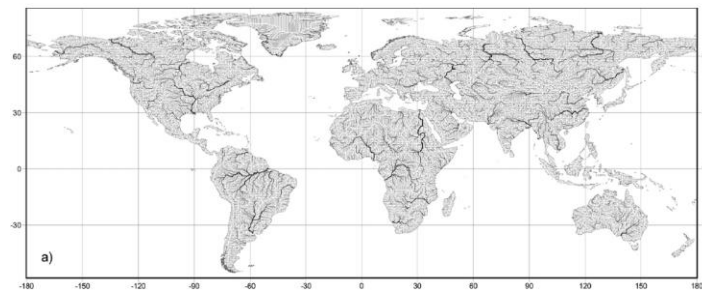


# Estimation of the base flow characteristic time scale for global applications

Ana **SCHNEIDER**, Agnès DUCHARNE, Anne JOST, Tom GLEESON

- Land Surface Models (LSMs) at global scale rely on high resolution parameters to better represent surface and groundwater flows.

Base flow characteristic time scale ( $\tau$ ): mean amount of time the groundwater will take to reach the stream in a given catchment



Döll and Lehner (2002)



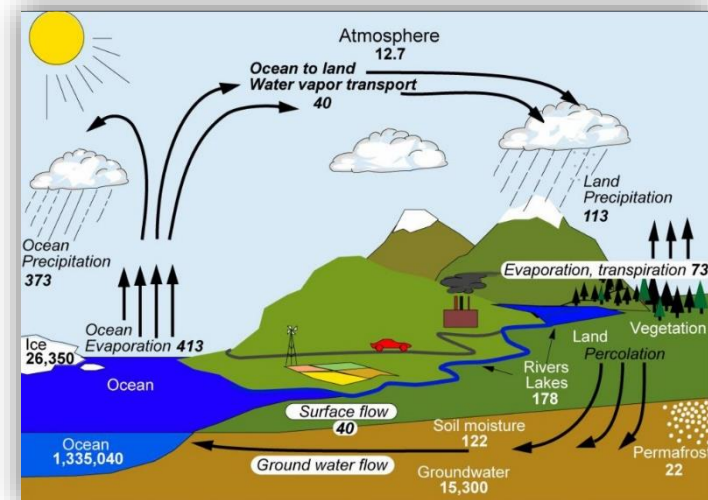
Lehner et al. (2008)



Hydro1k Streams  
Verdin and Greenlee (1998)

- $\tau$  applications:

- Estimate base flow in regions with no discharge measurements;
- In simple groundwater models such as the ones in global scale LSMs;
- Provide indirect index of groundwater vulnerability.



Trenberth et al. (2007)

**Objective:** estimate  $\tau$  at global scale based on the Boussinesq equation and available global data.

- $\tau$  was estimated based on the long-term solution of the flow recession equation proposed by Brutsaert (2005)

$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$

$\tau$  – base flow time constant (d)

$n_e$  – effective porosity (-)

$T_e$  – effective transmissivity (m<sup>2</sup>.d<sup>-1</sup>)

$\delta$  – drainage density (m<sup>-1</sup>)

Effective transmissivity:

$$T_e = k \cdot p \cdot D$$

$T_e$  – effective transmissivity (m<sup>2</sup>.d<sup>-1</sup>)

$k$  – hydraulic conductivity (m.d<sup>-1</sup>)

$p$  – empiric constant

$D$  – aquifer thickness

Drainage density:

$$\delta = \frac{\sum L}{A}$$

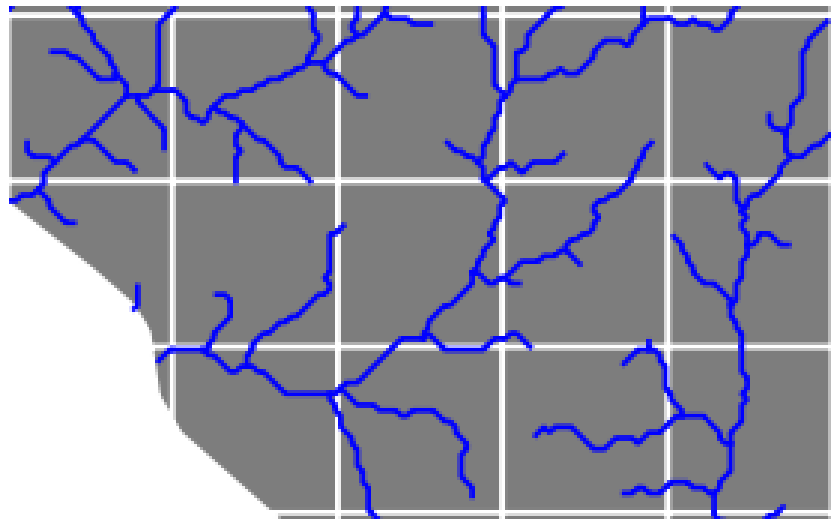
$\delta$  – drainage density (m<sup>-1</sup>)

$L$  – total river length (m)

$A$  – area (m<sup>2</sup>)

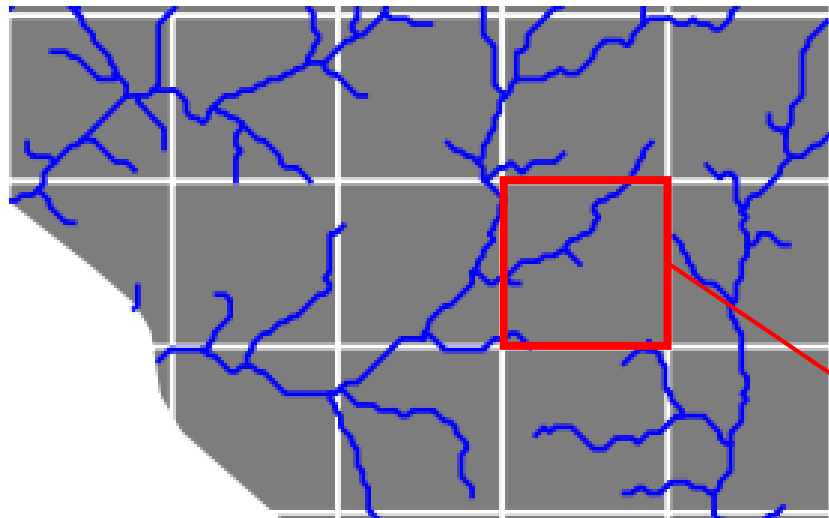
- $\tau$  was calculated inside a 7.5' grid:

$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$



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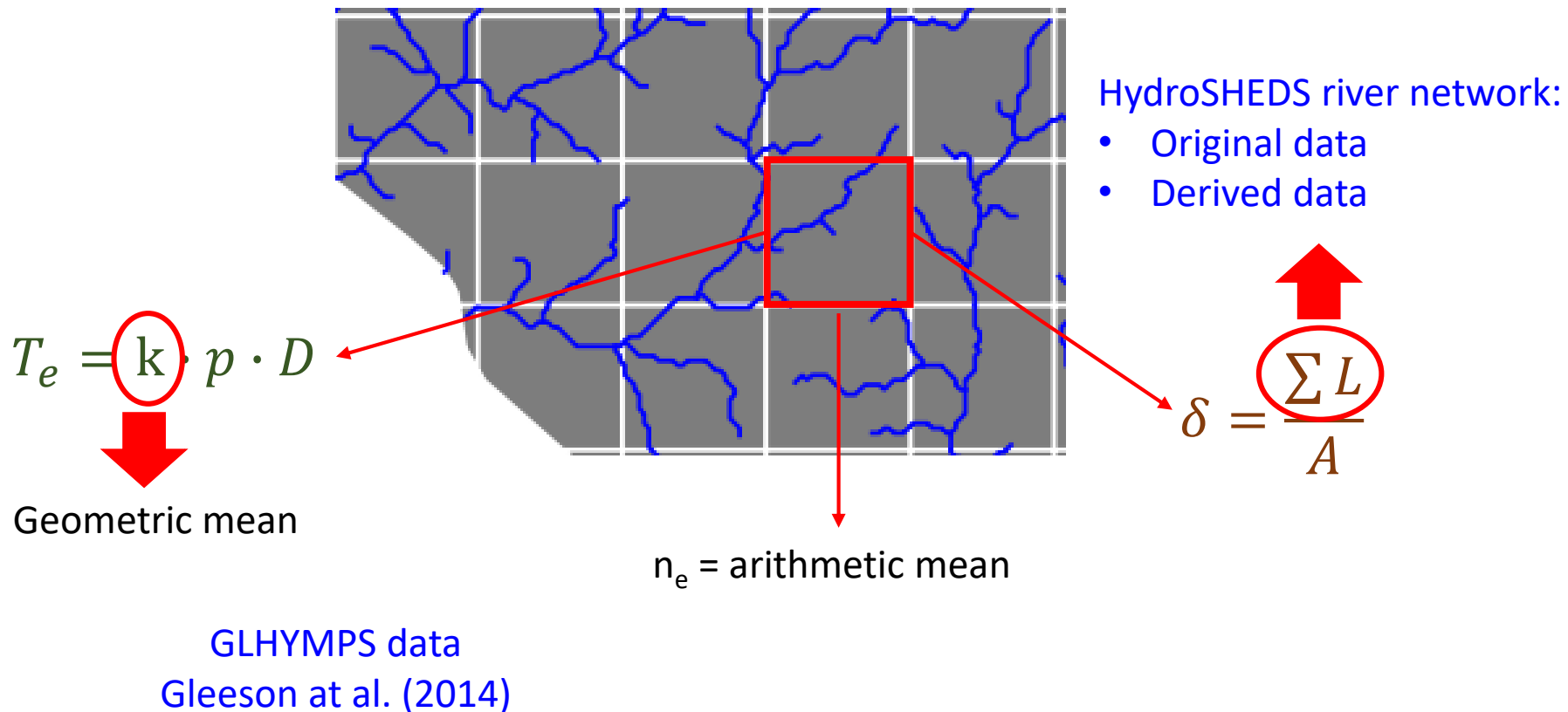
HydroSHEDS river network:

- Original data
- Derived data

$$\delta = \frac{\sum L}{A}$$

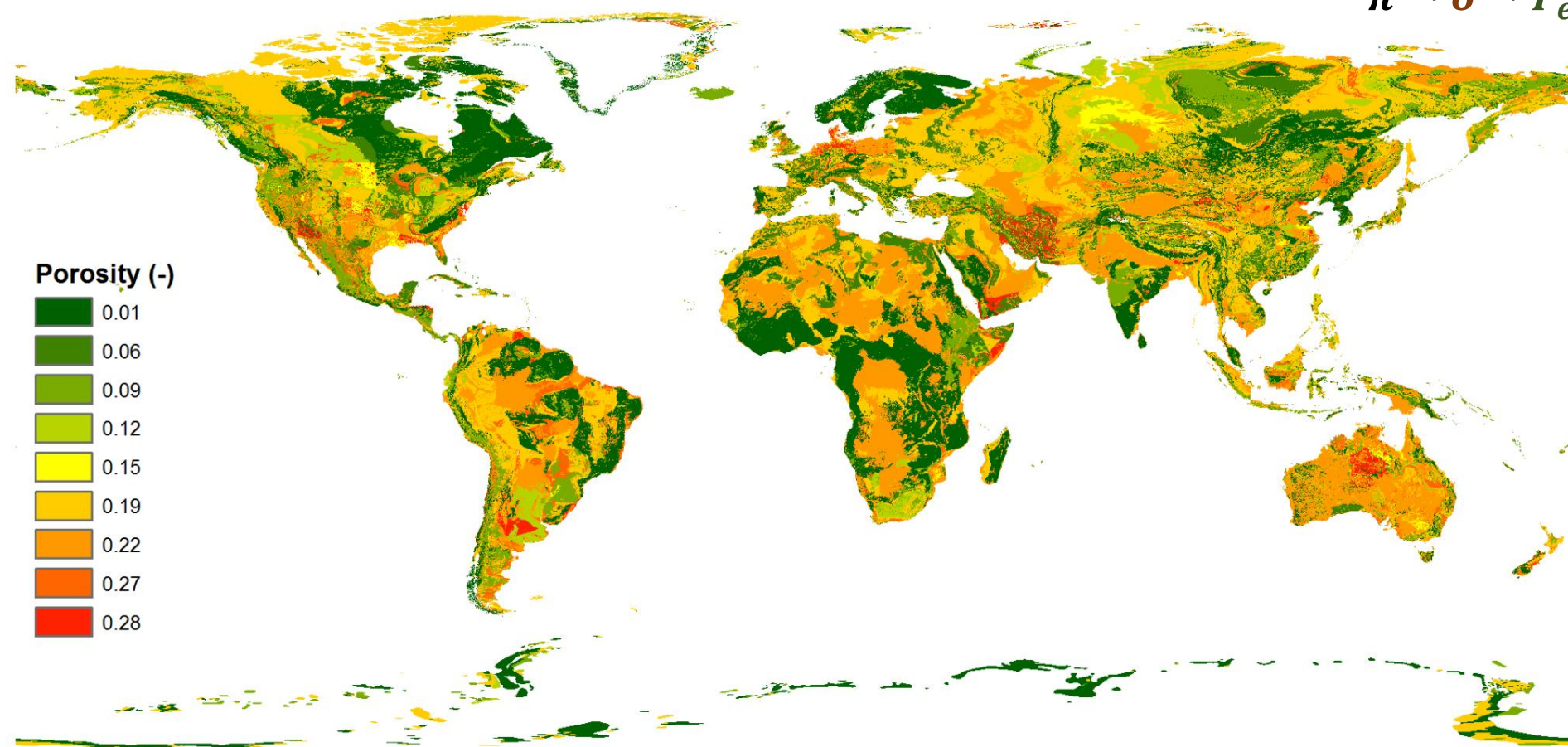
- $\tau$  was calculated inside a 7.5' grid:

$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$



## ✓ Effective porosity: mean total porosity values from GLHYMPS

$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$

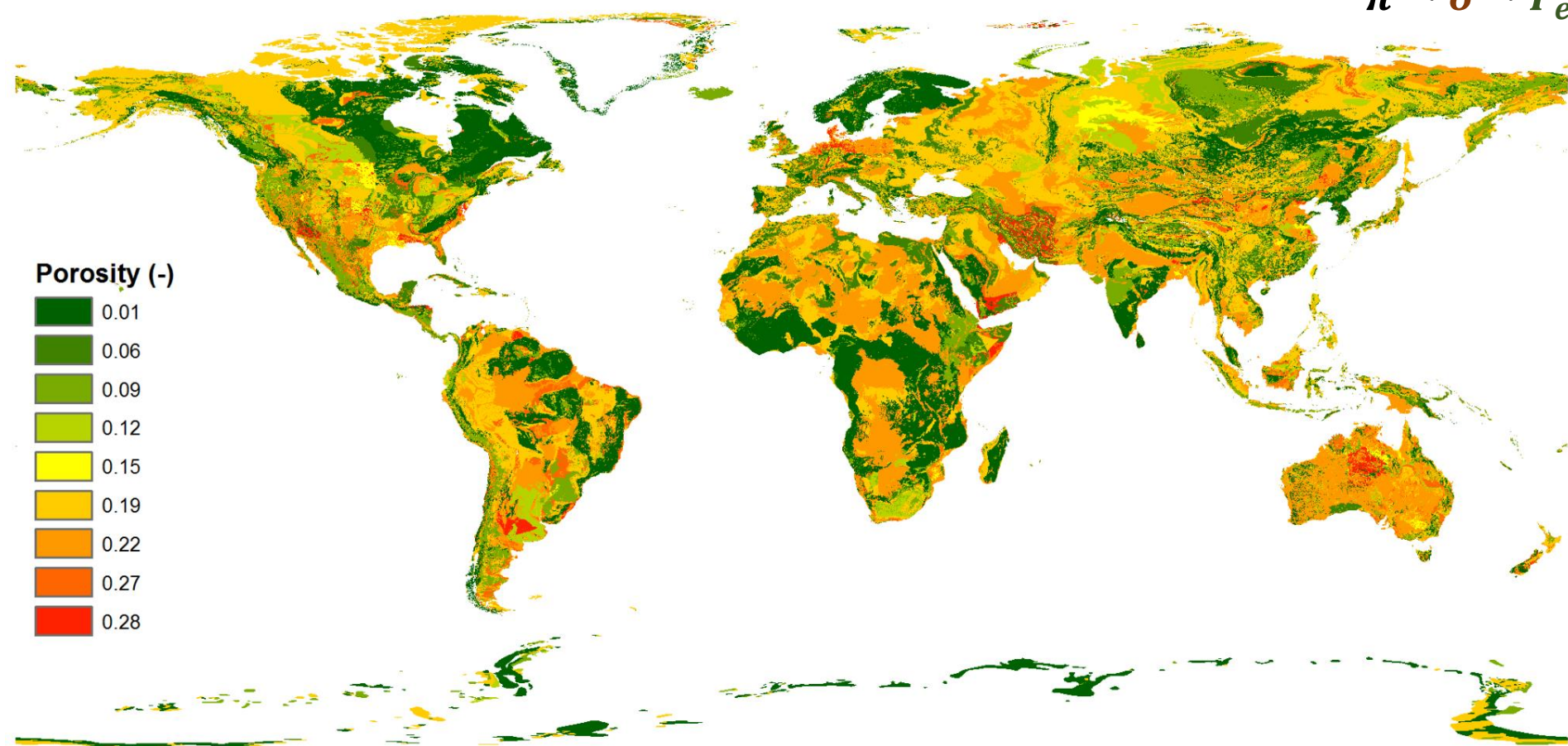




## ✓ Effective porosity: mean total porosity values from GLHYMPS

✗  $n_e$  from Johnson (1967) with lithology classes of Hartmann and Moosdorf

$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$



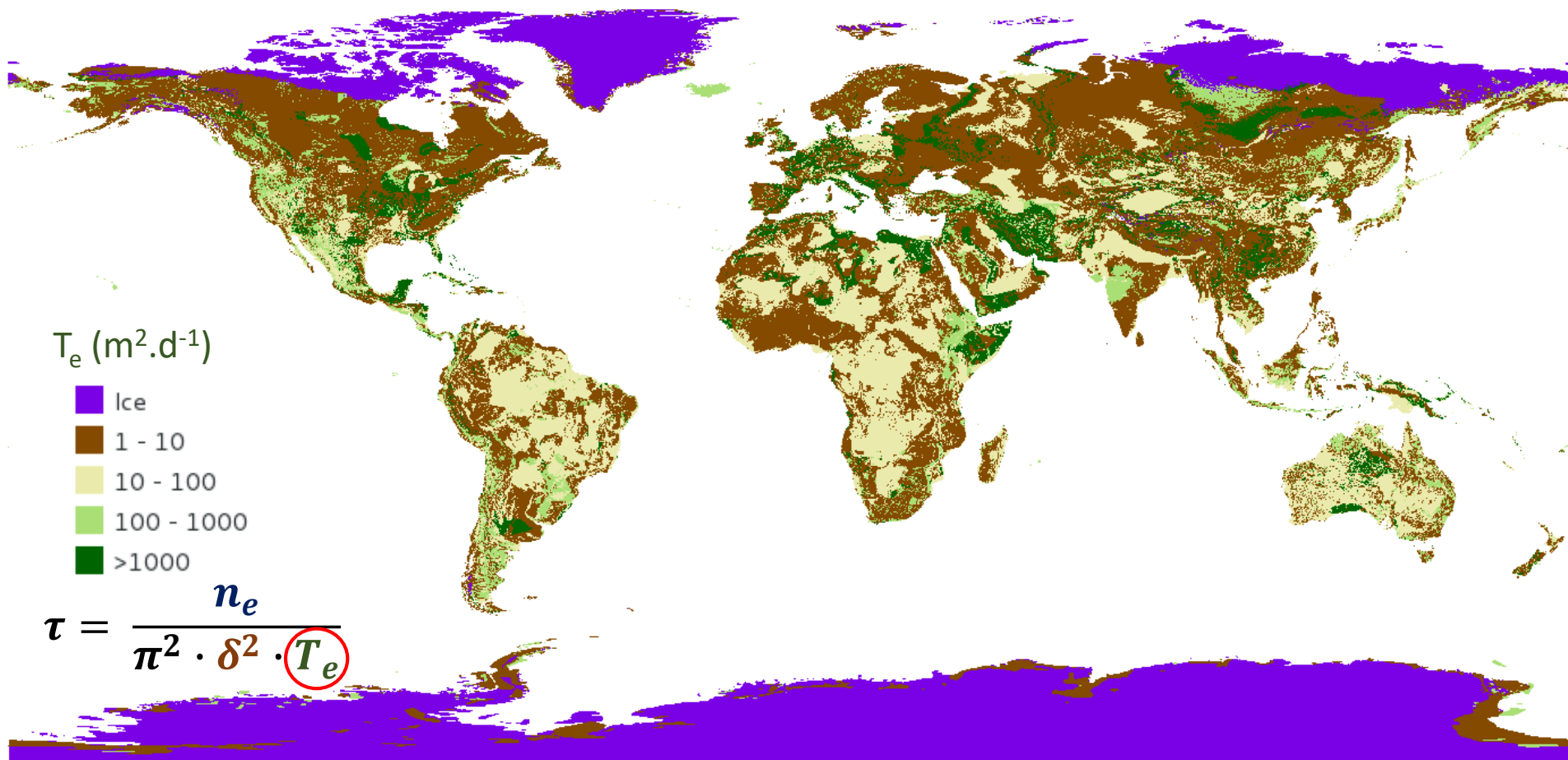
- Effective transmissivity

$$T_e = k \cdot p \cdot D$$

$k$  – geometric mean from GLHYMPS

$p$  – 0.3465 from Brutsaert (2005)

$D$  - 100 m from Gleeson et al. (2014)



- River network extraction from DEMs:
  - Flow direction and flow accumulation;
  - $A_{cr}$  (critical area): threshold from which a river starts to exist.
- At large scales is frequently used a single  $A_{cr}$  value for the entire domain!

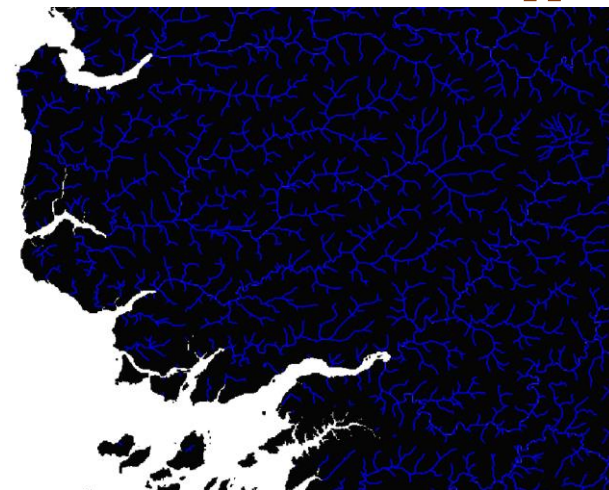
Neglects local lithology and climate effects that may be important.



