Forest landscape restoration and hydrological recovery in the humid tropics: what can be expected realistically?

L.A. (Sampurno) Bruijnzeel

Visiting Professor, King's College, London, UK &

Adjunct Faculty, TFAP, University of the Sunshine Coast, Qld, AUS

E-mail: sampurno.bruijnzeel@kcl.ac.uk

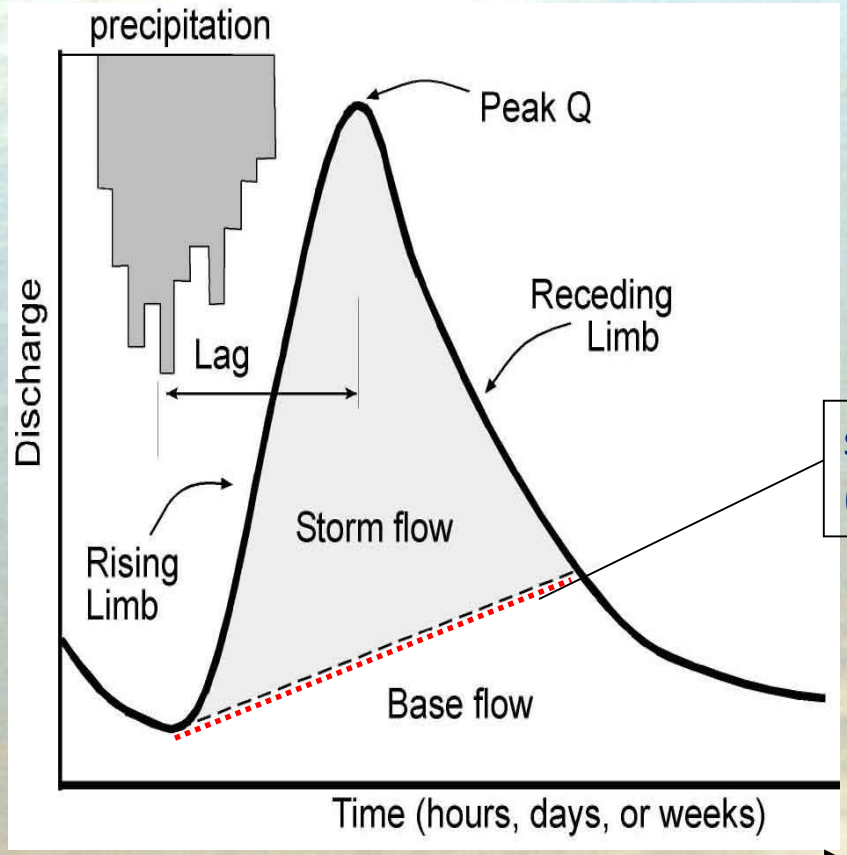
KING'S College LONDON

University of the Sunshine Coast

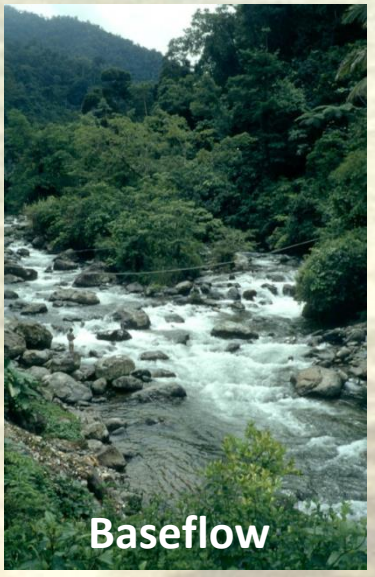
Forest Landscape Restoration: Making it work.
Manila, 26 February 2019

Definition of terms: baseflow vs. stormflow

During rain, the extra water from the hillsides leads to increased streamflow. This '***stormflow***' is often separated from '***baseflow***' through an (arbitrary) separation line…

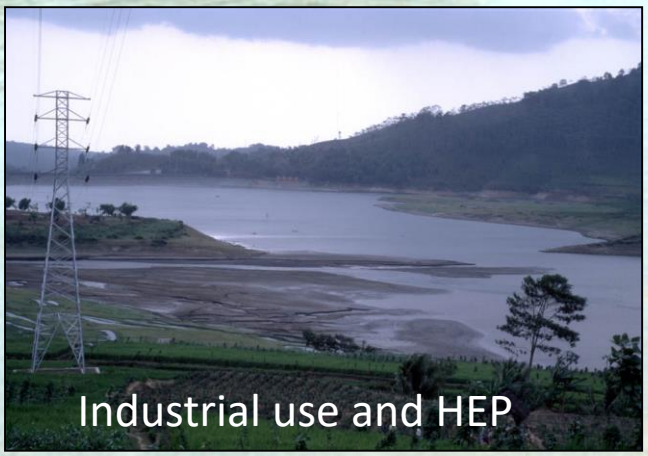


separation line (Hewlett approach)



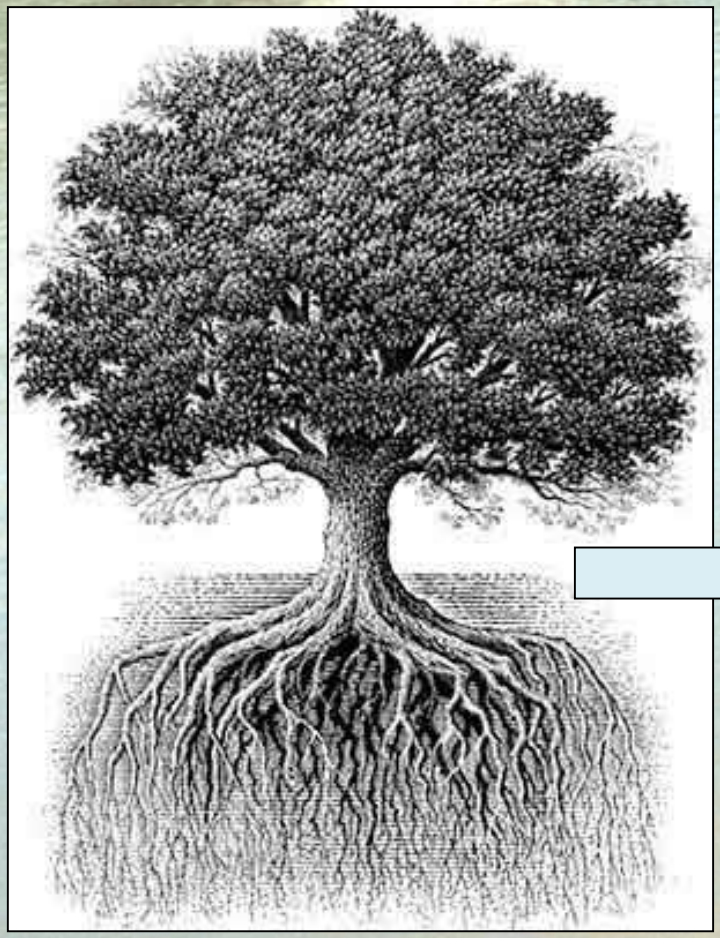
Importance of dry-season flows (baseflows)

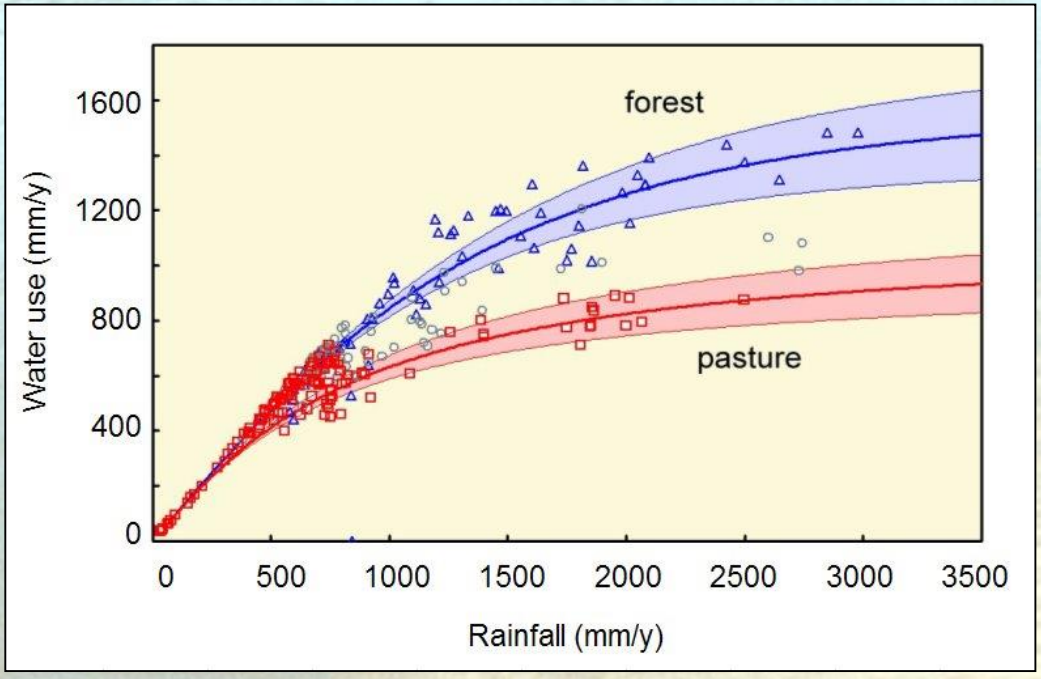

Irrigation


Industrial use and HEP


Navigability, fishing

Forest water use (ET) typically enhanced relative to crops / grasslands…

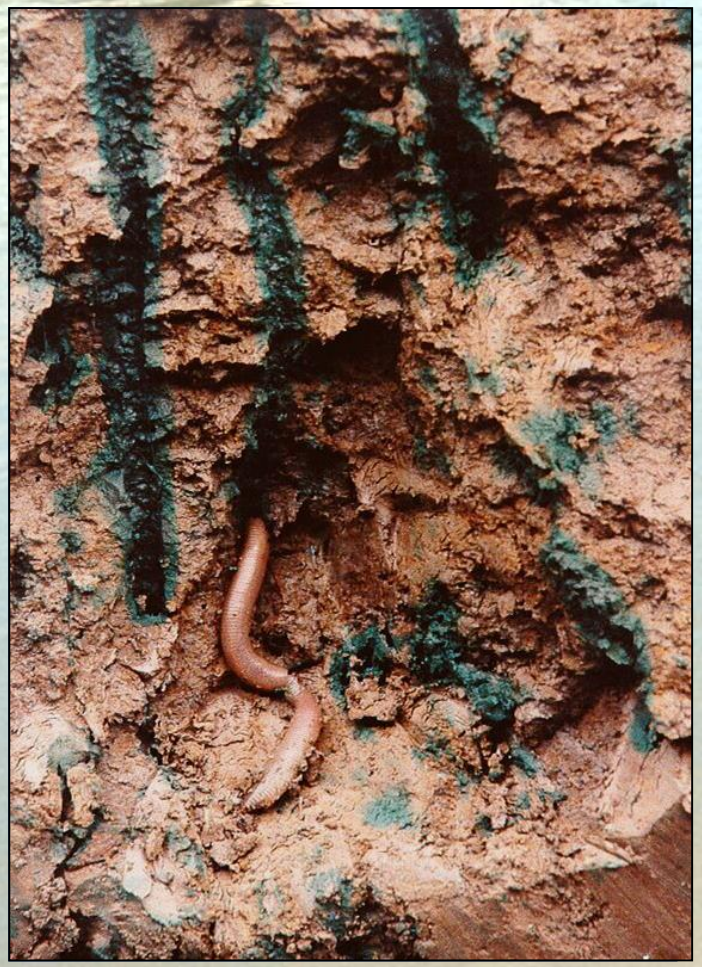




Zhang et al. (2001)

Trees/forests have greater leaf surface area, deeper roots and greater aerodynamic roughness than shrubs, grass or crops. Hence, tree- and forest water use (ET) is typically higher.

