Groundwater Governance: The biophysical basis

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Take as read…

- Scarcity of freshwater resources in India
- Massive and increasing dependence on groundwater
- Rapidly declining groundwater tables

- Various attempts at GW regulation:
  - Model bill 2005
  - State laws
  - CGWA/CGWB issues guidelines

Common goal: **Sustainable GW Use**

- Model bill has no explicit mention
- State laws:
  - “to control indiscriminatory exploitation” (GoK)
  - to avoid “serious environmental consequences” (Delhi)
- Model bill 2011:
  - “to promote sustainable GW use in the public interest”

What does Sustainable GW use mean?

- Lay understanding:

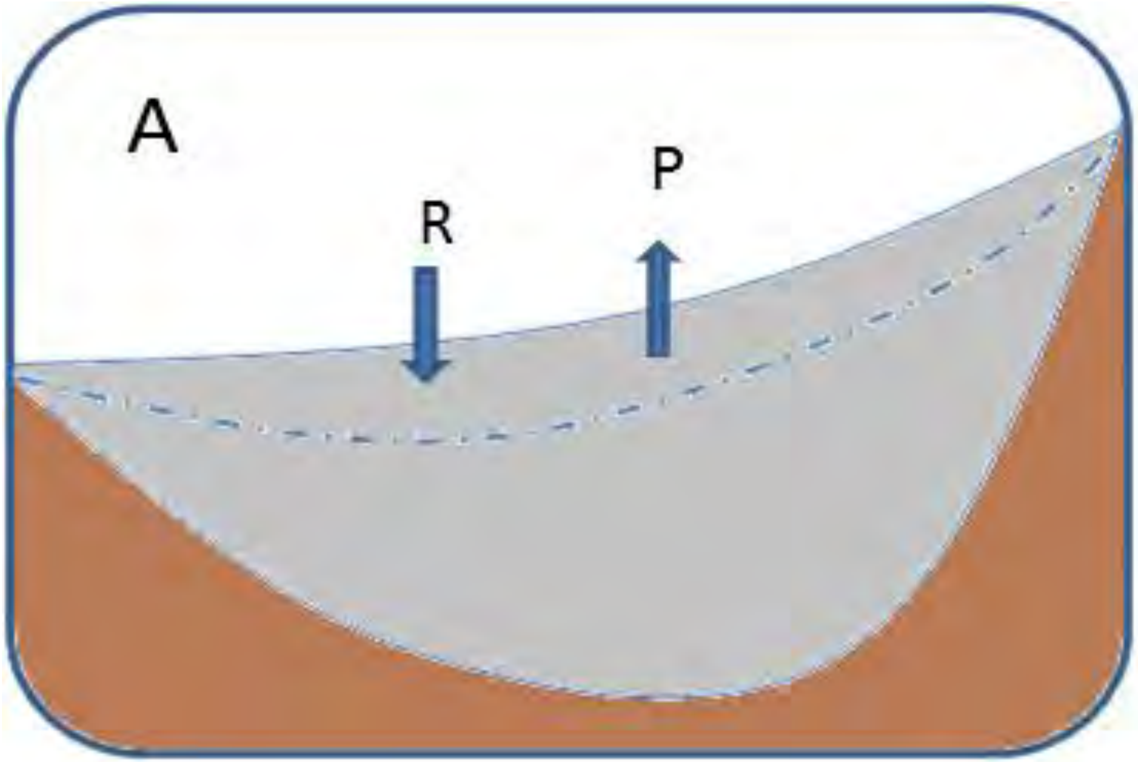
  PUMPING <= RECHARGE

- CGWB:

  PUMPING <= 95% of RECHARGE

This was earlier called “Safe yield”