Results in low and spatially constant  $\delta$  when compared to references.



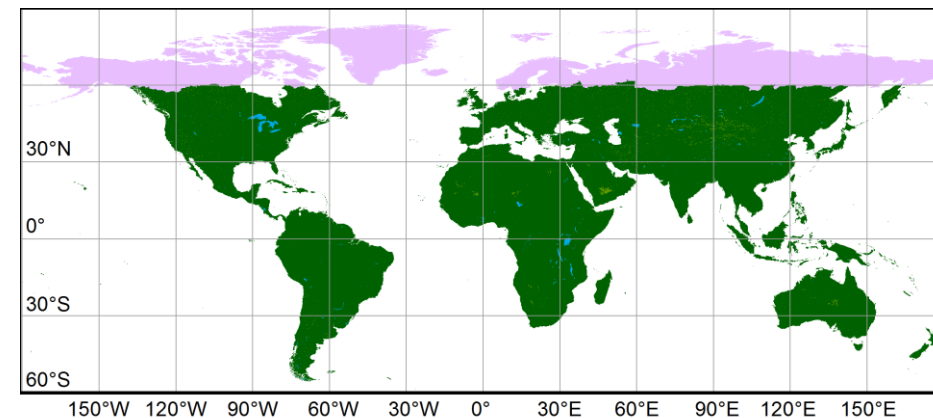
$A_{cr} = 100 \text{ pixels}$    $\delta = \frac{\sum L}{A}$



# • Which global river network we should use to calculate $\delta$ ?

## HydroSHEDS 15"

Lehner et al., 2008



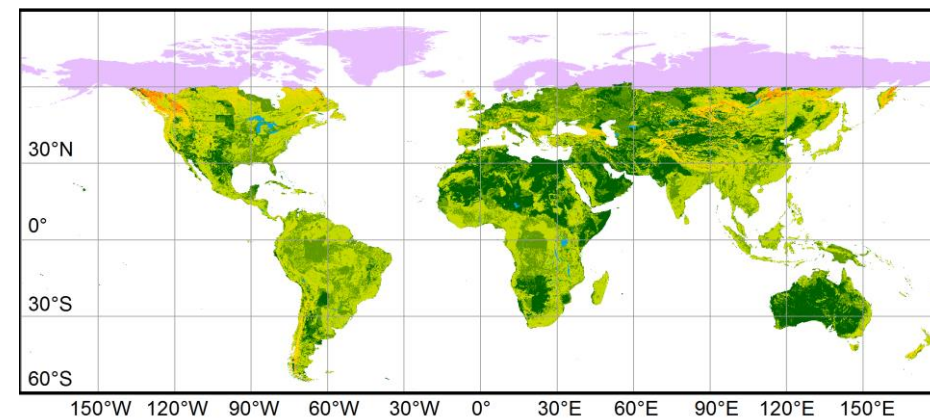
$\delta$  (km<sup>-1</sup>)

0,0 - 0,4	0,8 - 1,2	1,5 - 2,0	No Data
0,4 - 0,8	1,2 - 1,5	2,0 - 8,9	Water Bodies

- Single  $A_{cr}$  of 100 pixels for river network extraction;
- $\delta$  spatially constant and low (mean of 0.19 km<sup>-1</sup>)

## LCS2: lithology, climate, and slope

Schneider et al. (2016)



$\delta$  (km<sup>-1</sup>)