Baseflow from old-growth forest most dependable

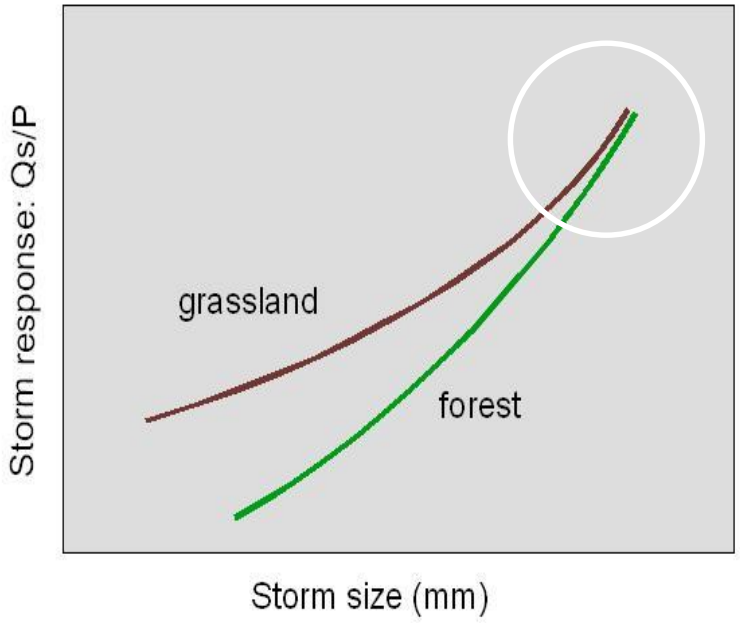


- Comparatively stable base flows from old-growth forests have led to the concept of the '*forest sponge*' (slow release of water during the dry season).
- High infiltration during rain afforded by an intact litter layer, high soil bio-activity and root decay (macropore formation).
- High forest water use creates room for absorption and storage of additional rainfall!

The ‘forest sponge’ has its retention limits!

Non-degraded storm runoff response to rainfall: Soil wetness as the dominant factor

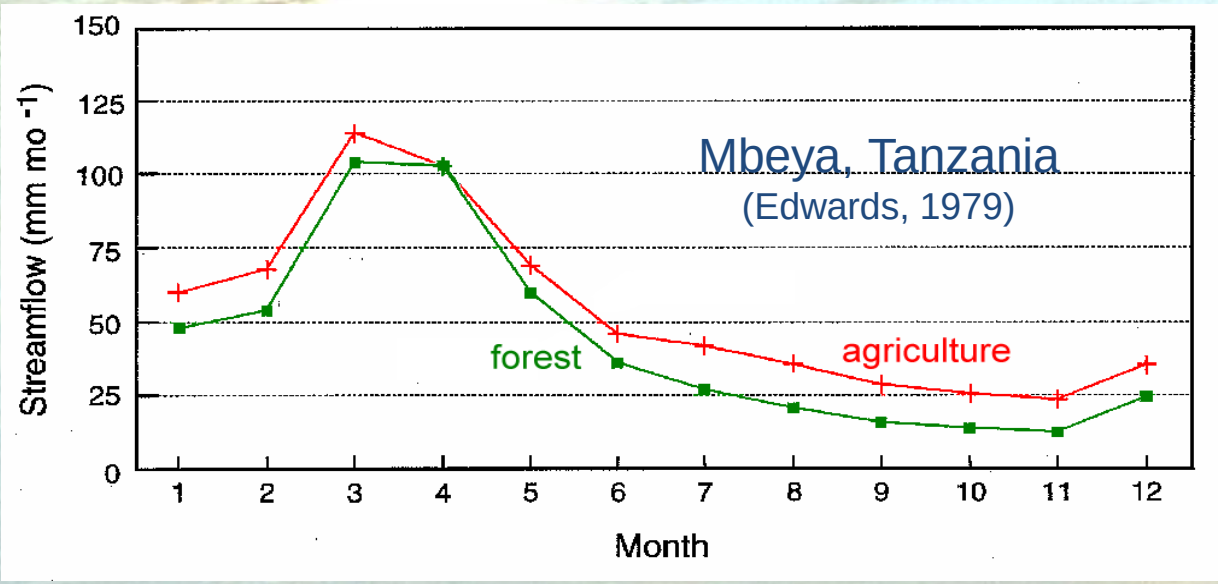
- ***For non-degraded soils:*** Difference in runoff response (to rain) between land covers becomes smaller as the *soil wetness* increases: => extreme cases ('floods') are not affected much by forest presence or absence (*soil's water absorbing capacity filled anyway*)…

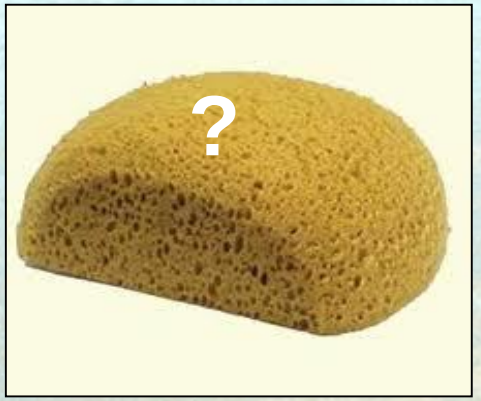


After Scott et al. (2005)

BUT: if soils highly degraded or surface impervious, *infiltration* rather than soil water storage becomes dominant governing factor!

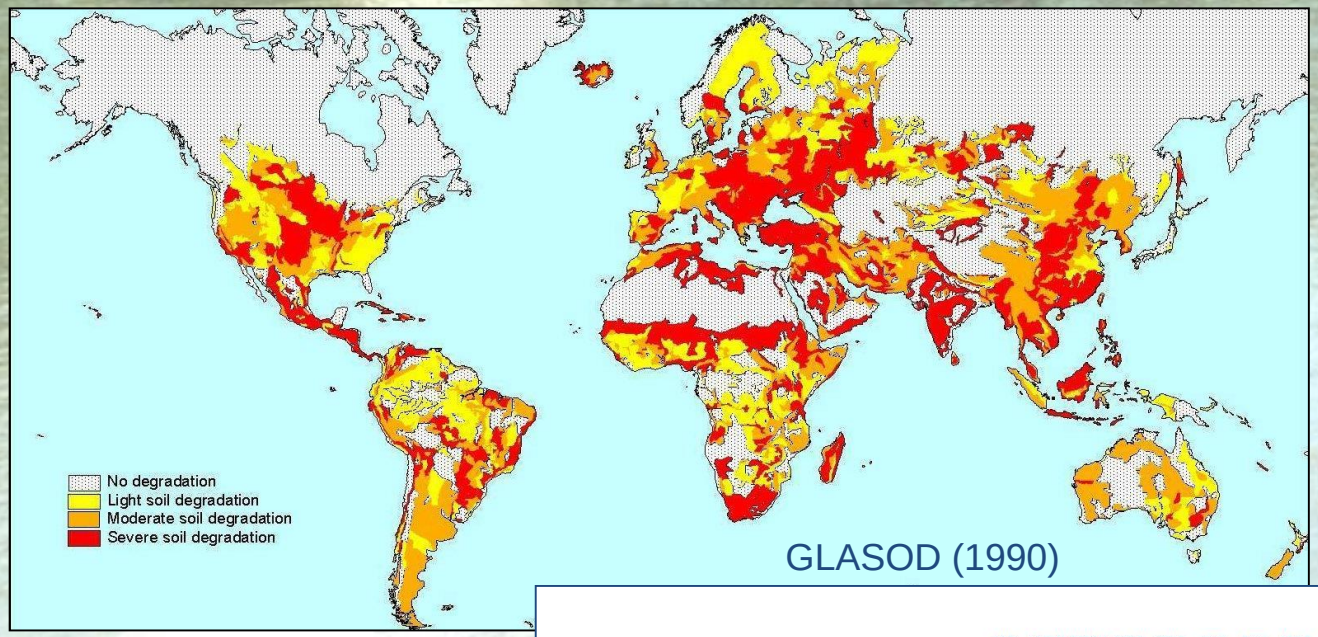
Maintaining infiltration after deforestation increases flows all through the year…





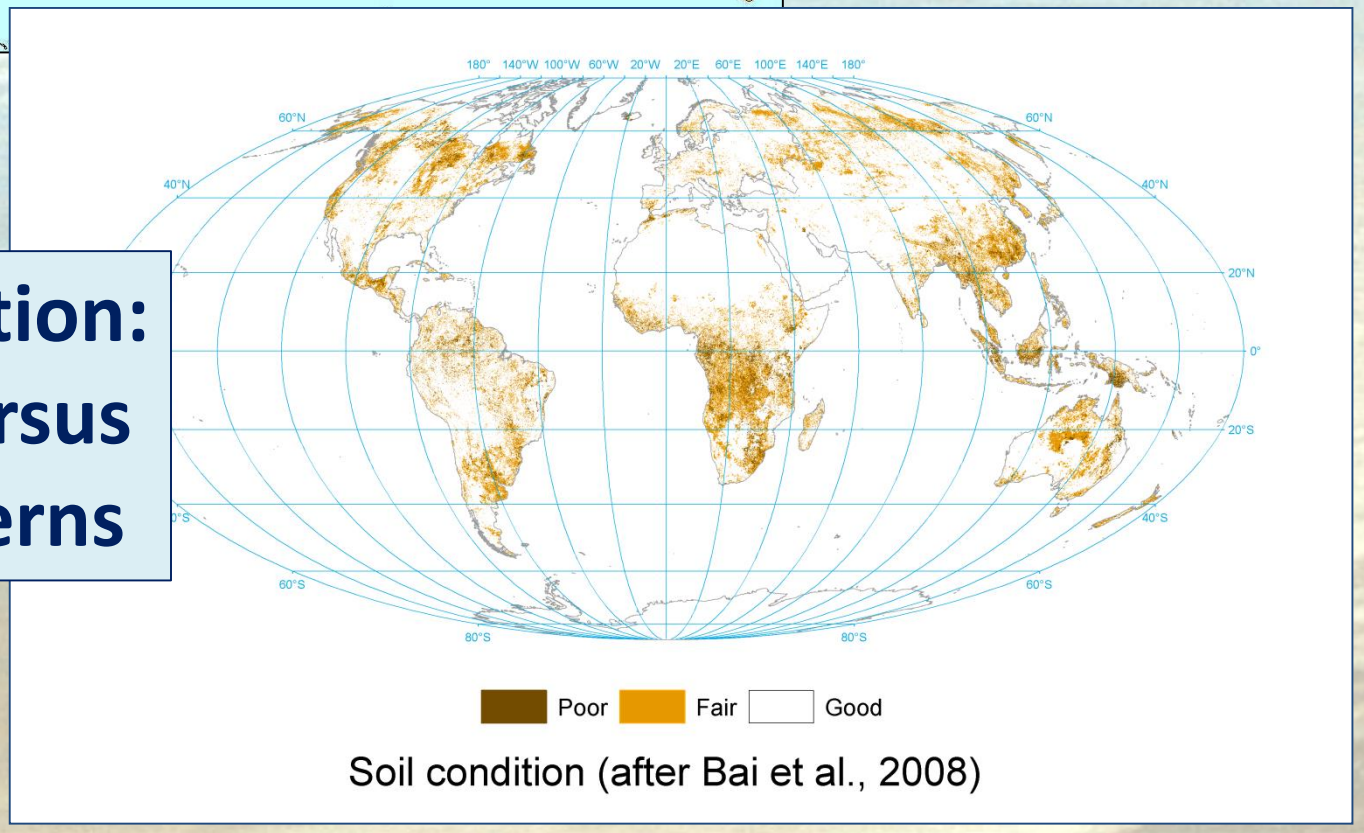
- **In the absence of soil degradation:**

forest removal leads to ***increases*** in dry-season flows due to the lower water use of annual crops/grass.