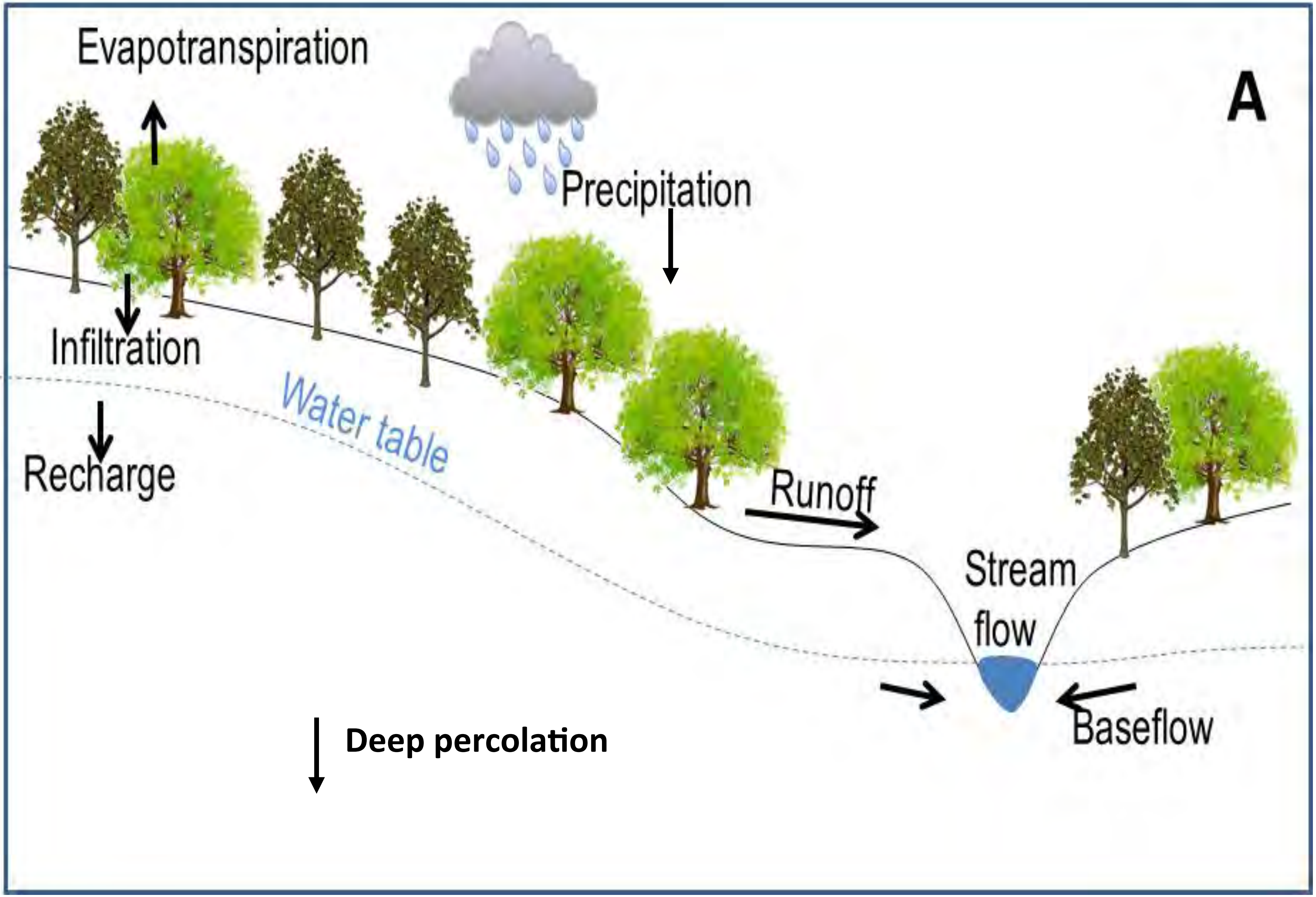
Basis: BUCKET MODEL



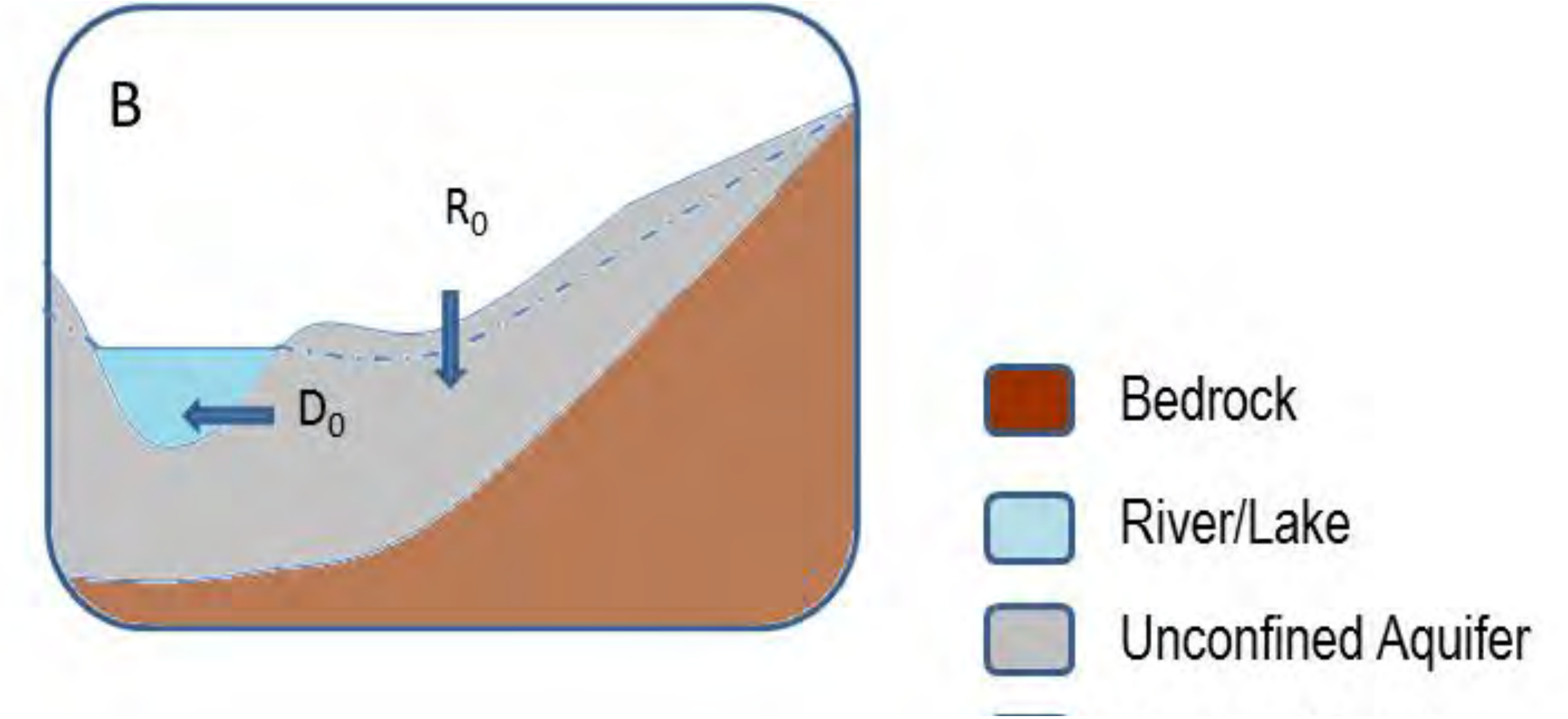
Only showing GW linked arrows

Based on a incomplete understanding of the hydrological cycle!

Hydrological Cycle

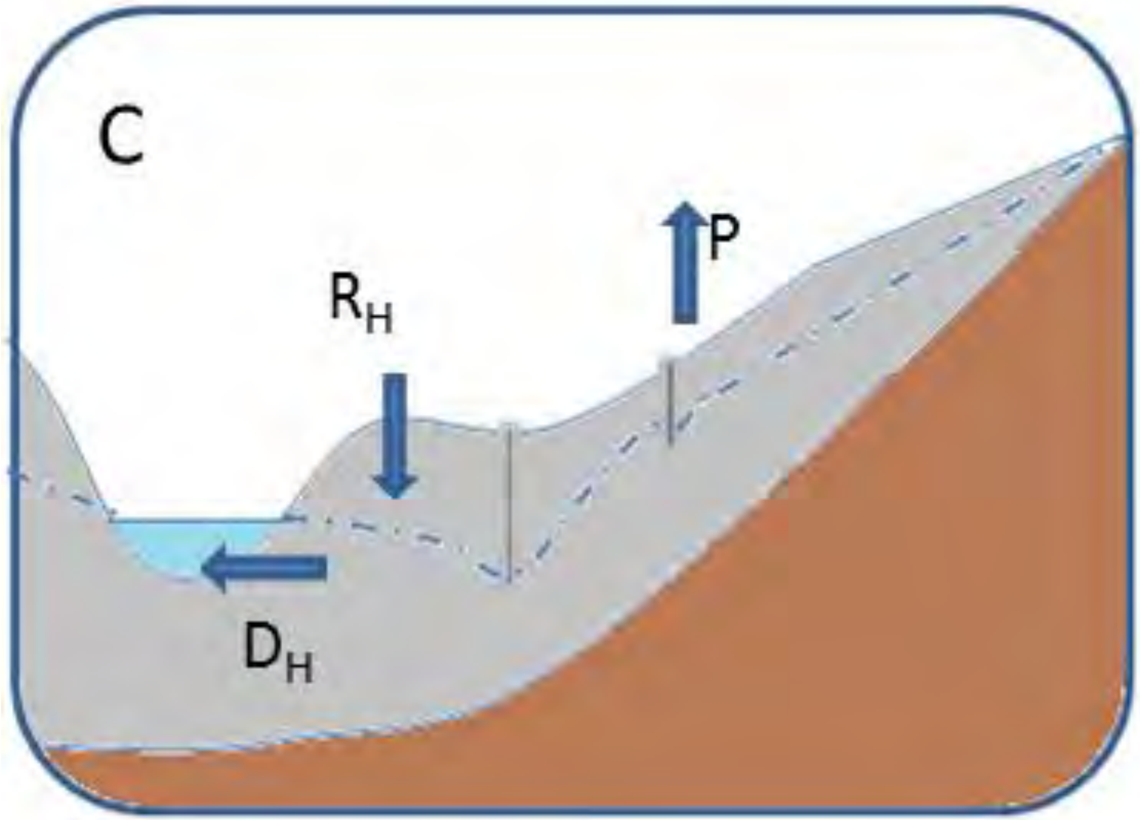


Under Pristine Conditions



$R_0 = D_0$ at steady-state

So under pumping:



$$dV/dt = R_H - D_H - P$$

& for steady-state: $P = \Delta D + \Delta R$

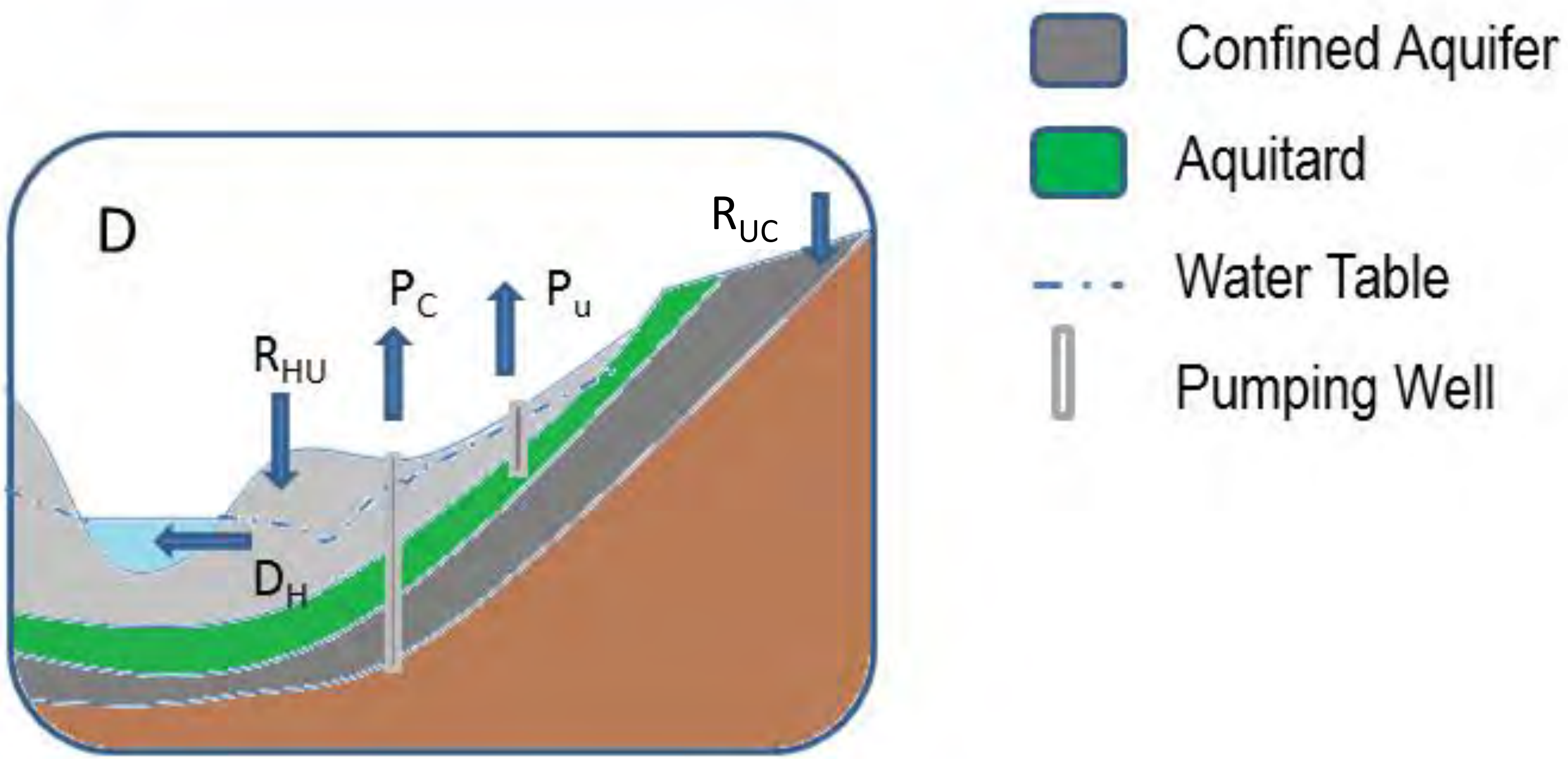
Meaning

For non-declining GW levels under pumping:

Net pumping must equal

 'captured recharge' + 'captured discharge'

More complicated aquifers



if confined aquifer does not have an exit, then under pristine conditions, R_{UC}=0

So pumping captures 'rejected recharge'

Normative implication

- "Sustainability" => inter-temporal or inter-generational equity
- But P ↑ => D↓ (or rejected R↓) => downstream or instream availability
- "Equity" or "Fairness" becomes the central concern!
  - Between upstream & downstream user
  - Between sectors (agriculture vs environmental amenity)

Hydrologists' response (in the West)

- Problems recognized first 1915 (Lee), then 1940s (Theis), then re-critiqued in 2000s (Bredehoeft and many others)
- Different levels proposed:
  - 'practical safe yield' = 'maximum sustainable yield' = allowing a minimum discharge
  - 'perennial safe yield' = rejected recharge + ET by unproductive vegetation (to be cut)
  - 'permissive sustained yield' = leave significant fraction of D_0 untouched
  - Appropriate only deep percolation
  - Other extreme: Planned depletion or permissive mining

Policy response (in OECD countries)

- EU water framework directive:
  - P should be < (R – streamflow requirements)
- But several USA states permit permissive mining or planned depletion
- Murray-Darling basin in Australia:
  - Strong requirements of ecosystem flows
- Some states in Australia: planned depletion!
- BUT: choices are all made **explicitly**

Response in India

- CGWB: GEC 1997
  - 4 categories:
    - Safe
    - Semi-critical
    - Critical
    - Over-exploited
  - Categorization done using two variables
    - Long term GW trends
    - Stage of GW development

CGWB method (GEC 1997)

Stage of Ground water Development	Significant Long term Decline		Categorisation
	Pre-monsoon	Post-monsoon	
<= 70%	No	No	Safe
>70% and <=90%	No	No	Safe
	Yes/No	No/Yes	Semi-critical
>90% and <=100%	Yes/No	No/ Yes	Semi-critical
	Yes	Yes	Critical
>100%	Yes/No	No/Yes	Over-Exploited
	Yes	Yes	Over-Exploited