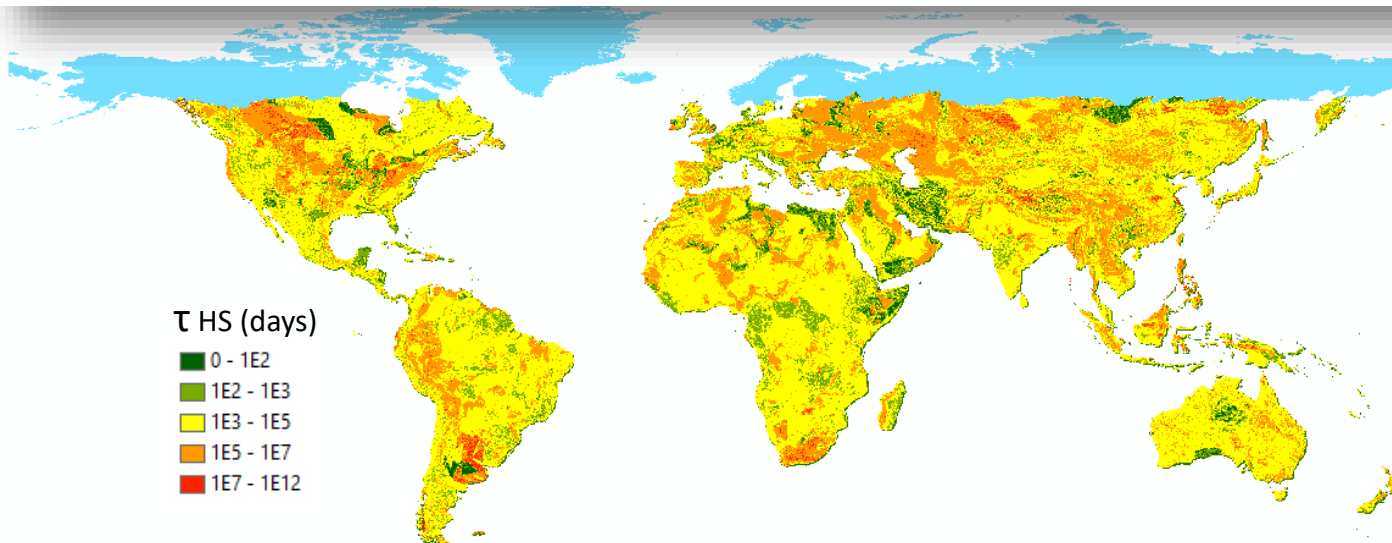
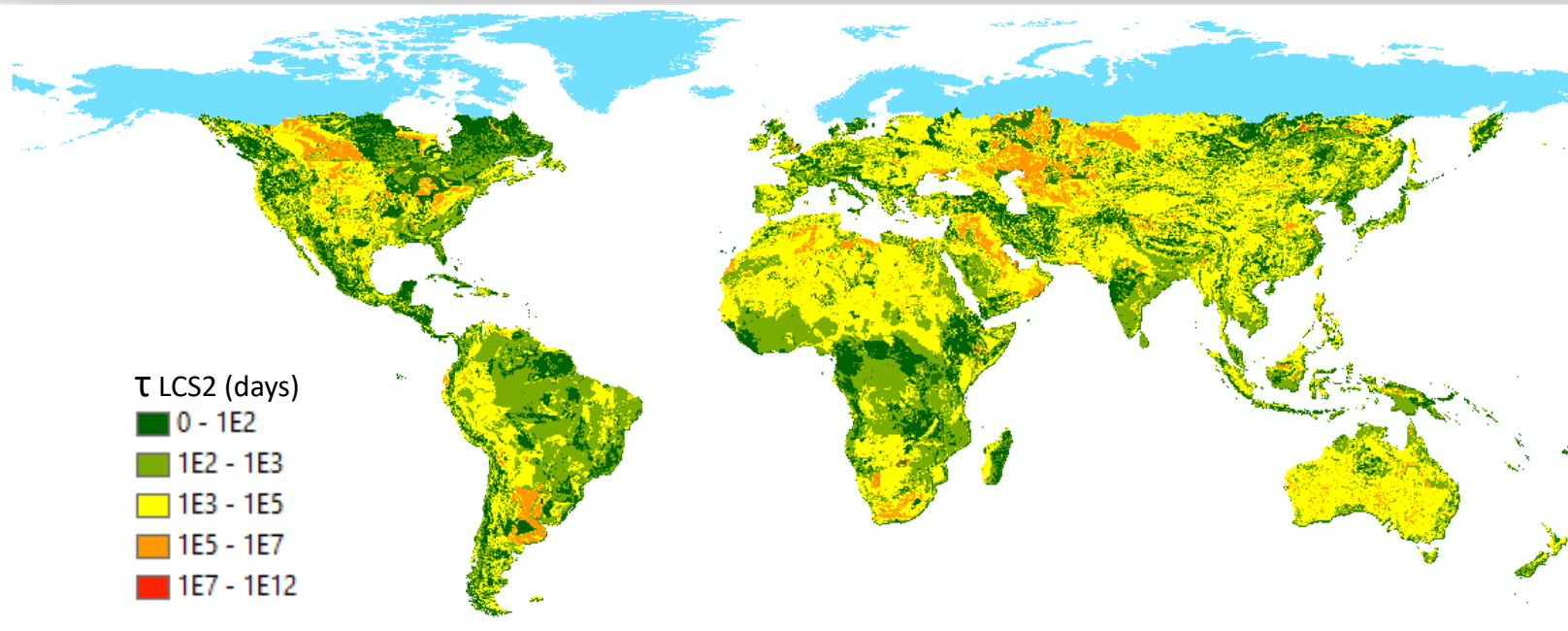
0,0 - 0,4	0,8 - 1,2	1,6 - 2,0	No Data
0,4 - 0,8	1,2 - 1,6	2,0 - 8,9	Water Bodies

- Variable  $A_{cr}$  depending on lithology, climate, and slope;
- $\delta$  spatially variable and with higher results (mean of 0.73 km<sup>-1</sup>)

$$\delta = \frac{\sum L}{A}$$

$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$





$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$

←  $\delta$  HS  
 $p = 0.3$

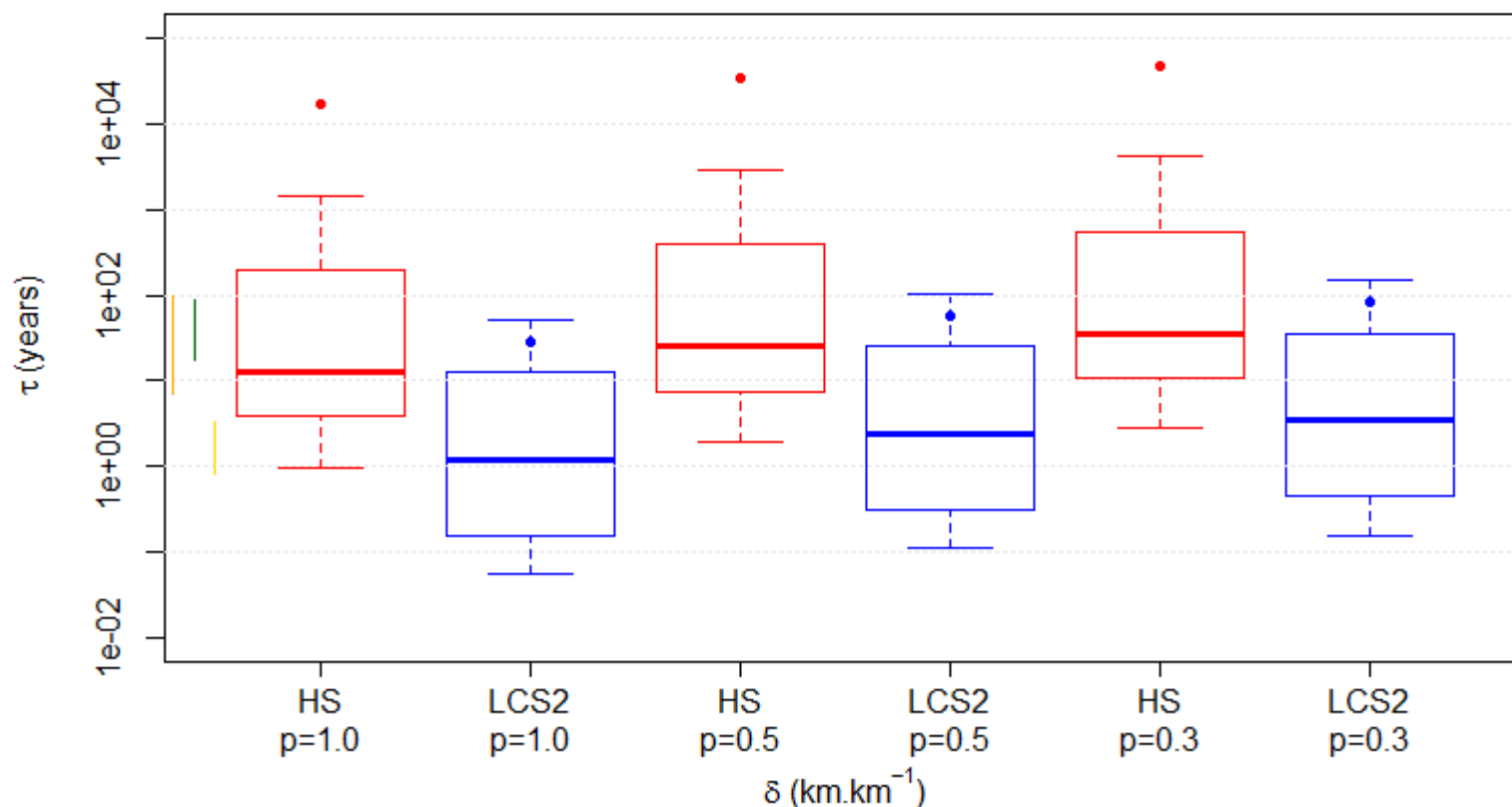
$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$