GLASOD (1990)

Soil degradation: potential versus actual patterns



Soil condition (after Bai et al., 2008)

Degradation and the loss of the ‘sponge’ effect: (much) greater runoff from impervious surfaces

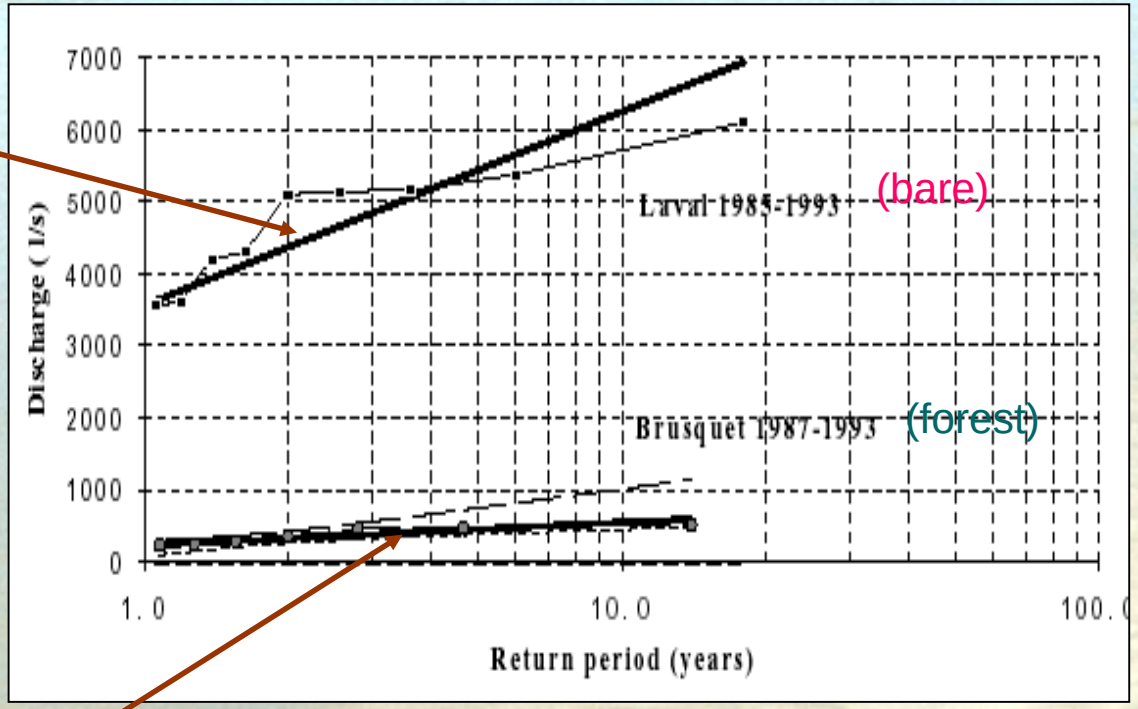

Repeated burning (RC <60%)


Metalled roads: RC >70%


Topsoil crusting (RC 30-40%)


Overland flow on landslip faces

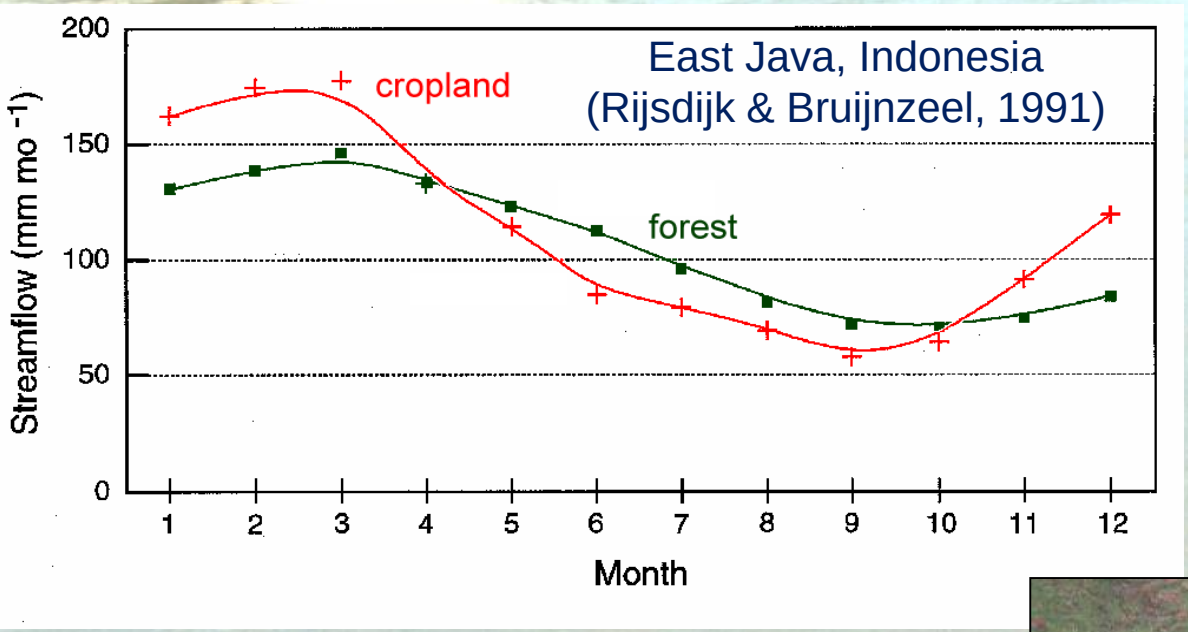
Surface degradation and stormflows: greater divergence between covers for higher rainfall

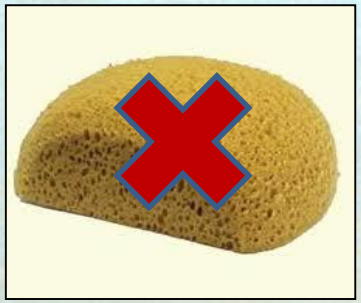


After Mathys et al. (1996)

Effect of impervious surface is greatest for largest storms!

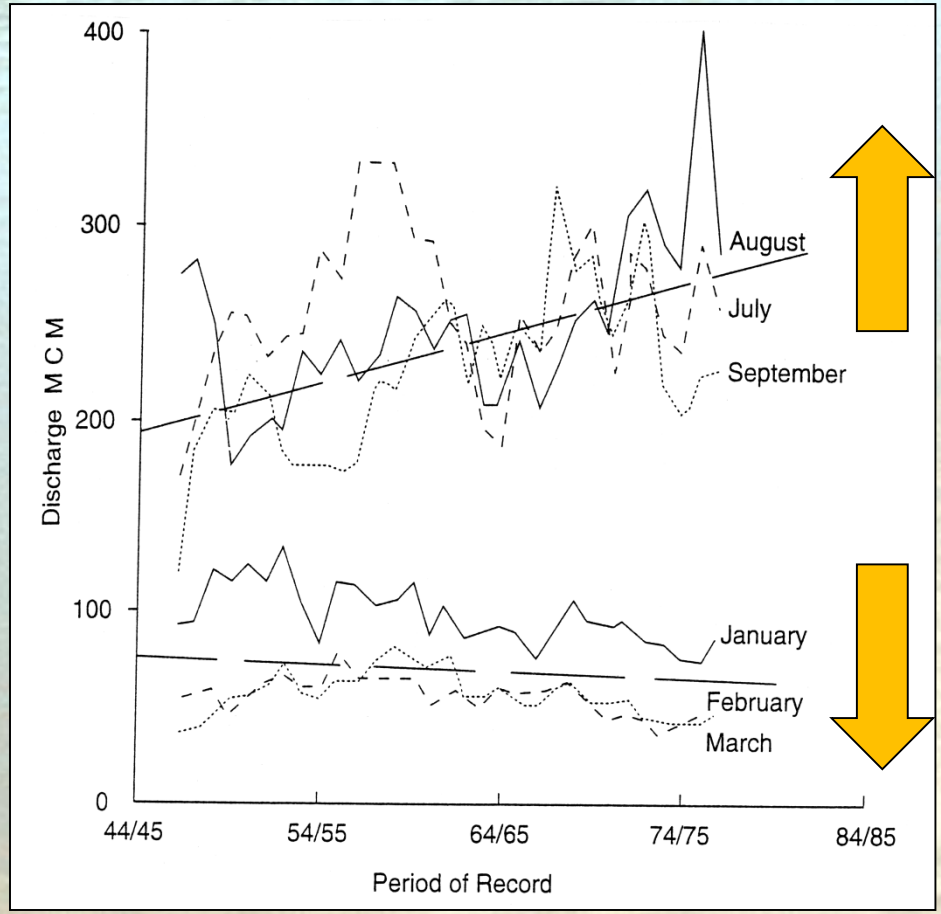
Strongly reduced infiltration after deforestation promotes 'floods and droughts'





- **Advanced soil degradation:** deforestation ***reduces*** dry-season flows due to increased water losses via wet-season surface runoff…

