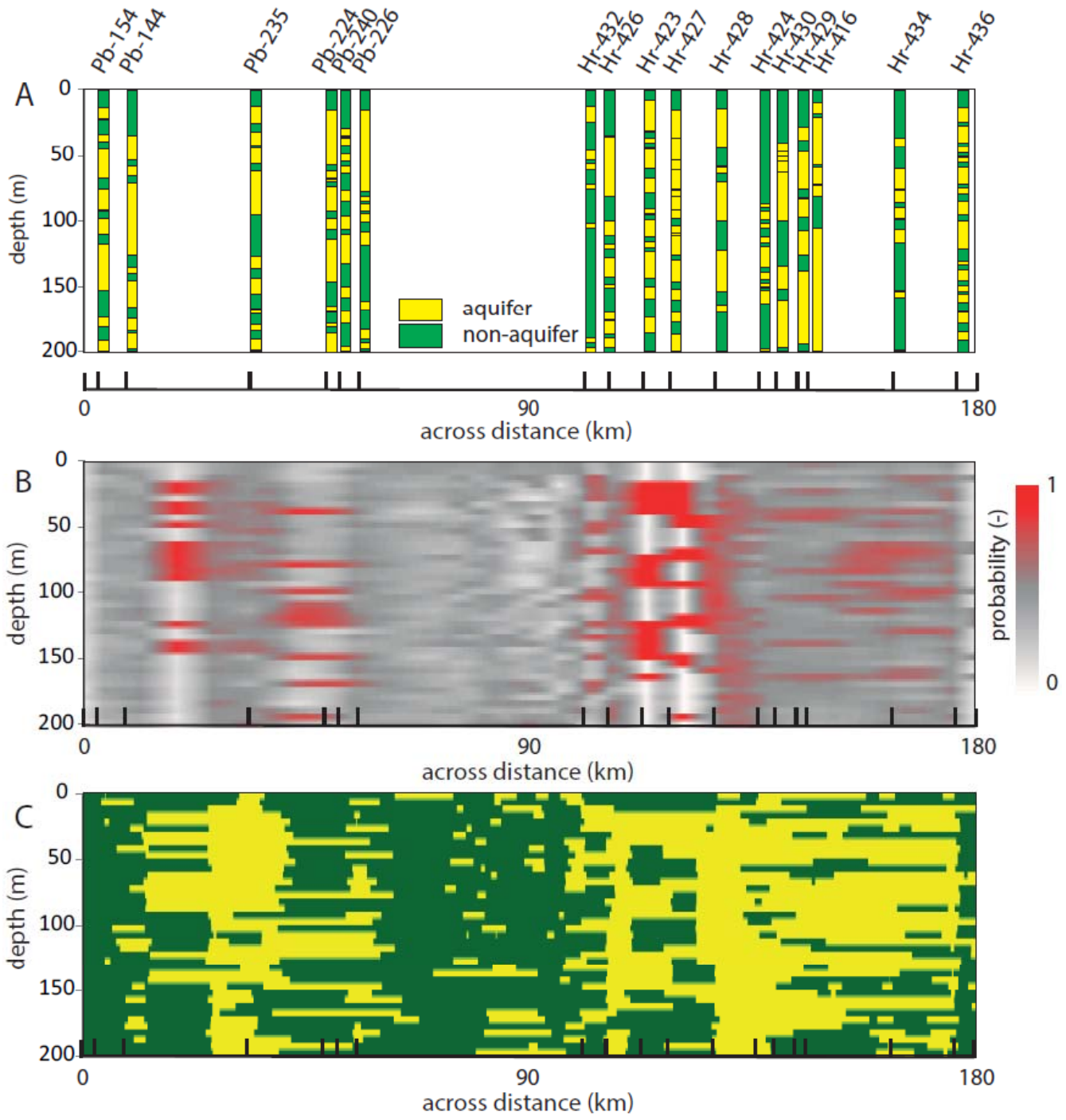
A Single solution for depth interval 80-90m with different iterations