- $\tau$  main uncertainty factor is drainage density

The choice of  $p \cdot D$  defines the effective aquifer thickness

$$T_e = k \cdot p \cdot D$$

— Land and Timmons (2016) — Eng and Milly (2007) — McGuire et al. (2005)

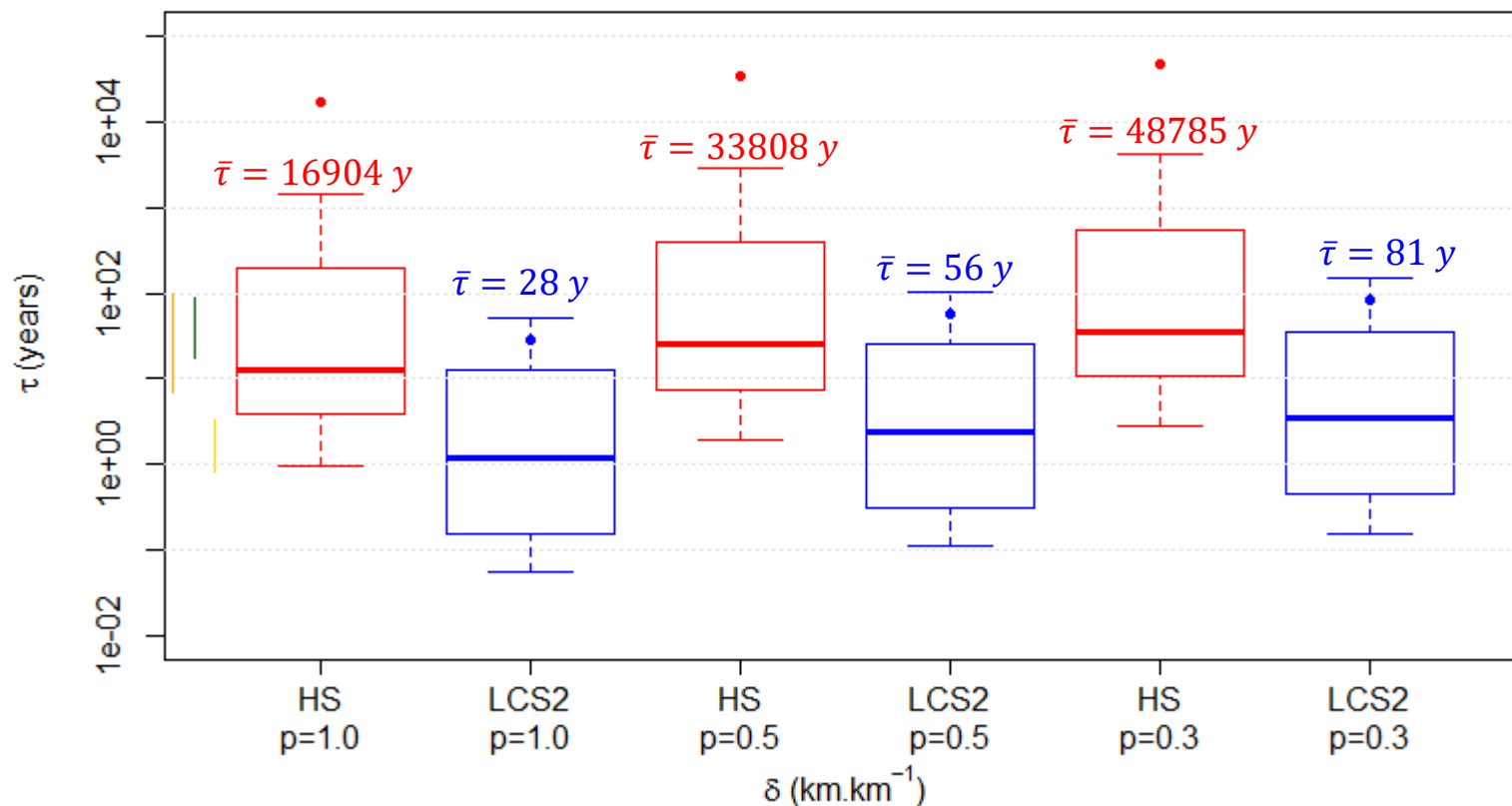


$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$

- $\tau$  main uncertainty factor is drainage density

The choice of  $p \cdot D$  defines the aquifer thickness for the transmissivity  $T_e = k \cdot p \cdot D$