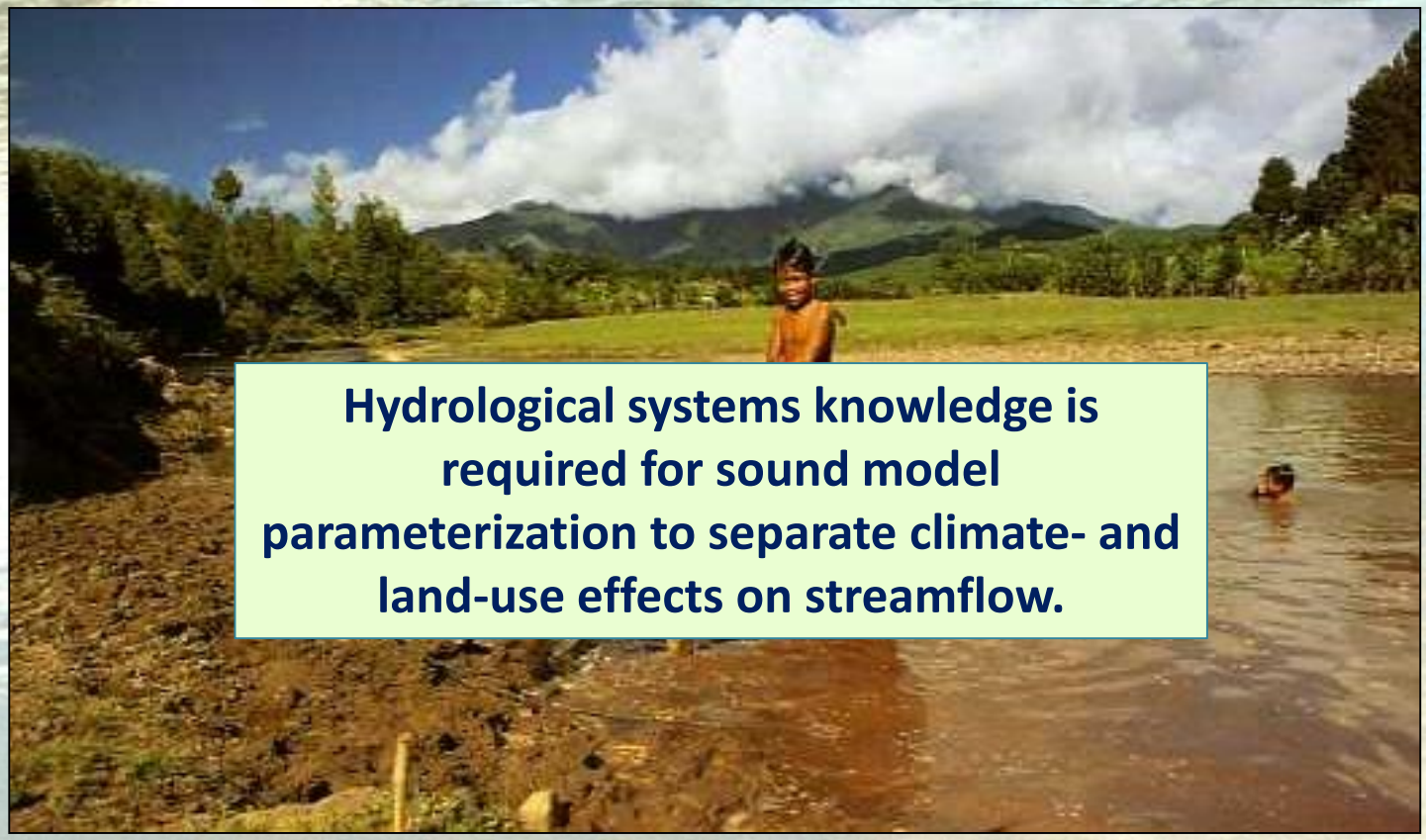
Hydrological change due to surface degradation: gradual, and rarely documented…



Upper Mahaweli, Sri Lanka (1100 km^2)

Madduma Bandara (1997)

Boosting dry-season flows: is it possible?



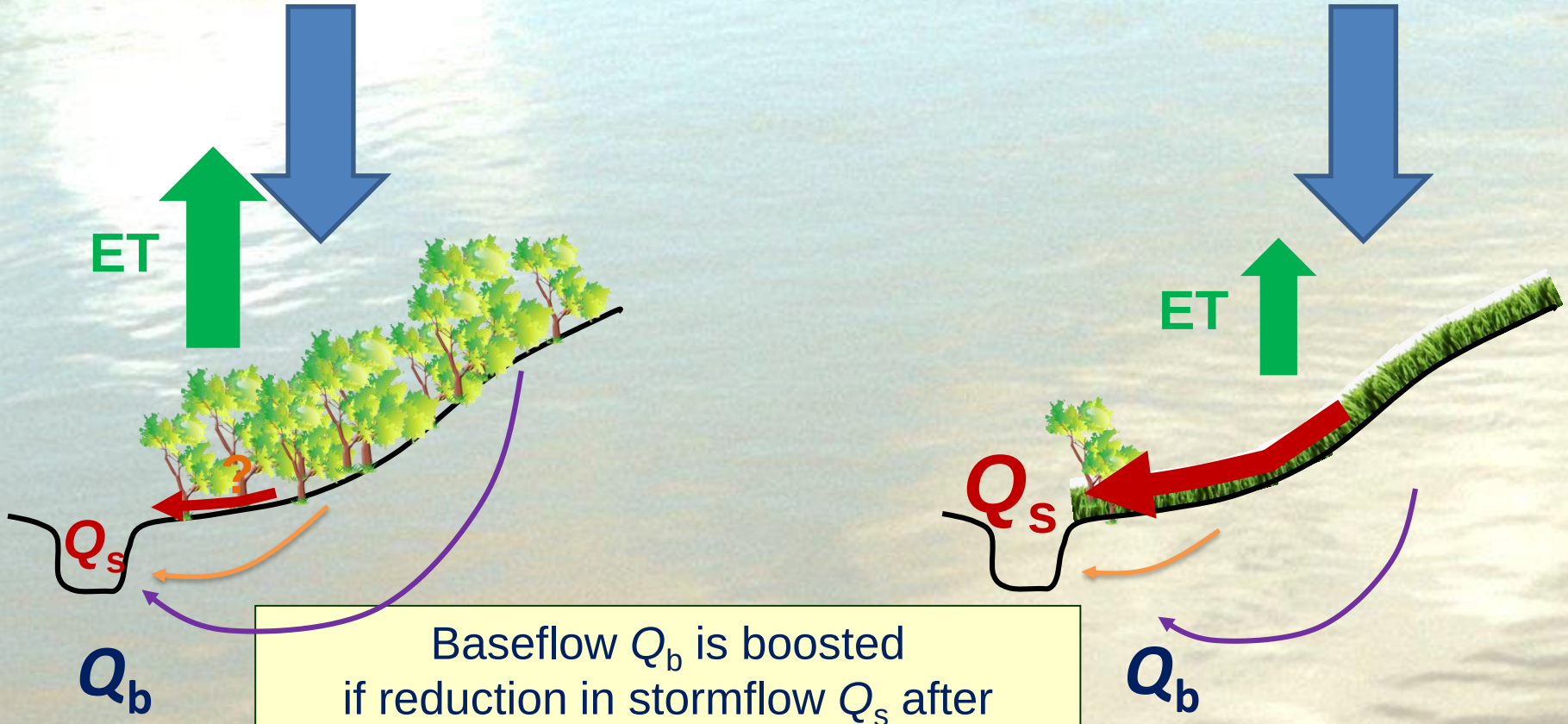
Hydrological systems knowledge is required for sound model parameterization to separate climate- and land-use effects on streamflow.

Can we restore decreased dry-season flows,
and if so, how is this achieved best?
Allow natural regrowth? Plant trees? Agroforestry?

Two key processes: vegetation water use (ET) *and infiltration*

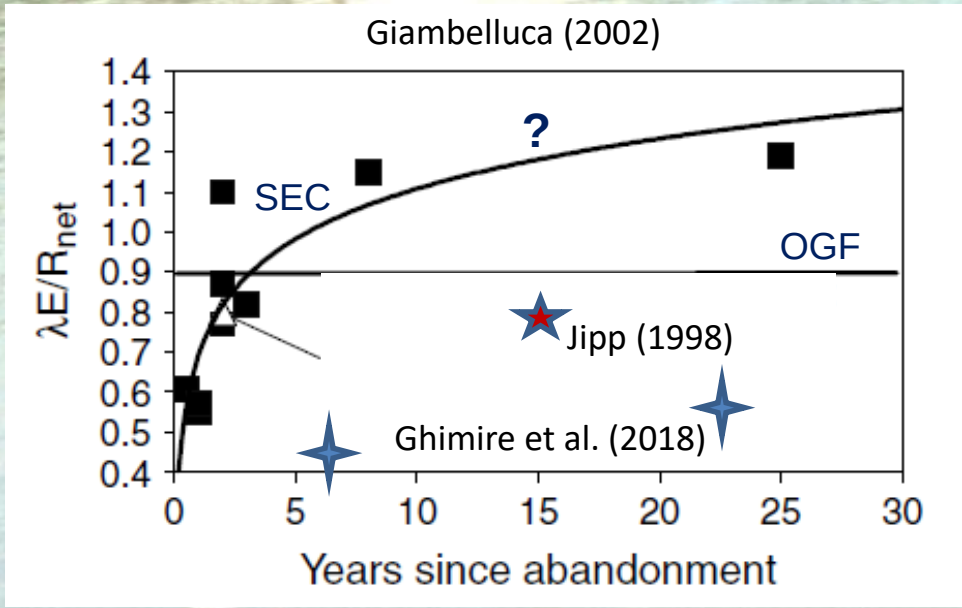
(Re)forested

Degraded



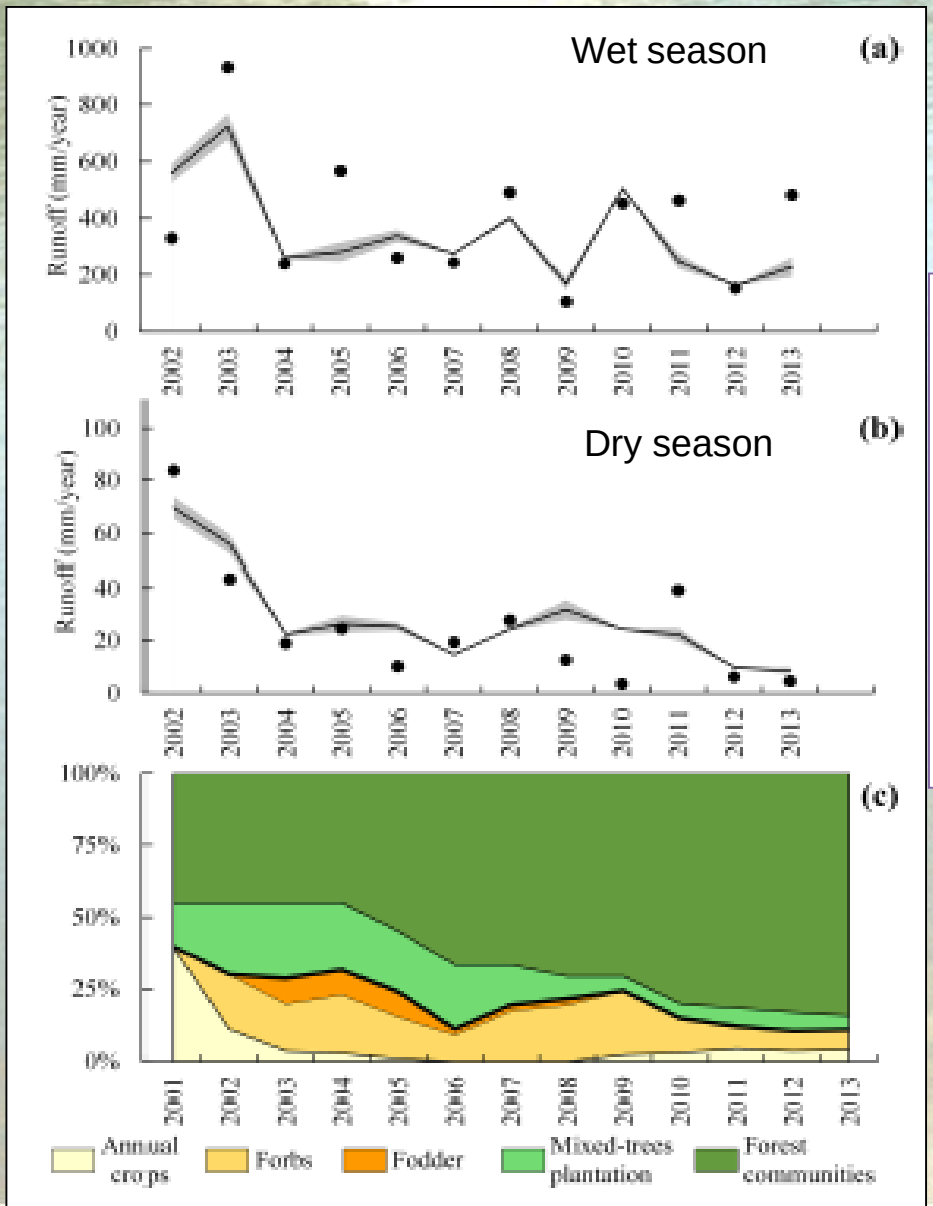
Baseflow Q_b is boosted
if reduction in stormflow Q_s after
forestation compensates increased ET