Stage of GW development

$$Stage\ of\ groundwater\ development = Annual\ gross\ groundwater\ draft / Net\ annual\ groundwater\ availability$$

NAGA = *recharge less a small allocation for natural discharge* (baseflow) (set at 5-10% of Recharge)

Problems

- Wrong model: **slighly leaky bucket model !**
- As a result: non-declining water level but 90% of discharge appropriation => "SAFE" category
- CWGB latest review: recognizes minimum discharge need, but no recommendation

Indian Water Policy

- “exploitation of ground water resources should be so regulated as not to exceed the recharging possibilities, as also to ensure social equity” (NWP 1987 and 2002)
- Hence no mention of discharge in Model Bill 2005
- Indeed, no mention of goals of criteria at all

Model Bill 2011

- Recognizes "the common pool nature of groundwater, which has an intricate relationship with rainwater and surface water (through natural recharge) and with surface water (natural discharge)"
- But section 4 (Regulation of GW): back to "safe yield"

Water Dispute Tribunals

- SW-GW link recognized, but
  - Too difficult to include/incorporate, or
  - Unidirectional link only SW → GW

- Examples:
  - KWDT 1962: seals off GW use from SW use
  - CWDT 2007: 60 pages on GW, but only about recharge of GW in canal commands
    - Still assumes upstream GW use is a separate source

Empirical evidence of linkage

- Many studies in the USA and elsewhere

- Ranade: theoretical connection: Narmada Valley
- Malaprabha river decline
- Arkavathy river: ATREE study

Impacts of Watershed Development

- More infiltration

- More GW pumping for agriculture

- So net GW discharge reduces

Normative implication

- "Sustainability" => inter-temporal or inter-generational equity
- But P ↑ => D↓ (or rejected R↓) => downstream or instream availability
- "Equity" or "Fairness" becomes the central concern!
  - Between upstream & downstream user
  - Between sectors (agriculture vs environmental amenity)
- Even in bucket model, equity is important

Role of GW

- Replenishable GW: Inter-season buffer
- Non-replenishable GW: inter-year buffer

Water policy

- Cannot have a separate GW policy or planning

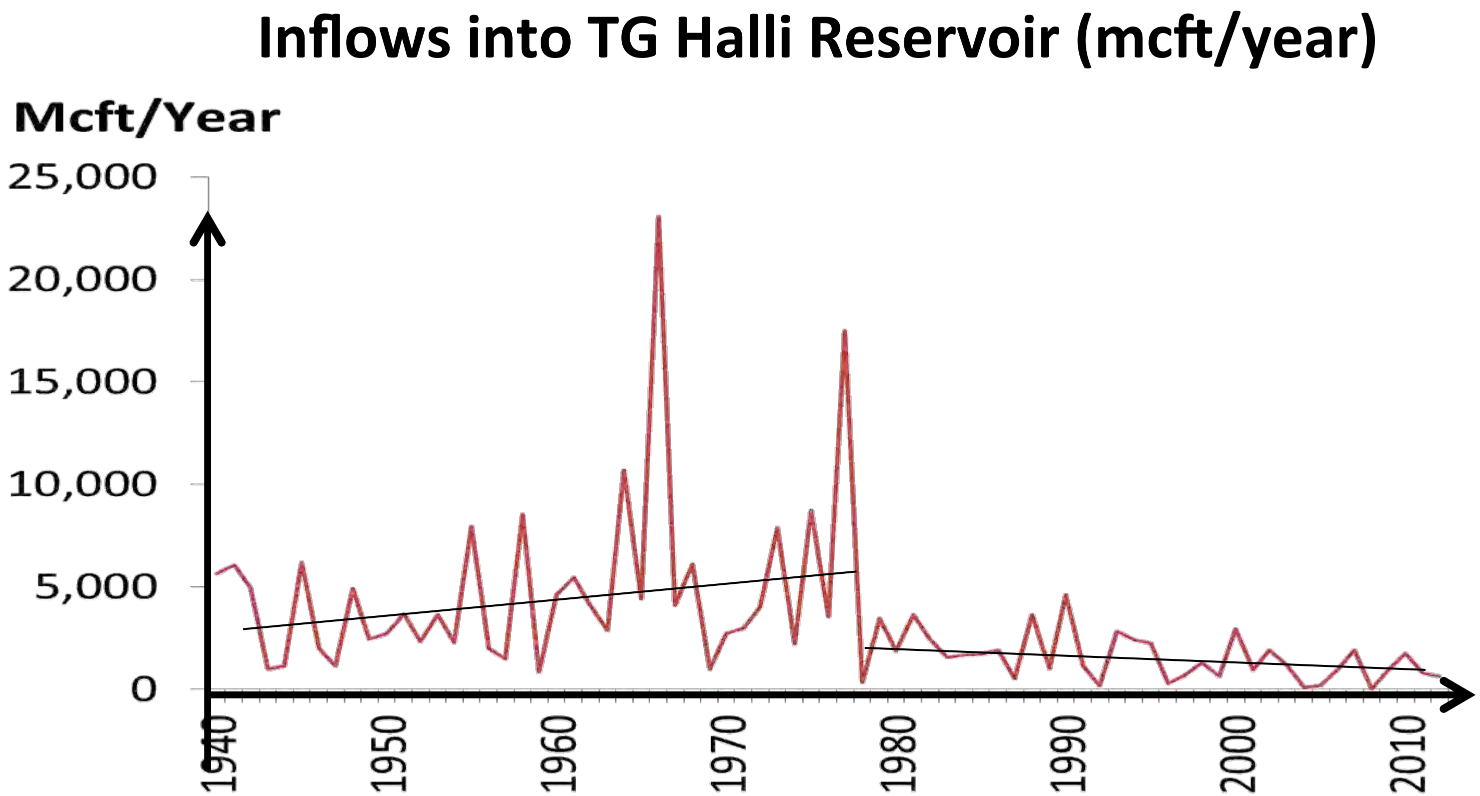
- No use may be necessary but difficult to implement ☺
- Explicit statements about how much discharge to appropriate or ET to reduce are required
- Water law: sustainable yield AND equitable sharing