— Land and Timmons (2016) — Eng and Milly (2007) — McGuire et al. (2005)

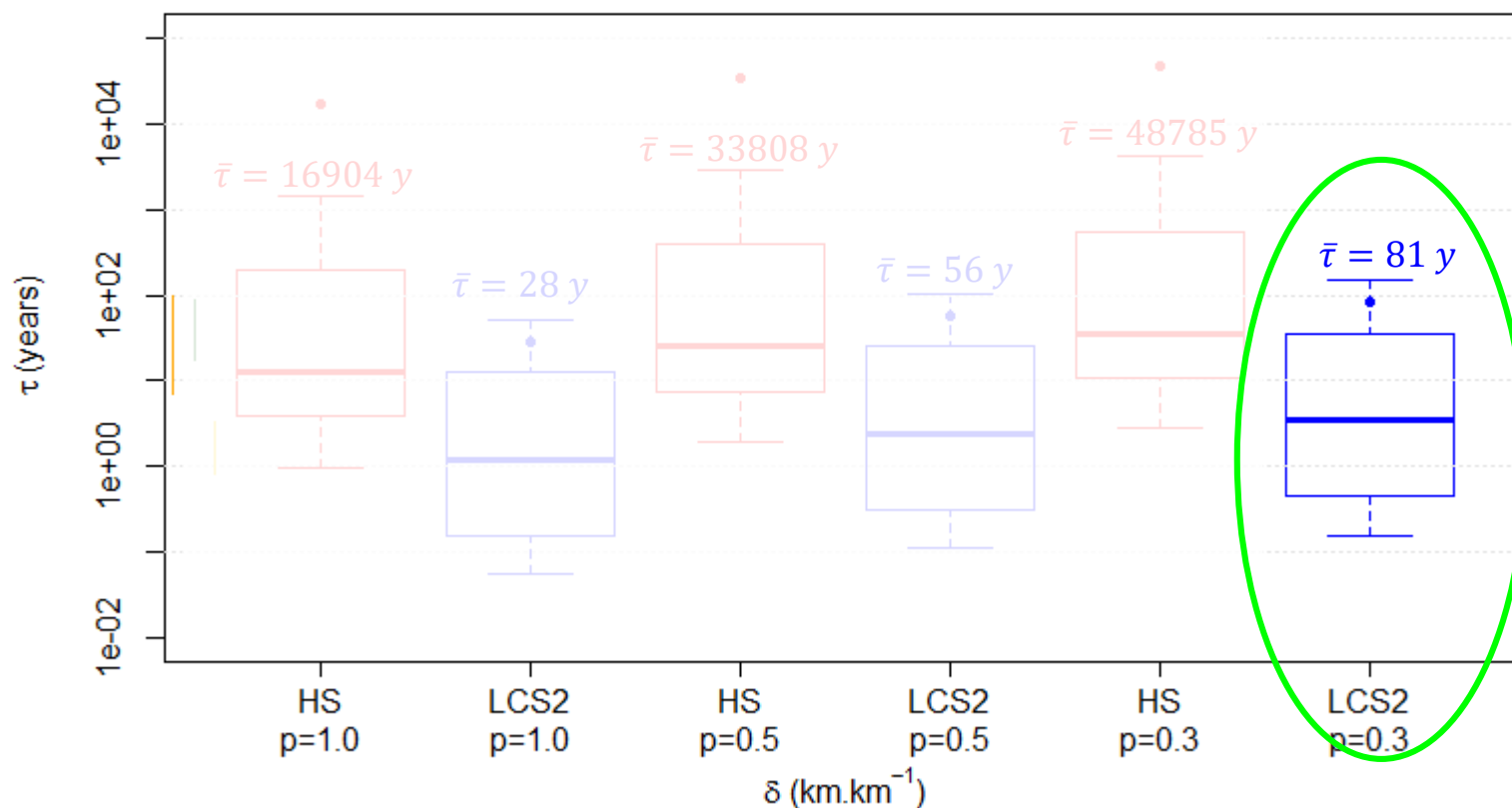


$$\tau = \frac{n_e}{\pi^2 \cdot \delta^2 \cdot T_e}$$

- $\tau$  main uncertainty factor is **drainage density**


The choice of  $p \cdot D$  defines the aquifer thickness for the **transmissivity**  $T_e = k \cdot p \cdot D$

— Land and Timmons (2016) — Eng and Milly (2007) — McGuire et al. (2005)





- Results closer to literature values with LCS2  $\delta$  in average:
  - Land and Timmons (2016): 17 to 88 years (6200 km<sup>2</sup> basin)
  - Eng and Milly (2007): 7 to 100 years (4 – 829 km<sup>2</sup> basins)
  - McGuire et al. (2005): 0.8 to 3.3 years (0.1 – 62.4 km<sup>2</sup> basins)
- The choice of the river network affects significantly  $\tau$ 
  - Better representation of the main patterns of river network reduced  $\tau$  average by a factor of 600 when compared to traditional methods of river extraction

- Effective transmissivity:
    - Uncertainty on effective aquifer depth
  - Effective porosity:
    - Tests associating effective porosity from Johnson (1967) with lithology classes of Hartmann and Moosdorf resulted in higher (0.14 – 0.26) values and lower variability than total GLHYMPS total porosity (0.01 – 0.28)
-  Next step: implementation of base flow formulation and time constant to ORCHIDEE model



Thank you for your attention!