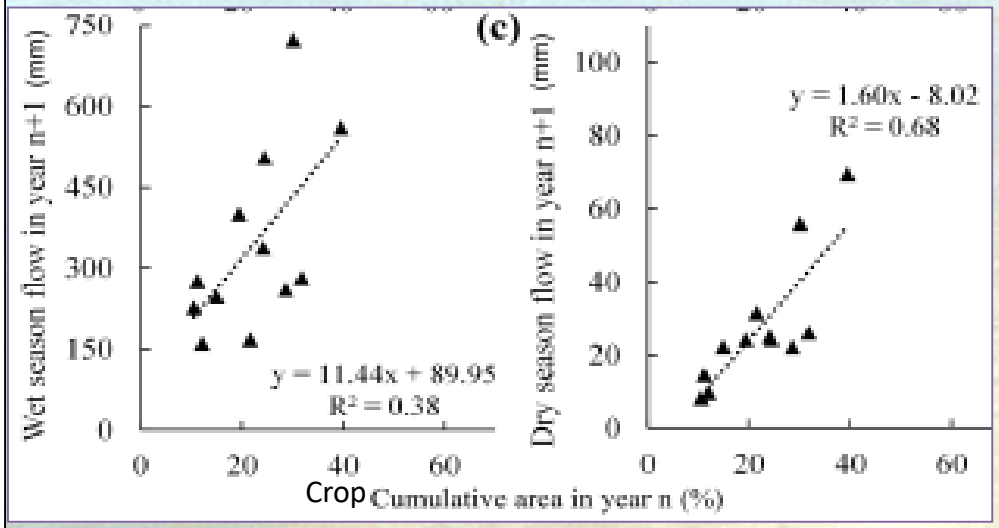
Water use of regenerating tropical forests: temporarily enhanced compared to old-growth?



Growth stage	Average max conductance (mmol/m²/s)	Range (mmol/m²/s)
Young successional	~845	400 – 2270 (*n* = 21)
Late successional	~310	105 – 695 (*n* = 24)

Declining flows during natural regrowth (Vietnam)

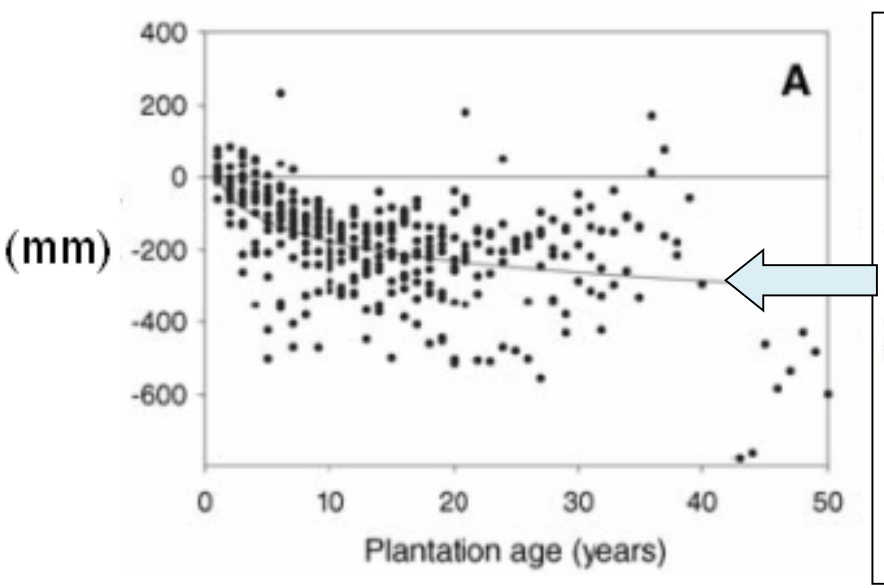




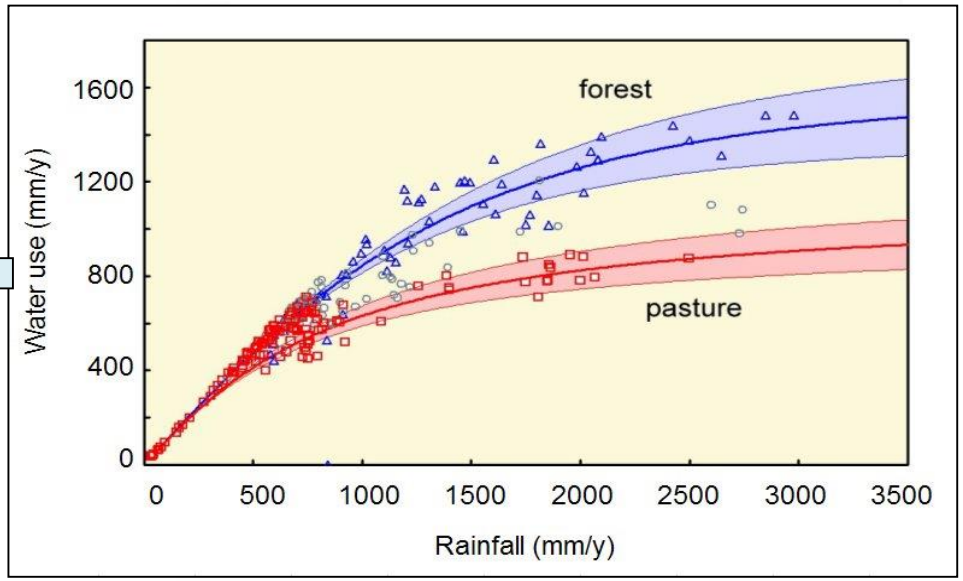
Lacombe et al. (2016)

Meta-analysis of forestation impact on local flows: more trees implies less flow *at all times of year*…

Change in *annual* streamflow

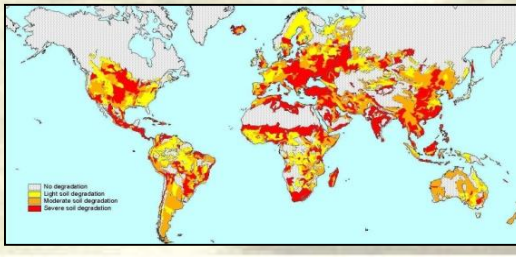


Jackson et al. (2005)

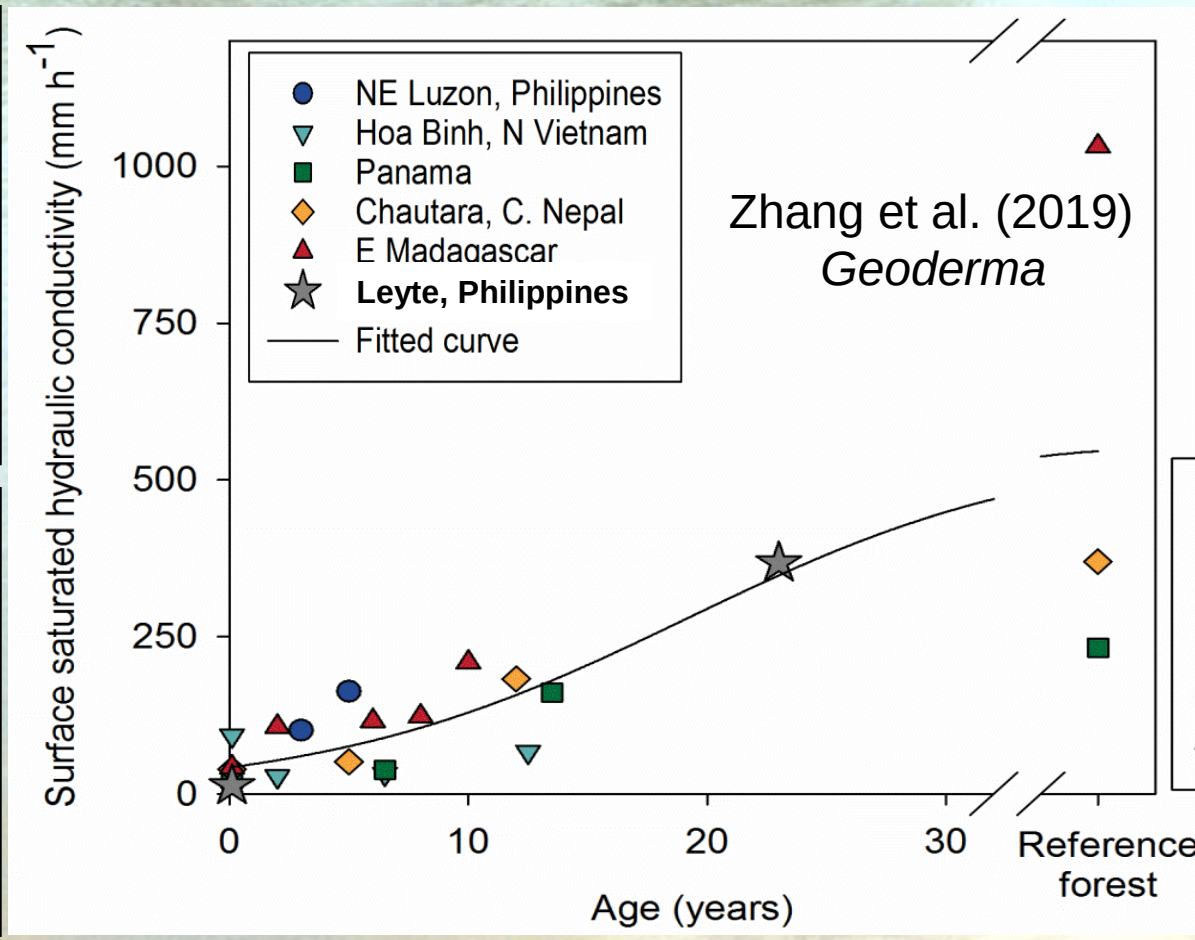


Zhang et al. (2001)

Only 3 tropical catchments, none degraded!
Hence no soil improvement effects included, only increased ET; few older plantations…