Water institutions

- Regulatory authorities only focusing on surface water allocation

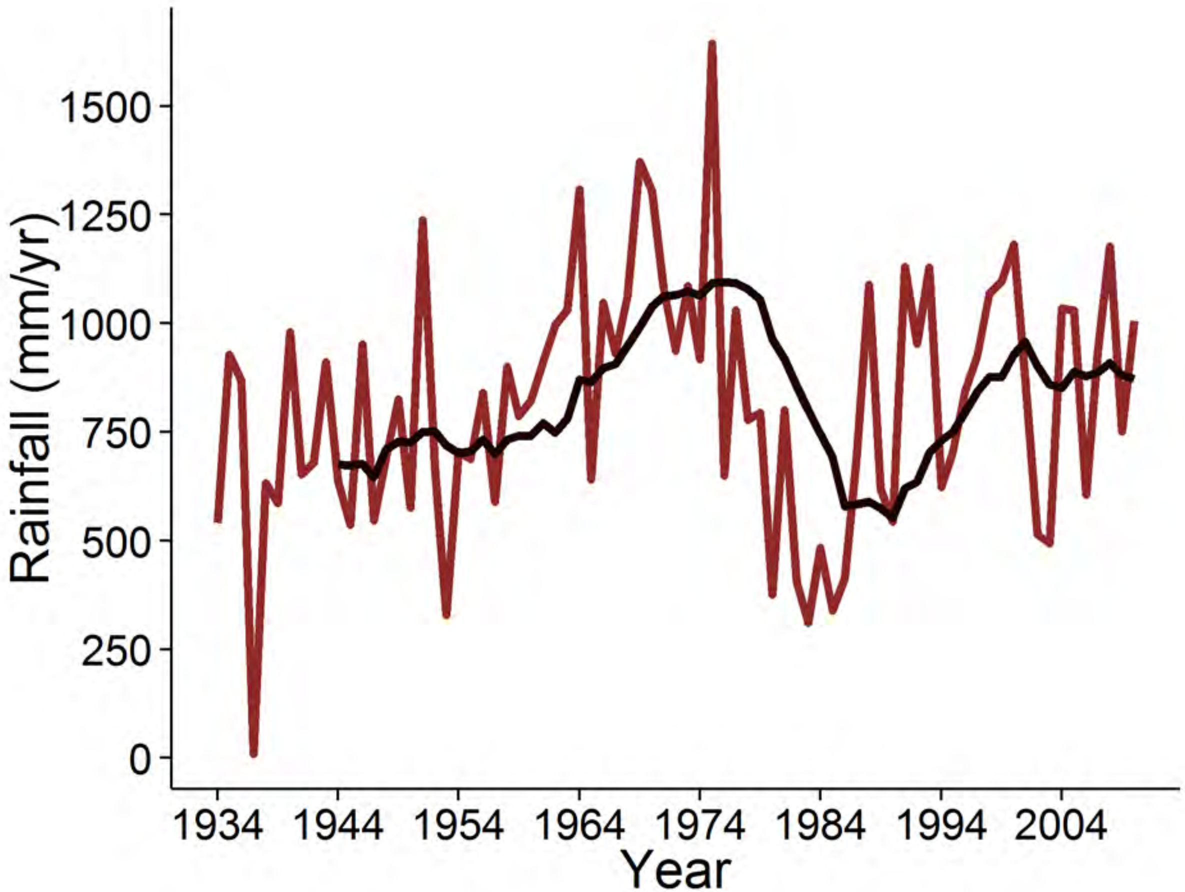
- Better monitoring of GW and integration with SW data
  - So not just aquifer mapping
  - Also GW movement between recharge and discharge points
- **Cooperative modelling of SW-GW system for decisions**

Inflows show a declining trend

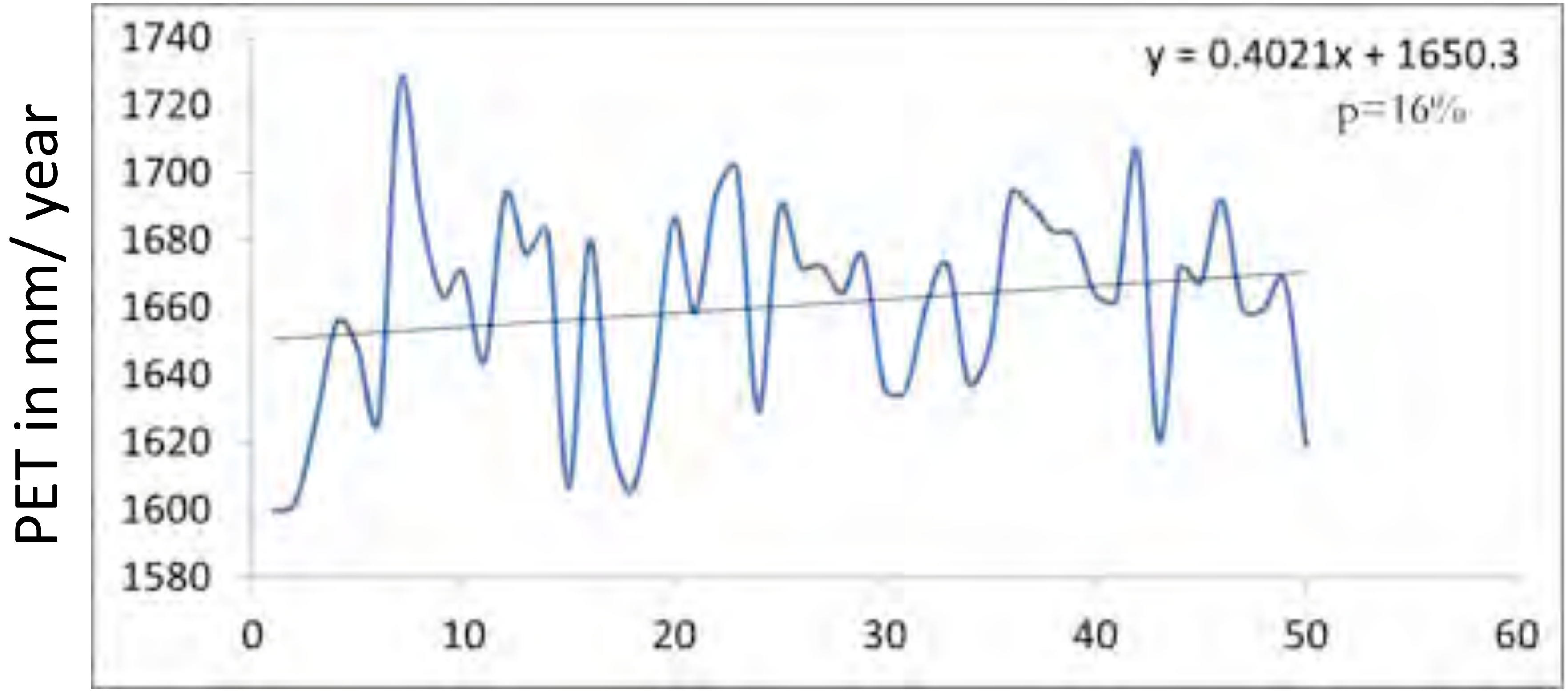


Inflows into the TG Halli reservoir, exhibit a <u>sharp declining trend</u> despite no new upstream dams.