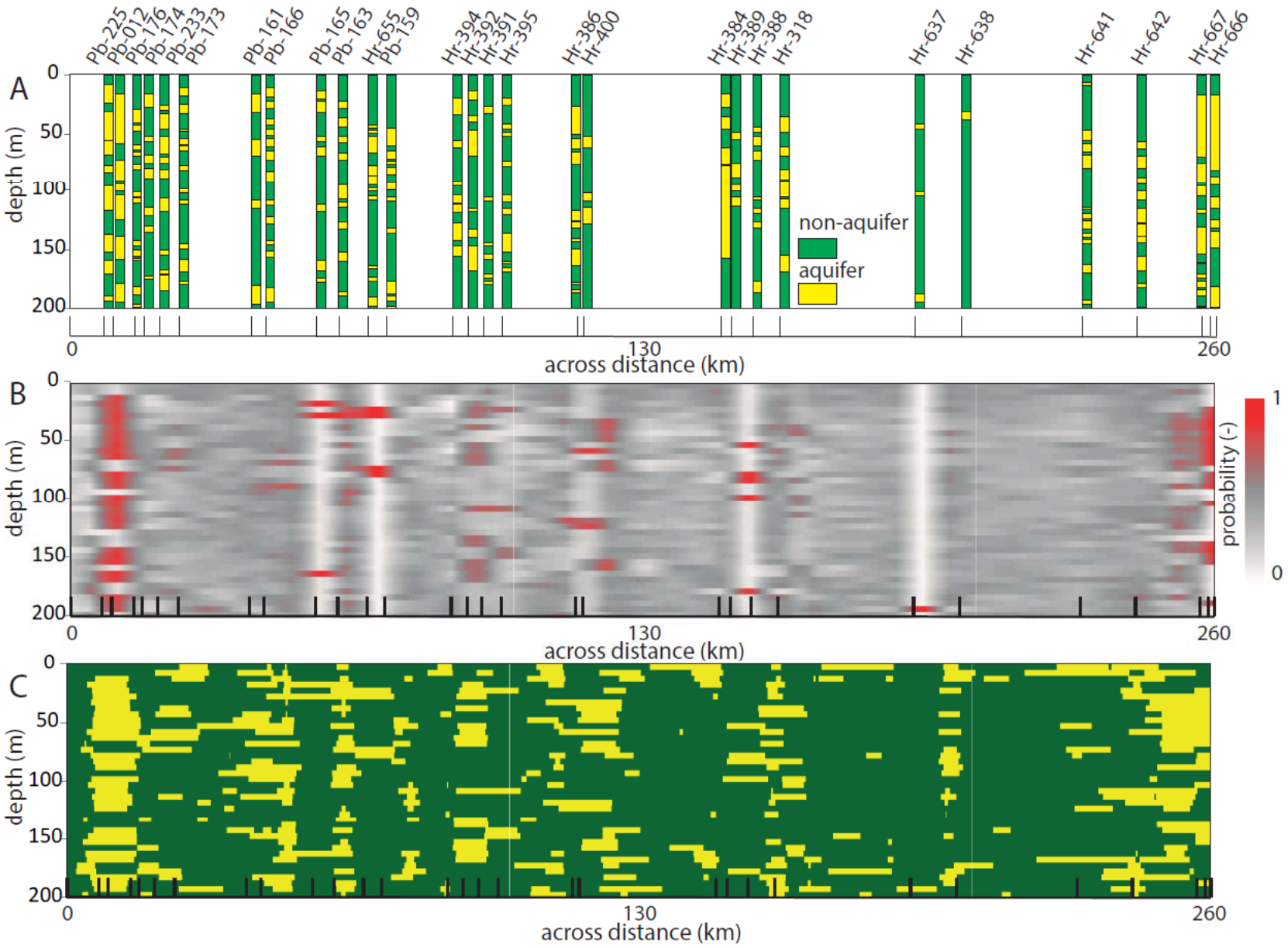
Medial Transect – Available logs

Cross-sectional probability

Cross-sectional aquifer map



Distal transect: borelogs, cross-sectional probability and aquifer map



Take Home Points

- Geomorphic units provide a convenient and consistent framework for understanding aquifer characteristics nd water level decline
- Aquifer systems are made up of buried, discontinuous sand bodies – deposited by large, Himalayan-fed fan systems
- The aquifer thickness distribution is uniform in depth,and aquifers do not thin downfan - indicates no change in depositional conditions
- The reduced-complexity probabilistic model provides 3D heterogeneity of aquifer bodies across the Sutlej-Yamuna fan over time.


And what do we get out of this?