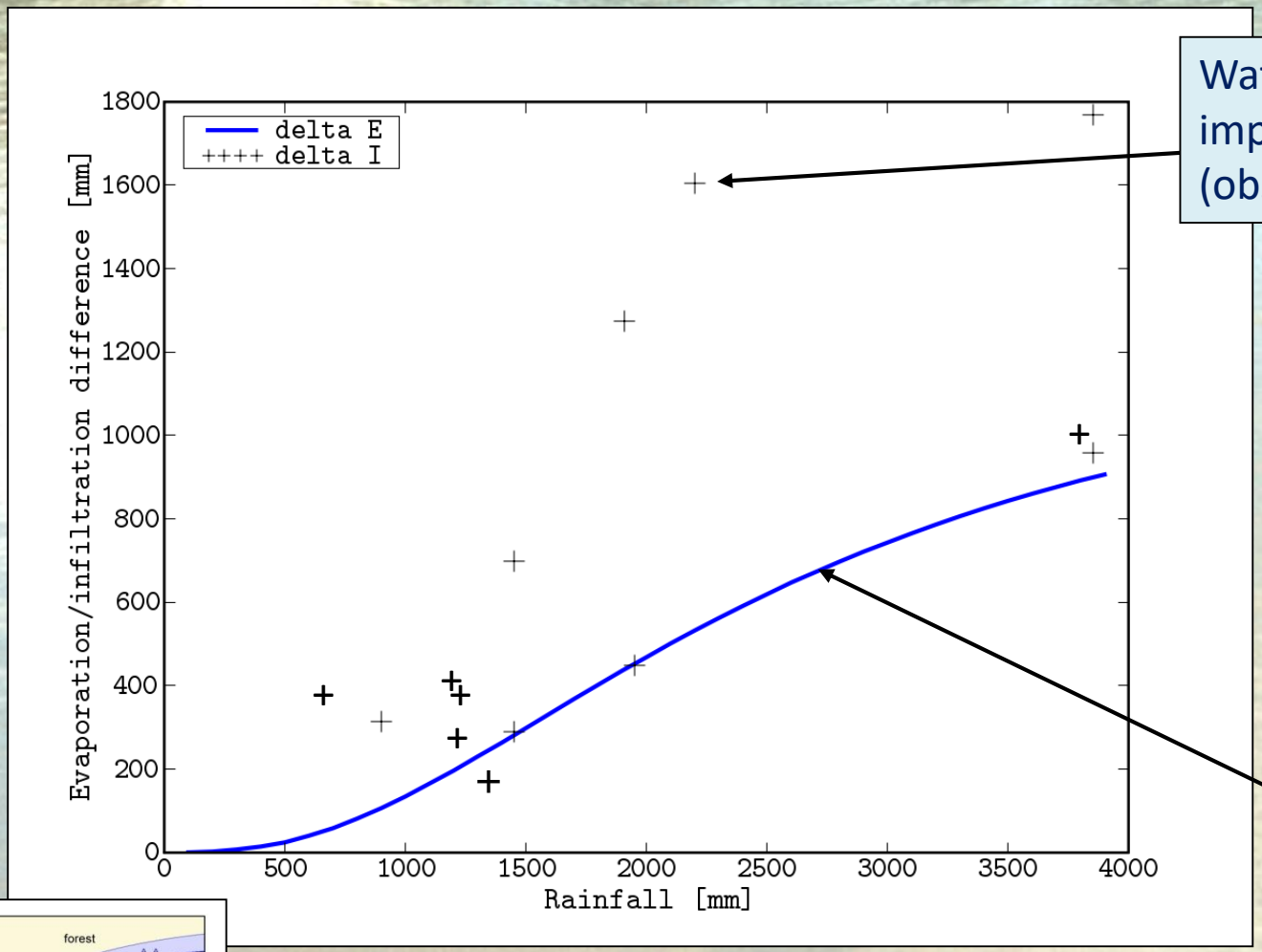
Soil hydrological recovery after forestation



- Rebuilding surface infiltration capacity requires ≥ two decades…
- But: repeated disturbance may be fatal…

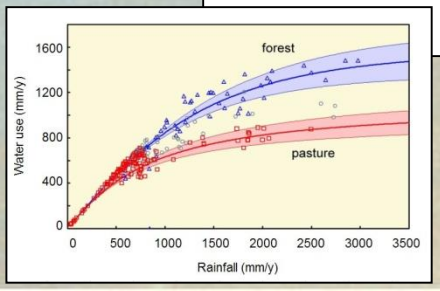
Re-creation of the ‘soil sponge’ and slope stabilization requires prolonged protection of soils and trees…

(Some) hope for the tree lovers…



Water gain by improved infiltration (observed data).

Maximum extra water loss due to higher ET after forestation (generic curve).



Updated from Bruijnzeel (2008)

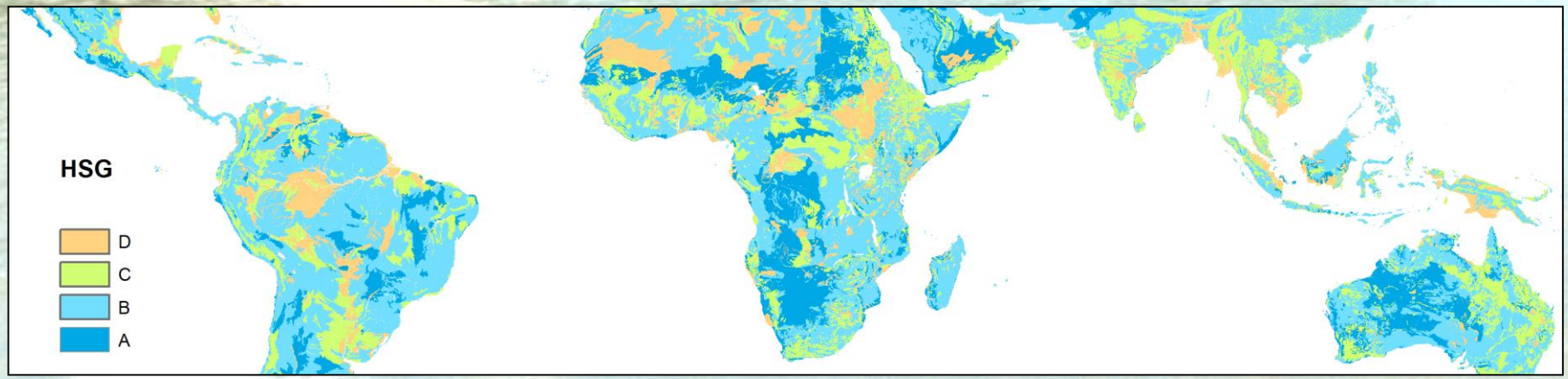
More than 2 billion hectare of degraded land world-wide that could be regreened: *where might we expect improved flows?*

Degraded
Deforested

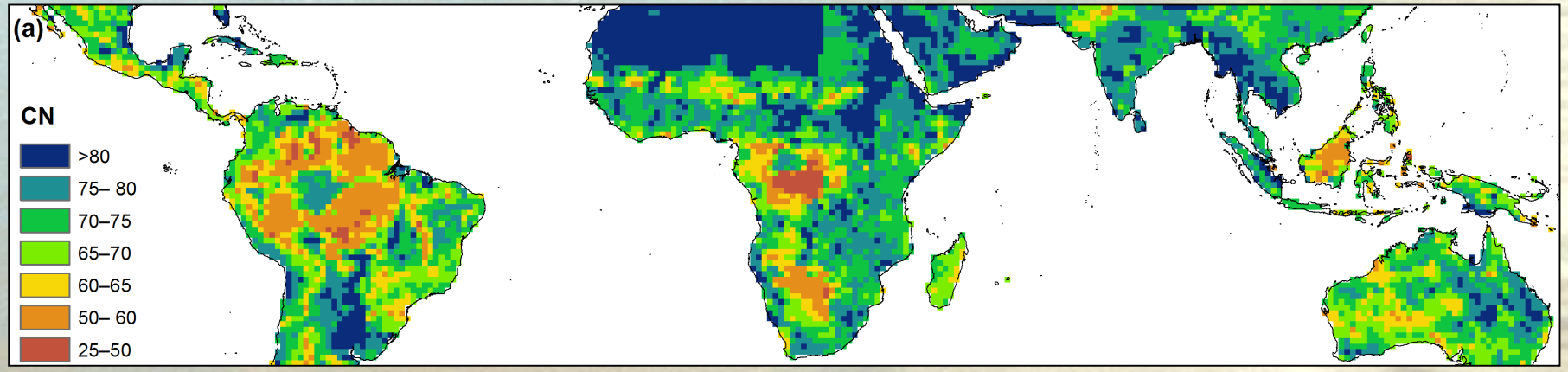
Curve number values (CN) based on soil texture and surface condition (cover, degradation, etc.) to estimate *current* annual storm runoff totals from long-term rainfall across the tropics (1^0 grid scale).

SOURCE: **WRI**, FLR, TEEB

Evaluating pan-tropical changes in stormflow

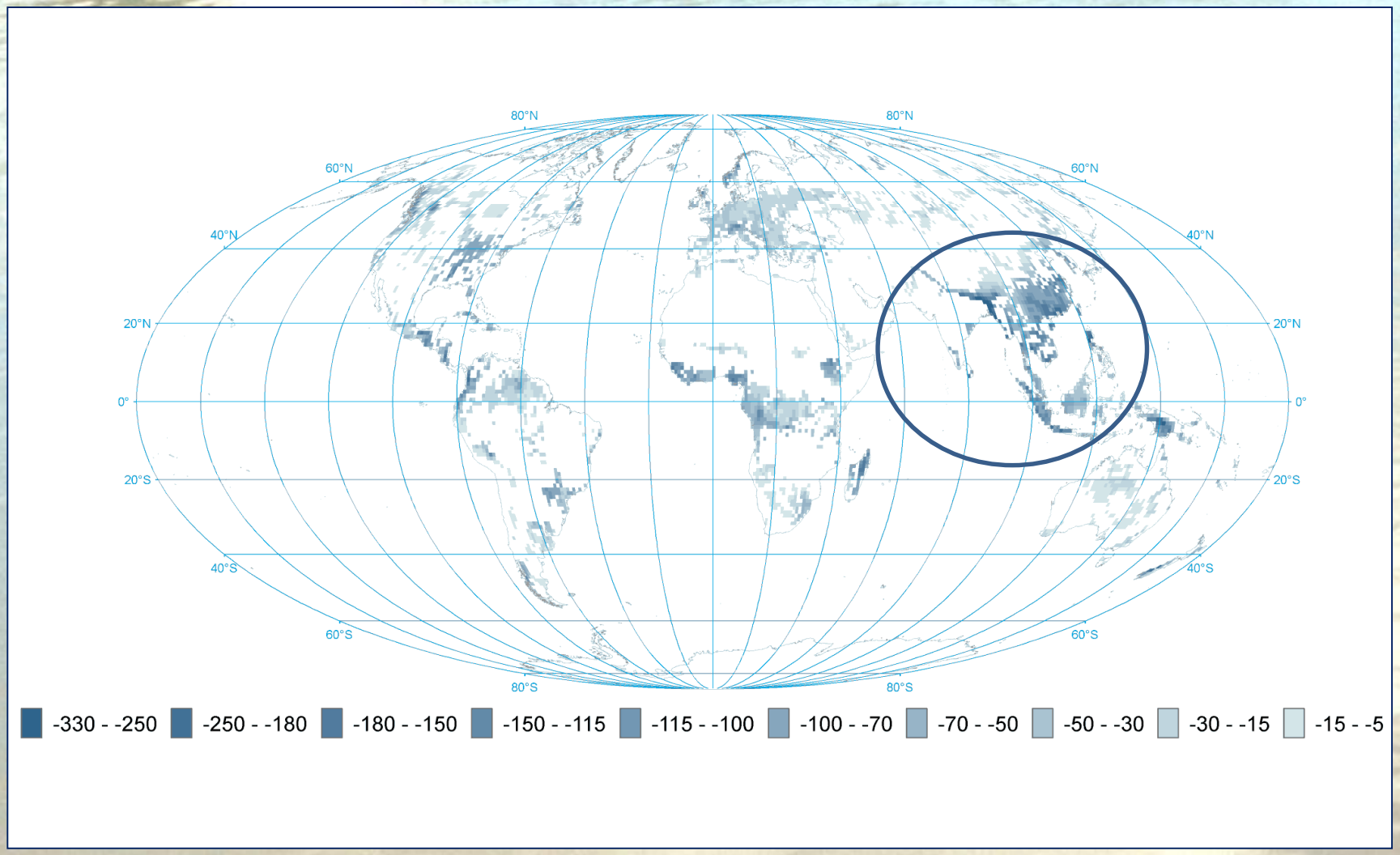


Map of Hydrological Soil Groups (HSG) based on the Harmonised World Soil Database (HWSD). A = high infiltration, D = very poor infiltration.