#1 -Decline in Annual Rainfall



#2 - Rise in temperature

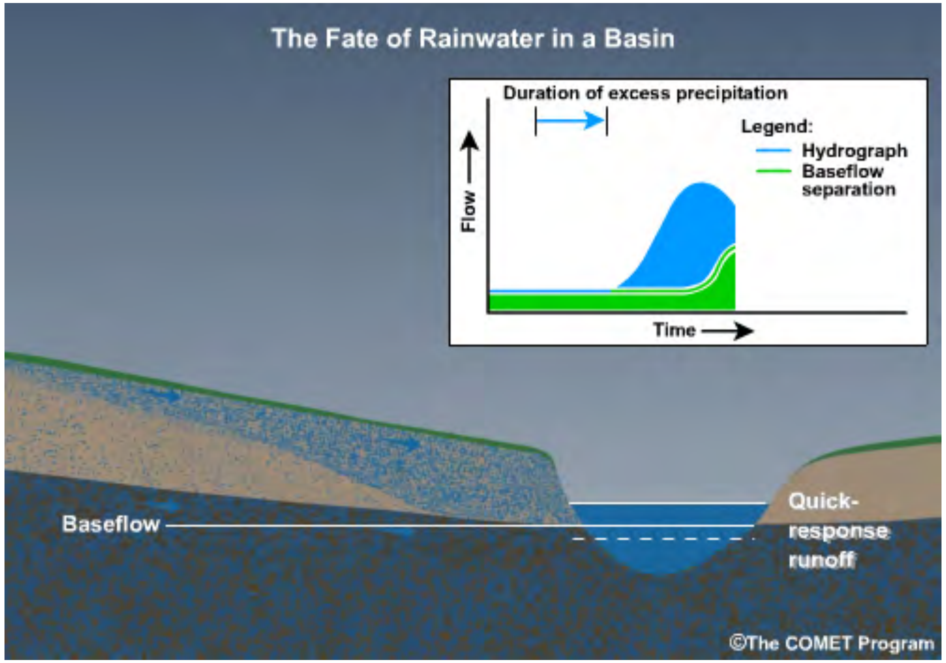


Potential Evapotranspiration (PET) estimated using Hargreave's Equation. PET does not show a statistically significant trend.

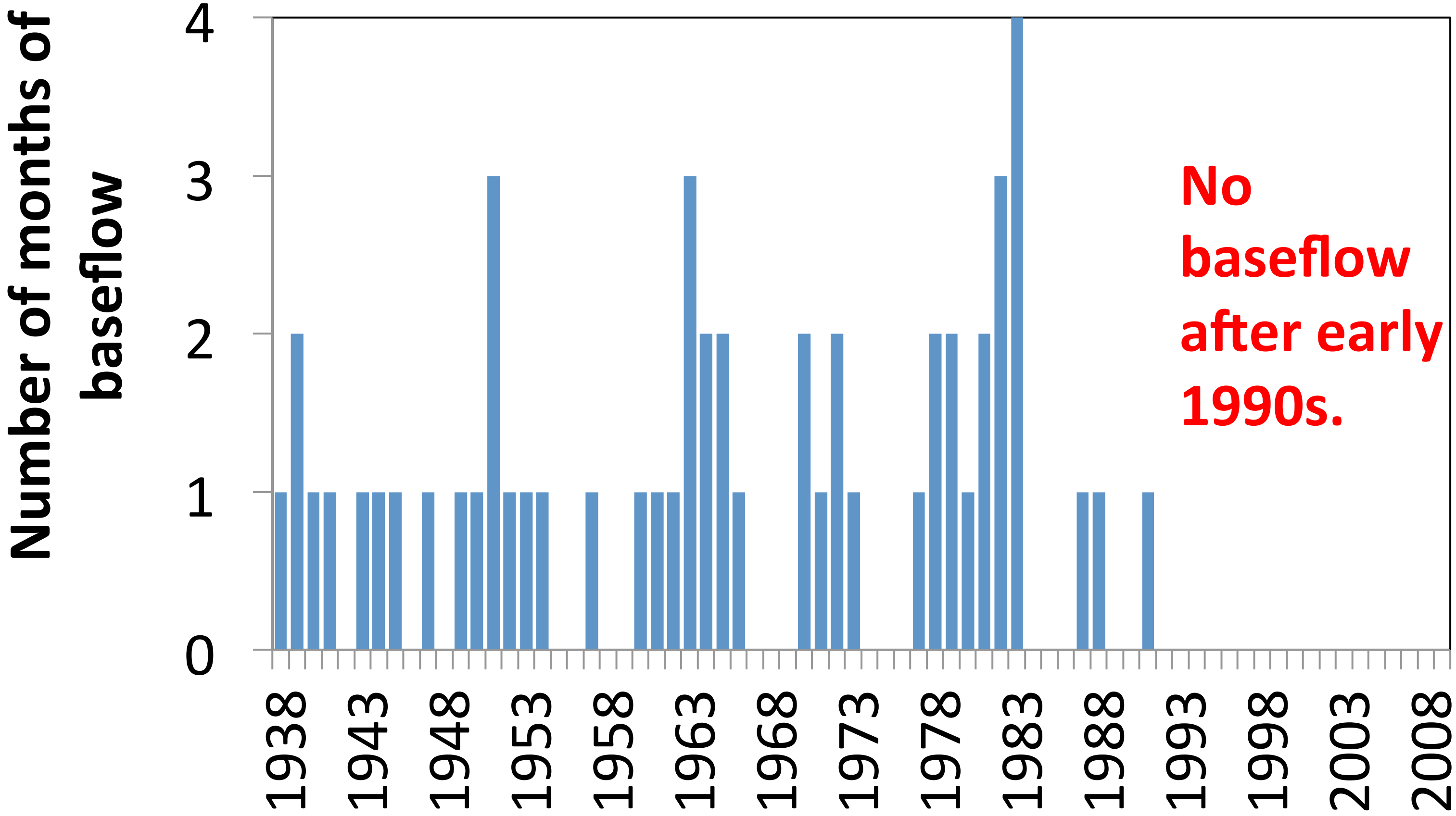
#3: Groundwater pumping

Ran a simple model to estimate loss of baseflow into TG Halli using a simple storage-discharge relationship between the aquifer and the stream.

To explain the baseflow loss we needed a water table drop of 2-6 m which was observed.

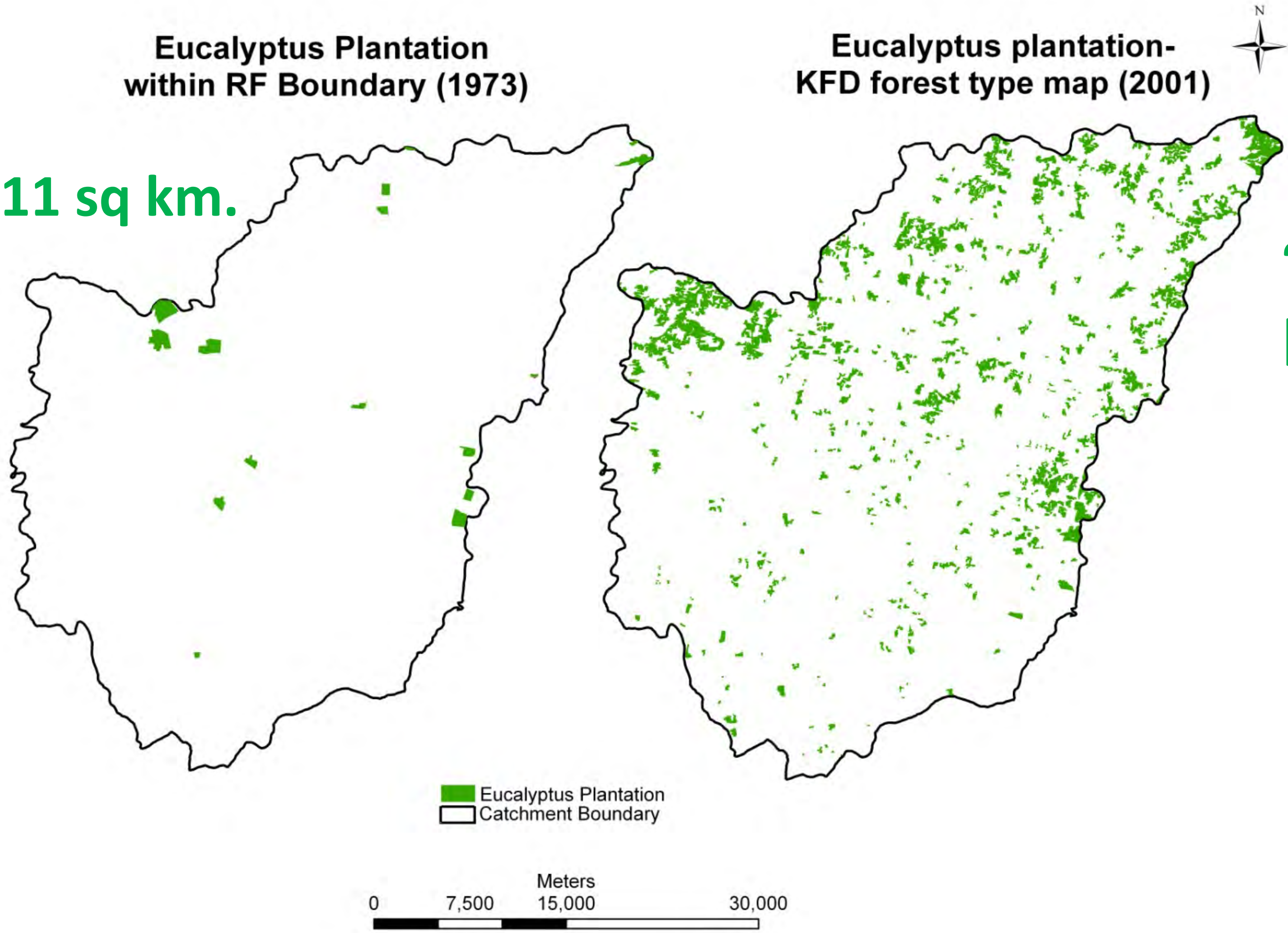


#3 - Groundwater Pumping



#4 - Eucalyptus Plantations

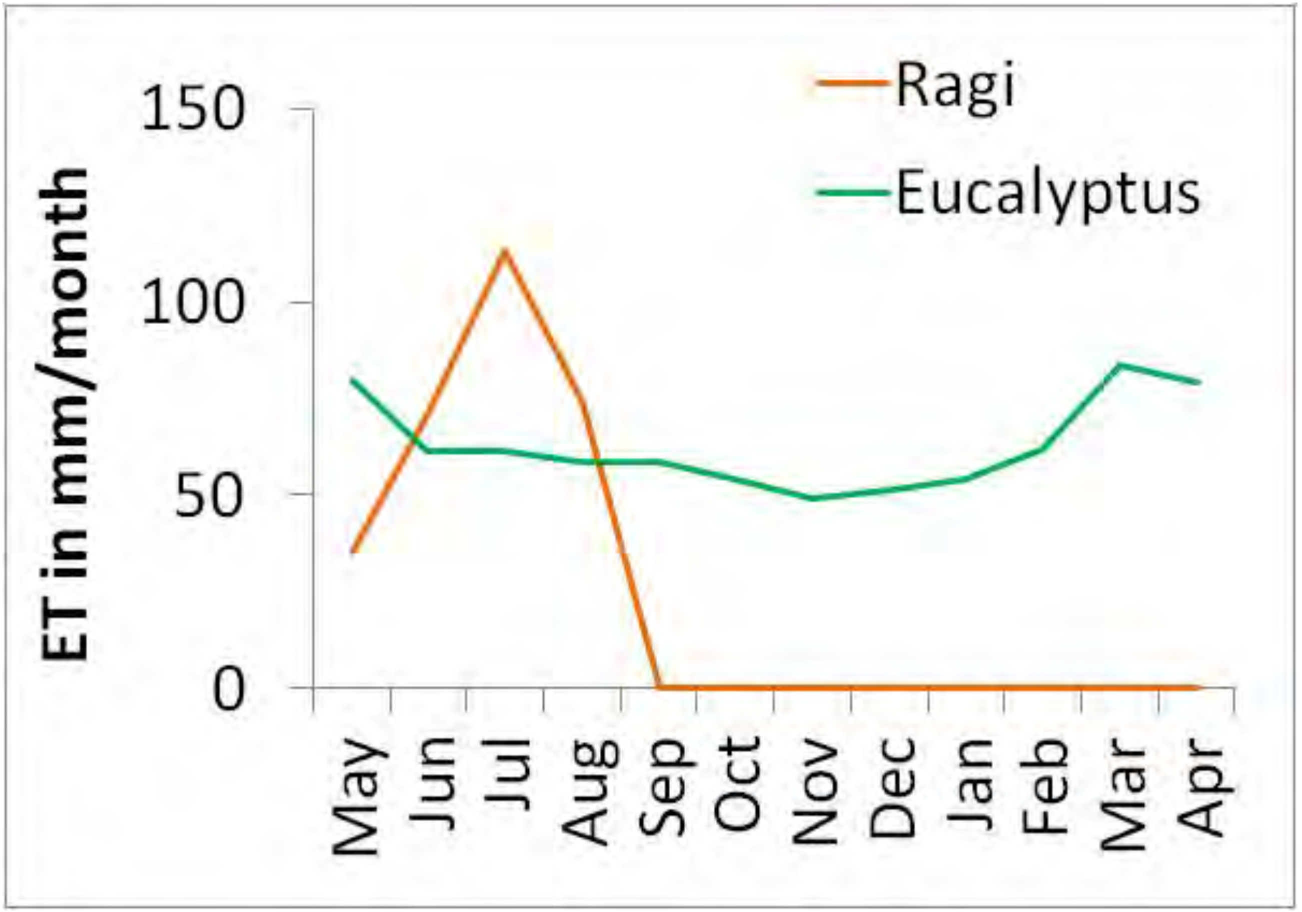
~11 sq km.