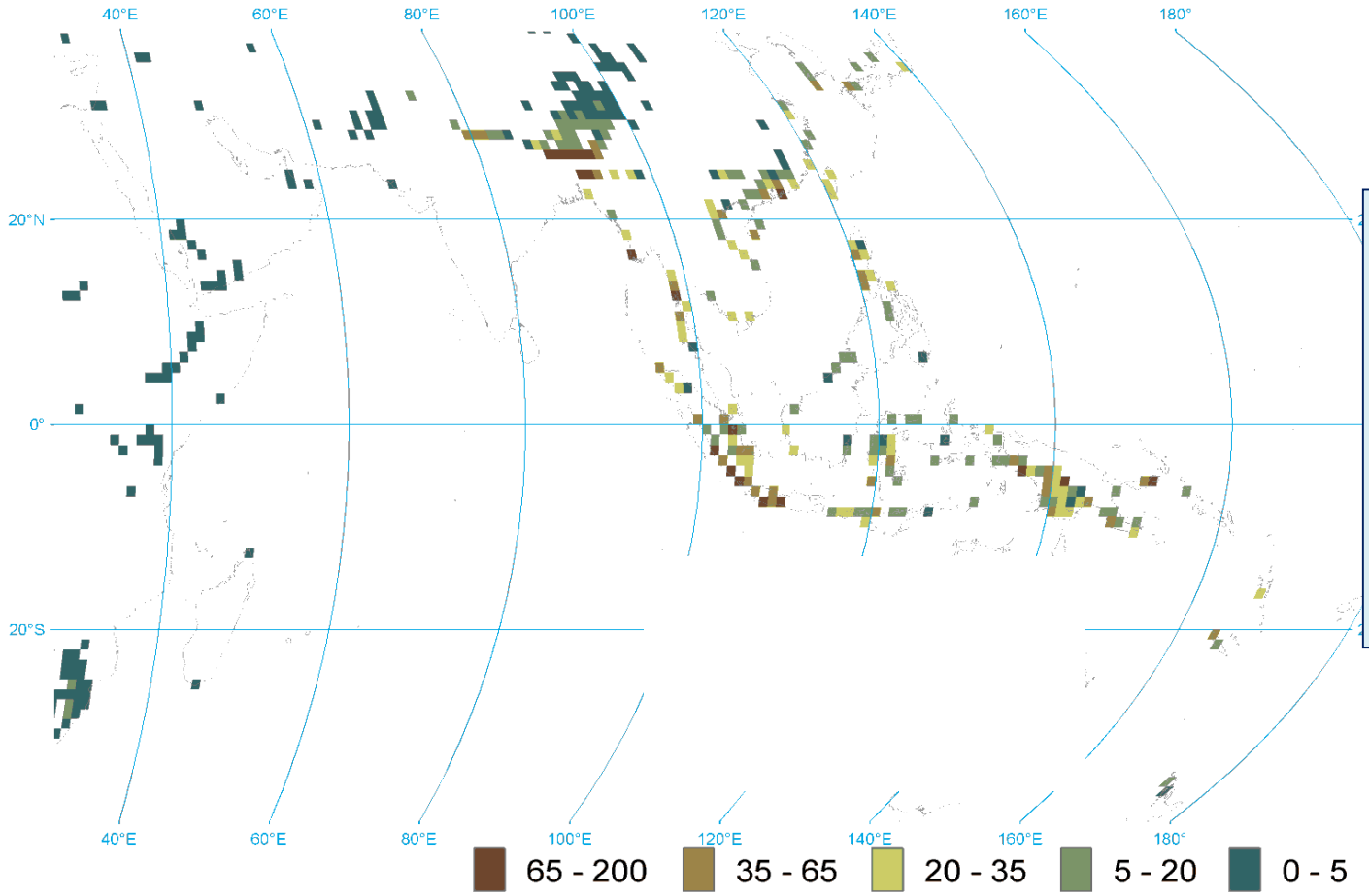


Pan-tropical CN-values for current (reference) conditions

Change in CN-based stormflow production ('gain') after foresting all degraded tropical land (mm/yr)



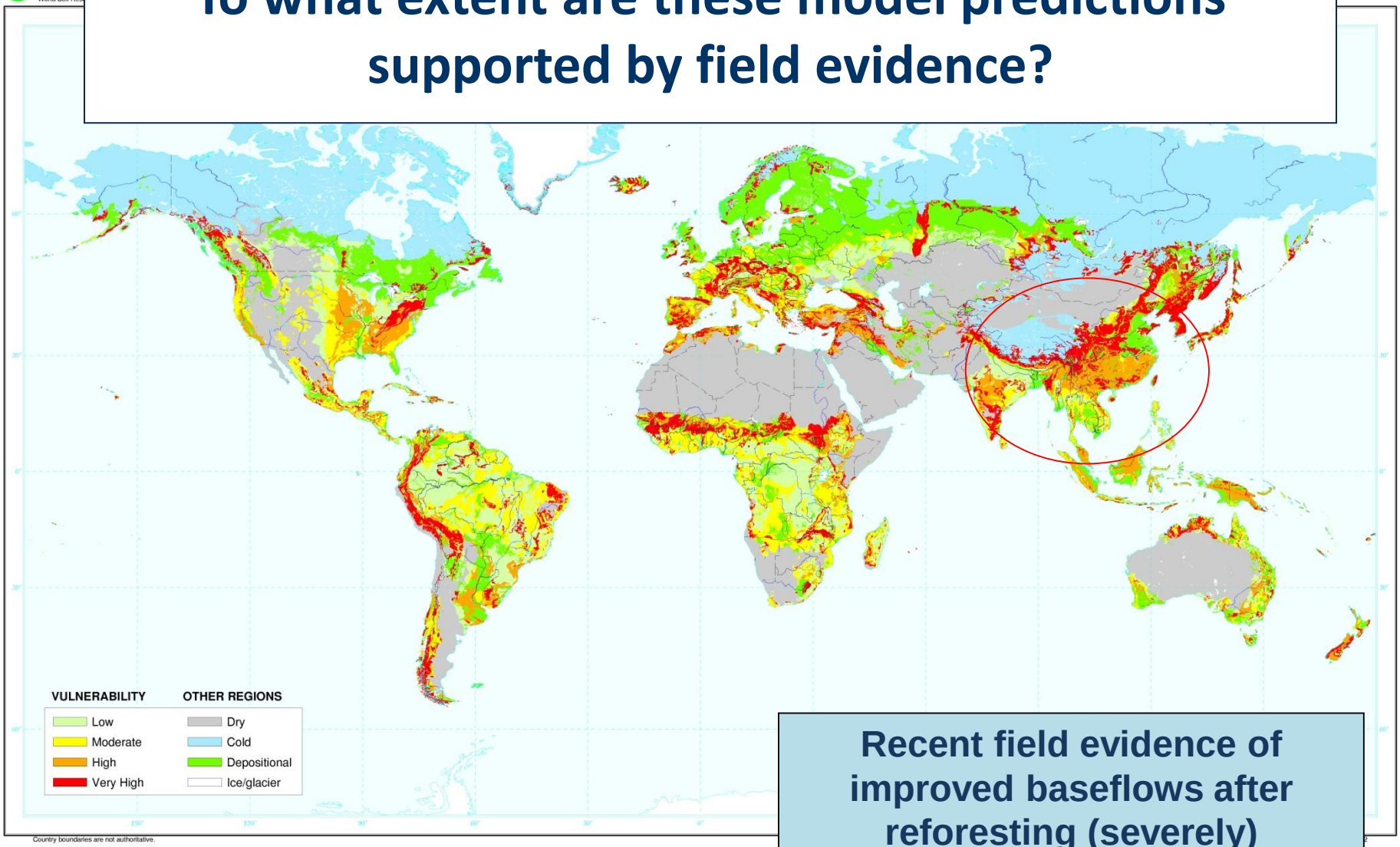
Areas with improved baseflows: zooming in on SE Asia…



Predicted ‘bright spots’ coincide with areas of high rainfall and advanced soil degradation.

Predicted net positive effect (mm/yr)

To what extent are these model predictions supported by field evidence?

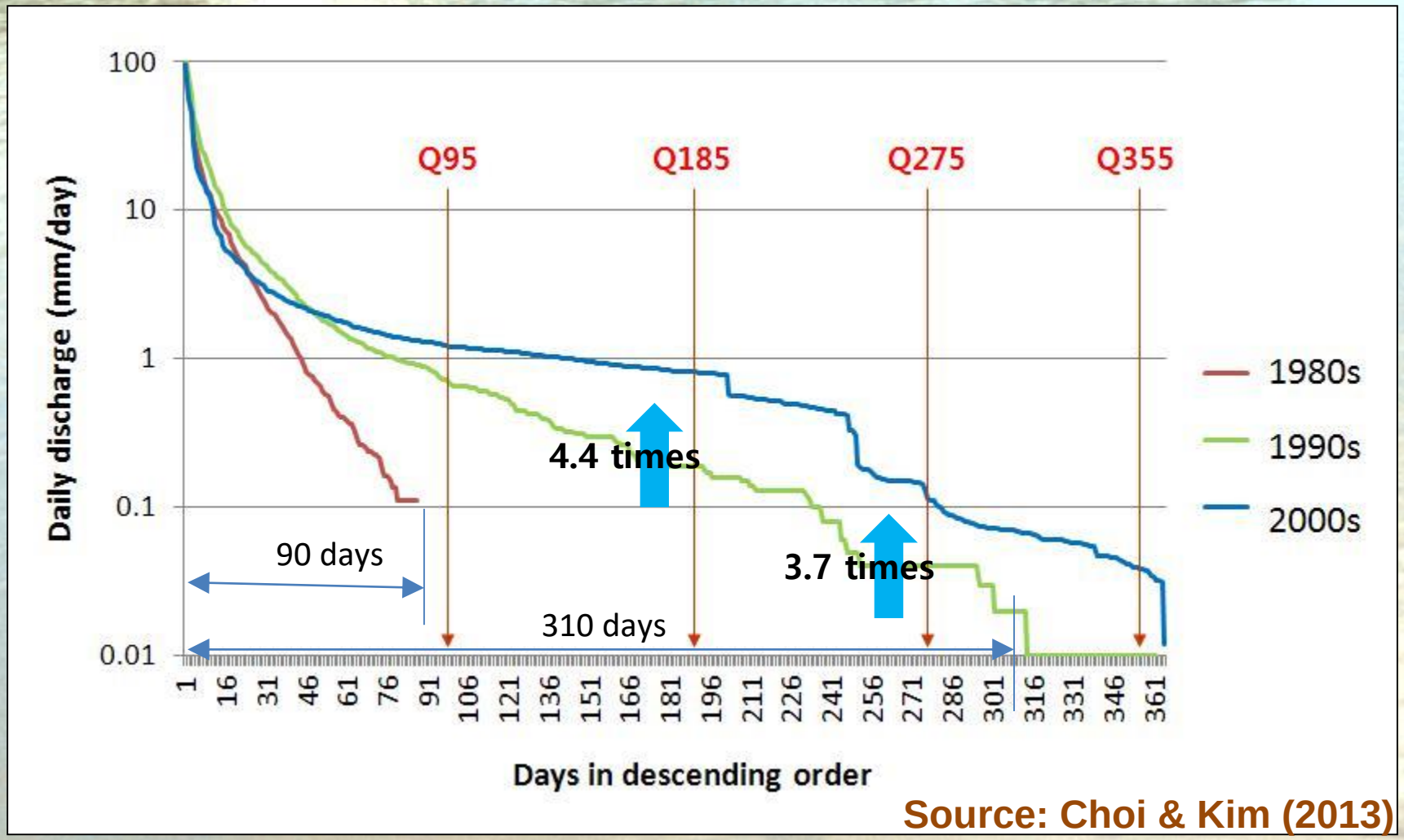


Recent field evidence of improved baseflows after reforesting (severely) degraded land in (S)E Asia: Korea, India, China, Philippines