~104 sq km.

Data Source: 1973 manually mapped by Sowmyashree and Sharad from 1973 Toposheet, 2001 data from KSRSAC Classified Image

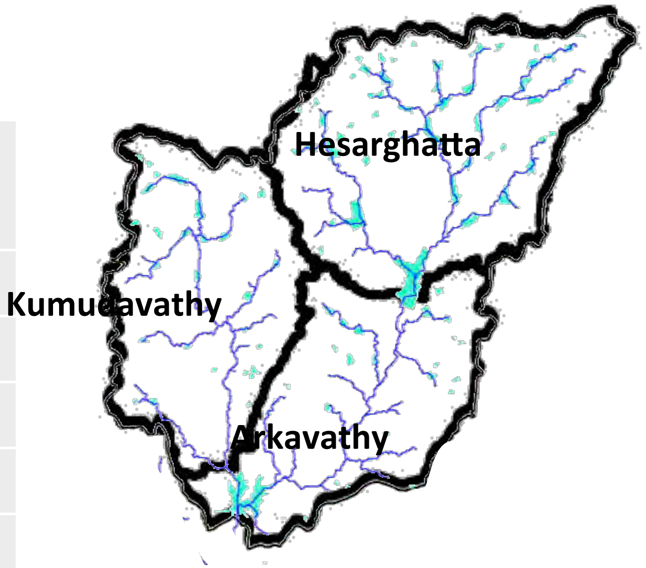
#4 - Eucalyptus Plantations



This means 94 sq. km of Eucalyptus conversion would translate to **85 Million Liters per day additional ET** in TG Halli catchment.

#5: Million Puddle Theory

Type	Hesarghatta	Kumudavati	Arkavathy
Check dam	70	65	142
Culvert	3	26	97
Bridge	4	23	31
Road	0	2	7
	90	**116**	**277**

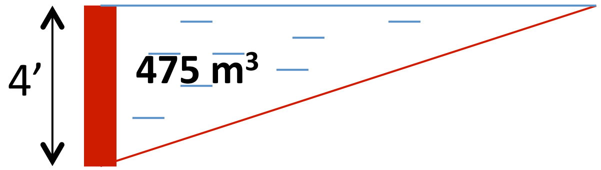


Source: CNNL 2013
(Based on consultant report)

#5: Million Puddle Theory

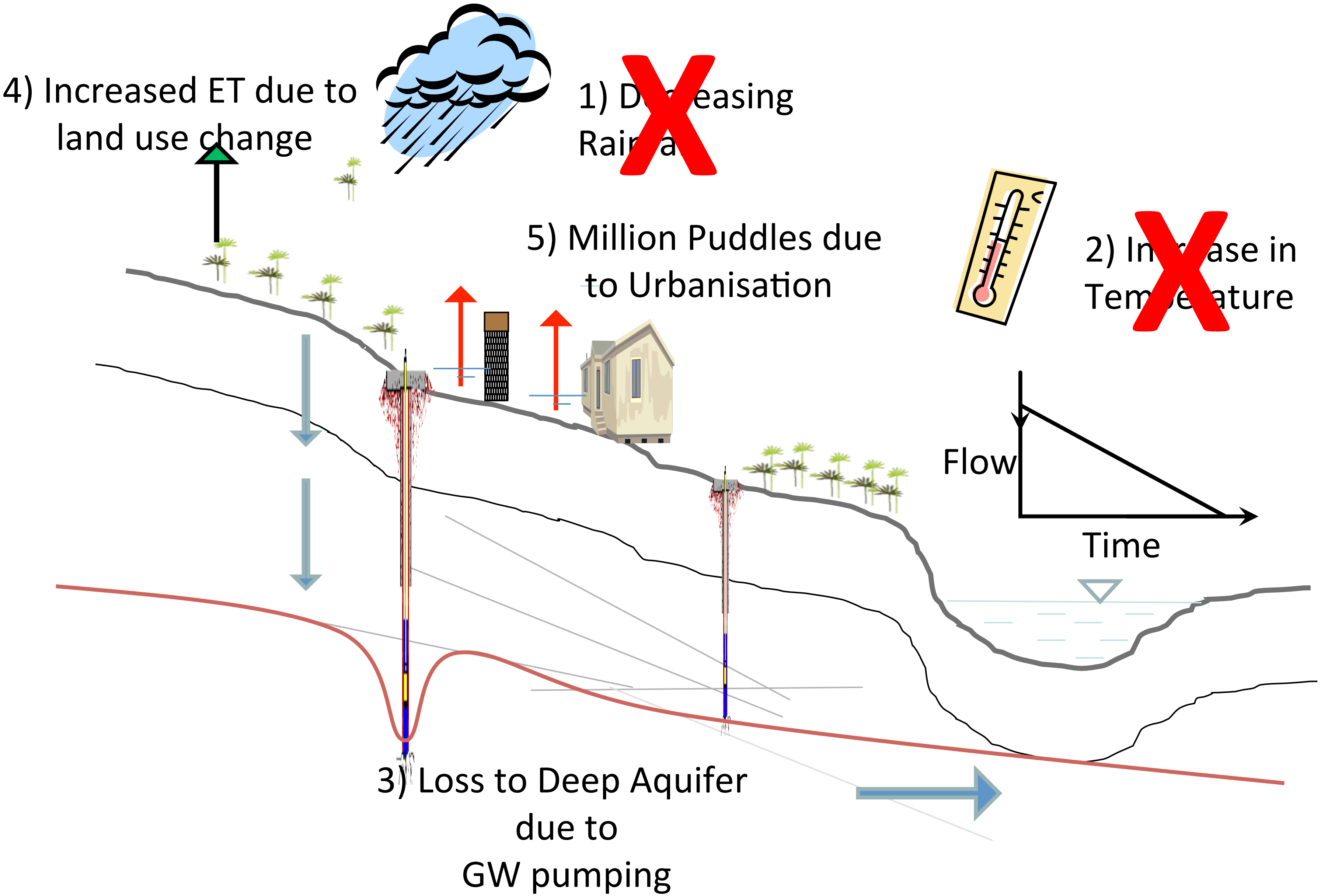
The check dam densities from our field surveys in both milli-watersheds (1.35/ sq km) were MUCH higher than these the 0.21/sq km reported by CNNL.
Our field measurements of check dam volume varied between (200-600 m^3).

Assuming 50% of the water evaporates and check dams capture rain from 20 rain events per year.



Estimated blockage/year ~ 5 To 20 MLD

Evaluated Alternative Hypotheses



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