Vegetation development in Yangjoo, S Korea, 1975 - 2005

Source: Choi & Kim (2013)

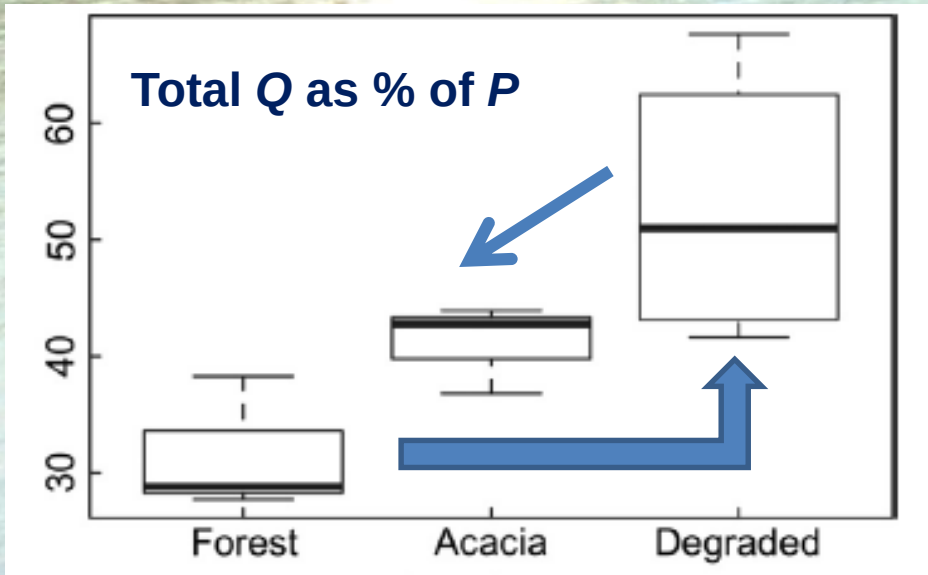
Improved flow duration: Yangjoo, Korea

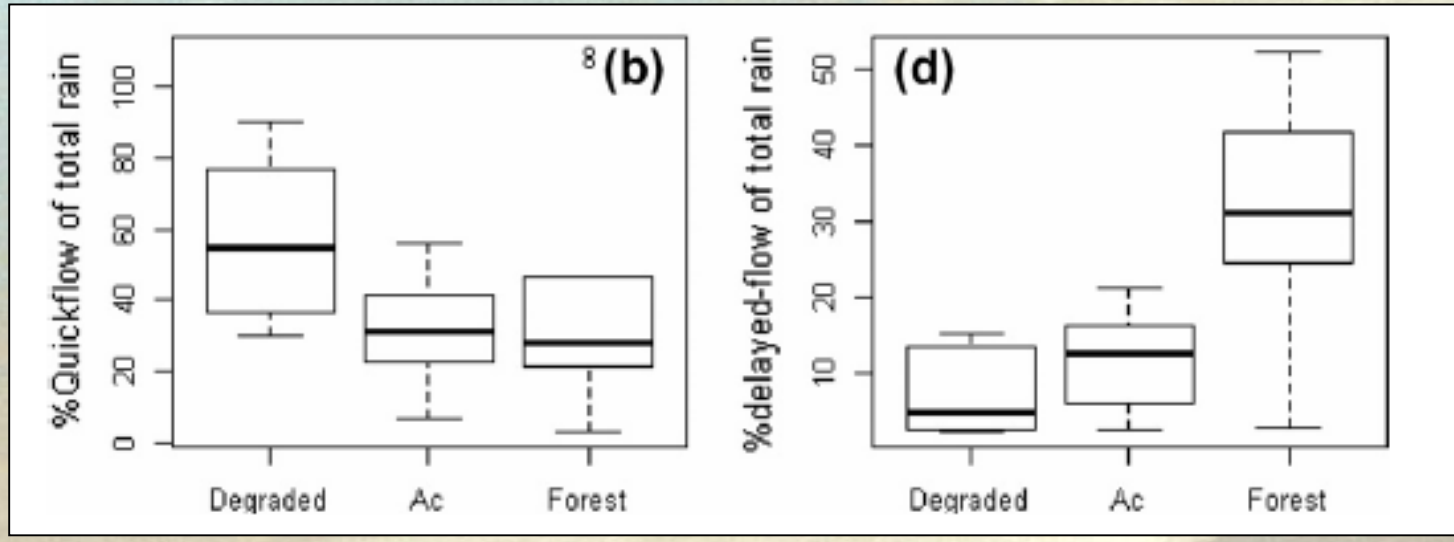


Source: Choi & Kim (2013)

Improvements in low flows as vegetation matures

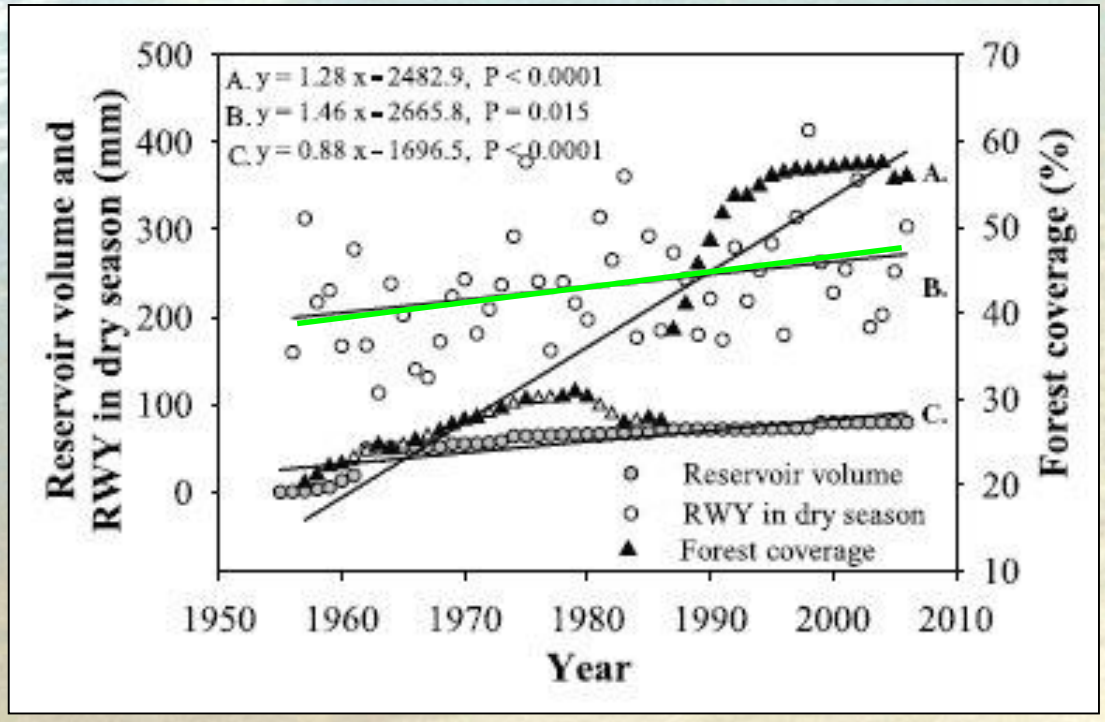
2. Some recovery of flow regime in SW India after reforestation with *Acacia auriculiformis* (7-12 yrs)





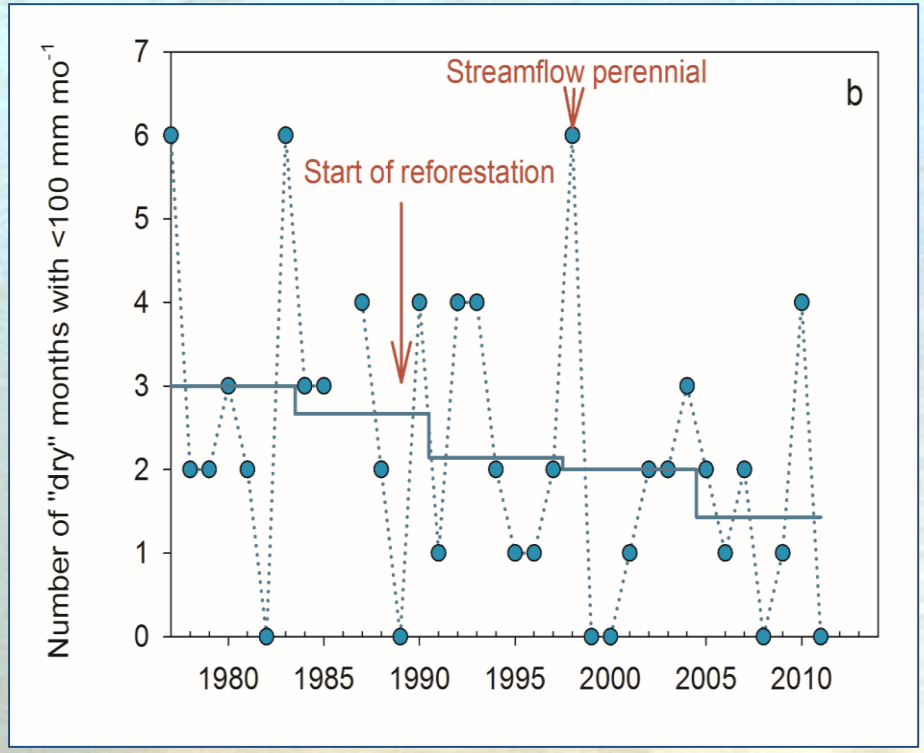
(Krishnaswamy et al. 2012

Positive impact of large-scale reforestation on baseflow: 3. SE China



Zhou et al. (2010)
(**10 000 km²**)

Anecdotal evidence of improved low flows, Leyte Island, the Philippines*



But, local climate wetting up!

*See companion presentation.

Tropical forestation and flows: What can be achieved?

- *Undisturbed forest maintains baseflows best.* ***Higher peaks ('floods') and lower baseflows ('droughts') when deforestation is followed by soil degradation.***

- **Surface degradation** is wide-spread but still **insufficiently represented in scientific experiments** and views.

- Adding trees on deforested land will *reduce* baseflows unless soil infiltration is improved enough.

Tropical forestation and flows: What can be achieved? - 2

- **Positive trade-off** between changes in plant water use and infiltration after reforesting degraded land is **possible**.
- **Predicted flow improvements greatest in highly degraded areas with high rainfall.**
- Given the risk of reduced flows after planting trees / natural regrowth, **agroforestry (lower water use?) should be given more serious consideration.**